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GEOLOGY AND ORE DEPOSITS

OF THE

BULLFROG DISTRICT, NEVADA

BY

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AND G. H. GARREY

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GEOLOGY AND ORE DEPOSITS OF THE BULLFROG DISTRICT, NEVADA.

By Frederick Leslie Ransome, William H. Emmons, and George H. Garrey.

INTRODUCTION.

By F. L. Ransome.

SITUATION AND ACCESS.

The name "Bullfrog district" is usually rather vaguely applied to a large tract of desert hills and mountains extending far to the north and west of the area here particularly described. For convenience, however, the name as used in this report will refer as a rule to the area mapped in Plate I, although account will be taken of a few mines and some scattered prospects lying short distances beyond its boundaries.

The position of the district is shown on the index map (fig. 1). Rhyolite, the principal town, lies 60 miles south-southeast of Goldfield, with which it is connected by the Las Vegas and Tonopah Railroad (73.5 miles) and the Bullfrog Goldfield Railroad (81 miles). To the south there is connection with Las Vegas, Nev., on the San Pedro, Los Angeles and Salt Lake Railroad, over the Las Vegas and Tonopah Railroad, a distance of 123.5 miles, and with Ludlow, Cal., on the Atchison, Topeka and Santa Fe Railway, over the Tonopah and Tidewater Railroad, 171 miles in length. The town of Rhyolite is situated at the south base of a short east-west range of hills that connects the Grapevine Mountains on the west with Bare Mountain and other irregular groups of peaks, ridges, and mesas on the east, and separates the Amargosa Desert on the south from a similar desert basin that extends north past Stonewall Mountain toward Goldfield.

The other towns in the district are Bullfrog, which adjoins Rhyolite on the south, and Beatty, 4 miles east of Rhyolite, on the so-called Amargosa River, a feeble rill of water that is fed by springs a few miles north of the town and is finally absorbed in the sand and gravel of the Amargosa Desert.

FIELD WORK AND AUTHORSHIP.

In the autumn of 1905 a topographic map of the most important part of the Bullfrog district, covering an area 7.25 miles from east to west and 2.9 miles from north to south, was made by Mr. William Stranahan, topographer, on the scale of 1:24,000, with contour intervals of 20 feet. This map shows the town of Beatty near its eastern margin and includes the Original Bullfrog mine on the west. Geo-

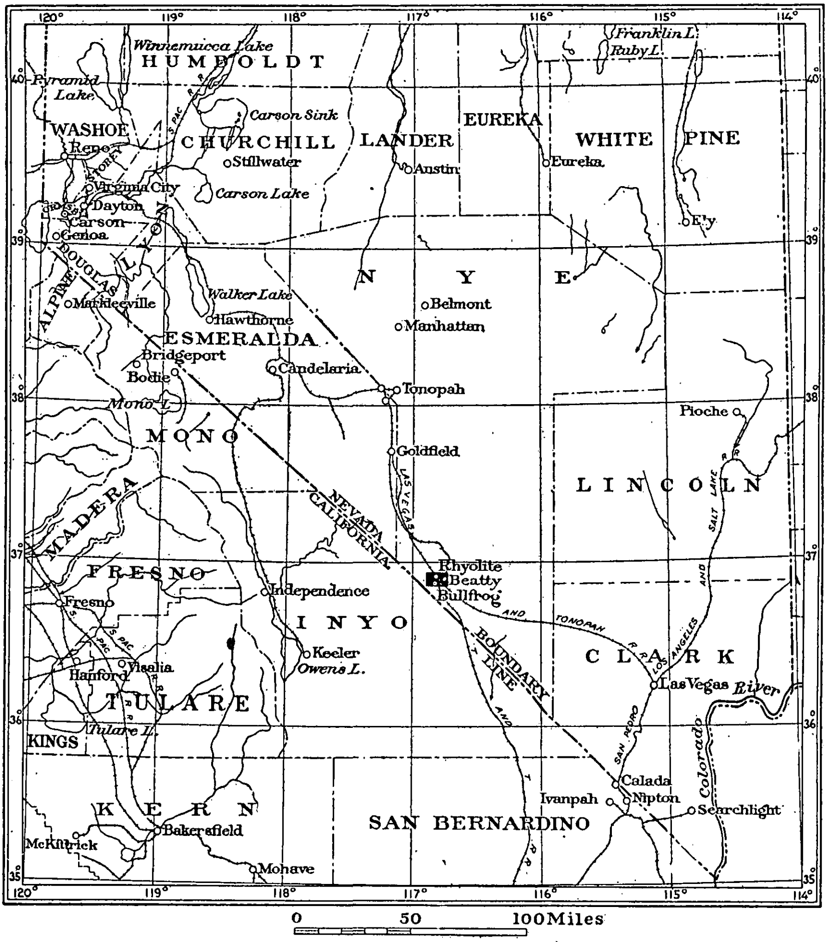


FIGURE 1.—Index map showing position of the Bullfrog district.

logic work was begun in December of the same year and carried on until March, 1906. Messrs. W. H. Emmons and G. H. Garrey mapped the rocks and studied in detail their relations and character, while Mr. F. L. Ransome devoted a shorter time to a general survey of the field and to the examination of the ore deposits.

In consequence of a change in the boundaries of the topographic map prior to the final engraving of the plate, Mr. Emmons revisited the district for a few weeks in January and February, 1907, and mapped geologically such additional area as was required by the modification of the original topographic base. Finally, in the summer of 1908, Mr. Ransome spent a week in the district studying mine workings opened since March, 1906.

The study of the general geology was carried out jointly by Messrs. Emmons and Garrey under the direct supervision of Mr. Ransome.

LITERATURE.

The Bullfrog Hills, lying aside from the routes followed by the transcontinental railways and being inconspicuous features in comparison with the loftier ranges and remarkable valleys of the Great Basin, appear not to have attracted the attention of the earlier geologic explorers in Nevada. The following list of publications dealing with the region is accordingly short, and those that appeared before the year 1906 deal merely with the region as a whole. Brief articles in the mining press have contributed at various times information regarding mining and milling progress, but these are not here listed, since they afford no important geologic information and are not of lasting interest:

Gilbert, G. K. Report on the geology of portions of Nevada, Utah, California, and Arizona; examined in the years 1871 and 1872: U. S. Geog. Surveys W. 100th Mer., vol. 3, Geology, 1875, pp. 32–33.

Gives a diagram showing the structure of the west face of Bare Mountain southeast of the Bullfrog district, with brief notes. Estimates that not less than 8,000 feet of bedded rocks is exposed.

Spurr, J. E. Descriptive geology of Nevada south of the fortieth parallel and adjacent portions of California: Bull. U. S. Geol. Survey No. 208, 1903. (Second edition in 1905.)

The route of this reconnaissance was north and west of the Bullfrog Hills. A general geologic map of this part of Nevada and California, "compiled from all available information," on a scale of 15 miles to the inch, accompanies this report. The area occupied by the Bullfrog Hills is shown as "fine-grained igneous rocks," and the same color is extended over Bare Mountain.

Ball, Sydney H. Notes on ore deposits of southwestern Nevada and eastern California: Bull. U. S. Geol. Survey No. 285, 1906, pp. 53–73.

An advance report on part of the material embodied in the following publication.

Ball, Sydney H. A geological reconnaissance in southeastern Nevada and eastern California: Bull. U. S. Geol. Survey No. 308, 1907, pp. 176–182.

Describes the general geology of the Bullfrog Hills and adjacent region. A geologic reconnaissance map on a scale of 1 : 250,000 (approximately 4 miles to the inch), covering 8,550 square miles, accompanies this report.

Krumb, Henry. Report on the Montgomery-Shoshone Consolidated Mining Company, New York, 1908.

The report deals particularly with the ore reserves, but contains some geologic data.

RANSOME, F. L. A preliminary account of Goldfield, Bullfrog, and other mining districts in southern Nevada; with notes on the Manhattan district by W. H. Emmons and G. H. Garrey: Bull. U. S. Geol. Survey No. 303, 1906.

An advance report superseded as regards the Bullfrog district by the present publication.

EMMONS, W. H. Normal faulting in the Bullfrog district: Science, n. ser., vol. 26, 1907, pp. 221-222.

A brief discussion of the mechanics of the faulting.

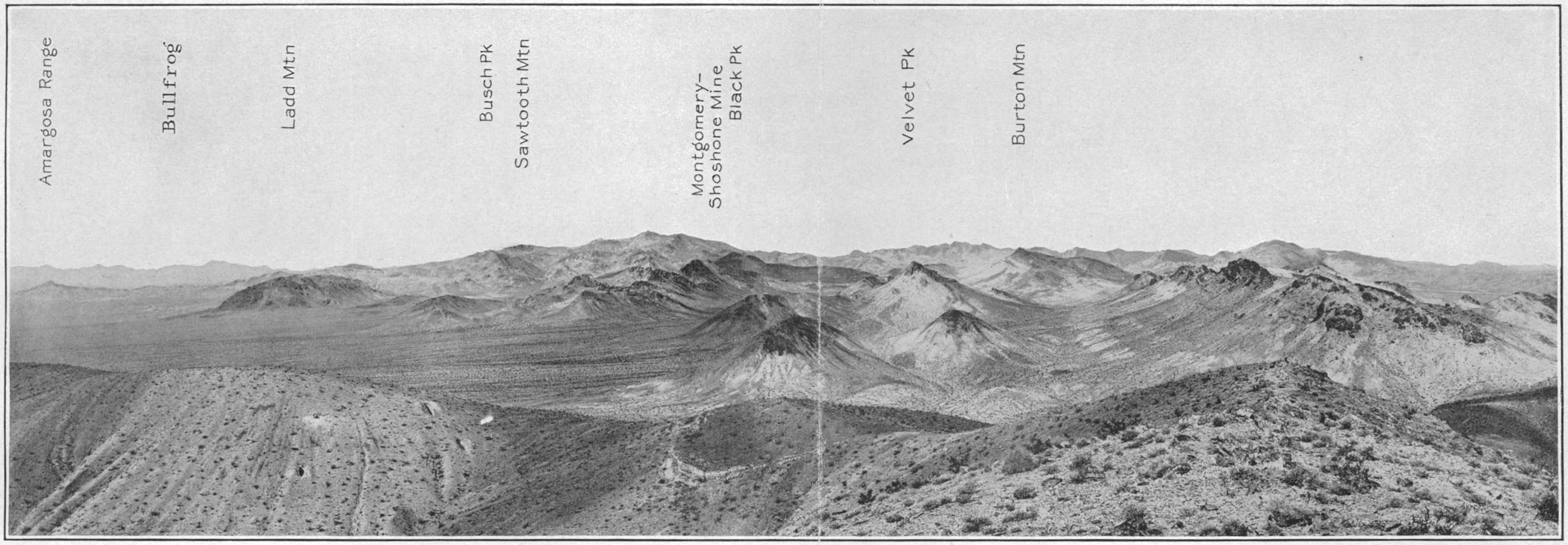
HISTORY OF MINING DEVELOPMENT.

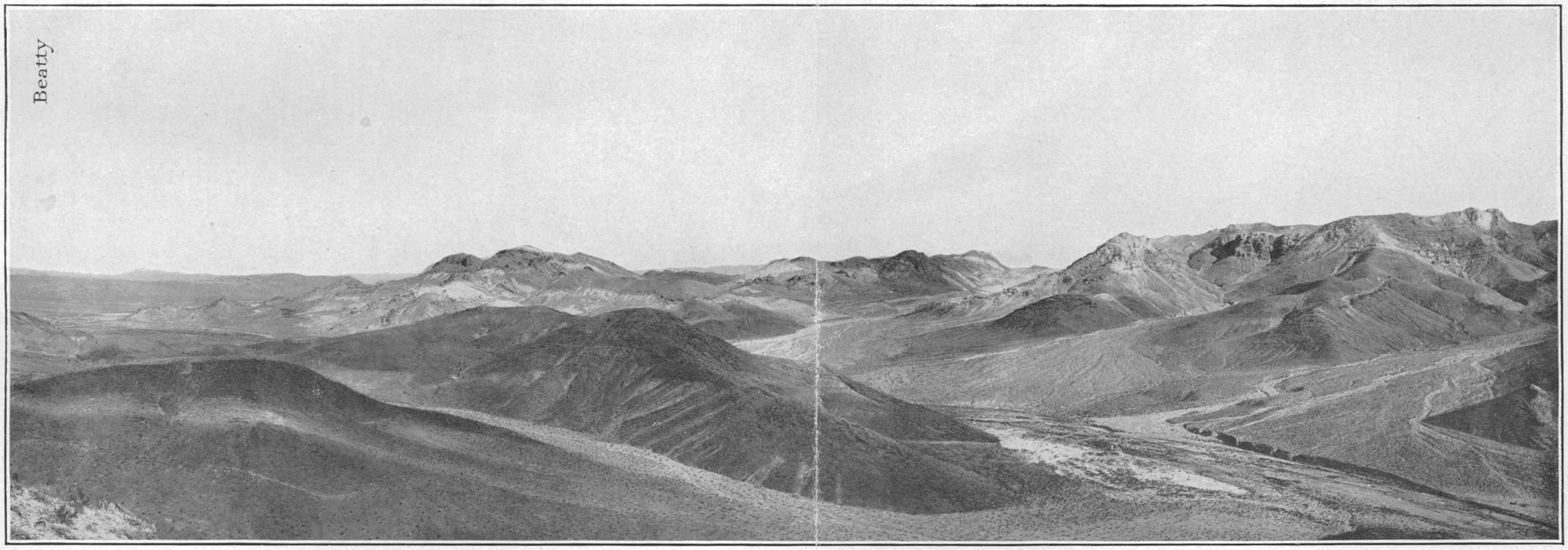
Long prior to the discoveries at Tonopah and Goldfield the springs in Oasis Valley, just north of the site of Beatty, proved attractive to a few wanderers, who established rude ranches along Amargosa River, the only stream of drinkable water within a radius of 40 miles. Occasionally prospectors traveling northeastward from Death Valley or northwestward from the springs at Ash Meadow would pass the night at one of these ranches, perhaps spend a few days examining the hills in the neighborhood, and then again set out over the desert plains.

The remarkable development of Tonopah and the finding of rich ore at Goldfield stimulated prospecting throughout all of southwestern Nevada, and the rapid advance of the material adjuncts to civilization into this most inhospitable region greatly lessened the hardship and danger that had hitherto attended a traveler far from bases of supply and vitally dependent upon scattered and easily missed springs. In the autumn of 1904 the Bullfrog claim was located on a prominent outcrop of quartz (see Pl. I), about 3 miles west of the site of Rhyolite. The name, which afterward became that of the district, is said to have been suggested by the green color of the ore, and the ironical humor that associated it with a place of scorching aridity is characteristic of the Nevada pioneers.

The usual rush of prospectors followed the first discovery, and most of the ground between the Bullfrog claim and Amargosa River was soon covered with claims. A settlement of tents, known as Amargosa City, sprang up near the Bullfrog claim, but when the center of interest shifted eastward to Bonanza and Ladd mountains the first town was abandoned for the settlements of Bonanza, Bullfrog, and Beatty. In February, 1905, a town-site company laid out the streets of Rhyolite and, by offering a certain number of lots free, succeeded in a few days in establishing this as the chief town of the district.

Up to the latter part of the year 1906 owners of claims were occupied chiefly in the development of their properties, it being impracticable to ship any but the richest ore under the conditions of transportation then prevailing; moreover, the most important mine, the Montgomery-Shoshone, was involved in litigation, which acted as





PANORAMIC VIEW OF THE BULLFROG HILLS FROM A POINT ABOUT 2 MILES SOUTH OF BEATTY.

The distant mountains to the left are the Grapevine Mountains, nearly due west of the observer; behind them is Death Valley. The hills geologically mapped on Plate I occupy the upper half of the panorama. Due north of the observer is Beatty, on Amargosa River, which appears also at the extreme right of the lower half of the panorama. East of the stream are the northern foothills of Bare Mountain. The relatively smooth, rounded hills in the foreground are composed of pre-Tertiary rocks.

an additional check on production. In the latter part of 1906 the Las Vegas and Tonopah Railroad reached the district, and by the middle of 1907 the Bullfrog Goldfield Railroad had been completed. Before the end of the year the Tonopah and Tidewater Railroad and the extension of the Las Vegas and Tonopah Railroad to Goldfield were in operation. Thus in a little over a year the new camp passed from desert isolation into the enjoyment of railway facilities superior to those of many long-established and highly productive districts.

With the completion of the railways the Bullfrog district began the shipment of ore and by the end of November, 1907, the Montgomery-Shoshone mine was producing ore and concentrates at the rate of about $150,000 a month, gross value. This fell off about half in the summer of 1908.

PRODUCTION.

Up to the end of the year 1906, as already stated, work in the district was confined mainly to prospecting and to blocking out ore. Prior to the beginning of that year the Montgomery-Shoshone, it is said, shipped about 100 tons of rich ore, the Original Bullfrog about 13 tons, and the Denver about 1,000 sacks. Small shipments were made in 1906 also from the Montgomery-Shoshone, Skookum-Bullfrog, Gibraltar, and Tramps groups of mines, but the amount is not recorded. During 1907 the production was 9,050 tons of ore, containing $132,428 in gold, $74,991 in silver, $112 in copper, and $7 in lead, a total of $207,538.[a]

TOPOGRAPHY.

The Bullfrog Hills (Pl. II) attain a maximum elevation of 6,095 feet above the sea, the highest point being about a mile beyond the northern boundary of the area covered by the detailed map. The hills, which are steep, rocky, and practically bare of vegetation, rise sharply from the gently sloping desolate plains that border them on the north and south. The marginal elevation of these plains ranges from about 3,300 feet on Amargosa River at Beatty to about 4,500 feet at Mud Spring, 4 miles north of Rhyolite, and the local relief of the hills is thus about 2,800 feet. Southeast of Beatty, Bare Mountain, which culminates in a peak 6,235 feet high, presents a steep southwest front to the Amargosa Desert and an eastern face almost as precipitous to an embayment of the same plain. On the north, however, the mountain, which is composed principally of schist, limestone, and quartzite, merges into hills (see Pl. II) which, in spite of the topographic break due to the Oasis Valley, are structurally and lithologically an eastern continuation of the Bullfrog Hills. To the

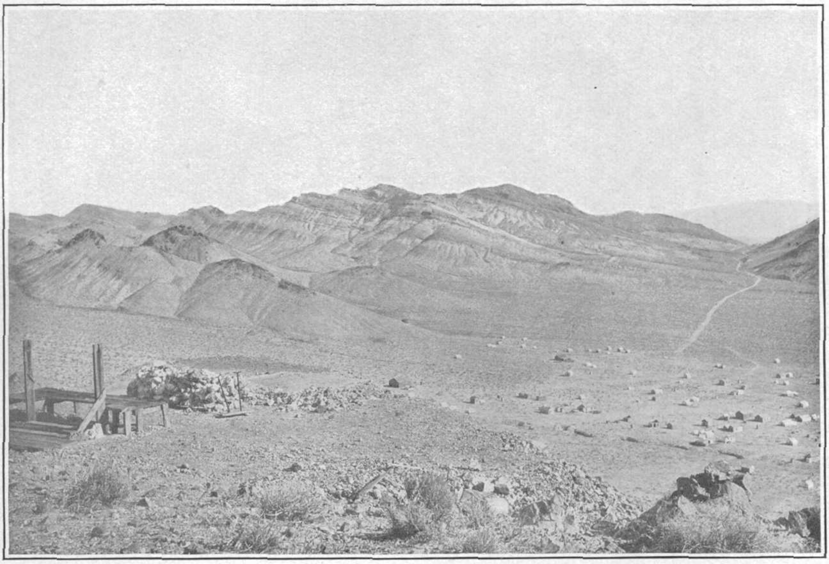
[a] Mineral Resources U. S. for 1907, pt. 1, U. S. Geol. Survey, 1908, p. 372.

west the Bullfrog Hills extend without any definite topographic or geologic break into the Grapevine Mountains.

The hills in the area particularly described in this report constitute a very irregular group, partly buried by the thick stony alluvium characteristic of the broad, undrained basins of arid Nevada. The upper limit of the alluvium, unlike that at Goldfield, is remarkably definite, and above it the rocky structure of the hills is laid bare to a degree highly satisfactory to the geologist. A view over the district from any commanding summit suggests at once that the region owes its main features to the cooperation of faulting and erosion acting on a thick series of lavas. Many of the ridges are obviously fault blocks, most of them tilted to the east, so that their western scarps show the horizontal banding of successive flows (see Pl. III), while their northeast faces exhibit merely the irregular pinnacles and ravines characteristic of the erosion of a dip slope of a single rock layer of generally homogeneous texture. Moreover, the individual white, gray, green, pink, brown, or black bands that represent the edges of different flows can never be traced far before they are sharply offset or cut off entirely in a manner that can be due only to faulting. The faults, accordingly, are not parallel but intersect one another, and it is evident that the irregularity of relief and the absence of continuous lines of parallel ridges and valleys are the visible expression of a complexly faulted structure. How far this expression is direct and how far it has been modified or transformed by erosion will be considered in another place. There are no perennial streams in the district except Amargosa River, but erosion, though fitful in its activity, proceeds at times with great energy, and the water that falls upon the hills undoubtedly accomplishes more erosive work than would the same quantity under the conditions prevailing in a humid country well covered with vegetation. The arid, stony slopes of the Bullfrog Hills (see Pl. II) are elaborately carved by running water, and Box Canyon, a mile west of Rhyolite, is striking testimony to the power of a stream that is probably active for only a few hours or a few days in the year.

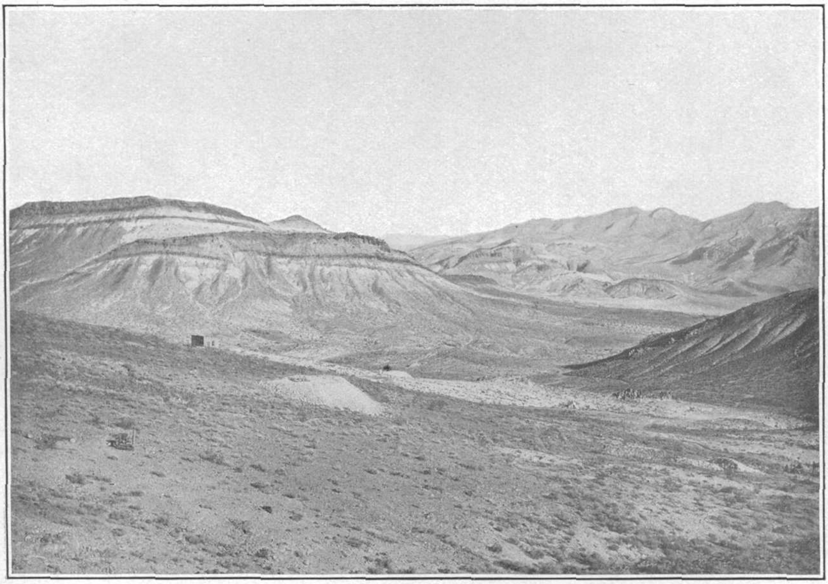
PRELIMINARY OUTLINE OF THE GEOLOGY AND ORE DEPOSITS.

The prevailing rocks of the area studied—the ones that give character to the topography and that contain the ore deposits—are rhyolitic flows of Tertiary age. Much older rocks, however, are exposed in the southwestern and southeastern parts of the district. These constitute a crystalline complex of quartz-biotite and quartz-muscovite schists, quartzite and quartz schist, marble, and injection gneisses, the last-named inclosing small masses of schistose greenstone derived from rocks originally of dioritic character. The complex as a whole represents ancient sediments (sandstones, shales, and limestones),



A. RAINBOW MOUNTAIN FROM THE HOBO SHAFT ON BONANZA MOUNTAIN.

The highest point is Black Peak, capped with quartz latite. The Montgomery-Shoshone mine is in the saddle to the right.



B. VIEW TO THE EAST FROM THE MONTGOMERY-SHOSHONE MINE.

On the left is Burton Mountain, in which rhyolites Nos. 11, 12, and 13 are repeated by a strike fault. The high hills to the right are part of Bare Mountain.

which have been crumpled and kneaded under high pressure and temperature in the zone of rock flowage. Remnants of a much less metamorphosed limestone, probably of Silurian age, rest in some places on the schist.

Probably more than one period of erosion was required to lay bare these once deeply buried schists. It is fairly safe to conclude that at the close of the extensive denudation to which western Nevada was subjected during Cretaceous time these schistose rocks with areas of the overlying Paleozoic limestone formed part of the worn surface over which the earliest Tertiary lavas spread. Although the schists now exposed in the district are found only in fault contact with the Tertiary rocks, there is little question that they are the fundamental terrane of the region and that, with some locally intervening Paleozoic limestone, they underlie the volcanic series of the Bullfrog district.

The Tertiary rocks, which have an aggregate thickness of at least 6,000 feet, cover most of the area and contain all the known ore bodies of importance. The greater part of the series is rhyolite, and sixteen successive formations of this rock have been recognized and mapped by Messrs. Emmons and Garrey. These formations are not necessarily individual flows. Some of them are really parts of a single thick flow, and others are certainly composed of several flows. Intercalated between the rhyolites are five flows of plagioclase basalt, one flow of quartz latite, some stratified tuffs, and finally, capping the series, a flow of quartz-bearing basalt. The effusive rocks are cut by intrusions of rhyolitic porphyry, plagioclase basalt, and leucite basanite. Most of the basalt dikes occupy fault fissures.

The Tertiary lavas and tuffs are generally conformable to one another, but at a few places slight erosional unconformity has been detected.

The entire series of volcanic rocks is divided by faults into a large number of blocks in each of which the flows are in general tilted to the east at angles up to 40°. The fault planes strike from northwest to northeast and dip generally to the west. The displacement, as a rule, is normal; that is, the hanging wall in each case has slipped down relatively to the foot wall. In consequence of this structure anyone traveling across the district from west to east will see the edges of the same flows repeated again and again in the successive western fronts of the ridges. To the production of this structure two types of deformation have contributed, according to Messrs. Emmons and Garrey. (See p. 82.) These were (1) a general tilting toward the east, such as would result from the development of a broad arch or monocline of which the eastern limb coincided with the Bullfrog district; and (2) step faulting with progressive downthrow to the west. The two processes were simultaneous and compensatory.

Their cooperation tended to minimize the actual vertical displacement of the flows from their original nearly horizontal position.

In that part of the district between Sawtooth Peak and Beatty the angle at which the flows are tilted is such as to carry them down toward the east more rapidly than they are brought up by the successive step faults. Consequently some of the older flows are here concealed and younger flows, not present in the western part of the district, make their appearance. East of Beatty, however, a fault of very great throw brings to the present surface the oldest of the rhyolite flows.

In addition to the dominant faults just referred to, there is another and possibly in part younger set, characterized by nearly northeast-southwest trends. In general the throws of the northeast faults are less than those of the north or northwest faults, but a few northeast faults show profound displacement. The northeast faults are particularly noticeable on the geologic map (Pl. I), owing to the manner in which they offset the outcropping edges of the various flows. The structural importance of the north to northwest faults is somewhat masked by the facts that they are in some cases partly or wholly covered by alluvium and are less numerous than those of the other system. The structure (see Pl. I) shows that under the band of alluvium between Bullfrog Mountain and Box Canyon must lie concealed one of the greatest faults in the district. Another important dislocation must be covered by the alluvium between Ladd and Montgomery mountains.

Most of the faults dip at high angles, but there are apparently two notable exceptions to this rule. The contact between the rhyolites and the pre-Tertiary rocks in the vicinity of the Original Bullfrog mine dips to the north at an angle of 18° to 20°. It is not well exposed but seems to be a plane of great disturbance. The various rhyolitic formations of Bullfrog Mountain dip to the east at considerable angles and are successively cut off at this contact. (See Pls. I and IX, *A*.) It is difficult to understand how normal faulting could take place on a plane so slightly inclined unless the displacement had a large horizontal component.

South of Beatty the relation of the Tertiary volcanic rocks to the pre-Tertiary metamorphic rocks is similar to that just described. The contact is probably a fault, although the actual exposures of it are not as satisfactory as could be desired. East of Beatty, however, the rhyolites are clearly faulted down against the limestones and quartzites of Bare Mountain. The fault here dips northward at angles between 50° and 65° and the rocks adjacent to the fissure are crushed.

In general, the rhyolites of the Bullfrog Hills appear to be bounded on the south by a nearly east-west fault or fault zone, which apparently has dropped them against a pre-Tertiary metamorphic terrane, forming the mass of Bare Mountain and exposed in a few low hills along the northern edge of the Amargosa Desert. The entire volcanic mass has been divided by other faults into numerous small blocks.

Many of the faults are accompanied by basaltic dikes. In some cases the dike fills the fault fissure and is not itself disturbed. In other cases the faulting is in part later than the intrusion, so that the dike has been fractured or crushed by the movement. A very common feature of these dikes is their lack of continuity, the basalt occurring here and there along a persistent fissure. This peculiarity is probably in part due to movements subsequent to the intrusion, but along many of the fissures the basalt appears to have been intruded only at intervals.

At no one place in the district is a complete section of the Tertiary lavas shown. This is not due to lack of exposures, but to the close spacing of the faults by which the country is dissected into blocks. Each flow or bed is, as a rule, exposed in two or more blocks, and since these partial sections can be correlated, it is possible by piecing them together to effect a restoration of the whole.

The deformation of the series by tilting and faulting was followed by extensive erosion, which sculptured the rocks into their present forms and has supplied the abundant débris now filling the valleys.

The ore deposits are for the most part nearly vertical mineralized faults or fault zones in rhyolite. Of the many faults shown in Plate I comparatively few have proved ore bearing, although it must be remembered that the district is undeveloped and that a number of the faults discovered in the course of the geologic mapping have not yet attracted the attention of prospectors. The presence or absence of mineralization bears no evident relation to the particular variety of rhyolite constituting the country rock and does not appear to be proportional to the degree of dislocation along the fissures, but apparently is governed mainly by locality. No ore is known, however, in any formation younger than rhyolite No. 12.

Most of the lodes are not simple veins, but are fissure zones containing numerous veinlets or stringers of vein material and in most cases showing no definite walls. The principal stringers are parallel with the sides of the lode as a whole, but they are linked by numerous irregular cross veinlets, and similar small stringers extend for varying distances into the country rock. The lodes range in width from a few inches to 10 or even 100 feet.

Originally the veinlets consisted of quartz and calcite carrying finely disseminated auriferous pyrite. The calcite, possibly associated in some places with other carbonates, varies in abundance. The larger stringers, such as those of the Hobo vein, at many places exhibit regular depositional banding or crustification. Many of the stringers are distinct fissure fillings, with a definite contact between them and their rhyolite walls. Examples of transition from vein filling to country rock, due to the silicification of the latter, are by no means lacking, however, although this process has not been carried to anything like the extent observable at Goldfield. Much of the quartz, including some good ore, has a fine granular texture and has in part been formed by the silicification of shattered or crushed rhyolite. Typical vein quartz, such as is characteristic of the gold veins of the Appalachians or Sierra Nevada or such as is found in the pre-Tertiary schists of the Bullfrog district, does not occur in the mines near Rhyolite, with the exception of the Original Bullfrog. The quartz is prevailingly fine grained, often of a porcelain-like texture, and is usually intercrystallized with calcite.

In the process of oxidation, which in most of the lodes has been facilitated by movements that have fissured or shattered the original filling, the crystals of pyrite are changed to specks of limonite, within which may occasionally be seen particles of native gold. The calcite is partly dissolved and partly changed to fragile cellular pseudomorphs of quartz. The development of earthy hydrous oxide of manganese is very characteristic of the oxidation of the calcitic veins of the district, and large portions of the lodes are made up of soft, dark, manganiferous earth, associated with residual masses of the original quartz and calcite and containing vugs and druses of secondary deposits of these two minerals.

All the ore thus far mined or opened is more or less oxidized and, as a rule, contains no sulphides. In the Original Bullfrog mine there is a little chalcocite, or copper glance, and in some undeveloped veins in the schists south of Beatty there are specks of galena, but the only sulphide thus far found in the other deposits is pyrite. Native gold, alloyed with various proportions of silver, is the only valuable constituent of most of the ores, although cerargyrite, or horn silver, is fairly abundant in the rich ore of the Montgomery-Shoshone mine. The gold is finely divided and is almost invariably found in the quartz, not in the calcite. Its characteristic association with little limonitic specks, representing oxidized pyrite, has already been referred to.

The ores, as sacked and shipped in the first year or two of activity, ranged from $100 to $700 a ton, but the deposits on the whole are very much lower in grade than those at Goldfield and the future of the district depends on the milling of material that will not average over $15 a ton.

The proportion of silver varies greatly in different mines, even when these are close together.

PART I.—GENERAL GEOLOGY.

By W. H. Emmons and G. H. Garrey.

PRE-TERTIARY ROCKS.

CRYSTALLINE METAMORPHIC FORMATIONS.

GENERAL DISTRIBUTION.

Bare Mountain, which lies to the southeast of the Bullfrog Hills, is composed largely of crystalline rocks, consisting in the main of quartzite, marble, and mica schists. In the Bullfrog Hills exposures of these rocks are restricted to the southern margin and in the area shown on the map (Pl. I) they occur at only two places, one about a mile south of Beatty and another south of the Original Bullfrog mine, these areas together covering only about 1 square mile. South of Beatty, in the southeast corner of the district, the structure of the schists is relatively simple, but in the area south of the Original Bullfrog mine pegmatite injections are so closely spaced that, in mapping on the usual scale, it is impossible to separate the pegmatite from the schists. To facilitate description the two areas will be discussed separately.

SCHISTS SOUTH OF BEATTY.

General character.—The crystalline rocks south of Beatty are in the main quartz-biotite schists, containing relatively thin bands of marble, and calcite-muscovite schists with subordinate bands of quartz-muscovite schists. The schists rest upon a quartzite equally metamorphosed and apparently belonging to the same series. The marble members of the series are much lighter in color than the quartz-biotite schists, are easily recognized, and may be followed along the strike for considerable distances. They furnish datum planes from which the structure of the rocks may in most cases be worked out and have been shown separately on the geologic map. The rocks are closely folded and as a rule dip northeastward.

Quartzite.—Quartzite is the oldest member of the series exposed in this locality, though it is quite possible that mica schists of greater age occur at horizons below the quartzite. The largest area of the quartzite forms the summit (elevation 3,640 feet) of the ridge 6,700 feet S. 40° E. of Blackcap Mountain, where it is brought into contact with the mica schist and limestone by a fault trending about northwest. The quartzite strikes nearly northwest and dips northeastward about 35°. East of this point, about 700 feet, it is again brought into contact with the mica schist by a fault trending northeast. To the west of this quartzite block are two smaller areas of quartzite overlain by mica schists in apparent conformity.

The quartzite is a grayish-brown rock with vitreous luster and is composed of small quartz grains of nearly uniform size, between which are a few flakes of biotite. The microscope shows that the quartz grains have been recrystallized and that their sawtooth boundaries are closely interlocking. A little muscovite has in places been developed between the grains. The rounded borders of the quartz grains remain only where they were partly protected by plates of mica. The undulatory extinction of all the quartz grains shows that they have been subjected to great strain. A little chlorite, rutile, and zircon are present. The quartzite is the metamorphosed product of a comparatively clean quartz sand too poor in alumina to form sufficient mica to give it a schistose structure. The muscovite, biotite, rutile, and zircon are of later age than the quartz and were formed during the process of metamorphism.

Quartz-biotite schist.—The quartz-biotite schist is the predominating crystalline rock and its thickness probably exceeds all other members of the series combined. The rock is dark gray, of satin-like luster in hand specimens, and appears to be composed almost entirely of flakes of black and white mica, whose parallel arrangement gives the rock a perfect schistosity. The microscope shows a great deal of quartz as small grains of nearly uniform size. In some varieties rounded grains of orthoclase, microcline, and sodic plagioclase are mingled with the quartz and in a few specimens calcite fills the interstices between the quartz grains. A considerable quantity of magnetite occurs in irregular patches, the longer axes of which lie parallel to the schistosity. A little rutile and zircon are present. Chlorite occurs as an alteration product of biotite. Certain layers of the biotite schist contain a few small garnets, which on microscopical examination prove to be greatly crushed and cemented together by biotite and muscovite. In the deformation of this rock the quartz grains, which are original, were rotated and oriented with the schistosity. The mica flakes, though occasionally bent, show much less deformation than the quartz, which proves that the quartz grains were rotated before the mica now surrounding them was formed and probably while they were embedded in clay.

Interbedded with the quartz-biotite schist are layers of quartz schist in which there is present a little muscovite but practically no biotite. In this rock the schistose structure is less developed than in the quartz-biotite schist. It is intermediate in composition between the latter and the quartzite, and in mapping has been included with the quartz-mica schist.

Marble and calcite schist.—The quartz-biotite schist grades also through calcite schist into nearly pure marble. On the south slope of the hill (elevation 3,520 feet) 6,200 feet S. 52° E. of Blackcap Mountain, three of these calcareous bands are present, one separated from the other by about 40 feet of quartz-biotite schist. The calcareous bands are long, thin lenses, usually from 5 to 40 feet thick, but at some places for a short distance along their strike thickening to nearly 100 feet. The schistosity is as a rule approximately parallel to the contacts of the quartz-biotite schist, though locally it makes considerable angles with them.

As a rule the rock which forms the calcareous bands is a gray or brown marble, nearly pure, in which the calcite grains are of nearly uniform size, a little less than 1 millimeter in diameter. There are a few flakes of white mica in this rock, but biotite is rare or absent. In places the marble grades into calcite schist by the addition of muscovite flakes, which are about 1 millimeter in diameter and have a parallel orientation, thus giving schistosity to the rock. Thin layers of calcite schist rich in quartz and biotite are locally present in the marble. The same minerals occur in the calcite schist as in the quartz-biotite schist, though there is much less biotite and considerably more calcite in the latter.

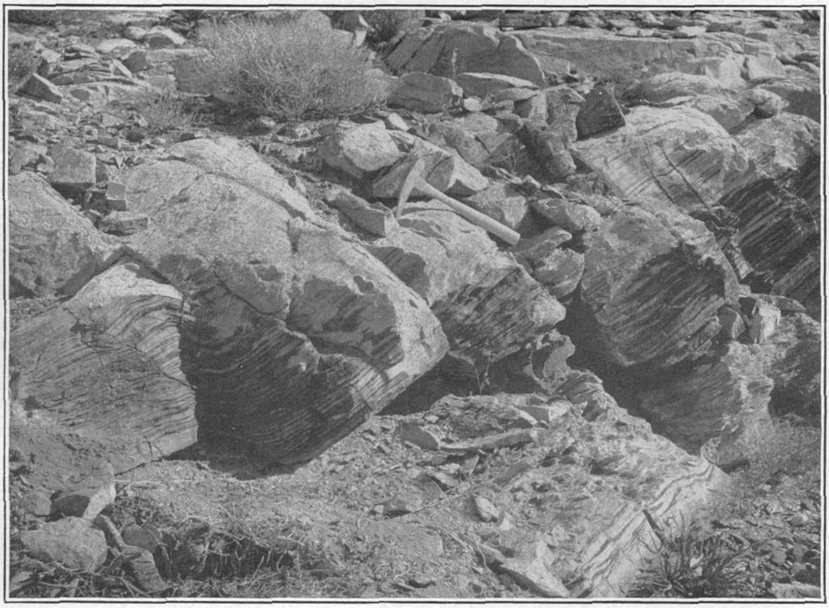
Pegmatite and quartz veins.—A few pegmatite veins and a larger number of quartz veins cut the schists. Such veins are most abundant in the more siliceous rocks and were not noted at all in the limestones. Most of these veins occur as rudely tabular bodies less than 2 inches wide, but a few of them have a width of several feet. These veins are represented both by quartz-filled fissures which run in various directions across the beds and by bunchy lenticular quartz veins parallel to the schistosity. They do not as a rule appear to be persistent in length and some of the outcrops are not much longer than they are wide. The pegmatite veins are composed of crystals of feldspar, quartz, and muscovite. Most of these crystals are less than an inch in diameter and many of them are shattered and crushed. Under the microscope orthoclase, microcline, and albite are seen to be present. The feldspars are closely interlocking with quartz and are for the most part of the same age, though small quartz veinlets, almost paper thin, cut the pegmatite. The pegmatite does not occur in rocks younger than the schists and is presumably pre-Silurian. The larger quartz veins, which are as abundant and more widely distributed than the pegmatite veins in the crystalline schist area south of Beatty, are composed almost entirely of quartz, but some of them contain a few paper-thin veinlets of white mica. These white quartz veins also carry a little galena in places. At one locality bunchy lenticular quartz veins in schist are distinctly cut by the pegmatite dikes. Quartz veins of the character of these in the crystalline schist area do not occur in the Tertiary lavas and accordingly, while there may be veins of different ages, all of them are probably pre-Tertiary.

Origin, stratigraphy, and age.—The schists south of Beatty are very clearly metamorphosed sandstones, shales, and limestones. When these sedimentary rocks were formed the conditions changed rapidly, so that thin beds of quartz sand containing a few rounded feldspar grains and some clayey material alternated with shales and limestone. The beds were metamorphosed under considerable pressure. The original quartz grains lost their rounded character and were cemented into a dense vitreous quartzite, in places squeezed to quartz schist. The shales, composed of clay containing numerous very small quartz grains and some iron oxide, were changed to mica schists, the character of the resulting schists depending on the proportion of quartz, clay, and iron compounds originally present. The pure limestones were recrystallized to marbles and those which contained more or less clay became calcite schists.

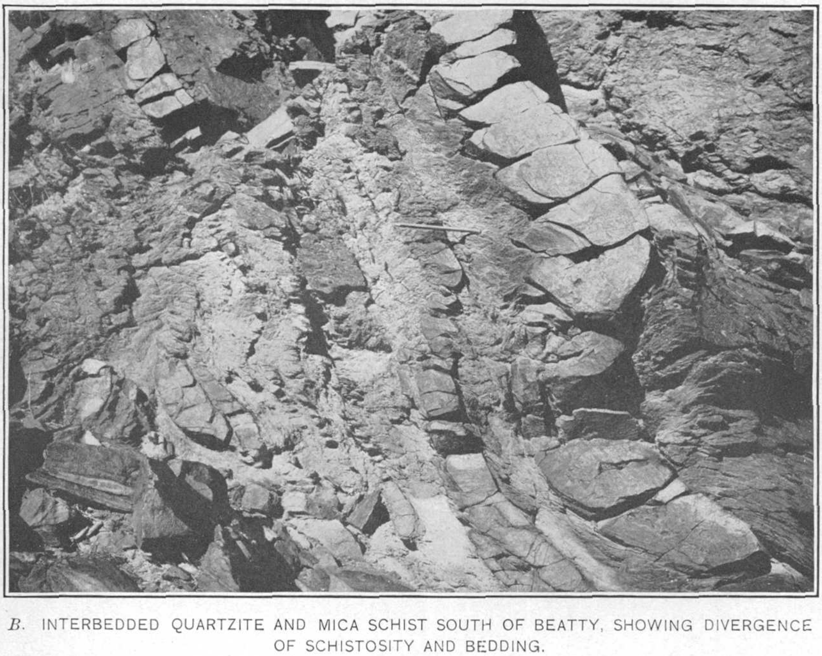
There was, so far as can be judged, very little addition of material to the sedimentary rocks in their metamorphism, but merely a partial chemical rearrangement of their elements to produce new minerals and a physical rearrangement of sand grains in the shales by which their longer axes were oriented in a nearly parallel direction and with the schistosity. In the more quartzose members, where there was only a little clay present, there was no such rearrangement of the quartz grains, since there was much less freedom of movement, a condition supplied by the softer clay.

The attitude of the metamorphosed series is defined at most places by the thin beds of included limestone and quartzite. (See Pls. IV, *A*, and V, *A*.) The usual dip is northeastward, but varies considerably, owing to the close folding to which the beds have been subjected. This is best shown on the summit of the ridge (elevation 3,640 feet) 6,700 feet S. 40° E. of Blackcap Mountain, just south of the border of the map, where a sigmoidal outcrop of one of the limestone layers indicates a narrow syncline pitching to the north. The predominant strike of the schistosity is to the northwest, approximately parallel to that of the bedding, and it dips at most places from 15° to 35° NE. In some places, however, the schistosity crosses the bedding, as is shown in Plate IV, *B*.

Overlying the schists there is a blue or buff limestone, not so much metamorphosed and less coarsely crystalline than the marbles of the schists. It has not been subjected to the close folding which has involved them, and is therefore younger, presumably Silurian,



A. METAMORPHOSED LIMESTONE IN SCHISTS 2 MILES SOUTH OF BEATTY.



B. INTERBEDDED QUARTZITE AND MICA SCHIST SOUTH OF BEATTY, SHOWING DIVERGENCE OF SCHISTOSITY AND BEDDING.

though no fossils were found at this place. The crystalline schists and the overlying limestone are faulted against the Tertiary rhyolites by the Amargosa fault, which is described on pages 74–75.

COMPLEX SOUTH OF THE ORIGINAL BULLFROG MINE.

General character.—The crystalline rocks south of the Original Bullfrog mine in the southwestern corner of the area of the special map are much more varied than those south of Beatty and record a more eventful geologic history. They include quartz-biotite schist, quartzite, and marble, which inclose small masses of sheared diorite or kindred igneous rocks. This complex is cut by pegmatite, which varies from bodies perhaps 100 feet across to paper-thin sheets that follow the cleavage planes of the schist. The pegmatite is also sheared and crushed, though not nearly so much as the rocks it cuts. Sheared rocks composed of quartz-biotite schist and pegmatite, in which the larger feldspars are drawn out into eyelike bodies, form augen gneiss. The pegmatite is in turn cut by veins of pure-white quartz, carrying a little pyrite. A quartz diorite dike cuts the crystalline rocks, and this in turn is cut by a diorite dike rich in hornblende. The schists are also cut by a branching dike of quartz porphyry which closely resembles the Tertiary lavas in general appearance and is probably of the same age.

Quartz-biotite injection schist, pegmatite, and augen gneiss.—Quartz-biotite injection schist, pegmatite, and augen gneiss form the larger part of this crystalline complex. The quartz-biotite schist is very much like that which occurs in the areas south of Beatty and like it is presumably metamorphosed shale. It is dark gray, with biotite as the most conspicuous mineral. The dip of the schistosity is from 40° to 60° E. At almost every outcrop there are light-colored layers of pegmatite composed of feldspar, quartz, and muscovite, paralleling the schistosity of the rock or in a few places crossing it. These vary from layers not much thicker than paper to those many feet across. Commonly a single sheet swells and narrows so as to appear in cross section as a number of lenses, joined end to end. Some adjacent pegmatite layers join, inclosing small, elongated masses of schist. Certain areas, some of them more than 100 feet across, are entirely pegmatite and in these the individual feldspars and quartz crystals are large, many of them several inches in dimension. The injections of pegmatite between the leaves are often closely spaced in the biotite schist and the resulting rock is finely streaked with thin alternating white and black layers of almost equal thickness. Where these layers are less closely spaced the rock becomes an injection gneiss. Figure 2 is a sketch of quartz-biotite schist which has been injected by pegmatite. In this sketch the very thin pegmatite bodies are not shown.

The schist, as seen under the microscope, is composed of quartz grains of nearly uniform size, rotated so as to lie nearly parallel with the cleavage and forming thin layers in places only one crystal thick. A little mica is associated with the quartz. Biotite is the more abundant mica and with muscovite occurs as overlapping scales, which together make almost continuous sheets alternating with quartz. Very subordinate amounts of magnetite, colorless garnet, rutile, and zircon are present. The pegmatite layers are a little thicker than the biotite or quartz layers and some of them are bounded on both sides by continuous layers of mica flakes, showing that the injection took advantage of the perfect cleavage of mica to enter the schists. Here and there rounded grains of orthoclase and sodic plagioclase occur among the quartz grains of the schist, but most of the feldspar is restricted to the pegmatite bands. The pegmatite consists of quartz, orthoclase, microcline, albite, oligoclase, and muscovite, with

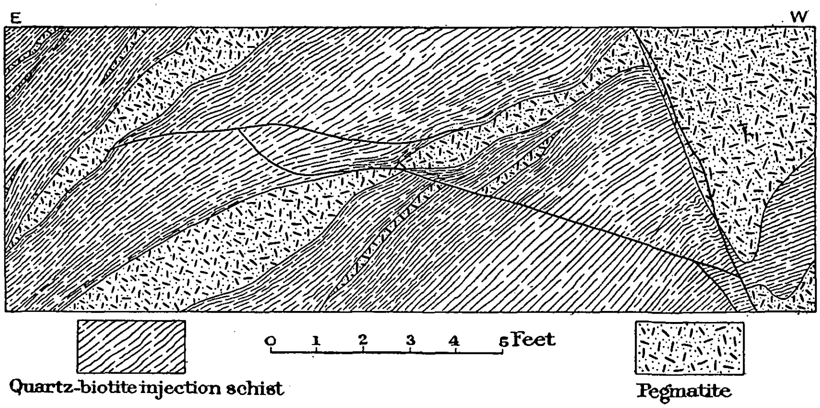


FIGURE 2.—Quartz-biotite schist cut by pegmatite. Many thin injections along the lamination of the schist are not shown. Sketch of the south side of a prospect pit south of the Original Bullfrog mine.

a little biotite, magnetite, and pyrite. The proportion of these minerals varies considerably in different places. The quartz and the feldspar crystals are much larger than those of the original schist and are more varied in size. They are closely interlocking and developed contemporaneously. At many places large crystals of feldspar up to one-half inch in diameter cause an appreciable swelling in the injection, especially where the pegmatite veins are narrow.

Quartz schist and quartzite.—Included within the quartz-biotite schist are layers or lenses of quartz schists and quartzite of about the same composition as those south of Beatty (see p. 20); but the quartz schist south of the Original Bullfrog mine has undergone greater metamorphism. In some of it the quartz grains have been mashed so that they are two or three times as long as they are thick, the longer axes lying in the direction of the schistosity. The quartzite and quartz schist grade into the quartz-biotite schist and are not con-

A. INTERBEDDED SCHIST AND QUARTZITE SOUTH OF BEATTY, SHOWING PARALLELISM OF SCHISTOSITY AND BEDDING.

B. SHALY VARIETY OF RHYOLITE NO. 1, WEST SLOPE OF SUTHERLAND MOUNTAIN.

tinuously exposed. They are not distinguished from the biotite schist on the map and the field evidence is insufficient for correlating them with the quartzite south of Beatty.

Marble.—About 200 feet S. 14° W. from the Big Bullfrog hoist there is a small outcrop of marble surrounded by quartz-biotite schist and by surface débris. The contact of the two rocks is not exposed, but the general appearance of the marble is much like that associated with the schist south of Beatty. It is much more coarsely crystalline than the overlying Silurian limestone presently to be described and it contains a little tremolite. It is presumably older than Silurian and probably belongs to the crystalline series.

Sheared diorite.—Just east of the Big Bullfrog shaft and trending N. 46° E. is an elongated area of a very dark schist which appears to be surrounded by quartz-biotite injection schist. A dike of the same material is shown in a prospect pit 250 feet S. 15° E. of the Big Bullfrog shaft. This dike has a trend of N. 5° E. and a dip of 35° E. Similar rocks occur at two or three other places lying loose upon the surface in the area of the crystalline schists, and it is probable that their distribution is more general than is indicated on the map. Under the microscope the rock is seen to be composed of hornblende, andesine, pale garnet, titanite, biotite, and zircon. Considerable quartz is present, but it is probably not original. The igneous rock has been subjected to the same kind of metamorphism that affected the sedimentary rocks, and has a well-developed schistosity. At no place was the sheared diorite observed in contact with the other schists, but it is presumably later than them and probably represents dikelike bodies that cut the sedimentary rocks from which the schists were formed.

Quartz veins.—Quartz veins are very numerous in the area of the crystalline schists. These vary in size from mere films to bodies several feet across. At most places they are pure, milky-white quartz, much like the quartz associated with feldspar and mica in the pegmatite. Veins of gray quartz and some of opalescent quartz are also present. They contain little or no calcite or other carbonates, such as are present in nearly all of the veins which cut the Tertiary lavas. The quartz veins in the crystalline area carry a little muscovite and magnetite and some of them inclose small masses of pyrite, which on the surface are in part oxidized. Some of these veins are said to contain a little gold, but none has been found rich enough to mine. These veins are not clearly separable from the pegmatites, as in one or two places pegmatite veins, 1½ feet or more wide, were seen to grade into massive pyrite, bearing white quartz with only an occasional small bundle of muscovite plates. The normal pegmatite, near where it grades into quartz, also shows the pyrite with oxidized borders, and this pyrite is in some places crystallized partly in the quartz and partly in the orthoclase feldspar. Possibly some of these veins are contemporaneous with the galena-bearing veins in the crystalline-schist area south of Beatty. The veins are undoubtedly not all of the same age, but some of them are younger than the pegmatite, since they cut both the pegmatite and the diorite dikes which intersect both the pegmatite and schist. The quartz in many of the most recent veins in the crystalline-schist area in the southwest corner of the district is of a grayish color. Under the microscope very minute quartz veinlets are seen to lie in the cleavage of crushed plagioclase of the pegmatite, showing that they were formed subsequently to the crushing movements.

Quartz diorite dike.—On the west slope of the low hill (elevation 4,020+ feet) in the southwest corner of the area studied a quartz diorite dike, trending a little east of north, cuts the schists and pegmatite. It is from 10 to 30 feet wide and is exposed almost continuously for about 1,800 feet. It is in turn cut by a more basic diorite dike and at the intersection its north end is offset toward the west. It is a light-colored, greenish-gray, fine-grained rock, containing a few small phenocrysts of hornblende. Under the microscope the texture is seen to be porphyritic. The rock is greatly decomposed and consists essentially of sericitized feldspar, in the main acidic plagioclase, intergrown with quartz, hornblende, and pyroxene. Much chlorite is present as a decomposition product of hornblende. Since this rock has no well-developed schistosity, it was presumably intruded into the schists after they were metamorphosed and it may be of Tertiary age.

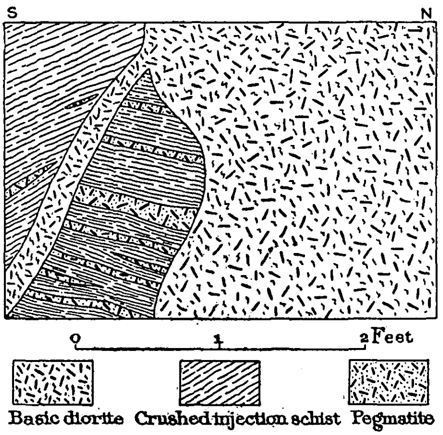


FIGURE 3.—Diorite intruding quartz-biotite injection schist and pegmatite; exposed in a prospect pit south of the Original Bullfrog mine.

Diorite dike.—A few feet south of the summit of the low hill (elevation 4,020+ feet) in the southwest corner of the area the schists, pegmatite, and quartz diorite dike are cut by a diorite dike, striking nearly due east and dipping about 50° N. Owing to the relation of its dip to the topography the outcrop curves northward at both ends, making a nearly semicircular band. The basic diorite is a dark-gray rock, relatively fresh, and contains many small crystals of hornblende and feldspar. Under the microscope it is seen to have a granular structure, and is composed of greenish-brown hornblende, oligoclase, orthoclase, quartz, apatite, titanite, magnetite, and zircon, with chlorite and calcite as alteration products. Hornblende constitutes about half the rock. The relation of the diorite to the schists and pegmatite is shown in figure 3. As shown by the map (Pl. I), the quartz diorite dike is offset or faulted by the basic diorite dike and is therefore the older of the two. Small quartz veinlets cut the diorite dike at several places.

SUMMARY.

The two areas of crystalline schists, one shown in the southeast corner and the other in the southwest corner of the special map, probably belong to the same general series of metamorphosed sedimentary rocks, but owing to the great metamorphism which they have undergone it is impossible to correlate them with certainty. Aside from the degree of pegmatization, the two series closely resemble each other lithologically. About a mile west of the northwest corner of the area shown on the Bullfrog map Silurian fossils were found in an unmetamorphosed limestone near and presumably overlying the crystalline series, showing that the folding and other processes of metamorphism took place in pre-Silurian time. The crystalline rocks must therefore be Ordovician or older. Briefly stated, their geologic history is as follows: A pre-Silurian series of shales and sandstones containing layers of limestone and intruded by basic igneous rocks was folded under such conditions as to develop very few fractures in the shales and limestones. At this time a well-defined schistosity was developed, at many places highly inclined to the original bedding planes. In both areas, but especially in the southwestern one, pegmatite was subsequently injected into the planes of schistosity and locally across them. Associated with this pegmatite, and probably of the same or slightly later age, are white quartz veins, probably of pegmatitic or igneous origin. After pegmatization the rocks were crushed and sheared again, but not so much as before, and quartz cemented the crushed minerals. Subsequently this complex was cut by a quartz diorite dike and later by a diorite dike rich in hornblende. Still later quartz veins cut the schists and diorites. The complex was also cut by a dike of quartz porphyry, probably in Tertiary time.

SILURIAN (?) LIMESTONE.

At two places in the area shown on the special map limestone overlies the crystalline schists. One of these is south of Beatty, where a long, narrow strip of limestone trending a little east of north is bounded on the west by the Amargosa fault. Another is just south of the Original Bullfrog mine and extends for about one-fourth mile northeast and southwest of it. A third area, 1 mile S. 83° E. of this mine, has a similar lithologic character and is probably of the same age; while a fourth outcrop is 2,500 feet S. 52° E. of Velvet Peak. Nearly everywhere this limestone is blue or buff and it is marbleized only where it is brecciated. The dense appearance distinguishes it from the more calcareous members of the crystalline rocks, which are everywhere crystallized to marble; muscovite, which is everywhere present in the latter, has not been noted in the younger limestones. On the south slope of the hill on which the Original Bullfrog mine is located several feet of soft red shaly material overlies the limestone and separates it from the Original Bullfrog vein quartz. To the east, near the Bullfrog Extension mine, this soft material is lacking but is probably equivalent in age to a much harder rock layer which resembles a silicified shale or a very fine grained dark-gray quartzite. The Bullfrog Extension shaft, which is inclined about 18° N., is driven practically on the dip of this dark-gray shalelike rock, which at this point appears to have a thickness of about 25 to 35 feet, as shown by its outcrops and by the cross section afforded by a shaft sunk through the shale about 200 feet northwest of the Bullfrog Extension mine.

Some 300 to 400 feet south and southeast of the Bullfrog Extension mine remnants of what appear to have been a quartzite layer are found between the shales and the bluish-gray, supposedly Silurian limestone. This quartzitic rock grades into the limestone below. Quartzite also overlies the limestone a mile S. 83° E. of the Original Bullfrog mine and has at its base gritty or conglomeratic beds. The exposed beds of limestone, quartzite, and gray shale are altogether probably less than 150 feet thick and on the map are all shown by the same pattern. The limestones are massive and the shales disturbed, but the strike of the contact as determined from exposures near the Original Bullfrog mine is N. 70° E. and the dip about 15° to 20° N. The sedimentary rocks strike more nearly east and dip at lower angles than the rhyolites lying to the north.

The limestone formation near the Original Bullfrog lithologically resembles one containing Silurian fossils, which outcrops about a mile west of the northwest corner of the area shown on the special map. These fossils were submitted to Mr. E. O. Ulrich, and his report on them is given below:

The lot of imperfect fossils collected near Bullfrog, Nev., submitted for determination, proved of unusual interest and importance. The fauna is unquestionably Silurian in age and the collection, though manifestly incomplete, is to be counted among the few far-western collections referred to this age that are sufficiently complete to make their age determination quite satisfactory. As a rule throughout the West the Silurian is underlain by much thicker deposits of Ordovician limestone, and the Silurian element of a section does not comprise more than from 50 to 100 feet at the top. If a quartzite—perhaps followed by a dark shale—overlies the limestone, both the quartzite and shale are likely to be of Devonian age.

Provisionally determined, the following genera and species are represented in the collection:

Cyathophyllum sp. near radiculum.
Streptelasma cf. spongaxis.
Streptelasma cf. conulus.
Omphyma cf. verrucosum.
Cystiphyllum sp. undet.
Stromatoporella sp. undet.
Heliolites interstinctus.
Calopœcia? sp. undet.
Cœnites sp. undet.
Cœnites sp. undet. (2).
Conchidium knighti?

The country is much faulted and the two outcrops of limestone could not be connected, but from general relations and similar lithologic character it is highly probable that the limestone overlying the schists is Silurian and that the quartzite and shale may be Devonian, but it is unsafe to make the correlation on lithologic grounds alone in this area, where faults of great throw are numerous.

TERTIARY VOLCANIC ROCKS.

LAVA FLOWS AND TUFFS.

INTRODUCTORY STATEMENT.

The stratiform Tertiary volcanic rocks include a great variety of eruptives, some of which are repeated many times in the series. There are sixteen rhyolite flows, five basalt flows, one flow of quartz latite, and one of quartz basalt. Sedimentary tuffs occur at two horizons between the flows. The general sequence is shown in the columnar section of figure 4. In the field the contrast between the different types is very sharp and in most instances the contacts between different formations of the same type are well marked. By the method of treatment followed here the earliest flow is described first and the succeeding flows are taken up in order of their age. Thus the descriptions of the five basalt flows are interspersed between the descriptions of rhyolites each at its appropriate place, as determined by its age relations—after the formation upon which it rests and before the formation which overlies it. Flows of the most basic type are shown to follow the flows of the most acidic type, and this sequence has taken place five times near the close of the period of the Tertiary eruptives; quartz latite and subsequently quartz basalt followed the fifth eruption of basalt.

GENERAL CHARACTER OF THE RHYOLITES.

The rhyolites of the Bullfrog district are in the main flows and flow breccias. They are nearly related mineralogically and chem-

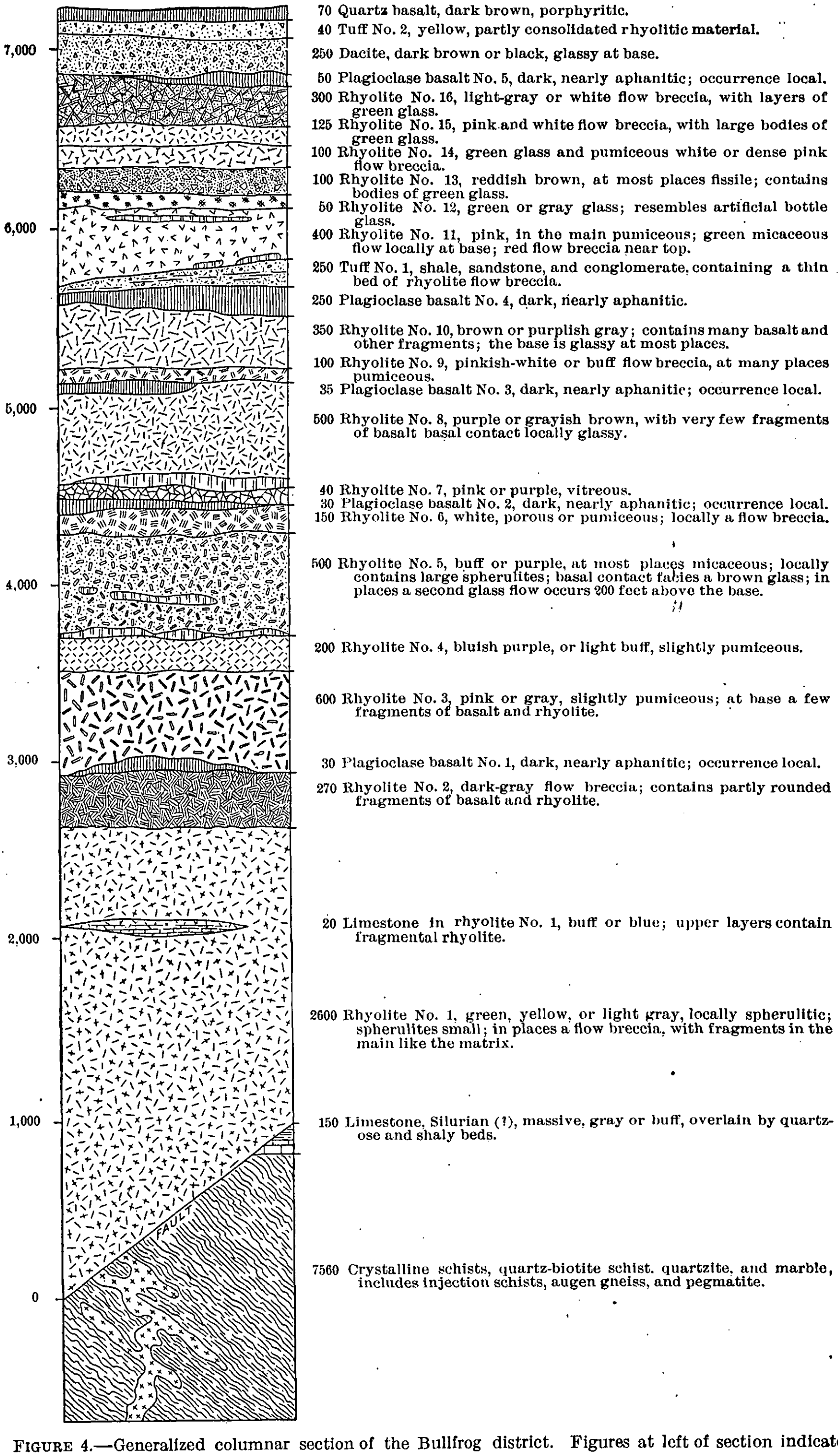


FIGURE 4.—Generalized columnar section of the Bullfrog district. Figures at left of section indicate scale in feet. Figures at right indicate thickness in feet.

ically, as is shown by petrographic examination and by the following partial analyses of material taken from widely separated horizons:

Partial analyses of rhyolite flows of the Bullfrog district.

[G. Steiger, analyst.]

Locality.	No. of rhyolite flow from base.	Reference in this paper.	SiO_2.	CaO.	Na_2O.	K_2O.
		Page.				
North slope Bullfrog Mountain	5	39	75.35	0.65	3.52	5.26
West slope Velvet Peak	(a)	44	73.71	1.20	3.35	3.01
Southeast slope Busch Peak	8	43	77.26	.58	2.96	4.65
West slope Burton Mountain	12	51	71.60	1.90	3.30	4.22

[a] Glass at base of 8.

The flows may be readily distinguished one from the other by differences in color and structure, or by the character of fragments contained, and less readily by slight mineralogical differences. The sixteen rhyolite formations shown on the map do not all represent individual flows, nor does the interpretation of the geologic history of the region necessitate as many divisions as have been made. The units mapped, however, are those which may with practice be recognized in the field and which therefore are most useful in working out the geologic structure. The individual flows range in thickness from 20 feet or less to about 2,600 feet. Some of them wedge out or become thin, but most of them are persistent throughout the area. The combined thickness of the sixteen formations is more than 6,000 feet. S. H. Ball[a] regards the rhyolites as early Miocene, but the evidence for this conclusion is not so complete as is desirable.

GENERAL CHARACTER OF THE BASALTS.

Six flows of basalt are interbedded with the rhyolites and tuffs. The first five are ordinary plagioclase basalts so nearly alike, both in appearance and in mode of occurrence, that it is impossible to distinguish them one from the other, except on stratigraphic evidence gained by the association of recognized rhyolite flows. These basalt flows are hardly so persistent in occurrence as the rhyolite flows, nor do they attain such great thicknesses. The plagioclase basalt flows are interbedded with the rhyolite flows and are therefore of contemporaneous age. Basalt No. 6 is a quartz-bearing plagioclase basalt and is the youngest lava flow of the series.

[a] Ball, S. H., Bull. U. S. Geol. Survey No. 308, 1907, Pl. I.

DETAILED DESCRIPTIONS.

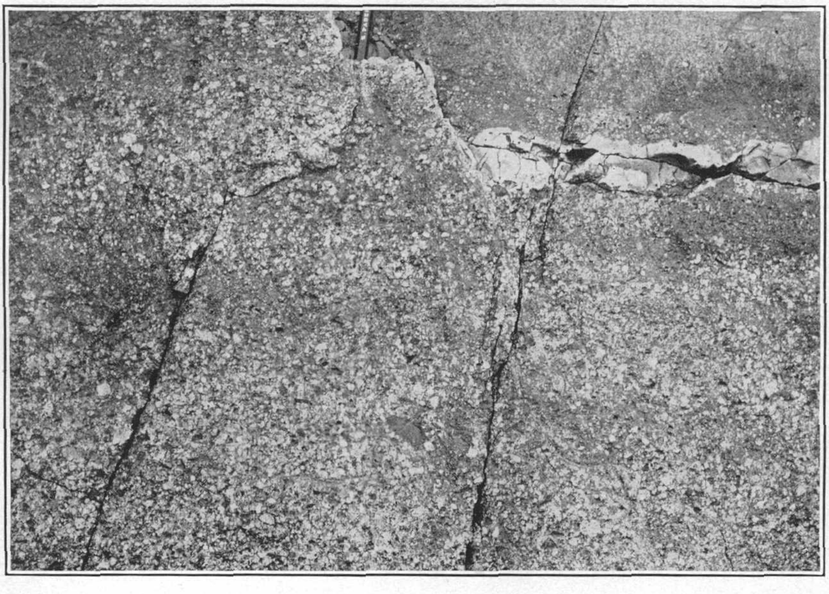
RHYOLITE No. 1.

Occurrence and distribution.—Rhyolite No. 1 is the lowest member of the series of Tertiary volcanic flows exposed within the Bullfrog area. All its visible contacts with the Paleozoic limestone and with the crystalline schists are due to faulting, and search outside of this area has failed to reveal the original base of the volcanic series. So far as known, there is no other flow below rhyolite No. 1, and it may rest directly upon the limestone or in part upon the crystalline schists. In the southeast corner of the area mapped a small block of Paleozoic limestone is faulted up into this rhyolite in such a manner as to suggest that the two formations occur close together in the geologic section there and that probably no great thickness of Tertiary rocks ever intervened between them. Rhyolite No. 1 is well exposed in Box Canyon, where it covers an area of more than 1 square mile. It forms the hills just west of the mouth of the canyon and probably underlies the flat to the north. It is also the rock of the low hills west of Sawtooth Mountain and occurs a few rods northwest of the Original Bullfrog mine. In the southeast corner of the area mapped there are several blocks of rhyolite No. 1 that are entirely surrounded by fault contacts with other rocks. A similar fault block occurs northeast of Beatty, just outside of the area mapped. The maximum thickness of the formation is probably not much greater than 2,600 feet. This, however, is only an estimate, since the base of the formation is not exposed.

General character.—Rhyolite No. 1 is a series of flows which includes a thin bed of limestone. The flows, though all of about the same chemical composition, vary considerably in texture and appearance. In color they are green, yellow, and light gray. The groundmass is fine grained or glassy and at most places contains phenocrysts of dull or glassy feldspar, quartz, and mica and rarely a crystal of hornblende. Feldspar is by far the most abundant and in certain facies quartz phenocrysts are entirely wanting. Where there are few quartz phenocrysts the groundmass is, as a rule, spherulitic and in places the rock is made up almost entirely of spherulites. These are uniform in size and appearance and where the material between them has weathered out they resemble small peas. None of the spherulites are more than one-fourth inch in diameter.

In some places the rhyolite is a flow breccia, the fragments being for the most part of the same material as the matrix. Fragments of basalt, which are abundant in the overlying flow breccia, are here very rare. The inclosed rhyolite fragments are, as a rule, small, but are never rounded. At many places these fragments are bright green and contrast strikingly with the dull, greenish-gray matrix.

A. APPARENT BEDDING IN RHYOLITE NO. 1, NORTHWEST OF BUCK SPRING.



B. NEARER VIEW OF PART OF PLATE VI, *A*, SHOWING ARKOSE-LIKE TEXTURE, DUE TO CLOSE CROWDING OF FELDSPARS.

The commonest variety is massive, slightly porphyritic rhyolite, but locally the rock is so finely banded and of such fine grain that it may be readily mistaken for shale. This resemblance is increased by a perfect parting between the bands on weathering, as is shown in Plate V, *B*. More massive layers of rhyolite are associated with the fissile variety, grading into them and dipping in the same direction. These layers are composed of a dense groundmass containing phenocrysts of feldspar, which are concentrated along parallel planes in such a manner as to give the appearance of an arkose sandstone (see Pl. VI, *B*)—a texture which is most typically developed in the gulch west of Sawtooth Mountain. The apparently shaly or sandy rhyolites, as a rule, dip eastward with other rhyolite flows. In Box Canyon there are several irregular bodies of the fissile rhyolite up to 20 feet in diameter, inclosed by the usual porphyritic variety of rhyolite No. 1. These appear to be blocks broken off by movement in the lava before it solidified.

Microscopical character.—In the normal facies of rhyolite No. 1 the texture is porphyritic and the groundmass exceeds the phenocrysts in volume. The larger phenocrysts are orthoclase, plagioclase, embayed quartz, and biotite, with very rarely a crystal of hornblende. All of these, except quartz, show crystal outlines. Smaller grains or crystals of magnetite, microcline, and apatite are present. The phenocrysts of orthoclase, which are most abundant, are partly altered to kaolin. The plagioclase is albite or oligoclase. Chlorite, serpentine, limonite, and sericite occur as aggregates, resulting from decomposition; calcite is very abundant as a secondary mineral, formed presumably in the process of weathering.

The groundmass is glassy or microcrystalline and the glassy varieties are in most cases devitrified. At many places the groundmass is made up almost entirely of spherulites. These are small spherical bodies, from 1 to 4 millimeters in diameter, composed largely of glass that contains a great number of minute rods of quartz and feldspar radiating from the center of the sphere. In some there is a shell of chloritic material near the surface of the spherulite, through which the radial rods pass. The spherulites completely or partly inclose phenocrysts of feldspar and biotite, but the large embayed quartz phenocrysts present at many places in this flow are not found in the most spherulitic varieties.

The banded fissile shaly rhyolites have a groundmass of brown glass inclosing microscopic phenocrysts of quartz and feldspar; the arkose-like beds have a glassy or indistinctly spherulitic groundmass, containing phenocrysts of the same minerals that are visible to the naked eye. The phenocrysts in this facies are concentrated in thin sheets parallel to the apparent bedding, giving the rock the banded appearance which is its most striking characteristic in the field. The bright-green color of the fragments in the brecciated varieties is due to a more nearly complete chloritization of their ferromagnesian constituents.

Limestone in rhyolite No. 1.—A thin layer or member of blue or buff limestone occurs at a few places in rhyolite No. 1. One exposure is about one-half mile north-northwest of Bullfrog Mountain, and another is on the east slope of the hill one-third mile northwest of Buck Spring. The layer is from 10 to 30 feet thick and dips eastward with the rhyolite. The upper part is thin bedded and contains fragmental rhyolite material, so that in a few localities these beds are almost indistinguishable from the arkose-like rhyolite which lies above them. The limestone is about 500 feet below the top of rhyolite No. 1.

Under the microscope the limestone appears finely crystalline, and it contains, besides calcite, minute dark opaque bodies, which may be organic material. Chalcedonic silica is segregated in small bodies throughout the rock.

The limestone was probably laid down in a shallow basin during a period of relative quiescence between the time of the outpouring of the rhyolite flows which occur below and above. The three outcrops mentioned are probably portions of the same bed.

Age and origin.—The first rhyolite is the earliest Tertiary formation exposed in the area mapped. It records at least two outpourings of lava, separated by a period of time long enough for the formation of 30 feet of limestone; this period was not necessarily great, for limestone may be formed in shallow basins at a relatively rapid rate. The rhyolites below and above the limestone are indistinguishable in the field and in the laboratory, and it is probable that similar conditions of eruption and cooling prevailed during the formation of the flows. The broken rhyolite fragments in the flow-breccia facies are of the same material as the matrix and show that movement of the lava continued after solidification had begun. The planes of fissility which separate the shaly or sandy layers are not to be regarded as the limits of separate flows. The banding was probably caused by a spreading out of local concentrations of phenocrysts of quartz and feldspar by the motion of the cooling and still liquid or viscous lava before complete solidification took place. Since the eruption of rhyolite No. 1 it has been tilted so that it now dips eastward at angles up to 40°.

RHYOLITE No. 2.

Occurrence and distribution.—Rhyolite No. 2 lies above rhyolite No. 1 and is conformable with it in dip. It is generally overlain by rhyolite No. 3, though there is in some places a flow of basalt between. Rhyolite No. 2 outcrops on the southwest slope of Bullfrog Mountain, just north of the Original Bullfrog mine (see Pl. I), where it is in contact, by faulting, with Silurian (?) limestone. It occurs also on the lower parts of the slopes of Sawtooth Mountain and on the peak just south of it, and thence extends eastward for a few rods beyond the bottom of Box Canyon. There are no other outcrops of this rhyolite in the Bullfrog area. In the mountains to the east of Box Canyon it is either wanting or is covered by more recent flows. The thickness of this formation west of Bullfrog Mountain is about 400 feet.

General character.—Rhyolite No. 2 is a flow breccia—that is, a lava which in flowing has gathered up fragments of its own congealed and broken crust or fragments of other rocks. The rock is dull purplish gray, grayish white, or dull pink and contains many fragments of various kinds. The matrix has an aphanitic groundmass, which does not appear glassy in hand specimens. It contains inconspicuous phenocrysts of dull white feldspar, quartz, and mica. Most of the fragments, some of which are partly rounded, are less than 2 inches in diameter and consist of basalt, rhyolite, and dark glass. Most of them are distinctly darker than the matrix. Though they occur persistently throughout the formation, they are most abundant near its base. The character and quantity of fragments distinguish this flow from those below and above it.

Microscopical character.—The texture of the matrix is porphyritic, the phenocrysts being orthoclase, quartz, oligoclase, biotite, and apatite. These are embedded in a glassy or partly devitrified groundmass which exhibits lines of flow suggesting an eutaxitic texture. Calcite is abundant in some thin sections. The matrix contains fragments of spherulitic rhyolite, brown glass, devitrified porphyritic rhyolite, and basalt. The rhyolite fragments are very similar to and were probably derived from rhyolite No. 1, which lies below this flow. The basalt fragments have a groundmass in which the parallel arrangement of the small feldspars shows flowage. The phenocrysts are plagioclase, altered olivine, magnetite, and biotite. The embedded fragments are generally more decomposed than the matrix.

Age and origin.—This rhyolite flow breccia was erupted after rhyolite No. 1. The fragments are very largely pebbles or detrital material which it picked up as it flowed along the surface. Much of this material came from the earlier rhyolite (No. 1) over which it flowed. The basalt fragments are not unlike the plagioclase basalt flows of the Bullfrog area (Nos. 1 to 5), but since the earliest basalt flow known in this district lies above rhyolite No. 2, the basalt pebbles must be from a still earlier though similar basalt flow, which has been eroded or is now covered up by later formations. The abundant foreign material in this flow breccia shows that there was a period of erosion between the extrusion of the first and second rhyolites.

Apparently rhyolite No. 2 was spread upon a nearly level surface, but it has since been tilted so that it now dips steeply toward the east.

PLAGIOCLASE BASALT No. 1.

Occurrence and distribution.—The earliest basalt flow exposed in the Bullfrog area occurs above rhyolite No. 2 and below rhyolite No. 3. It outcrops on the slopes of the peak south of Sawtooth Mountain, where it forms the conspicuous dark faulted band visible from the flat northeast of the Original Bullfrog mine. West of the summit of this mountain this flow is about 40 feet thick, but it thins rapidly toward the north and there is only a small isolated remnant on the west slope of Sawtooth Mountain. Plagioclase basalt No. 1 dips eastward with the associated rhyolites.

Petrography.—Basalt No. 1 is a very dark, rather weathered rock, which is almost aphanitic but contains a few red or green specks of altered olivine. In places it is vesicular, especially near the base, and the vesicles as a rule are filled with light-colored secondary minerals. Basalt No. 1 closely resembles later plagioclase basalts and can not be distinguished from them lithologically. Its identification depends, therefore, on its association with certain rhyolite flows. Microscopical study shows no essential differences between the plagioclase basalts. A description of basalt No. 3, based on the examination of fresher and more abundant material than was available for the study of basalt No. 1, is given on page 44.

Age and origin.—Basalt No. 1 probably represents a single flow that followed closely the intrusion of the flow breccia, rhyolite No. 2, which lies below it. The flow breccia has a nearly uniform thickness below every exposure of the basalt and apparently no erosion occurred between the two eruptions. There was, however, some erosion after the basaltic eruption, for the isolated remnants of basalt above the flow breccia indicate that it was once more extensive and was removed in part before the outpouring of the third rhyolite.

RHYOLITE No. 3.

Occurrence and distribution.—Rhyolite No. 3 lies conformably above the first basalt. On the south slope of Bullfrog Mountain and on the west slope of Sawtooth Mountain basalt No. 1 is wanting, and rhyolite No. 3 rests upon rhyolite No. 2. Rhyolite No. 3 forms the summit and most of the south spur of Sawtooth Mountain and covers a large area to the northeast of this peak, but does not extend eastward far beyond the bottom of Box Canyon. On the west slope of Sawtooth Mountain rhyolite No. 3 is broken by northeast-southwest faults into several blocks, which are successively depressed to the northwest. On the west slope of Sawtooth Mountain its thickness is about 750 feet, but it thins to the west and on Bullfrog Mountain is probably not more than 500 feet thick. It dips east with the other lavas.

General character.—Rhyolite No. 3 is a slightly pumiceous or vesicular pink, light-brown, or light-gray rock, which contains phenocrysts of feldspar, quartz, and black mica. The basal part of the sheet contains a few small dark fragments of rhyolite and basalt and by reason of this resembles rhyolite No. 2 in color and texture, but the inclosed fragments are smaller and less abundant. The two rhyolites, if they were not separated by the basalt flow on the peak south of Sawtooth Mountain, might be considered a unit. The upper part of the sheet is, as a rule, a darker pink or brown than the basal part and shows flow lines. Narrow lenticular cavities from 1 inch to 2 inches long and one-eighth inch thick occur throughout the upper half of the formation. These are bubbles or vesicles drawn out by movement during the cooling of the lava. Many of them are filled with chalcedonic quartz.

Microscopical character.—In this rock, which is porphyritic, the groundmass greatly exceeds in volume both phenocrysts and fragments. It is glassy, in places pumiceous, but nowhere spherulitic, and is only slightly devitrified. The phenocrysts are quartz, orthoclase, plagioclase, magnetite, biotite, and apatite. Plagioclase, though less abundant than orthoclase, occurs in larger phenocrysts, some of them with a length of 3 millimeters. They range in composition from albite to sodic andesine. Biotite is fresher than in the rhyolite previously described, and quartz is not so much resorbed.

Age and origin.—Rhyolite No. 3 represents one or more lava flows that followed the extrusion of basalt No. 1. The time intervening between the two eruptions was probably short, but was long enough for the partial erosion of basalt No. 1.

RHYOLITE No. 4.

Occurrence and distribution.—Rhyolite No. 4 lies conformably above rhyolite No. 3 and under the basal glass of rhyolite No. 5. It occurs just west of the summit of Bullfrog Mountain, which its rudely semicircular outcrop partly incloses. It is also exposed on the west slope of Sawtooth Mountain, where it is faulted into several short overlapping blocks. Its exposures are confined to these localities. It is approximately 200 feet thick on Bullfrog Mountain and somewhat less than that on Sawtooth Mountain.

General character.—This rhyolite is in most places bluish purple or light buff, but locally may be almost white. It is slightly pumiceous and consequently its surface is dull and spongy. It is as a rule nearly aphanitic, but a relatively rare facies shows a considerable number of phenocrysts. Of these, quartz and glassy feldspar are the most abundant; black mica and magnetite occur sparingly.

Included fragments are rare and those present appear to be of the same composition as the matrix. The most pumiceous portions appear as blotches, surrounded by denser or lithoidal rhyolite. The blotches appear to be mainly due to the development of a vesicular texture in place, but some of them may be included fragments of a more pumiceous rhyolite.

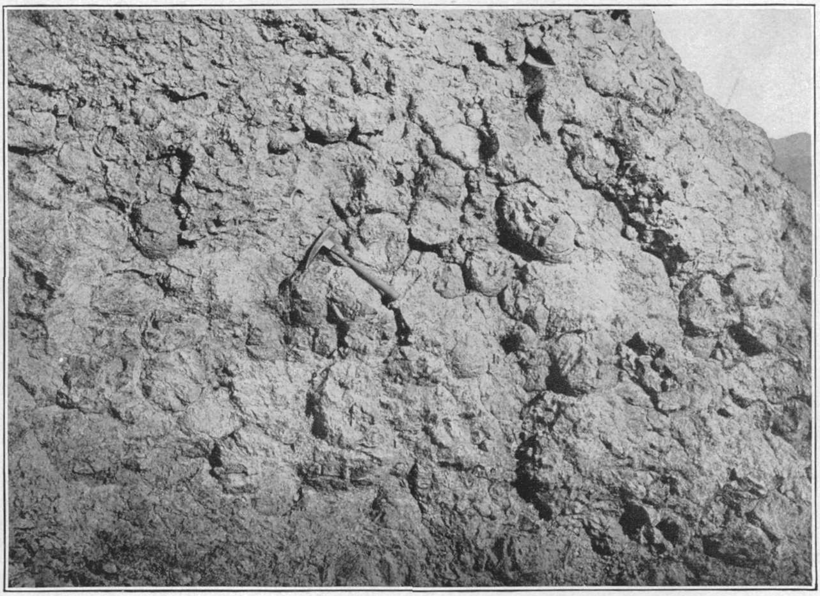
Microscopical character.—The groundmass, which exceeds the phenocrysts in volume, is usually devitrified and contains minute particles of quartz, feldspar, magnetite, and biotite. The biotite, however, is not conspicuous in hand specimens. Some of the microphenocrysts may be due to incipient devitrification, but most of them are probably original. The groundmass also incloses larger phenocrysts of the same minerals. Of these, quartz is more abundant than orthoclase and plagioclase is less abundant than either. Rhyolite No. 4 is more porous than the upper portion of rhyolite No. 3 and is consequently more decomposed. Biotite is magmatically altered and is replaced by minute crystals of magnetite. Small fragments of the same composition as the matrix are present in some parts of the flow.

RHYOLITE No. 5.

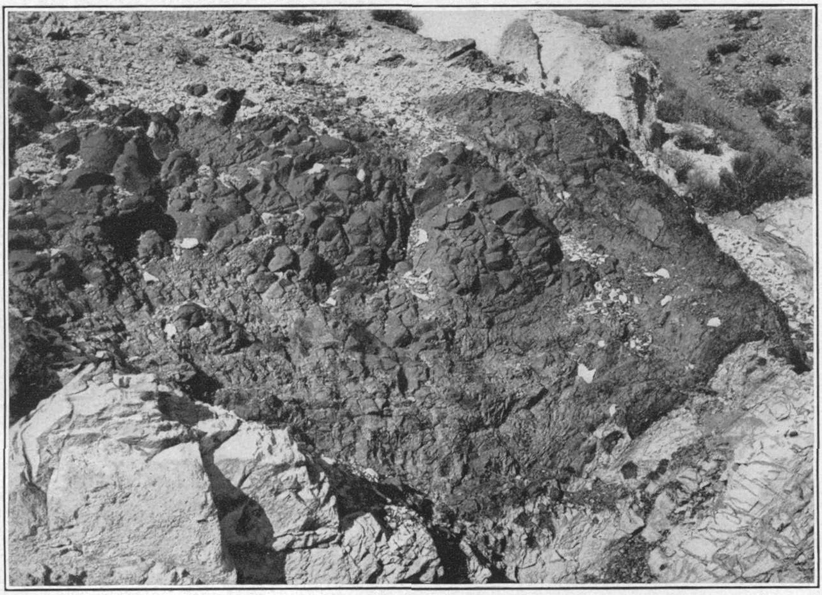
Occurrence and distribution.—Rhyolite No. 5 forms the summit of Bullfrog Mountain (see Pl. I) and, dipping east nearly with the surface, covers a large part of the north and south slopes. It also forms the summit and most of the east slope of Sawtooth Mountain. It becomes thicker to the east and is exposed over almost the entire southeast slope of Sutherland Mountain for a vertical distance of 800 feet. On Ladd Mountain it is the buff to pale purplish-gray rock that lies below the conspicuous white layer on the west slope. (See Pl. XI, *A*.)

General character.—Rhyolite No. 5, though presenting several facies, usually has characteristics that distinguish it from the other rhyolites. At Bullfrog Mountain it is a compact purple rock, at many places containing rhyolite fragments which are slightly pumiceous and of lighter color than the matrix. Quartz, glassy feldspar, and black or bronze mica phenocrysts are present. In some varieties mica phenocrysts are very abundant and serve to distinguish this rock from all other rhyolites in the district.

The lower part of the formation is exposed only on Bullfrog Mountain and on the south slope of Sawtooth Mountain. At both localities a band of brown glass, with a maximum thickness of about 20 feet, forms the base of the flow. Near the summit of Sawtooth Mountain a similar glass occurs about 200 feet above the base. These glass bands are at most places distinct and easily recognized and are convenient horizons for tracing boundaries and faults. The glass is of approximately the same chemical composition as the more



A. SPHERULITES IN RHYOLITE NO. 5, ON SAWTOOTH MOUNTAIN.



B. AN INCLUSION OF BASALT IN RHYOLITE NO. 6, IN THE SADDLE BETWEEN SUTHERLAND MOUNTAIN AND BUSCH PEAK.

crystalline rhyolite, but contains fewer phenocrysts. In some varieties the groundmass constitutes as much as 90 per cent of the rock.

Spherulites are common in rhyolite No. 5. They are numerous at the base of the west slope of Ladd Mountain and on the summit of Sawtooth Mountain (Pl. VII, *A*), but are most strikingly developed east of Beatty, about one-half mile beyond the eastern border of the area mapped. A few occur on Bullfrog Mountain, but they are rare on the slopes of Sutherland Mountain. The spherulites are globular rhyolitic bodies, commonly from 2 to 12 inches in diameter, but some of them are much larger; for example, some of those east of Beatty are 3 or 4 feet in diameter. They are, as a rule, purplish gray, though brown when in the basal glass, and do not differ markedly from the lithoidal facies in color and texture. Only when the rock is slightly weathered is the bounding surface of the sphere conspicuous. Southeast of Sutherland Mountain rhyolite No. 5 is nearly aphanitic, dense, and of a light-buff tint. Toward the west and south this facies grades into the purple micaceous facies.

Distinguishing features.—The formation is so variable in appearance that it is likely to be confused with other rhyolites. It is distinguished from rhyolite No. 1 by its fresher aspect, by the greater size of its spherulites, and at some places by the presence of many large, dark mica phenocrysts, which are never abundant in the older rhyolite. It differs from rhyolite No. 3 in having locally a spherulitic crystallization and more and larger crystals of biotite. Small fragments of basalt, such as occur at places in rhyolite No. 3, are rare or wanting in rhyolite No. 5.

Microscopical character.—The rock is porphyritic; the groundmass is glassy, in some places microspherulitic, in many macrospherulitic. The spherulites contain macrophenocrysts, though hardly as many as the lithoidal portions of the rock. Where not spherulitic, the groundmass is, as a rule, composed of minute alternating light-brown and colorless bands of glass, which curve around the phenocrysts and around the few angular rhyolite fragments that are present, suggesting an eutaxitic texture. The phenocrysts are orthoclase, biotite, quartz, albite, oligoclase, and magnetite. They are similar in size and character to the phenocrysts of the other rhyolites, with the exception of the biotite crystals, which are, as a rule, much larger and more numerous. Orthoclase is commonly more abundant than all other phenocrysts. Magnetite is relatively rare. The phenocrysts are comparatively fresh; orthoclase is slightly kaolinized; mica is in some places altered; chlorite and calcite are present in a few sections. A partial analysis of a specimen from the lithoidal portion of this flow is the first one given in the table on page 31.

The basal glassy contact facies under the microscope shows a groundmass similar to that of other facies, but is more largely glass, is of a darker color, and contains fewer phenocrysts.

Age and origin.—Rhyolite No. 5 consists of two or more lava flows, which followed closely the eruption of rhyolite No. 4. The glassy layers are not distinct eruptions, but are the rapidly cooled basal parts of successive flows.

RHYOLITE No. 6.

Occurrence and distribution.—Rhyolite No. 6 lies conformably above rhyolite No. 5 and is covered by basalt No. 2, or, where that is wanting, by rhyolite No. 7. It is the conspicuous white layer which from the town of Rhyolite is plainly visible on Busch Peak and on Sutherland and Ladd mountains. Its distribution is wider than that of any of the earlier rhyolites, since it occurs near both the eastern and western borders of the area mapped and is repeatedly exposed in many of the intervening fault blocks. The thickness of the formation varies from a few feet on the east slope of Bullfrog Mountain and near the head of Box Canyon to about 300 feet on the south slope of Montgomery Mountain.

General character.—Rhyolite No. 6 is at most places a porous or pumiceous flow breccia containing basalt and other fragments, some of which are of considerable size. Light-colored rhyolite fragments are more abundant but less conspicuous than those of basalt. In the most common or pumiceous facies the matrix is, as a rule, pure white, a characteristic which distinguishes this flow from all other rhyolites of the series. Locally, the denser varieties have a pale-pink color. Only a few phenocrysts are present, namely, quartz, clear feldspar, and black mica. In places there are dendritic figures in the fracture planes, due to the infiltration of manganese compounds, possibly derived from the overlying basalt. Fragments of other rhyolite, of basalt, and fragments like the matrix are included, and some of them are slightly rounded.

Microscopical character.—The texture is porphyritic. The groundmass, which constitutes more than 80 per cent of the rock, is composed almost entirely of cellular or pumiceous glass. The cavities are lined or filled with secondary quartz. Phenocrysts of quartz, orthoclase, plagioclase, and mica are small and nowhere abundant. All except orthoclase are unaltered, and as a rule it also is fresh. The plagioclase ranges from albite to calcic oligoclase. Calcite is present as a secondary mineral. A dark, opaque mineral in minute particles, probably manganese dioxide, forms mosslike aggregates.

Basalt bodies in rhyolite No. 6.—On the saddle between Sutherland Mountain and Busch Peak and on the slopes below it, both east and west, there are several long, narrow bodies of basalt, some of which are vertical or nearly so. Viewed from a short distance away, these have every appearance of basalt dikes. Some of them are only 6 to 12 inches wide, of nearly uniform width, and from 30 to 40 feet long, while others are several feet in width and up to a hundred feet in length. One of these masses is shown in Plate VII, *B*. Close inspection shows that the rhyolite is the younger rock, for its flow lines are clearly influenced by its contact with the basalt, as is shown in figure 5, which is a sketch of the contact of the two rocks. Rhyolite apophyses fill indentations in the basalt, and angular fragments of basalt are considerably more numerous in the rhyolite immediately in contact with the basalt than they are a short distance away. This latter feature suggests that the larger basalt bodies are probably blocks caught up in the flow rather than that they are dikes intruded into a still viscous rhyolite. Such contacts were not noted anywhere else in the area. The blocks are of such local distribution that they are not distinguished on the map (Pl. I), but are colored like the intrusive basalt.

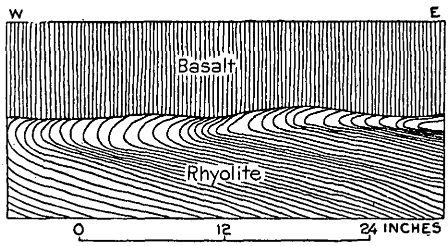


FIGURE 5.—Section of the contact between rhyolite No. 6 and an included mass of basalt.

PLAGIOCLASE BASALT No. 2.

Occurrence and distribution.—Plagioclase basalt No. 2 is a flow that lies conformably above rhyolite No. 6 and below rhyolite No. 7. With the exception of a small patch in the saddle east of Bullfrog Mountain this basalt is exposed only in the mountains between Box Canyon and the town of Rhyolite. To the east of Rhyolite it is wanting, as is shown by the many exposures of the section at the horizon where it should appear. Its maximum thickness is about 60 feet. The dip of basalt No. 2 is very gentle on the slopes of Busch Peak, but is much steeper on the east slope of Bonanza Mountain.

Microscopical character.—Basalt No. 2 is a dark, dense, nearly aphanitic though usually vesicular rock resembling basalt No. 1. Under the microscope it exhibits a groundmass composed of roughly parallel lath-shaped plagioclase crystals with a smaller amount of glass, magnetite, and microcrystalline white silicates in the interstices between the laths. The groundmass incloses large phenocrysts of olivine. The plagioclase is altered and is largely replaced by minute shreds of calcite or sericite. Much of the olivine has been replaced by silica which is as a rule stained by limonite. The groundmass contains chlorite and serpentine. Most of the vesicles are filled with secondary minerals, which commonly are thin films of calcite surrounding spheres of chalcedony.

Age and origin.—There was no considerable erosion between the eruption of rhyolites No. 6 and No. 7, for the latter always rests upon rhyolite No. 6 where basalt No. 2 is absent. The basalt, then, was never an extensive flow and its original limits were probably but little greater than those indicated by its present exposures.

RHYOLITE No. 7.

Occurrence and distribution.—Rhyolite No. 7 rests conformably either upon basalt No. 2 or, where that is eroded or not present, upon rhyolite No. 6. Rhyolite No. 7 is one of the most constant in color, distribution, thickness, and general appearance, and for that reason is of especial value as an aid to the interpretation of structure. It is exposed on Bullfrog Mountain, Sawtooth Mountain, Bonanza Mountain, Sutherland Peak, Busch Peak, Ladd Mountain, Montgomery Mountain, and on each of the ridges to the southeast of Montgomery Mountain. Its maximum thickness is about 50 feet.

Microscopical character.—This rhyolite varies in color from pale to deep pink or pinkish purple. As a rule it is vitreous and it is everywhere slightly porphyritic. The phenocrysts are quartz, clear feldspar, and subordinately biotite. At some places the rock is rather porous, owing to the presence of minute lenticular masses of spongy or pumiceous rhyolite. Small fragments of other rocks occur at places in this rhyolite, and basalt fragments are in some places numerous. These were apparently picked up by the rhyolite as it flowed over basalt No. 2.

Under the microscope the groundmass is seen to be glassy and fresh and to have nearly everywhere an eutaxitic texture. The phenocrysts are orthoclase, quartz, albite, biotite, magnetite, and apatite, the last two being very small.

RHYOLITE No. 8.

Occurrence and distribution.—Rhyolite No. 8 lies upon rhyolite No. 7 except on the north slope of the peak east of Bullfrog Mountain, where for a short distance rhyolite No. 7 is wanting. It is as widely distributed as rhyolite No. 7 and since it is much thicker it covers a larger area. It forms most of Bullfrog, Bonanza, Ladd, Montgomery, and Paradise mountains and of the ridges southeast of the last named, but its greatest development is on Busch Peak and in the low hills to the east. Most of its exposures form dip slopes on the east sides of the mountains and ridges. Its thickness varies from 400 to 800 feet.

Microscopical character.—Aside from its brown and dark-gray glassy basal facies, rhyolite No. 8 is clear purple at most places, but locally, especially where weathered, it is purplish gray, dark grayish brown, or nearly white. The groundmass is close and even and at many places vitreous. Here and there it contains a great many white blotches less than an inch in diameter, which are in the main included fragments of spongy rhyolite, but some appear to have been pumiceous or frothy spots drawn out by movement in the cooling lava. There are invariably phenocrysts of clear feldspar and quartz. Biotite flakes, though present at places in considerable quantity, are smaller and not as conspicuous as those in rhyolite No. 5. Fragments of other rocks are nowhere abundant and those which do occur in this flow are rhyolites of various darker shades than the matrix. The brown basalt fragments, which are very numerous in rhyolites No. 9 and No. 10, are rare indeed in rhyolite No. 8. This difference is important, since in many cases it is the only characteristic which distinguishes rhyolite No. 8 from rhyolite No. 10. Under the microscope the texture is seen to be porphyritic; the groundmass, which in volume exceeds the phenocrysts, is glassy and the more vesicular portions are devitrified. Commonly flow lines encircle the phenocrysts, which are quartz, orthoclase, albite, oligoclase, and biotite. Small grains of magnetite and crystals of rutile are present in some specimens.

A chemical analysis of a specimen from this flow, made by Mr. George Steiger in the Survey laboratory, is given below. According to the quantitative system of classification the rock is an alaskose, a very siliceous subrang to which many rhyolites belong.

Analysis of rhyolite No. 8 from the southeast slope of Busch Peak (B. 374).

[George Steiger, analyst.]

SiO_2	77.26	H_2O+	.96
Al_2O_3	11.54	TiO_2	.18
Fe_2O_3	.85	CO_2	None.
FeO	.13	P_2O_5	Trace.
MgO	.20	MnO	.03
CaO	.58	BaO	None.
Na_2O	2.96	SrO	None.
K_2O	4.65		
H_2O-	1.03		100.37

Basal facies.—At many places where the base of rhyolite No. 8 is exposed the basal facies is a brown or dark-gray glass about 50 feet in maximum thickness. At some places, as on Sutherland Mountain, Ladd Mountain, and Busch Peak, it is either entirely lacking or is represented only by a semivitreous facies. The glassy layer is also lacking for short distances at a few points along the base of rhyolite No. 8 in the numerous outcrops southeast of Montgomery Mountain. This glass grades into the purple rhyolite and is therefore the contact facies of the flow. The phenocrysts in the glass are the same as those in the overlying purple rhyolite; the matrix, though distinctly glassy and showing perlitic cracks, has about the same composition as the matrix of the rest of the flow. A partial chemical analysis of this glass is the second one given in the table on page 31. The analysis shows that the glass contains a slightly higher percentage of lime and soda than the lithoidal facies, but this may not be true for large masses, since the minerals of the phenocrysts in the two facies are in about the same proportion in each.

PLAGIOCLASE BASALT No. 3.

Occurrence and distribution.—Plagioclase basalt No. 3, where present, overlies rhyolite No. 8 and underlies rhyolite No. 9. It is not a persistent flow, but it is present at several places on the low hills southeast of Busch Peak, on the west slopes of Montgomery Mountain, and in the ravine northeast of Ladd Mountain. At many places on the low hills and ridges southeast of Montgomery Mountain the basalt is wanting and rhyolite No. 9 rests directly on ryholite No. 8. Its maximum thickness is 50 feet, but at most places it is much thinner. The number and widespread distribution of basalt fragments in overlying rhyolites Nos. 9 and 10 suggest that basalt No. 3 once covered a large area and was eroded before the extrusion of rhyolite No. 9.

Microscopical character.—Basalt No. 3 is, as a rule, less weathered than basalts Nos. 1 and 2, and phenocrysts of olivine are visible at many places on fresh surfaces, but it does not differ otherwise in general appearance from the earlier basaltic flows. The microscope shows that the denser facies from the middle of the flow are holocrystalline, but vesicular contact facies contain a variable proportion of glass. In the more crystalline varieties the groundmass is made up of labradorite laths of various sizes, between which are smaller crystals or grains of augite, magnetite, apatite, titanite, biotite, hematite, chlorite, and serpentine. Phenocrysts of olivine, distinctly larger than the plagioclase laths, show characteristic alterations to serpentine and iron oxides.

RHYOLITE No. 9.

Occurrence and distribution.—Rhyolite No. 9 overlies plagioclase basalt No. 3 or, where that is absent, rests directly upon rhyolite No. 8. Its maximum thickness is about 250 feet, but in most places it is less than 60 feet thick. Half a mile north of Busch Peak rhyolite No. 9 is wanting and the glassy basal portion of rhyolite No. 10 rests directly upon rhyolite No. 8. Rhyolite No. 9 is more easily eroded than rhyolites Nos. 8 and 10 and consequently is not a conspicuous member of the series. It never caps hills, but is exposed in saddles or on slopes. It dips east with the associated lava beds.

Microscopical character.—Rhyolite No. 9 is at most places a pinkish-white or buff, more or less pumiceous flow breccia; but on the low hills east of Busch Peak it is purple or purplish pink and rather compact. As a rule it contains many small fragments of dense gray rhyolite, gray pumiceous rhyolite, and basalt. The phenocrysts are quartz, clear feldspar, and biotite.

Where pumiceous this formation is easily recognized, but the denser facies is likely to be mistaken for rhyolite No. 10 where the basal glass of the latter is not present. Where only a few basalt fragments occur in rhyolite No. 9 the dense purplish variety is likely to be confused with rhyolite No. 8, unless basalt No. 3 intervenes.

Under the microscope the texture is seen to be porphyritic; the groundmass, which exceeds the phenocrysts in volume, is glassy and in the more pumiceous varieties devitrified. The phenocrysts are quartz, orthoclase, albite, and oligoclase. A little biotite is present, and altered varieties contain limonite.

RHYOLITE No. 10.

Occurrence and distribution.—Wherever its base is exposed rhyolite No. 10 rests upon rhyolite No. 9, except at a point 2,500 feet north of Busch Peak, where it rests upon rhyolite No. 8. It is overlain conformably by basalt No. 4. Rhyolite No. 10 is exposed at many places in the central and eastern portions of the Bullfrog area, where, like rhyolite No. 8, it forms the eastern dip slopes of many of the hills. The summits of most of the smaller hills northeast, east, and southeast of Busch Peak, of Montgomery and Paradise mountains, and of Velvet Peak are composed of this rock. The thickness of the flow is fairly uniform and attains a maximum of about 400 feet.

General character.—The base of rhyolite No. 10 is nearly everywhere a grayish-brown to brownish-black glass, with a maximum thickness of 20 feet. This grades upward into the less glassy facies, which constitute the greater part of the formation. Except the basal glass, rhyolite No. 10 is brownish gray or purplish gray and contains fragments of rhyolite, basalt, and, rarely, schist. The matrix has many phenocrysts of quartz and feldspar and a few biotite flakes. The lower part of the formation, including the glass, is a flow breccia containing at most places many fragments of basalt and dark rhyolite, which are less numerous in the upper part. The purple varieties are not so bright and clear in tint as those of rhyolite No. 8, and where the rock is slightly weathered it is rusty and is generally a little lighter in color than rhyolite No. 8.

Rhyolite No. 10 may be easily confused with the least pumiceous varieties of rhyolite No. 9, but the upper surface of the latter flow is almost everywhere clearly defined by the glassy base of rhyolite No. 10. Rhyolite No. 10 is at most places easily distinguished from rhyolite No. 8 by the greater number of dark fragments which it contains and especially by the presence of basalt fragments, but on the slopes of the hills just west of the Indian Springs road, which skirts the west base of Rainbow Mountain, foreign fragments are very rare in the upper part of rhyolite No. 10, and the two formations may therefore be confused where the lower part of rhyolite No. 10 is faulted out of sight.

Microscopical character.—The texture of all varieties is porphyritic. The basal facies is composed of fresh brown or nearly colorless glass, in most sections eutaxitic and containing phenocrysts of quartz, orthoclase, albite, oligoclase, magnetite, and biotite, with fragments of basalt and devitrified rhyolite. The minute bands of the groundmass curve around both phenocrysts and fragments. The middle and upper parts of the formation have a glassy groundmass, in places devitrified and locally spherulitic, which contains phenocrysts and fragments similar to those of the basal facies and a large number of minute grains of quartz and feldspar without crystal outlines (anhedrons), which are not present in such quantity in the basal glass. The less vitreous appearance of the upper part of the formation is probably due largely to its more numerous phenocrysts.

PLAGIOCLASE BASALT No. 4.

Occurrence and distribution.—Plagioclase basalt No. 4 lies above rhyolite No. 10 and below either rhyolite No. 11 or tuff No. 1 where the latter two are present. The basalt is conformable with the associated beds and dips toward the east at high angles. It is exposed on the west slope of Rainbow Mountain, on both sides of the Indian Springs road, near the border of the area mapped, and also in the flat three-fifths of a mile S. 40° W. of Black Peak. It also occurs as a long, narrow strip about 1,600 feet east of the Montgomery-Shoshone mine and covers a large area along the road between the Montgomery-Shoshone mine and Beatty. It also forms a large part of the lower northeast slope of Velvet Peak and of the ridge which extends northwest from this peak. Dipping with the slope of this mountain it descends to the flat and disappears below tuff No. 1. There is no cliff exposure where its thickness can be measured, but the width of its outcrop and the steep inclination of associated beds indicate that it is much thicker than any preceding basalt flow. The width of outcrop of the flow to the southeast of Paradise Mountain is explained in part by a strike fault. But even with such a fault the maximum thickness of this flow is about 500 feet. This thickness, however, may be local, for it appears less at the exposure of this flow on the west slope of Rainbow Mountain.

A narrow block of this basalt occupies a part of the Montgomery-Shoshone fault zone, as described on pages 106–108.

Microscopical character.—In the field and under the microscope basalt No. 4 closely resembles basalt No. 3, which is described on page 44. Both are vesicular at many places. At two localities in the Bullfrog district outcrops of leucite basanite at the horizon of basalt No. 4 are partly or entirely surrounded by the basalt. In the preliminary account[a] of this district basalt No. 4 was described as leucite basalt. The study of additional material shows that the flow as a whole is a plagioclase basalt, but contains relatively small masses of leucitic rocks, of which the more crystalline are leucite basanite rather than leucite basalt. The leucite basanite is further described on page 58.

TUFF No. 1.

Occurrence and distribution.—Volcanic tuffs, including some shale, sandstone, and conglomerate, are exposed at several places along the road between Beatty and the Montgomery-Shoshone mine. The sedimentary rocks rest upon plagioclase basalt No. 4 and underlie a green micaceous rhyolite flow breccia—the base of rhyolite No. 11. At no place is a complete section of these rocks exposed, and on account of their narrow distribution and intergradations the several members have been mapped together.

At a point 3,000 feet N. 81° E. of the Montgomery-Shoshone mine shale is exposed in a prospect on the west slope of the low hill north of the forks of the road, where it is faulted against rhyolite No. 10 to the east and is apparently shattered by the movement. The shale also occurs north and east of this hill in a flat, where its presence is shown only by débris on the surface; it is also exposed east of the road and about 400 yards southeast of the summit of this hill in a prospect where it is much disturbed and dips 55° E. This dip is apparently local, for it is steeper than that of associated beds. Southeast of this point the shale, here containing calcareous concretions and septaria, lies directly upon basalt that dips about 20° E. Shale is exposed also on the northern end of the ridge that extends northwest from Velvet Peak; it dips approximately with the slope of the hills. Toward the southeast the shale becomes very thin or disappears, for conglomerate beds occur within a few feet of the top of the basalt with approximately the same dip. The conglomerate is very coarse, bowlders of rhyolite and basalt more than 1 foot in diameter being very common. The material of many of these can be identified with that of earlier lava flows. Above the conglomerate are a few feet of fissile calcareous sandstone which, on the parting planes, show cylindrical worm impressions. These beds are not persistent, as they were not found to the north of this outcrop.

About 3,000 feet S. 3° E. of Burton Peak a fine-grained unconsolidated sandstone containing many small pebbles, mainly basalt, out-

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[a] Op. cit., p. 49.

crops just below the base of rhyolite No. 11. Though the base of this member of the tuff is not exposed, it apparently lies above the calcareous sandstone and probably grades laterally into the green shale that, farther north, lies immediately below the base of rhyolite No. 11. It thus appears that the green shale that outcrops at the northwest end of this group of discontinuous exposures of sedimentary rocks is probably contemporaneous with and equivalent in age to the conglomerates, sandstone, and shale at the southeast end. About 900 feet northwest of the bench mark (3,547 feet) on the Beatty road south of Burton Peak a small, low knob, defined by the 3,560-foot contour on the topographic map, rises above the flat. This knob, entirely surrounded by wash, is composed of rhyolite flow breccia. The matrix is a light porous gray rhyolite and contains fragments of basalt and rhyolite, many of which are more than 2 feet in diameter. It does not resemble any of the principal rhyolite formations and is assumed to be a flow which occurred during the formation of the tuff. On account of its very small area it is not separated from the tuffs in mapping. The average thickness of this entire group of sedimentary rocks is estimated at 250 feet.

Microscopical character.—The green shale, which at the northwestern end of the area covered by the tuff makes up the entire thickness of the sedimentary beds, is seen under the microscope to be composed mainly of small particles of glass, sometimes arranged with their longer axes approximately parallel. Very minute crystals of calcite and a little mica and magnetite are also present. Chlorite is abundant and gives the rock its green color.

The fissile calcareous sandstone with worm impressions is made up largely of very small angular quartz fragments and smaller calcite aggregates, with a few angular fragments of feldspar, mica, and magnetite and some secondary chlorite.

The conglomerate beds contain many bowlders that have the same microscopical character as rhyolite No. 10. The basalt fragments are in the main decomposed, are very vesicular, and have their vesicles filled with calcite; they are similar to the basalt of the first, second, and third flows, but no leucite basanite was noted.

Age and origin.—The sedimentary rocks, which collectively constitute tuff No. 1, were deposited in water after the eruption of basalt No. 4. The fresh condition and angular outlines of many of the fragments show that they were not subjected to great weathering or to long transport by running water, and much of the material may have fallen as volcanic débris directly in water, where it mingled with water-borne débris. The rhyolite flow breccia contained in the formation represents a lava flow of small extent which was extravasated while the tuffs were being formed.

RHYOLITE No. 11.

Occurrence and distribution.—Rhyolite No. 11 outcrops on the west slope of Rainbow Mountain, where it lies above basalt No. 4 and, like it, dips east. It also forms most of the lower slopes of Burton Peak and extends east as far as Beatty. A broad area of this rhyolite is exposed because strike faults which have vertical displacement less than the thickness of the rhyolite repeat its outcrops. South of Burton Peak this formation rests on tuff No. 1. Where it is not a capping formation it is overlain by rhyolite No. 12. Its thickness is about 700 feet.

General character.—Rhyolite No. 11 is made up of a number of thin flows and flow breccias, the lowest of which is a pale-green micaceous flow breccia, at most places about 5 feet thick. About a mile east of the Montgomery-Shoshone mine, on the Beatty wagon road, this green flow lies directly on the shaly green tuff. It is easily distinguished from other formations which overlie it and is the base of every exposure of the formation between the Montgomery-Shoshone mine and Beatty. Its frequently faulted outcrop approximately parallels the road and may be traced almost continuously for more than a mile. It has not been recognized on the west slope of Rainbow Mountain. Here the basal members of rhyolite No. 11 are less consolidated than the upper ones and may represent a mud flow which covered this area before the eruption of the upper members.

Pink flows of varying thickness lie above the green micaceous flow, giving a total thickness of 600 to 750 feet. The larger portion of the formation is pumiceous and spongy, though at several localities it is very dense, the two facies grading laterally one into the other. The groundmass is dull or vitreous, according to the density of the rock, and contains phenocrysts of feldspar, partly resorbed quartz, and black mica. There is a considerable range in the relative abundance of the phenocrysts, black mica being very abundant in the basal flow and comparatively rare in the upper ones. Small fragments of rhyolite, basalt, and crystalline schists are at most places present, though as a rule they are not abundant. Near the top of the division there is a prominent red flow breccia, composed chiefly of rhyolite fragments, some of which are a foot or more in diameter. This flow, though not separately mapped, is persistent and has proved a useful structural datum plane.

Microscopical character.—The texture of rhyolite No. 11 is porphyritic; the groundmass is a devitrified glass, here and there spherulitic, and as a rule it exceeds in volume the phenocrysts of orthoclase, quartz, albite, oligoclase, biotite, magnetite, and apatite. Of the minute included fragments rhyolite is most abundant, basalt is common, and schist is rare. No leucite basanite could be identified among the fragments examined. The color of the basal green micaceous flow is due to chlorite, probably an alteration product of biotite. The red flow breccia near the top of the formation owes its color to a staining of the groundmass by iron oxide.

RHYOLITE No. 12.

Occurrence and distribution.—Rhyolite No. 12 lies conformably above rhyolite No. 11 and is exposed as a narrow band about 40 feet wide on the west slope of Rainbow Mountain. This band is faulted to the east, just north of the Steinway mine, and forms a narrow strip trending west of north on the west side of the ridge upon which is the Steinway shaft. The same flow outcrops around the summit of Burton Mountain and forms the conspicuous green band on the west slope. Here its thickness is about 70 feet.

General character.—This flow is a green or gray glass, streaked at some places with pinkish bands, and contains a few small phenocrysts of feldspar and quartz. It is invariably fresh, of vitreous luster, and both in appearance and mode of fracture it closely resembles green bottle glass. Flow lamination is developed at many places and the alternating green, gray, or pink bands, less than 1 inch thick, are a striking feature of the formation.

Microscopical character.—A glassy, perlitic groundmass constitutes 95 per cent of the rock. It is generally brown in thin section, is not devitrified, and contains small phenocrysts of quartz, orthoclase, oligoclase, biotite, magnetite, hornblende, and hypersthene, and minute prisms of augite. The groundmass immediately surrounding the femic (ferromagnesian) crystals is bleached and the resulting halos contrast strikingly with the brown groundmass. They are very slightly birefringent and vary in width with the size of the minerals which they surround. The biotite scales, for example, are from 1 to 2 millimeters in diameter and have halos from 0.2 to 0.4 millimeter wide, and prisms of hypersthene about 0.3 millimeter thick and twice as long are surrounded by halos 0.15 millimeter wide. The halos are of equal width on ends and sides of crystals and are not present around quartz or feldspar. The crystallites are concentrated in bands, most of them less than 1 inch thick, and in the bands there is a partial linear orientation of the longer axis of the crystallites. Their discoloring effect upon the groundmass, when they are closely spaced, produces the pink bands noticeable in hand specimens. It is perfectly clear that the ferromagnesian minerals continued to grow after the lava came to rest and that in the process of growth they absorbed from the still liquid magma those constituents that give it color. In the part of the magma from which this subtraction took place incipient crystallization began and proceeded far enough to give a slight birefringence to the glass of the halos. The effects of absorption extend farther into the groundmass around the larger crystals, but when volumes are considered the crystallites or small crystals have been increased proportionately more than the larger ones.

A chemical analysis of rhyolite No. 12, made in the Survey laboratory, is given below. According to the quantitative system of classification the rock is tehamose, a type reported from California, Montana, and elsewhere:

Analysis of rhyolitic glass (B. 164) from the west slope of Burton Peak, 50 feet below the summit.

[George Steiger, analyst.]

SiO_2	71.60	TiO_2	0.25
Al_2O_3	12.44	ZrO_2	.01
Fe_2O_3	1.00	P_2O_5	.08
FeO	.65	MnO_2	.06
MgO	.06	BaO	.03
CaO	1.90	SrO	.03
Na_2O	3.30		
K_2O	4.22		100.22
H_2O	4.59		

Age and origin.—Rhyolite No. 12 is probably a single flow whose eruption closely followed rhyolite No. 11. It was formerly more widely distributed than it is at present and, together with rhyolite No. 11 and later formations, it has probably been eroded from the hills south of the Montgomery-Shoshone mine and perhaps from the mountains west of Rainbow Mountain.

RHYOLITE No. 13.

Occurrence and distribution.—Rhyolite No. 13 followed closely the extrusion of rhyolite No. 12 and outcrops as a narrow band paralleling this rock on the west slope of Rainbow Mountain. It also forms the summit, the knoll on the western spur, and most of the eastern slope of Burton Mountain. Its maximum thickness is about 200 feet.

General character.—Rhyolite No. 13 is in the main reddish brown or grayish brown, but in places contains layers of green glass that resemble rhyolite No. 12. Rhyolite No. 13 has a dense, glassy groundmass and contains a few phenocrysts of feldspar, quartz, hornblende, and mica. Intricately curving flow lines are strikingly developed at every outcrop and at most places weathering has produced a parting between them which distinguishes this flow from the other rhyolites.

Microscopical character.—The texture is porphyritic; the glassy groundmass is in the main devitrified, is in some varieties spherulitic, and greatly exceeds the phenocrysts in volume. It is pink in thin section and originally was slightly vesicular, but most of the vesicles have been lined or filled with secondary quartz. The spherulites are smaller than those of rhyolites Nos. 1 or 5 and are not visible in hand specimen. The phenocrysts are orthoclase, quartz, albite, oligoclase, mica, green hornblende, and magnetite. These resemble the phenocrysts in other flows described, though hornblende is more abundant than in the earlier rhyolites.

RHYOLITE No. 14.

Rhyolite No. 14 outcrops on the west slope of Rainbow Mountain, on which it lies conformably above rhyolite No. 13. It is composed of thin flows of green glass resembling rhyolite No. 12, alternating with spongy white or dense pink rhyolite flow breccia, in which the fragments are like the matrix. When viewed at a distance from a point west of Rainbow Mountain (Pl. III, *A*) this formation and rhyolite No. 12 appear as thin dark-green bands that contrast strongly with the other flows. The lower green layer, rhyolite No. 12, is almost entirely green glass, but rhyolite No. 14 contains more lithoidal material. This, however, is not conspicuous, and from a distance the formation appears almost homogeneous owing to the greater prominence of the green glass. The maximum thickness of rhyolite No. 14 is approximately 200 feet.

RHYOLITE No. 15.

Occurrence and distribution.—Rhyolite No. 15 occurs only on Rainbow Mountain and represents one or more flows which closely followed the eruption of rhyolite No. 14. It is made up of pink or white flow breccia containing fragments like the matrix and inclosing large flat bodies of green glass, of which the longer axes lie approximately in the plane of the flow. Some of these bodies are about 40 feet long and 10 feet thick. They are too small to be separate flows and are either an example of flow banding on a large scale or fragments of rhyolite No. 14 caught and buoyed up by the viscous moving lava, which later, upon solidifying, formed the white flow breccia. If this view of their origin is correct the blocks are now close to their source, for their flat shape, weight, and size would have prevented them from being carried far without breaking into smaller and more stable forms. The maximum thickness of rhyolite No. 15 is 175 feet and it dips steeply toward the east with the associated lavas.

Microscopical character.—The texture is porphyritic. The lighter-colored facies closely resembles rhyolite No. 11, though it is in most places less pumiceous. The groundmass is a devitrified glass and as a rule exceeds in volume the phenocrysts, which are quartz, oligoclase, orthoclase, mica, magnetite, and hornblende. In the more porphyritic facies the proportion of orthoclase to oligoclase is greater than in the more nearly aphanitic facies, which indicates that the groundmass is on the whole richer in alkalies than are the phenocrysts. The green glass contained in rhyolite No. 15 is similar to that of rhyolite No. 12.

RHYOLITE No. 16.

Rhyolite No. 16 is the youngest rhyolite exposed in the Bullfrog district. It outcrops on Rainbow Mountain, forming the summit and extending eastward to the saddle between this mountain and Black Peak. Another area, in contact with this one by faulting, occurs just north of the Montgomery-Shoshone mine, and its southeastern edge forms the hanging wall of the Montgomery-Shoshone fault in the Providence mine. A third outcrop occurs as a long strip of irregular width to the northeast of the Providence mine, where it is largely masked by talus from Black Peak. The maximum thickness of rhyolite No. 16 is about 400 feet. At the base of the formation is a flow of green glass of variable thickness, which is greatest at the summit of Rainbow Mountain. Above the basal flow is a light-colored rhyolite flow breccia, much of it cellular or spongy, which contains many blocks of green glass, ranging from less than 1 inch to more than 10 feet in diameter. The outcrop north of the Montgomery-Shoshone mine and also the one northeast of the Providence are of the upper light-colored variety, which at both places contains large bodies of green glass, a feature by which this formation may be easily distinguished from all rhyolites that precede rhyolite No. 12. Under the microscope, as in the field, the lower flow of green glass is similar in appearance to rhyolites No. 12 and No. 14. The upper flow breccia is like the light-colored flow breccia of rhyolite No. 15. Rhyolite No. 16 is conformable with the formations above and below it.

PLAGIOCLASE BASALT No. 5.

Plagioclase basalt No. 5 lies conformably above the latest rhyolitic formation (rhyolite No. 16) and is overlain by quartz latite. Its only outcrops are on the southern and western slopes of Black Peak. The thickness of the flow varies considerably; it reaches a maximum of about 60 feet one-fourth mile north of the Montgomery-Shoshone mine, but thins out rapidly northward, and disappears just south of the saddle between Black Peak and Rainbow Mountain. North of this saddle the basalt is wanting and the quartz latite rests directly upon rhyolite No. 16. The irregular upper surface of the flow suggests that the basalt was eroded before the eruption of the quartz latite, and further evidence of this is afforded by the presence of a thin bed of tuff containing fragments of basalt and rhyolite, which occurs only at one place about 800 feet S. 3° W. of the saddle between Rainbow Mountain and Black Peak. Owing to its very narrow distribution, this tuff is not represented on the map, but is included with the basalt. In the field and under the microscope basalt No. 5 resembles basalt No. 3, which is described on page 44. It probably represents a single lava flow which was extravasated upon a nearly level surface. Later it was tilted eastward with the associated flows.

QUARTZ LATITE.

Definition.—Quartz latite is a glassy or fine-grained (microcrystalline) rock, of which the silica content is between that of rhyolite and andesite. As a rule it is porphyritic. It contains orthoclase, plagioclase, usually oligoclase or andesine, quartz, and a small amount of one or more of the ferromagnesian minerals—dark mica, hornblende, and pyroxene. It is the volcanic equivalent of quartz monzonite and occurs as flows and dikes.

Occurrence and distribution.—Quartz latite forms the dark capping which gives Black Peak its name. It also forms the summit of the peak just east of Black Peak and, dipping eastward, nearly with the slope, it constitutes the ridge that descends from that peak to the flat. Northward from the saddle between Rainbow Mountain and Black Peak the base of the quartz latite rests upon rhyolite No. 16; to the south of this saddle it rests upon basalt No. 5, except at one small exposure about 800 feet south-southwest of the saddle, where a thin bed of tuff lies between the basalt and the quartz latite. The quartz latite is a flow about 250 feet thick.

General character.—The quartz latite is dark brown or nearly black and is in places glassy, especially near its base. Phenocrysts of feldspar are abundant, those of quartz less so. Nearly everywhere it contains mica, which is as a rule golden bronze. The base and to a less extent the upper part of the flow are vesicular. This flow is much fresher in appearance than basalt No. 5, upon which it sometimes rests, is not quite so dark in color, and may further be distinguished from the basalt by the greater abundance of dark mica foils.

Microscopical character.—The texture is porphyritic; the groundmass, which exceeds the phenocrysts in volume, is glassy, seldom devitrified, rarely spherulitic. It contains many laths of plagioclase which vary in length from 0.1 to 0.4 millimeter. In some sections the longer axes of the plagioclase laths are oriented in the same direction, suggesting the texture sometimes called trachytic. The larger phenocrysts are oligoclase, andesine, quartz, and biotite. Smaller ones of orthoclase, biotite, augite, ilmenite, magnetite, titanite, and apatite are also present.

An analysis of the quartz latite made in the Survey laboratory is given below. According to the quantitative system of classification the rock is toscanose. Its composition is very close to that of many quartz latites and of the dacite from McClelland Peak, Washoe, Nev.[a]

[a] Hague, A., and Iddings, J. P., Bull. U. S. Geol. Survey No. 17, 1885, p. 33.

Analysis of quartz latite (B. 172) from the top of Black Peak.

[George Steiger, analyst.]

SiO_2	63.34	H_2O+	1.16
Al_2O_3	15.46	TiO_2	1.53
Fe_2O_3	4.14	CO_2	None.
FeO	.39	P_2O_5	.22
MgO	.66	MnO	.04
CaO	2.01	BaO	.15
Na_2O	3.89	SrO	.03
K_2O	5.31		
H_2O-	1.89		100.22

TUFF No. 2.

In the saddle just east of the summit of Black Peak a bed of yellow, partly consolidated tuff, composed of very finely comminuted material, lies upon the quartz latite and separates it from the overlying quartz basalt. This bed, about 40 feet thick, is of well-stratified material, chiefly rhyolitic, and represents the accumulation of volcanic débris in a body of water which was probably of very slight extent. Since it contains little if any of the underlying quartz latite it may be a volcanic ash that fell directly into the water and was not washed from the surrounding land. This outcrop is all that remains of tuff No. 2, for to the east it is in contact by faulting with quartz latite, which forms the summit of this ridge to the east. Tuff No. 2 dips eastward at a steep angle with the associated lava flows.

QUARTZ BASALT.

Occurrence and distribution.—The latest lava flow exposed in the Bullfrog district is a quartz-bearing basalt which lies above the youngest tuff and forms the summit of the spur just east of Black Peak. To the east of this spur the quartz basalt has been depressed by a north and south fault which brings it into contact with the quartz latite, so that only a very small body of it remains. The quartz basalt dips eastward with the other lavas and has a minimum thickness of about 70 feet.

Microscopical character.—The quartz basalt is dark grayish brown and differs but little in color from the quartz latite; the groundmass is not so dense and glassy, the phenocrysts are larger, and those of quartz are more abundant. Olivine is not visible in hand specimens. The microscope reveals a dark, glassy, devitrified groundmass thickly dotted with magnetite and augite and in places slightly spherulitic. It contains many small laths of labradorite and andesine, as a rule about 0.4 millimeter long, the arrangement of which is slightly trachytic. Phenocrysts of andesine, oligoclase, orthoclase, and embayed quartz are present, and smaller ones of olivine, augite, mica, and magnetite. Rarely there is a phenocryst of hornblende. Olivine is almost completely altered to serpentine; otherwise the rock is fresh. Quartz is especially abundant for a rock containing olivine, but is unquestionably original. An analysis of the quartz basalt made in the Survey laboratory from a specimen taken from the knob just east of the summit of Black Peak is given below. According to the quantitative system of classification this quartz basalt is hartzose, which is a type rather more siliceous than the usual quartz basalt. A quartz basalt from Lassen Peak, California, described by J. S. Diller,[a] has only a little less silica.

Analysis of quartz basalt (B. 314) from the summit of the small knob 400 feet east of the summit of Black Peak.

[George Steiger, analyst.]

SiO_2	59.72	H_2O+	1.38
Al_2O_3	14.63	TiO_2	.95
Fe_2O_3	3.40	CO_2	1.12
FeO	2.37	P_2O_5	.40
MgO	2.69	MnO	.10
CaO	6.55	BaO	.04
Na_2O	3.28		
K_2O	3.33		100.68
H_2O-	.72		

Age and origin.—The quartz basalt represents a single flow and may at one time have covered a considerable portion of this area. Its eruption probably occurred soon after that of the quartz latite, and so far as is shown in the Bullfrog district this eruption was the last that flowed over the surface, though some of the basalt dikes may represent volcanism of still later age.

INTRUSIVE ROCKS.

RHYOLITE PORPHYRY.

A relatively large intrusive mass of rhyolite porphyry with very irregular crosscutting boundaries occurs west of Box Canyon on the south slope of the low hill (elevation 4,280+ feet) 6,000 feet N. 86° E. of the Original Bullfrog mine, where it cuts through rhyolite No. 1. When fairly fresh it is gray or grayish green, but when weathered or much altered it is brown. It contains phenocrysts of feldspar, quartz, and biotite. The feldspar phenocrysts are white or pale green and where the rock has disintegrated perfect crystals up to one-fourth inch long may be picked out of the sand. The quartz phenocrysts are clear, colorless, or milky white. The biotite flakes are much decomposed. Under the microscope the groundmass is seen to be fine grained, but at most places it is more crystalline than the groundmass of rhyolite No. 1 and it is at no place glassy or spherulitic. It is composed of feldspar, quartz, apatite, and zircon, thickly dotted

[a] Bull. U. S. Geol. Survey No. 148, 1897, p. 196.

with chlorite, magnetite, and serpentine. In some sections it contains minute lath-shaped crystals of plagioclase, the orientation of which suggests the trachytic texture. The phenocrysts are orthoclase, albite, oligoclase, chloritized biotite, titaniferous magnetite, and altered forms suggesting a derivation from hornblende. The rhyolite porphyry in general appearance and in mineral composition more closely resembles the crystalline facies of rhyolite No. 1 than any of the other rhyolites, and it may be an intrusive contemporaneous with upper flows of that formation.

West of the Big Bullfrog mine and on the east slope of the low hill (elevation 4,020+ feet) in the southwest corner of the area mapped a rhyolite porphyry dike trending N. 20° E. cuts the crystalline schists. It is light gray or yellowish gray and contains smaller phenocrysts than the rhyolite porphyry intrusive west of Box Canyon. Under the microscope the groundmass is seen to be composed of quartz, orthoclase, and iron oxides, and it is rather more coarsely crystalline than the groundmass of the other rhyolite porphyry intrusive. Chlorite is not abundant and hornblende was not noted. The phenocrysts are quartz, orthoclase, and albite.

PLAGIOCLASE BASALT DIKES.

Occurrence and distribution.—Within the area included in the special map about forty plagioclase basalt dikes cut the Tertiary lavas. These vary in width from a few feet to nearly 100 feet and some of them may be traced continuously for 1,000 yards. At most places they occur along fault fissures and consequently their general trend is from north to northeast, and their dip is as a rule west or northwest. Some of them are undisturbed and adhere to the rocks which they cut, but by far the larger number are shattered and crushed, and their sides show striæ and slickensides, indicating that movement has occurred since intrusion. Many of them are discontinuous, thinning out and ending, to reappear along the same strike. This lack of continuity is probably due partly to incomplete filling during intrusion and partly also to faulting after the intrusion, with slight divergences between the planes of faults and dikes. The dikes are less resistant to weathering than the rhyolite, which they cut, and consequently exposures of them are not prominent. At very many places their presence is marked only by a ravine or slight depression, along the bottom of which there is a thin and interrupted streak of basalt débris.

General character.—The basalt dikes closely resemble the basalt flows and can not ordinarily be distinguished from them in the field by lithologic features alone. Both have vesicular and dense facies and it is in some cases impossible to determine whether or not a given body of basalt is intrusive unless its contact with other rocks is visible.

On the southwest slope of Ladd Mountain, for example, is a branching basalt dike about 2 feet wide which is undisturbed by faulting and which cuts through rhyolite No. 6. At the contact this dike is vesicular and glassy, while near the center it is almost free from vesicles and is microcrystalline. Vesicular facies of plagioclase basalt also occur in dikes at many other localities, and it is possible in almost every instance to find some vesicular fragments in the basalt débris which marks the presence of a dike in a ravine.

Microscopical character.—The dikes are glassy or microcrystalline and contain many small laths of plagioclase, whose average composition is that of labradorite. Either olivine or its decomposition product is invariably present. Augite occurs in most specimens and in some is abundant. Small grains of titaniferous magnetite and crystals of apatite are numerous. Serpentine, chlorite, and calcite are present in most sections as alteration products of the ferromagnesian minerals. On account of their proximity to planes of movement that are or have been channels for circulating water, most of the dikes are more altered than the basalt flows.

Age and relation to flows.—There is no evidence concerning the age of those dikes that do not follow fault planes, except that they are younger than the lava flows that they cut. Basalt dikes cut rhyolite No. 10 and older formations, but they have not been discovered in the younger rhyolites. All the basalt dikes may not be of the same age, and it is probable that they were connected with basalt flows and fill the channels through which these issued. The age relations between dikes and faults are further discussed on page 72.

LEUCITE BASANITE.

Definition.—The essential constituents of leucite basanite are leucite, feldspar, and olivine, though nepheline, pyroxene, magnetite, biotite, apatite, and other minerals are often present.

Leucite basanites are nearly related to leucite basalts in composition but contain feldspar in addition to leucite. In the preliminary account of the Bullfrog area[a] the leucite basanite was referred to as leucite basalt, but examination of material collected subsequent to the date of that report shows that in the more crystalline facies considerable plagioclase is present.

Occurrence and distribution.—The leucite basanite of the Bullfrog area is known to outcrop at only three places: On the flat west of Rainbow Mountain, on the flat north of Montgomery Mountain, and on the south slope of the hill (elevation 3,580+ feet) about 4,000 feet south of Beatty. In each of these places the leucite basanite is partly or completely surrounded by plagioclase basalt and its

[a] Ransome, F. L., Garrey, G. H., and Emmons, W. H., Preliminary account of Goldfield, Bullfrog, and other mining camps in southern Nevada: Bull. U. S. Geol. Survey No. 303, 1907, p. 49.

relations to the other igneous rocks could not be determined. At two of these localities the leucite basanite occurs at the horizon of basalt No. 4, but the outcrop south of Beatty is at the horizon of basalt No. 2. If the leucite basanite is intrusive it may all be of the same age; but if all the masses are parts of lava flows their eruptions were separated by the extrusion of a considerable thickness of rhyolite and plagioclase basalt. No dikes of leucite basanite have been discovered in the rhyolites and it can not be widespread, for the examination of 60 thin sections of the basaltic rocks showed leucite in three only. A number of pebbles were examined from rhyolite No. 11, the overlying flow breccia, and all were found to be plagioclase basalts. But since it is impossible to distinguish the plagioclase basalt and the leucite basanite in the field, small masses of the latter may have been overlooked and mapped as basalt.

Microscopical character.—The leucite basanite is a black, nearly aphanitic rock which in fresh specimens shows phenocrysts of olivine more or less altered to iron-stained decomposition products. The microscope reveals the following minerals, approximately in the order of their abundance: Augite, olivine, leucite, magnetite and ilmenite, plagioclase, nepheline, biotite, apatite, and zircon. The microcrystalline groundmass is composed of augite, leucite, and nepheline thickly dotted with small crystals of biotite, magnetite, ilmenite, and serpentinized olivine. Apatite is for the most part included in leucite. In some of the leucite crystals the longer axes of the included apatite crystals are oriented parallel to the boundaries of leucite. In the more crystalline varieties small laths of labradorite are present in considerable quantities. The phenocrysts are augite and olivine. Calcite is usually present and olivine is partly or completely altered to serpentine.

An analysis of the leucite basanite made in the Survey laboratory is given on page 60. The norm of this rock, calculated according to the method proposed by the quantitative system of classification, is also given. The principal differences between this theoretical composition and the mode or actual composition of the rock are as follows: Orthoclase is rare or wanting in the mode and there is enough leucite (6.10 per cent) to account for all of the potash present; there is a little less nepheline and a little more albite than is shown by the mode; the pyroxene is probably aluminous, for corundum is absent in the mode; a little biotite and secondary calcite are present.

In the scheme for the classification of igneous rocks proposed by Cross, Iddings, Pirsson, and Washington, this rock belongs to the portugare order, docalcic rang, and persodic subrang. The rang and subrang have not been named. Rocks of this subrang have been analyzed from various European localities but have not hitherto been reported from the United States. It is suggested that amargase and amargose (from the Amargosa Desert) would be appropriate names for the rang and subrang respectively.

Analysis of leucite basanite 2,000 feet southwest of summit of Rainbow Mountain (B. 107).

[George Steiger, analyst].

SiO_2	43.62	ZrO_2	0.02
Al_2O_3	12.73	CO_2	.63
Fe_2O_3	4.89	P_2O_5	.82
FeO	4.10	SO_3	None.
MgO	9.37	S	None.
CaO	11.62	MnO	.12
Na_2O	2.96	BaO	.16
K_2O	1.30	SrO	.14
H_2O-	1.91		
H_2O+	3.94		99.79
TiO_2	1.46		

NORM.

Orthoclase	7.78	Apatite	2.02
Albite	15.20	Diopside	31.05
Anorthite	13.07	Olivine	7.12
Nepheline	5.40	H_2O, etc	6.50
Corundum	1.63		
Magnetite	7.19		99.70
Ilmenite	2.74		

SUMMARY OF THE TERTIARY ERUPTIONS.

In Tertiary time, probably in the early Miocene, rhyolite No. 1 was erupted in two or more flows, separated by an interval long enough for the formation of 30 feet of limestone. Little is known of the surface upon which rhyolite No. 1 was poured out, for the base of the volcanic series is not exposed; but it is unlikely that lava of any considerable thickness underlies the oldest visible rhyolite formation. Rhyolite No. 2 flowed out upon the nearly level surface of rhyolite No. 1, but before its eruption there was an extrusion of basalt that is not exposed in the area mapped. There was also an interval of quiescence and erosion long enough for disintegration and weathering of the basalt, for the surface upon which rhyolite No. 2 flowed was covered with partly rounded débris of basalt and rhyolite.

The eruption of basalt No. 1 followed that of rhyolite No. 2, probably with little erosion between. It was a thin flow of small extent and was followed by the successive eruptions of rhyolites Nos. 3, 4, 5, and 6, each of these formations being fairly uniform and persistent rhyolite. No. 3 probably consists of more than one flow, and this is certainly true of rhyolite No. 5, which in some places contains two basal contact glasses. Rhyolite No. 6 was followed by the eruption of basalt No. 2, which is a little thicker than basalt No. 1 and covers a greater area.

Rhyolite No. 7 followed basalt No. 2. There was a little erosion and weathering between, but this was apparently of such character as to leave only slight depressions or very gentle slopes, for the small and nearly uniform thickness of rhyolite No. 7 shows that it flowed upon an even surface. It was followed by rhyolite No. 8, with little or no intervening erosion. The two flows are locally separated by the basal glassy contact of rhyolite No. 8, which, above the glass, is very uniform in texture and appears to represent a single flow. Basalt No. 3, thin and very local in occurrence, followed rhyolite No. 8. It was perhaps formerly much more extensive, for the succeeding rhyolites Nos. 9 and 10 contain many angular basalt fragments, which were apparently picked up as they flowed over the surface. The very persistent basal glass of rhyolite No. 10 shows that these two formations are separate flows.

Basalt No. 4, which followed rhyolite No. 10, is the thickest and most persistent of all the basalt flows. After its eruption there was a period of relative quiescence, during which a basin formed, into which the débris from the surrounding country was washed. But there was some volcanic activity while the tuff was deposited, for at one place it contains a thin bed of rhyolite flow breccia. Following the formation of the tuff, rhyolites No. 11 to No. 16 were erupted, probably with very short intervals between. These are pink and white flow breccias, alternating with green or brown glass. They are all much the same in composition and of fairly uniform thickness. They were apparently once more extensive, but have been eroded from the larger part of the area. Rhyolite No. 16 was followed by basalt No. 5, and this by an eruption of quartz latite. A thin bed of stratified tuff was deposited upon the quartz latite, and upon that quartz basalt was extravasated. Some of the lavas, probably before all were erupted, were intruded by quartz porphyry, plagioclase basalt, and probably by leucite basanite. Exposures of intrusive rocks are confined to lavas older than rhyolite No. 11, and it is possible that most of the intrusive bodies were formed before this rhyolite was erupted.

The intrusive rhyolite porphyry is closely related to the rhyolites in composition and may represent some of the rhyolite lava that ascended to the surface through channels which the porphyry now occupies; but it seems unlikely that any considerable portion of the rhyolite magma ascended by these supposed conduits, for there is no pronounced metamorphism of the rocks in their vicinity and the dip or thickness of the lava beds do not appear to be related to the intrusive masses in any way that suggests the latter as a source. The principal sources of the rhyolite flows have not been identified. They may be covered by later lavas or may be buried beneath the wash of the desert flats. The nearly uniform thicknesses of most of the flows shows that they spread over a flat surface; the beds that do thin out are not thickest at any common geographic point that might be assumed as their source. Some of them are thickest in the eastern part of the district, others in the western part. The lavas may have poured out through numerous conduits.

Some of the basalt dikes may fill channels through which some of the basalt flows reached the surface. The rocks have the same composition and differ very little in crystallinity of groundmass. Many of the dikes, however, are clearly younger than the beginning of the faulting and the tilting by which all the flows are affected.

The many flows of basalt interbedded with the many flows of rhyolite show that highly acidic eruptions alternated with basic eruptions. The flows followed one another so closely that it is improbable that each flow represents a new differentiation product from a common magma. It is more likely that the two kinds of lavas were supplied from different sources through alternately opened vents.

There is no evidence of tilting and faulting during the period of lava flows. The fact that the basalt dikes do not occur in rocks as recent as rhyolite No. 11 suggests that they may be in the main older than this flow; since, however, so many of the dikes are obviously related to the fault systems and since these faults cut all flows, the absence of dikes from rhyolite No. 11 and from younger flows may be merely a feature of areal distribution.

QUATERNARY ALLUVIUM.

The youngest formation in the Bullfrog district is the so-called wash, which covers a large area and is composed of sand, gravel, angular detritus, and large bowlders. It merges with the talus of the slopes and occupies the depressions between the mountains. Only the upper portion of the wash is exposed, for there are no deep canyons in it. The Amargosa shaft, sunk at a point 3,100 feet S. 15° W. of the summit of Ladd Mountain to a depth reported to be 330 feet, is entirely in wash. If the slope of Ladd Mountain were projected it would pass only a little more than 100 feet below the bottom of this shaft. It thus appears that here, at least, the slope of the rock surface under the wash is nearly or quite as steep as the average slopes of the mountains. The mountainous area once had greater relief than at present and the low places have been gradually filled up with waste from the hills. This process is still going on through the agency of many small, intermittent streams, as is the case in most desert countries.

The fragments that compose the wash are from all the formations exposed; they range in size from dust to bowlders over a foot in diameter. Some of them are subangular; others are imperfectly rounded, but very few appear to have been transported any great distance. In many places the dust in the wash is consolidated, much as adobe bricks are hardened in the sun.

GEOLOGIC STRUCTURE.

OUTLINE.

The preceding sections discuss the characteristics of the various rock formations, their distribution, and their sequence. This section on geologic structure treats of the deformation by faulting and tilting which gave the rocks their present attitudes.

After the eruption of the quartz basalt, which is the latest lava flow represented on the geologic map, and near the close of the Tertiary or in early Quaternary time, the various lavas and tuffs lay nearly horizontal, one above the other. There are slight erosional unconformities between some of the formations, but the series throughout the area included about the same members, so that if a number of drilled holes, each a mile or more deep, had been put down at various places, before the country was faulted and tilted, each would have encountered approximately the same succession of volcanic materials. The present distribution of the rocks is very different, for flows which are among the earliest cap some of the highest hills, and at several localities the oldest rhyolite outcrops at higher elevations than the latest lava flow, the quartz basalt.

TILTING AND FAULTING.

TERMINOLOGY.

The displacement of strata on one side of a fissure with reference to those on the other side is called a fault. Most fault fissures are inclined and the vertical angle by which a fault plane departs from a horizontal plane is called the dip. The direction of a horizontal line in the fault plane is the "strike" of the fault. When the hanging wall appears to have dropped with reference to the foot wall the fault is a "normal" fault, and when the foot wall appears to have dropped with respect to the hanging wall the fault is "reverse." All the faults in the Bullfrog district, so far as known, may be classed as normal faults.

Many faults are marked by slickensides, which are smooth, polished surfaces resulting from movement along the fault plane. The slickensided surfaces as a rule are scratched or striated by the grooving action of harder particles or projecting points as one wall moves upon the other. These striæ show the direction of relative movement of the walls.

A "fault zone" consists of two or more nearly parallel fault fissures with thin sheets of country rock between them. In places intersecting fractures connect the main fissures and these cross fractures may be so numerous that the rock in the fault zone is much fractured or is crushed.

The usage of geologists is not uniform regarding the nomenclature of the elements of faults. J. E. Spurr[a] first proposed a terminology to be used where data are complete, but when broad areas are described the facts obtainable are rarely or never adequate to define every detail of all the fault movements. As a rule the structure is expressed by vertical sections, taken where exposures are best and rarely at right angles to the strike of all the faults shown. Sections used in text-books to illustrate the elements of faulting are, as a rule, drawn at right angles to the strike of the fault plane.

In the study of the structure of tilted beds that have been faulted three sets of planes are to be considered: (1) The top or base of a bed or some similar horizon, (2) the plane of the fault, and (3) the plane of the section under discussion. Where the bed is faulted by a straight fault plane there are two lines of intersection formed by the fault plane and the upper or lower surfaces of the separated portions of the bed. Ordinarily these two lines are approximately parallel. Unless the strike of the fault is the same as the strike of the beds the two lines of intersection between the upper or lower surface of the bed and the fault are inclined to a horizontal plane. Sections drawn across the strike of the fault cut these lines at two points which may be used as datum points from which the apparent horizontal, vertical, and inclined elements of a fault, as shown in the section, are calculated. The position of these two points with respect to each other is different in vertical sections drawn in different directions through the same fault. It is convenient to have terms that apply only to a given section under discussion, without reference to a plane at right angles to the fault plane and without regard to the origin of the fault movement. This will be accomplished by prefixing the adjective "apparent" to the names of various elements. Description of what may be called the geometry of faulting is thus kept distinct from inference as to the cause of the movements.

"Apparent vertical displacement" is used in this report to designate the vertical distance between or the difference in elevation of two points that are the intersections of the two separated portions of a bedding or similar datum plane with the fault and that are in the plane of a vertical section chosen at random. This usage is illustrated by figure 6, where the apparent vertical displacement is measured by dropping a vertical line *ab* from the higher point *a* to a horizontal line passing through the lower point *c*, both lines being in the plane of the section under discussion. The apparent vertical displacement would be represented by *ab*, whatever angle the section makes with the strike of the fault. As thus used the term has definite meaning only for the section under discussion.

[a] Geology of Aspen mining district, Colorado: Mon. U. S. Geol. Survey, vol. 31, 1898, p. 251.

The term "apparent horizontal displacement" is used in this report to designate the horizontal distance between the intersections of two faulted parts of a bedding or similar plane with the fault plane, in any vertical section. The apparent horizontal displacement is represented in figure 6 by *cb*, which is the horizontal line drawn from the lower point of intersection *c* to the perpendicular from *a*, the upper point of intersection of the stratum with the fault plane, all lines being drawn in the plane of the section.

Similarly, the distance (*ac* in the diagram) between the faulted edges of a datum plane, measured along the line common to the plane of the fault and the plane of a section under discussion, may be called the "apparent throw" and will coincide with the real throw only when the section described makes a right angle with the fault plane.

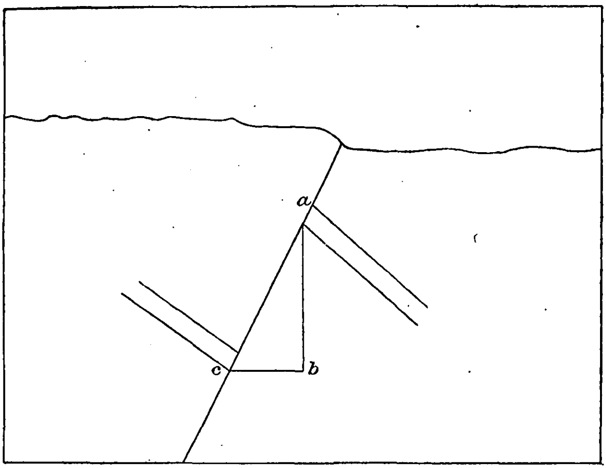


FIGURE 6.—Diagram illustrating apparent vertical and horizontal displacements. See text for explanation.

According to Spurr,[a] "offset may be used to designate the perpendicular distance between the intersection of corresponding planes in the two parts of any faulted body with a horizontal plane, such as the earth's surface may be considered to be, the planes being projected for the purpose of measurement if necessary." Where such a projection is necessary the parts of the planes are said to be offset with "gap," and where a line representing the offset intersects a faulted stratum or other datum plane at two places without such projection of the bed the stratum is said to be offset with "overlap."

CRITERIA FOR THE RECOGNITION OF FAULTING.

The original attitude of sedimentary rocks is horizontal, or nearly so. If water-stratified rocks are laid down upon a steep slope the

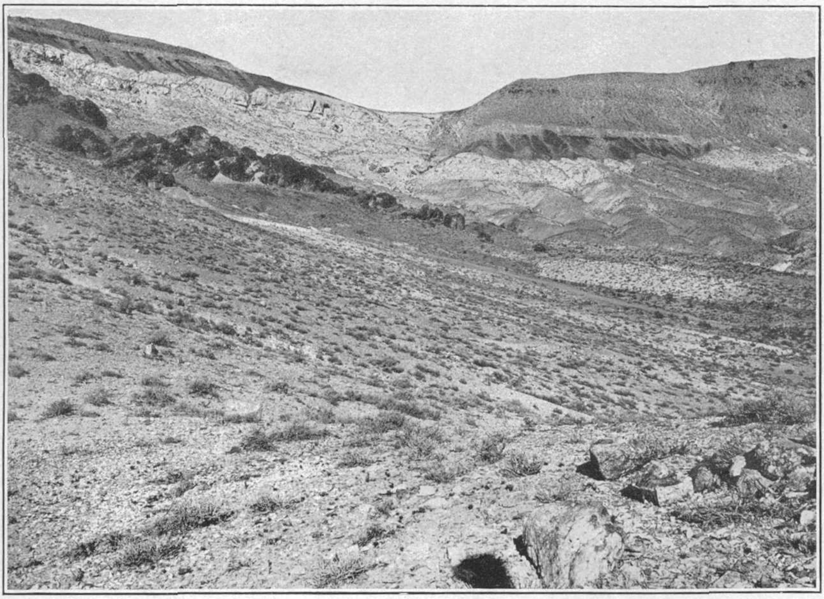
[a] Op. cit., p. 162.

thickness of the bed will vary and the base may have a steep inclination, but the bedding planes will in most cases be approximately horizontal. Similarly, a molten lava flowing over a surface first fills the deepest places and consequently is thickest there. Most of the lava flows here described are of nearly uniform thickness and hence flowed on a nearly level surface. Where a lava is highly viscous a considerable initial inclination of the upper surface of the flow may also result, and, consequently, this surface may dip steeply even when it has not been deformed by movement; but in that case the thickness of the flow usually varies greatly. Lava moves while it is cooling, and before it solidifies may become highly viscous and thus develop flow lines which are steeply inclined when solidification takes place. Accordingly, flow lines do not show the original attitude of the lava beds and can not be depended on for measurement of dip and strike, but the dip and strike may be safely measured on the bedding planes of water-laid tuffs between the flows, or along contacts between basalts and rhyolites of comparatively uniform thickness or between rhyolites of different color or composition. The occurrence of the brown contact glass at the base of several of the rhyolites in the area here discussed is of great assistance in determining the attitude of the flows.

In many of the mountains of the Bullfrog district, especially when viewed from the south, as in Plate II, the flows may be observed dipping below the surface at steep angles. Sutherland Mountain and the south slope of Busch Peak are exceptions, for in these the dip is very gentle. While the strike of the formations varies considerably in different fault blocks, the average is approximately north and south and the average dip is about 27° E.

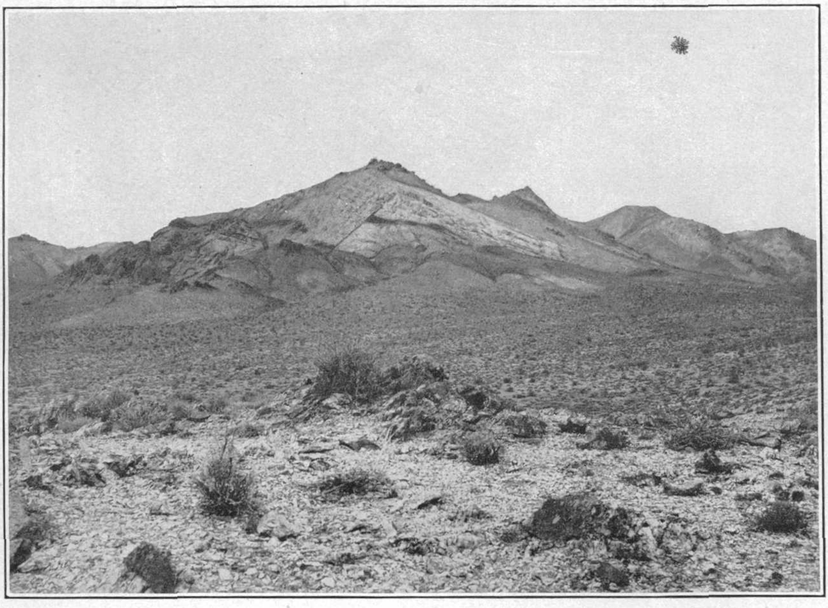
The lavas are shattered, jointed, and traversed by small fractures or parting planes, which trend in almost every direction. Some of these have the direction of flow lines; others strike approximately with the flows; some are nearly parallel to faults, while others are at about right angles to them; still others apparently make large angles with all other structural features. Altogether they form a most irregular network. None of the rocks that are younger than the crystalline schists have been closely folded and there is little or no suggestion of even gentle arches or troughs.

Owing to the rugged character of the topography, the absence of vegetation, and the abundance of prospect pits in this district, exposures are unusually good and many of the faults may be traced without interruption for considerable distances. Where associated flows contrast strongly in color, as the basalt or the dark-glass flows with the light-colored rhyolites, faults may be recognized a mile or more away. Examples are the Saddle fault, northwest of Rhyolite (see Pl. VIII, *A*), the fault which crosses the glass flow on the west



A. SADDLE BETWEEN SUTHERLAND MOUNTAIN AND BUSCH PEAK, FROM THE SOUTHEAST.

Showing the Saddle fault with downthrow on right. The dark flow of basalt No. 2 is cut obliquely by the Denver fault at the right of the illustration.



B. FAULT ON SOUTH SLOPE OF HILL SOUTH OF SAWTOOTH MOUNTAIN.

spur of Burton Peak, and the faults on the south side of the mountain south of Sawtooth Mountain (Pl. VIII, *B*); these faults are among the most conspicuous features of the near landscape around Rhyolite. Where flows closely resemble one another it is very difficult to trace faults, but fortunately in many such cases basalt dikes or débris of basalt marks the fault plane. An example is the northern portion of the Hobo fault, on the hills northwest of the Las Vegas and Tonopah Railroad station. Along a part of its length rhyolite No. 8 forms both the hanging and the foot wall, and abundant and almost continuous basalt débris along this fault plane becomes a useful guide. When both hanging and foot walls of a fault are the same rock and basalt is absent, it is difficult or impossible to trace the faults accurately. These are the conditions along that portion of the Denver fault on Busch Peak north of the outcrop of basalt No. 2, which it displaces. Wash covers

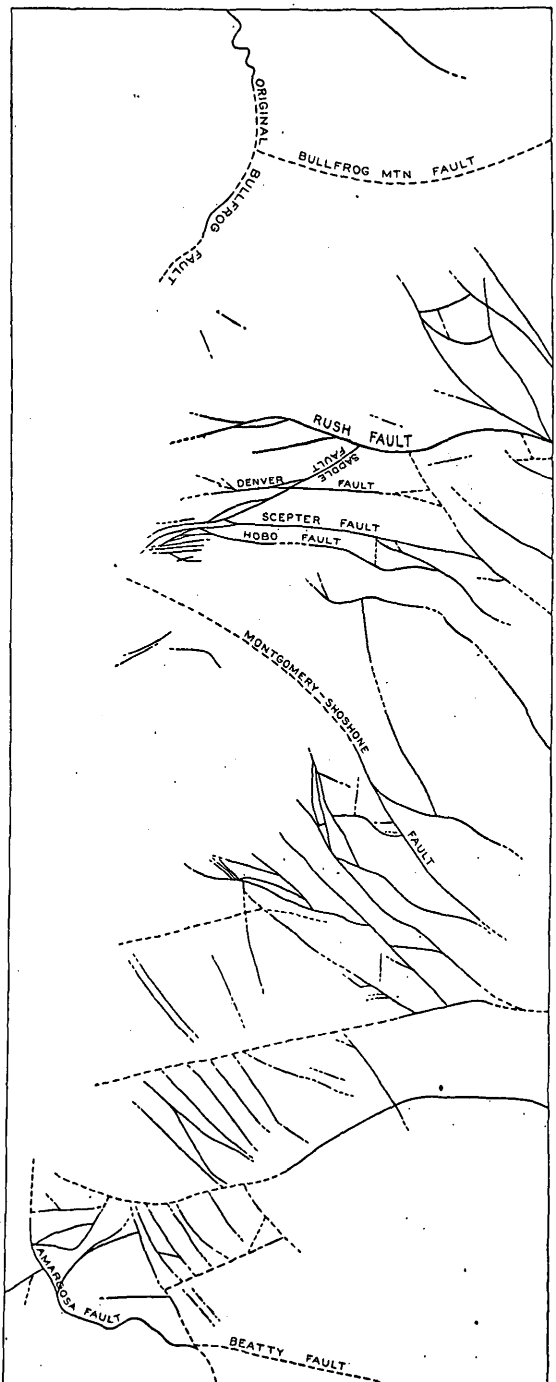


FIGURE 7.—Plan of the principal faults in the Bullfrog district.

up a large number of faults; some partly, others completely. For example, the structure and succession of Ladd and Montgomery mountains show that a fault striking northwest, with a vertical displacement of many hundred feet, occurs between the two mountains, but no part of its outcrop is exposed. The Montgomery-Shoshone fault can be traced accurately along a part of its course, but after it passes into the flat southwest of the Polaris mine only its approximate location can be determined. Since the beds which form Bonanza Mountain have been depressed with respect to those which form Ladd

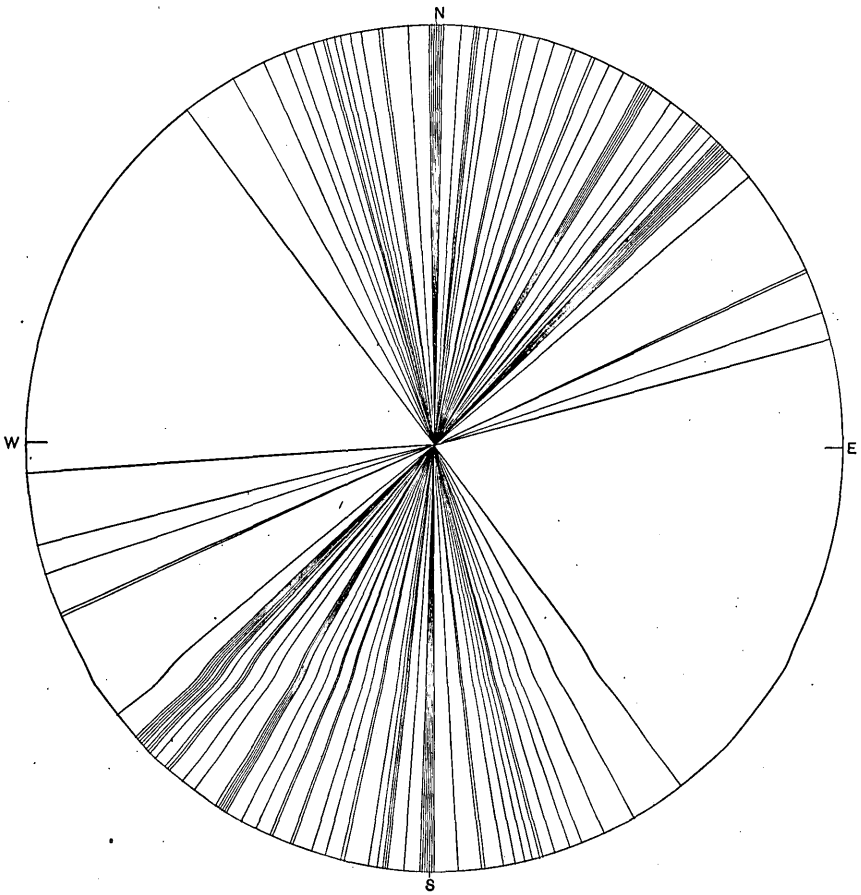


FIGURE 8.—Diagram showing strikes of faults.

Mountain by about as much as the vertical displacement of the Montgomery-Shoshone fault, it is certain that this fault, or one with approximately equal throw, passes under the wash somewhere between the two mountains.

STRIKE, DIP, AND COORDINATION OF FAULTS.

Nearly 100 faults have been recognized in the area shown on the map (Pl. I, pocket). Some extend almost across the area, and others are short. (See fig. 7.) There are two fairly well defined fault systems, one striking nearly north and south and the other striking N. 30° to 50° E. A number of faults, however, do not fall into either system. Among these are several faults concealed by wash, which probably strike northwestward. The courses of 65 faults, including all the more important ones of which the strike is clearly shown, are platted in figure 8. It is worthy of note that the west-northwest and east-southeast octants of the circle are free from faults—that is, none of the faults platted strikes more than 45° west of north. Most of the fault planes dip westward or northwestward. In figure 9 the dips of 65 faults are platted through a common center, and of these only 16 dip eastward. The average dip of the faults platted is 62°. All of the faults dip 35° or more, with the exception of the Original Bullfrog fault and the Amargosa fault,

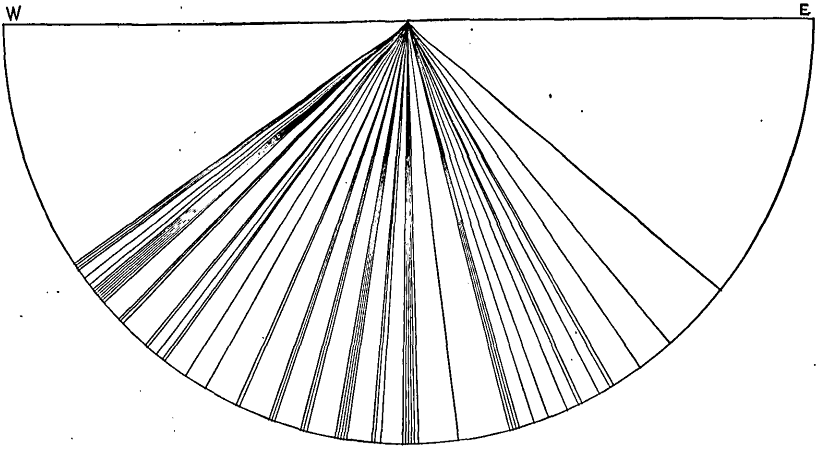


FIGURE 9.—Diagram showing dips of faults.

which at some places appear to have a very flat dip. These are not platted in figures 8 and 9. The average throw of the westward-dipping faults is greater than the average throw of the eastward-dipping faults.

CHARACTER OF FAULTS.

All of the faults for which sufficient data for classification are at hand are normal—that is, the hanging wall appears in every case to have been depressed. The fault fissure along which the ore body of the Denver mine occurs appears at first glance to be an exception. On level 3 the fissure dips toward the east; at this point both hanging and foot walls consist of rhyolite No. 5 and it is impossible to determine which wall has gone down. On the south slope of Busch Peak, at the horizon of basalt No. 2, the west wall very clearly has been depressed. This would imply that the fault is reverse, provided that it continues to dip east; but the straight outcrop over a diversified topography shows that this portion of the Denver fault is vertical. The Saddle fault, of greater throw than the Denver fault, makes an intersection with the latter between the Denver mine and Busch Peak, so that there are four blocks formed by the cross faults. If the Denver fault and the Saddle fault were formed at the same time, it is highly probable that each of the four blocks formed at the intersection moved independently, so that the east or foot wall may have dropped at the Denver mine, while the west wall dropped at Busch Peak. Thus the Denver fault may be normal at both places.

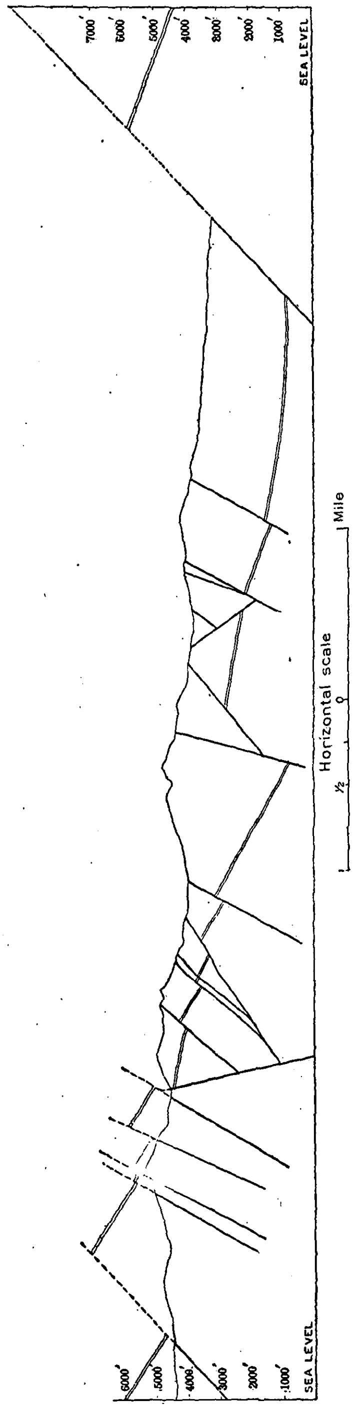


FIGURE 10.—Diagram illustrating displacements along section A–A′, Plate I.

VERTICAL DISPLACEMENT OF FAULTS.

The vertical displacement of the faults, measured in a plane at right angles to the strike, varies from 2 or 3 feet to more than a mile. In figure 10 rhyolite No. 7 has been platted in section along the line A–A′ on Plate I, the section being extended both eastward and westward a little beyond the boundaries of the area mapped. Where older flows outcrop, rhyolite No. 7 has been placed in the position which it very probably occupied before it was eroded, and where younger flows outcrop it has been platted below them, at a distance equal to the average thickness of the elsewhere intervening formations. This figure shows diagrammatically the apparent vertical displacement of the faults. It is to be noted that the faults of greatest apparent vertical displacement are the Beatty fault and the Bullfrog Mountain fault and that the Montgomery-Shoshone and Rush faults also have considerable apparent vertical displacement. The sum of the apparent vertical displacements of all the west-dipping faults which this ection crosses is 12,500 feet, and the sum of the apparent vertical displacements of the east-dipping faults is 1,250 feet. The difference is 11,250 feet, and from inspection of this figure it appears that this amount of depression toward the west has resulted from faulting. Section A–A is further discussed on page 81.

Since the faults are all normal and figure 8 shows the dip of faults plotted through a common center, this figure also shows the prevailing direction of throw. While 16 of the 65 faults dip eastward, the throw of all but three of these is very small. The great downthrow by faulting is in the main toward the west.

STRIATIONS.

Striations or grooves on slickensided surfaces along fault planes are made by hard particles or hard projecting points of rock rubbing against softer rock. They show that one or the other wall has moved in one of two opposite directions.[a] Where there has been more than one movement along a fault plane the striæ formed by the first are likely to be erased by the last, and so those remaining, as a rule, record only the latest movement. Slickensided surfaces with two or more sets of superposed striæ have been observed, however, in other places; for example, in the Georgetown district, Colorado. Where hard particles formerly projected from one of the walls these are likely to have been worn asymmetrically, and the most worn side in this case should be the side representing the direction from which the opposite wall moved with respect to the wall in which the worn particle is embedded. The application of this criterion in the Bullfrog district is not very conclusive, however, owing to the slight differences in the hardness of the rocks. Striations are abundant, however, and a great many of these pitch at angles up to 70°. The average inclination of the striæ observed is about 60° from the horizontal, showing that the element of lateral movement was important. Lateral movement is further discussed on page 85.

RELATIVE AGES OF FAULTS AND FLOWS.

The quartz basalt which outcrops just east of the summit of Black Peak is the latest lava flow represented in the Bullfrog area. This flow is faulted about 150 feet by a fault which is joined by the Steinway fault and which ends at the Montgomery-Shoshone fault. Thus this fault appears to be not later than the Montgomery-Shoshone fault and there is nothing to show that practically all of the faulting did not occur after the extrusion of the quartz basalt. If any con-

[a] This is speaking in terms of one wall with respect to the other, for the scientists studying the results of the San Francisco earthquake found that the faulting movement was not confined to the movement of a single wall, but that both walls moved from their former positions, though in opposite directions.

siderable faulting occurred during the interval between the extrusion of rhyolite No. 1 and the quartz basalt, at some place in this area of exceptionally good exposures lava flows should be found covering the earlier faults or in flow contact with fault scarps. Further, such faulting, if accompanied by great displacement, would give a great variation in the thickness of succeeding flows and much of the geologic column would almost certainly be wanting above the higher fault block. The nearly uniform thickness of each flow and the persistence of most of them indicate that they suffered little displacement by faulting during the period of extrusion.

RELATIVE AGES OF FAULTS AND DIKES.

It is clear from an inspection of the geologic map (Pl. I) that the basalt dikes and the fault systems are very intimately connected. The determination of the relation between the intrusion of the dikes and the maximum displacement along the fissures is not, however, so easy as might at first glance appear. The true solution of the problem must reconcile the following facts: (1) No dikes have been found in any formation younger than rhyolite No. 10. (2) The greater number of the dikes occur along the fault fissures. (3) The principal faulting has displaced all of the flows, including those younger than rhyolite No. 10. (4) A very few of the dikes are adherent to both walls, are not traversed by a plane of movement, and consequently are of later age than any of the displacement at that place. On the other hand, the erratic and disconnected outcrops of dikes along many other faults, together with their slickensides, show that there has been much faulting since the intrusion of the dikes.

The amount of crushing and slickensiding along a fissure is not always proportional to the amount of displacement which has occurred between the separated ends of a formation. It is not uncommon to find very smooth, well-defined slickensides and one or both of the walls greatly crushed where the displacement has been very slight. On the other hand, great movement may take place along a plane no thicker than a knife blade and the rocks on either side be not greatly shattered.

It is necessary to conclude that the plan of the present fault systems was outlined by fissures before the intrusion of the dikes. It is conceivable that this initial fissuring took place not later than the eruption of basalt No. 4, that the dikes were then injected, and that consequently the main displacement along the fissure systems and dikes took place some time after the dike intrusions. Another view is that the dikes are younger than any of the flows and were intruded while the main faulting was in progress or after it had been effected.

The first view, which we are inclined to favor, is supported by the absence of dikes from formations younger than rhyolite No. 10

and by the discontinuous and disturbed conditions of the dikes. Further, the vesicular character of the dikes indicates that they formed under slight pressure and where gases could escape. They are therefore presumed to have formed before the hundreds of feet of lavas succeeding rhyolite No. 10 had been extravasated. The second view, regarded as a little more probable by our colleague, Mr. Ransome, is supported by the coincidence of dikes and faults and the absence of any considerable offsetting of the dikes by cross faults. He attaches less weight than do we to the absence of dikes from the younger flows, since this may be an accident of regional distribution, and he considers the disturbed condition of many of them as due to minor movements, subsequent to the great faulting. The problem is apparently not susceptible of definite solution under present conditions, and the two views given are to be taken rather as representing merely slight differences of opinion in regard to the comparative value of different lines of evidence than as the expression of firmly held conclusions.

EROSION SINCE FAULTING.

Figure 4 represents in a general way the position and distribution of the flows before deformation. After faulting, the same flow in

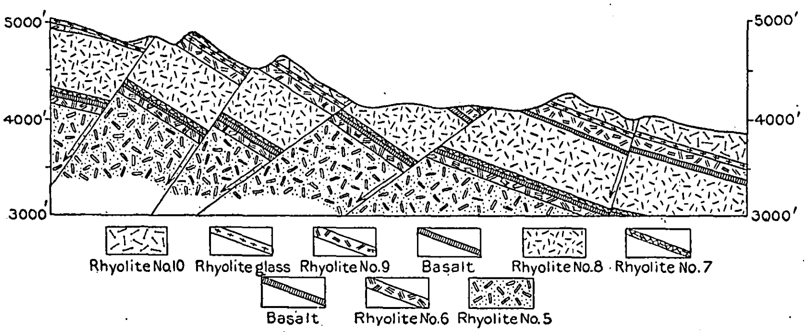


FIGURE 11.—Section northeast of Busch Peak, illustrating the erosion of fault blocks.

some of the blocks occurred far above its position in others. The maximum erosion since faulting began must have been at least 5,000 feet in order to expose the lower flows. Figure 11 is a section drawn through the summit of a hill (elevation 4,700 feet) 2,300 feet northeast of Busch Peak. It shows the result of erosion where the rocks are of unequal hardness. In this section rhyolite No. 10, which is very dense and resistant, forms the summits of the hills, while rhyolite No. 9, which is spongy and easily eroded, forms the saddles. Erosion must have accompanied faulting and the summits of the mountains may never have been very much higher than they are to-day. In general the present topography is the result of the dislocation of tilted beds, combined with extensive and unequal erosion, rather than the direct expression of faulting.

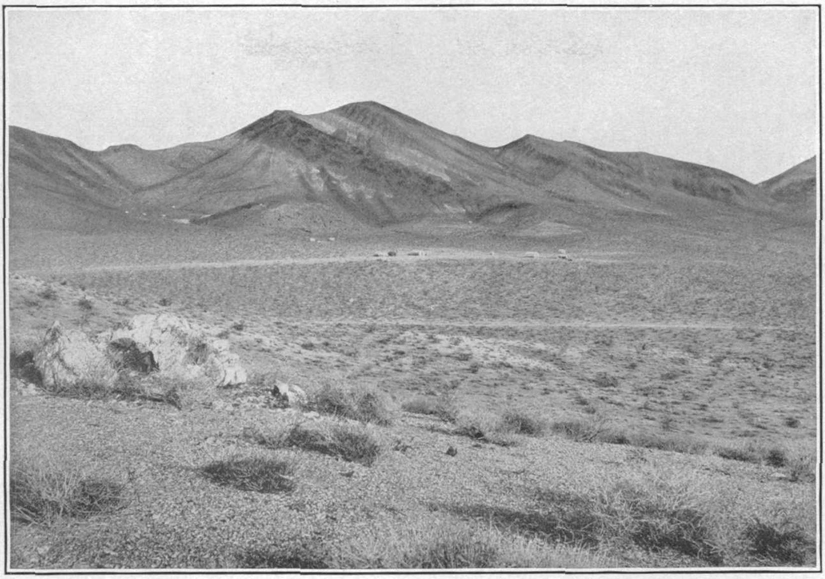
DETAILED DESCRIPTIONS OF FAULTS.

ORIGINAL BULLFROG FAULT.

At the Original Bullfrog mine the rocks northwest of the vein are rhyolite flows No. 1 and No. 2. They strike N. 10° E. and dip about 25° E. (See Pls. I and IX, *A*.) South of the Original Bullfrog vein Silurian (?) limestones, with the associated quartzites and shale, strike approximately east and west and dip from 15° to 20° N. The relations of the rocks show that the vein occurs in a fault zone along which there has been great displacement. The outcrop, as shown on Plate I, is very sinuous, owing to the low north dip of the fault. The outcrop of the vein is at some places 200 feet wide. The vein material is white quartz, which cements a great number of brecciated fragments of rhyolite, shale, and limestone. The limestone under and south of the vein is also greatly crushed, and is traversed by many small veinlets trending in all directions. They are in the main much less than 1 inch wide and are composed of quartz and calcite. The Bullfrog Extension incline, which dips 18° N. and is located about 1,300 feet N. 70° E. of the Original Bullfrog mine, was, at the time of the visit, wholly in a thin layer of shaly material which lies above the limestone. The position of the rhyolite flows to the north, however, shows that the Original Bullfrog fault lies only a short distance north of the shaft. Eastward the fault passes under the wash, but the fact that limestone similar to that near the Original Bullfrog mine outcrops 1 mile S. 83° E. of that mine and is in contact by faulting with rhyolite No. 1 to the north indicates that the two exposures are on the same fault. The amount of displacement can not be determined at this point, but it is probably considerable.

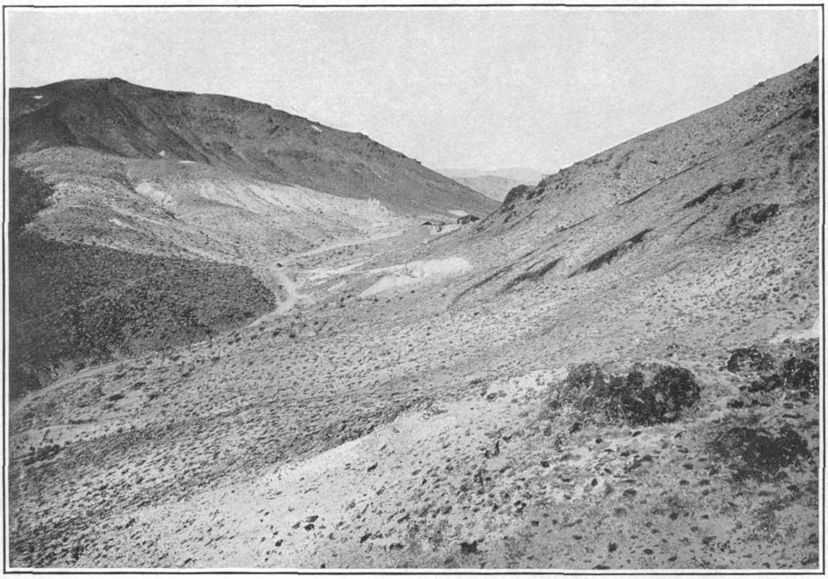
AMARGOSA FAULT.

About 5,200 feet N. 86° E. of Velvet Peak the Tertiary lavas are faulted against the Silurian (?) limestone by the Amargosa fault. This contact extends south 3,300 feet to a point where the crystalline rocks are also faulted against the lavas. The latter contact here bends rather abruptly to the southwest and may be followed for about 2,600 feet to a point where it passes under the wash. The lava flows just north of the fault strike N. 30° W. and dip about 10° E., successively younger lavas being thereby brought in contact with pre-Tertiary rocks on the southeast. The dip of the fault is very low, as is shown by its outcrop (Pl. I), and the throw is probably greater than at the Original Bullfrog mine. The fault fissure on which is the Wildcat (or Bonanza) prospect, which lies to the east of the area



A. BULLFROG MOUNTAIN FROM THE SOUTH.

The low hills in the foreground are composed of limestone and shale, against which the volcanic flows forming the mass of the mountain are faulted. The Original Bullfrog vein outcrops along the face of the rounded hill in the left-middle distance.



B. MONTGOMERY-SHOSHONE FAULT.

The observer is looking northeast along the line of the fault, which passes through the saddle. The light rock on the left is rhyolite No. 16, above which are basalt No. 5 and quartz latite. On the right is rhyolite No. 10.

mapped, also has a low north dip and its throw is comparable to that of the Amargosa fault. The two faults may join under the wash of Amargosa River. Both the Original Bullfrog fault and the Amargosa fault have very low dips and both have Tertiary rhyolite on the hanging wall and pre-Silurian schists on the foot wall. The nearest outcrops of these two faults are more than 5 miles apart and the country between is covered by wash, but the line of contacts between the schist and the rhyolites suggests the presence of either a single continuous fault or else of a zone of profound faulting trending eastward along the southern margin of the Bullfrog Hills.[a]

BEATTY FAULT.

The low hill 1,500 feet northeast of Beatty and just east of the area mapped is composed of rhyolite No. 1, while rhyolite No. 11 outcrops just west and south of town. The rhyolites dip east at low angles and under the wash they must be separated by a fault, which has been named the Beatty fault. This has an apparent vertical displacement (see fig. 10) of about 5,000 feet and the west block is depressed with respect to the east block. The fault probably joins the Amargosa fault and perhaps has fully as great a throw as the latter. It is assumed that it dips toward the west and this direction of dip seems most consistent with the dip of the Amargosa fault near the junction. It is platted on the section with a steeper dip than that of the Amargosa fault, which is lower than the average dip of the faults.

BULLFROG MOUNTAIN FAULT.

The position of the flows north of Bullfrog Mountain with reference to those west of Sawtooth Mountain shows that between them, beneath the wash, is a fault with an apparent vertical displacement of about 2,400 feet. (See fig. 10.) This fault probably joins the Original Bullfrog fault. The dip is assumed to be 45°, which is approximately an average for the larger faults.

MONTGOMERY-SHOSHONE FAULT.

The fault zone that passes through the Montgomery-Shoshone mine is composed of two or more closely spaced and nearly parallel fissures which, collectively, will be called the Montgomery-Shoshone

[a] Since the field work of Messrs. Emmons and Garrey was finished, the Ali Baba shaft in the town of Bullfrog has been sunk to a depth of 300 feet. The shaft went through 200 feet of alluvial material or wash and then into rhyolite. At the bottom the rhyolite is shattered and veined, the vein material being similar in general character to that of the Original Bullfrog vein. When visited in August, 1908, the 300-foot level, which had been driven 121 feet N. 66° E. from the shaft, was all in this vein material. Since then, according to a letter from Mr. A. J. Klamt, the superintendent, the drift passed into red shaly material and then into limestone. These conditions are similar to those at the Original Bullfrog mine and indicate that the Original Bullfrog fault continues east under the wash south of Bonanza Mountain. Mr. Klamt reports that the contact between the rhyolite and limestone dips 30° W. This is probably a local irregularity, and more extensive work would be likely to show a general dip of the fault contact to the north. It is not known, however, what are the relations between the Original Bullfrog and Montgomery-Shoshone faults south of Bonanza Mountain. (See Pl. I.)—F. L. R.

fault. At the shaft of this mine there is a well-defined fissure striking N. 65° E. and dipping 85° NW. Rhyolite No. 10 forms the southeast or foot wall and a down-faulted strip of basalt the northwest or hanging wall. The rhyolite, which on the surface forms the south or foot wall at the shaft, is a dense purplish-gray rock, almost free from dark fragments and in general appearance not unlike rhyolite No. 8, but west-southwestward this grades into a rhyolite containing many small, dark rhyolite and basalt fragments—the lower part of rhyolite No. 10. Still farther west the glassy basal facies of rhyolite No. 10 outcrops above rhyolite No. 9. The foot wall at the shaft, therefore, is the upper part of rhyolite No. 10. The underground relations of the fault zone are described on pages 106–108.

It is a current opinion among mining men that rhyolites Nos. 8, 9, and 10, which compose Montgomery Mountain, will be found on the south slope of Black Peak within 300 or 400 feet of the surface, but when the section is studied this appears very unlikely, for north of the fault zone rhyolite No. 16 outcrops at many places, and this, in the normal sequence, is separated from rhyolite No. 10 by flows of many hundred feet in total thickness, as is shown in the generalized section of figure 4.

In a trench about 400 feet northeast of the shaft 60 feet of basalt is exposed. At its north end the basalt is truncated by a fault dipping 50° NW. and the hanging wall is of crushed rhyolite. Its south end is similarly faulted, its contact with the rhyolite dipping about 60° NW. In the Providence mine, which is about 1,200 feet northeast of this trench, a finely slickensided surface, striking N. 42° E. and dipping 45° NW., is exposed. (See p. 111.) The hanging wall is rhyolite No. 16, with its characteristic glassy fragments, while basalt, much crushed and altered, forms the foot wall. Gray rhyolite (No. 10) lies immediately southeast of the basalt. Between rhyolites Nos. 16 and 10 the basalt for its entire width of 35 feet is sheared and crushed, as described on page 112.

The country to the northeast of the Providence mine is partly covered by débris from the hills to the west and the fault plane is not exposed, but there are a few outcrops of the foot-wall and hanging-wall rocks, so that the position of the fault is approximately known. Here rhyolite No. 16, or the quartz latite, where this has not been eroded, occurs on the northwest side and rhyolite No. 10 outcrops east of the fault. A few yards north of the Bullfrog-Shoshone shaft a block of basalt lies between rhyolite No. 16 on the west and rhyolite No. 10 on the east and is probably a remnant of the same basalt fault block that is visible in the Providence and Montgomery-Shoshone mines. Northeast of this outcrop the fault passes under the wash. West of the Montgomery-Shoshone shaft the fault appears in the Polaris workings and still farther west it passes under the wash.

Figure 12 shows that the flows on Bonanza Mountain are depressed with reference to those on Ladd Mountain about 1,600 feet, which is a figure of the same order as the apparent vertical displacement of the Montgomery-Shoshone fault, as shown on section A–A, Plate I. It is assumed that this fault passes between the two mountains and continues southwest toward the town of Bullfrog.

The 2,000-foot apparent vertical displacement of this fault, as shown on the vertical section represented by figure 10, is obtained by calculating the thickness of the flows displaced and is a fairly accurate estimate.

Two groups of metalliferous veins, one represented by those of the Montgomery-Shoshone mine and one by the veins on the south slope of Bonanza Mountain, are situated on opposite sides of this fault and, so far as known, are the only veins so situated. Both groups strike

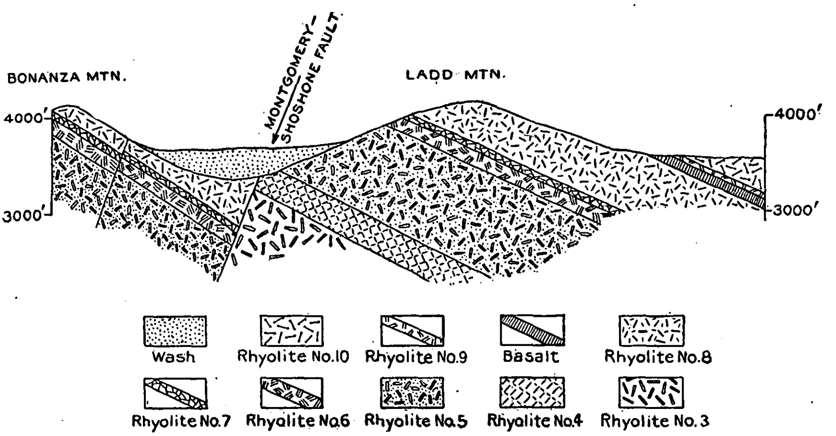


FIGURE 12.—Section through Bonanza and Ladd mountains, showing inferred position of the Montgomery-Shoshone fault.

approximately in the same general direction and have a somewhat similar mineralogical composition. The conjecture that they are a single vein group displaced by the Montgomery-Shoshone fault has been entertained, but no satisfactory evidence for its support has been found.

A mile N. 49° E. of the Montgomery-Shoshone shaft there is a group of prominent rock outcrops 800 feet long and 100 feet wide, which trends N. 30° E. The rocks stand from 20 to 30 feet above the nearly flat surface and have been incorrectly regarded by some as the silicified outcrop of rocks along the extension of the Montgomery-Shoshone fault. The rocks themselves are brecciated and in some places cut by veinlets of white quartz. Careful mapping at this place showed that the outcrop or reef is the faulted portion of a hard layer of rhyolite No. 11, which outcrops on the west spur of Burton Mountain and occurs at many places from 50 to 75 feet below the top of rhyolite No.

11. This layer, being harder than the more pumiceous rhyolite below and above, withstands erosion better and for the same reason is more easily fractured, but so far as is known it does not carry ore.

RUSH FAULT.

West of the summit of Sutherland Mountain the Rush fault does not show its dip, but its course is marked by a line of basalt débris. Rhyolite No. 5 outcrops on the east side of this line, while rhyolite No. 1 is exposed almost continuously along the west side. In the draw southeast of the hill (elevation 4,540+ feet) three-eighths mile north of Sutherland Mountain a small mass of rhyolite No. 7, with characteristic pink color, forms the east wall, which here is dropped down about 100 feet by a cross fault (the Saddle fault) that joins the Rush fault at this point. North of this point there is very little basalt along the outcrop of the Rush fault, though several small masses of it are exposed in prospect pits. This portion of the fault strikes a few degrees west of north and dips about 65° E. Its course here is gently sigmoidal as the fault descends the east slope of Box Canyon toward the north. The walls of this portion of the Rush fault are at many places crushed and there are slickensided surfaces parallel to the plane of the principal fault. The Rush fault is one of the few faults in the Bullfrog district that dip east. Its apparent vertical displacement where it is crossed by section A–A′, Plate I, is estimated to be 700 feet, and the displacement is considerably greater west of Sutherland Mountain. This shows that there has been unequal tilting of one of the fault blocks during settling.

SADDLE FAULT.

The Saddle fault passes over the saddle between Sutherland Mountain and Busch Peak and is conspicuous from Rhyolite (Pl. VIII, *A*). Where it joins the Rush fault rhyolite No. 5 forms its southwest and rhyolite No. 7 its northeast wall. In the saddle there is a remnant of basalt No. 2 on the southwest side of the fault and some of the same basalt occurs 100 feet lower on the northeast side. East of the saddle the slickensided faulted surface of rhyolite No. 6 dips about 70° NE. Farther southeast this fault appears to cross the Denver fault, though its intersection is not exposed. Both the Saddle and the Denver faults are mineralized near their intersection, and the distribution of the outcrops of the veins shows that neither fault is thrown very much out of line at the junction. Southeast of the crossing of the Denver fault is exposed a slickensided surface that strikes N. 16° W. and dips 63° NE. Toward the south this fault is concealed, but it is probably one of the two faults that inclose a horse of rock and, uniting beyond, pass through the Eclipse and Tramp shafts on the west slope of Bonanza Mountain. (See Pl. I.)

DENVER FAULT.

The Denver fault continues northward from the Denver mine and crosses the summit of the ridge joining Bonanza and Sutherland mountains, where its position is shown by a small patch of basalt, probably a faulted dike. The fault plane is concealed north of this point and since both walls are rhyolite No. 5 it can not be followed continuously. A mineralized fissure appears along the strike at an elevation of about 4,300 feet and a similar vein 2½ feet wide, standing slightly above the rhyolite, outcrops a few rods to the north of the intersection of the Denver fault with the Saddle fault. North of this point the Denver fault may be followed nearly to the top of Busch Peak, where it apparently splits, each portion joining a northeast-southwest fault a few rods north of the summit of Busch Peak. The vertical displacement of the Denver fault where it cuts basalt No. 2 on the south slope of Busch Peak is, as measured on a section at right angles to the strike of the fault, approximately 50 feet, and its nearly rectilinear outcrop over a diversified topography shows that this part of the fault plane is nearly vertical.

SCEPTER FAULT.

The Scepter fault, which apparently joins the east fork of the Saddle fault near the summit of the ridge north of the Eclipse shaft, outcrops also at an elevation of 4,200 feet on the northeast slope of this ridge. It is best exposed in the tunnel of the Voorhees-Murphy lease as a wide zone of shattered rock, striking north. Here its east wall is rhyolite No. 6 overlain by basalt No. 2 and rhyolite No. 7, and its west wall is rhyolite No. 5. At this point the dip is very steep to the east or else vertical. The fault probably passes a short distance west of the Great Eastern shaft, although it may be represented by a small fracture, with a dip of 75° E., which was encountered in that shaft. A short distance farther north the fault is more easily recognized and may be traced with only short interruptions across the basin, where brownish vitreous rhyolite (No. 5) forms its west or foot wall and porous white rhyolite (No. 6) its hanging wall. In a prospect pit a few rods southeast of the summit of the hill (elevation 4,180+ feet) three-fourths of a mile northwest of Rhyolite a slickensided surface is exposed, dipping 72° E. The hanging wall is basalt and the foot wall is rhyolite No. 5. The strike here is about N. 7° E. and the gouge streak along the fault slip is more than a foot wide. Farther north this fault brings rhyolites Nos. 6 and 7 on the west into contact with rhyolite No. 8 on the east. North of this point both walls are rhyolite No. 8, and since no basalt dike marks its course it is impossible to trace the fault farther. A slickensided surface, nearly vertical and with grooves and striæ perpendicular to the strike, occurs near the place where the projected line of the fault crosses a canyon west of the spring that is about 600 feet northeast of the summit of Busch Peak. It is assumed that this striated surface is on the Scepter fault. The vertical displacement of the Scepter fault, as shown in a vertical section at right angles to the strike, is approximately 100 feet. The east wall was depressed. A west-dipping fault, which is probably coincident with the Lester vein for part of its course, joins the Scepter fault on the crest of the ridge north of the Lester shaft, which is on the west slope of Bonanza Mountain.

HOBO FAULT.

A fault striking N. 10° E. and dipping 55° W. joins the Hobo vein at the Hobo shaft. The vein is shattered at the fault and is marked by a slickensided surface, but exploration has not yet exposed the vein west of the fault and the throw of the fault can not be determined at this point. This fault, with approximately the same strike and dip, is also exposed on the surface in several prospect pits north of the Hobo shaft. (See Pl. XI, *B*.) Here a brecciated and slickensided basalt dike occupies the fissure. Rhyolite No. 6 forms the foot wall on the east side, while the hanging or west wall is rhyolite No. 8. North of these pits patches of basalt occur at intervals along the fault. The Hobo fault passes under the dump from the upper east-west crosscut tunnel of the Golden Scepter mine and still farther north it is covered by wash; but it is again exposed on the east slope of the hill (elevation 4,180+ feet) three-fourths of a mile northwest of Rhyolite, where there is a fault contact between basalt on the east and rhyolite No. 8 on the west. The fault plane here dips west and strikes approximately with the Hobo fault, as projected northward from its exposures on the east slope of Bonanza Mountain. Farther north the outcrop of this fault ascends the east spur of Busch Peak, bending sharply to the east as it rises, in consequence of its west dip. For the same cause it bends sharply west down the hill northward to the spring northeast of Busch Peak. Its presence is indicated by basalt débris nearly all the way. At the spring, where it is joined by a fault striking a few degrees east of north, the Hobo fault dips 35° W. and strikes about N. 25° E. It may be traced northeast of this point almost continuously for several hundred feet and it is exposed in a prospect (elevation 4,120 feet) on the northwest slope of the hill (elevation 4,260+ feet) 1,200 yards northeast of the summit of Busch Peak. At this point it dips about 35° W.

The vertical displacement of the Hobo fault, as measured on a plane at right angles to its strike on the Hobo claim, is less than 100 feet, and the west side or hanging wall has been depressed. The vertical displacement, measured in the same manner, east of Busch Peak near the spring above mentioned, is greater than this and where the section A–A′ crosses the fault the apparent vertical displacement is estimated at 300 feet. This increased displacement toward the north may be explained by a differential throw, the north end of the western block being depressed more than the south end; or there may be one or more cross faults under the wash that unite with the Hobo fault from the east and allow the portion of the east block north of the intersection to move independently.

MECHANICS OF THE DEFORMATION.

GENERAL RESULT OF THE MOVEMENTS.

The attitude of the flows and tuffs in nearly every block of the fault mosaic is known through the presence of basal contact facies or of thin layers that contrast sharply with layers above or below them. The position and dip of the fault planes between the individual blocks are known from exceptionally good exposures on the surface and underground. The data are therefore full enough to warrant considerable confidence in the interpretation of details of structure as shown in the geologic map and in the various cross sections. Section A–A′, Plate I, is constructed through Black Peak and Burton Mountain. Figure 10 is an extension of section A–A′, drawn to include some beds exposed east of Beatty, outside of the mapped area. It is not quite perpendicular to the strike of the faults or flows, though at most places it crosses both, making large angles with their strikes. These angles have been taken into consideration in platting faults and beds on the section. They cause, in most cases, an apparent flattening of dip in the diagram and make the flows appear a little thicker than they are. The faults are represented as extending down with the dip observed at the surface. In the case of faults concealed by wash a probable dip was assumed. Figure 4 is a columnar section giving the estimated average thickness of the beds.

In figure 10 rhyolite No. 7 has been projected under later strata of known position and above older ones, its position being determined from the thickness of associated beds near by or from the average section as given on page 30. Most of the dips of flows as platted were observed near the plane of the section, but where the rocks are concealed by wash their dip was assumed. Figure 10 represents a length of 8 miles. Rhyolite No. 7 is represented in each fault block as extending to the next fault west, and if necessary is projected upward with the dip observed or assumed at the surface. The diagram may be objected to as unduly extending actual observation, but it so nearly represents the true relations of the beds as to be useful in clarifying discussion of the data, which for an intricately faulted and tilted region are unusually full.

In the fifteen fault blocks in which rhyolite No. 7 appears in this section the total downward depression due to tilting (the sum of the vertical legs of the right triangles shown in fig. 10) is about 13,000 feet, the projection of the flow (the sum of the horizontal legs of the triangles) is 30,000 feet, and the extent of rhyolite No. 7 in the plane of the section (approximately the sum of the hypotenuses of the triangles) is 33,600 feet. The figure shows a slope to the east, due to tilting, that averages about 39 feet in 100 feet along the flows and corresponds to an average dip of about 23° E. in the plane of the section. This, however, does not represent the actual dip of the flows but only their apparent dip in the section of figure 10. Since the strikes of the flows are not exactly at right angles to the plane of the section, the actual dip is greater than the apparent dip. Sixteen field measurements of dip near the plane of the section average 27°, which may be taken as a very close approximation to the average actual dip of the flows.

The sum of the apparent horizontal displacements of all faults as shown on this section is 12,240 feet, which, added to the projection of rhyolite No. 7 on a horizontal line, equals the total length of the section, or 42,240 feet (8 miles).

There are nineteen faults in all represented in figure 10 and of these all but two dip west. According to the interpretation made, rhyolite No. 7 is displaced by fourteen of the faults, of which two have a downthrow to the west. Measurements of these blocks, as shown in the figure, give for the sum of the apparent vertical displacements of all faults, 13,750 feet; for the sum of the apparent vertical displacements of the faults which depress rhyolite No. 7 to the west, 12,500 feet; for the sum of the apparent vertical displacements of the two faults which depress rhyolite No. 7 to the east, 1,250 feet. Thus the apparent net depression of rhyolite No. 7 toward the west, resulting from all faults, is 11,250 feet. Tilting depresses this same rhyolite 13,000 feet to the east. The total apparent depression eastward, due to tilting and to downthrow to the east by faulting, is about 14,250 feet. Thus this flow as projected is only 1,870 feet lower at the east end of the section than at the west, and the tilting and faulting are nearly compensatory.

RELATIVE AGES OF TILTING AND FAULTING.

The tilting of the lavas occurred before or after they were faulted, or else the two processes went on together. Tilting before faulting is represented diagrammatically by figure 13, where an originally horizontal flow *ab* is tilted through 27° to *ad* and then faulted to *cd*. If it is assumed that tilting occurred before faulting, then rhyolite No. 7 (along the plane of section shown in fig. 10) after tilting should have been 13,000 feet lower at the east end of the 33,600-foot section of rhyolite No. 7 than the same bed was at the west end. If the period between the deformation by the two processes were long enough for any considerable erosion, evidence of such relief should be preserved in this or adjacent districts in the form of a thick accumulation of derived sediments. These sedimentary rocks would now be faulted but not tilted. There is, of course, the possibility that nearly horizontal faulted sedimentary rocks of later age than the lavas do occur below the desert flats and that beds of the same age

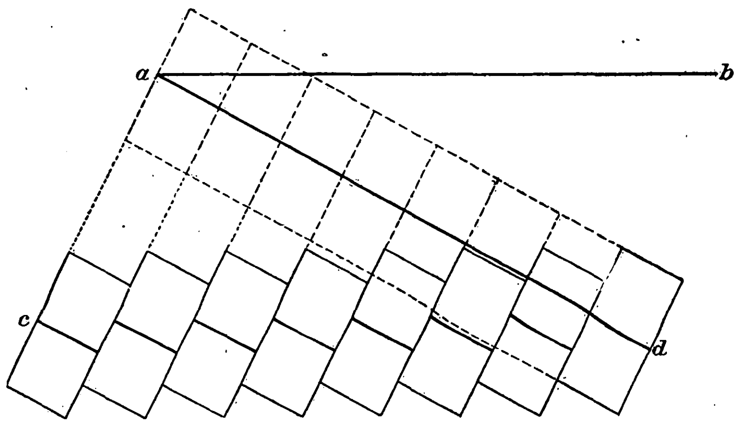


FIGURE 13.—Diagram illustrating tilting before faulting; vertical section at right angles to the strike of the faults. The originally horizontal flow *ab* is tilted to *ad* and then faulted to *cd*.

have been eroded from the higher country; but if all of the faulting had followed all of the tilting, with erosion and deposition between, the chances would have been good for the preservation of remnants of horizontal sedimentary beds, since faulting alone has caused displacement of more than a mile and without active simultaneous erosion must have produced that much relief. The absence of

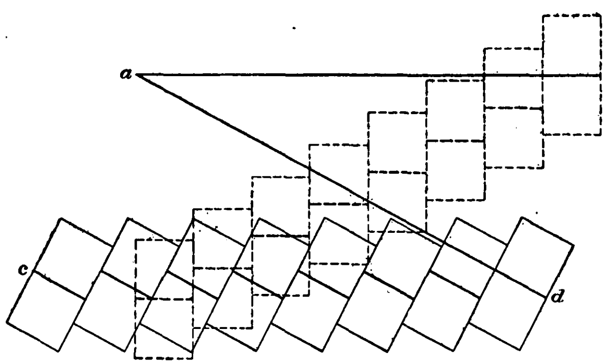


FIGURE 14.—Diagram illustrating faulting before tilting; vertical section at right angles to the strike of the faults. The originally horizontal flow is faulted with downthrow to the left and the series of blocks as a whole is then tilted to the position *cd*.

faulted but untilted rocks of later age than the lavas points toward the conclusion that the lavas were not tilted very long before they were faulted.

Faulting before tilting is represented diagrammatically in figure 14, where the bed *ab* is faulted with downthrow to the west, the segments taking the position shown by the dotted lines. If the series is tilted 27° with *b* as an axis, these blocks take the position of the solid lines. If all of the tilting shown in figure 10 had occurred after all of the displacement by faulting, then there should have been a very great relief before tilting, for faulting, as expressed in this section, depressed the rocks 11,250 feet. If erosion had taken place between the operation of the two processes, unless it were vigorous enough to carry all of the detrital material entirely beyond the area examined, the débris should now form tilted sedimentary rocks, not faulted, and some remnants of such rocks would very probably remain at some place within or near the area. Although at many places the beds on different sides of a

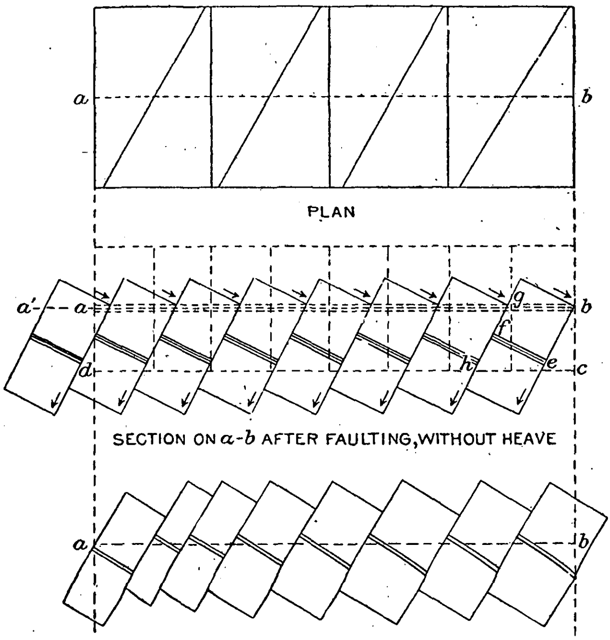


FIGURE 15.—Diagram illustrating simultaneous faulting and tilting. See text for explanation.

fault dip at different angles, there is very little variation of dip within single blocks. This fact further suggests the interdependence and contemporaneity of the faulting and tilting. The Silurian (?) limestone south of the Original Bullfrog fault does not conform in strike and is less steeply tilted than the lava flows to the north of the fault. If it is assumed that the hanging wall went down in this case, it follows that the east end of the block moved a greater distance than the west end in order to tilt the strata on the north side of the fault to the east. If all the tilting occurred before all the displacement along the fault the beds on the two sides of the fault plane would probably be inclined at about the same angle. The short geologic time which has elapsed since the beginning of the deformation of the lavas by faulting and tilting suggests further that the two processes were nearly if not quite contemporaneous.

If faulting and tilting went on together, the effect would be that of rotation, each block moving more or less independently of adjoining blocks. Such movement is represented diagrammatically in figure 15, where the flow AB is cut by regularly spaced vertical fissures and the blocks are rotated independently without any tilting of the mass as a whole. As shown in this figure the horizontal distance through the blocks along the line A′–B is about 12 per cent greater after rotation than before, and in consequence the area of the horizontal section through A′–B is likewise increased 12 per cent, providing the width of the faulted area remains the same. If rotation occurred without extension along the line A′–B′ then there must have been a great horizontal movement or heave of the blocks along the fault planes while they were faulting. As shown in plan in the upper portion of this diagram, the faults cross one another, making angles of about 35°. This forms wedges, some of which present sharp edges to the plane of the section. If during deformation some of these wedges moved broad-part forward (at right angles to the line of the section) there would be room for the remaining blocks to settle without such great extension along the plane of the section. This horizontal element of movement along the faults of the Bullfrog district is recorded by inclined striæ on fault planes.

HORIZONTAL COMPONENT OF MOVEMENT ALONG FAULT PLANES.

The striations on the slickensided surfaces of the faults in the Bullfrog area make angles that vary from a fraction of a degree to 90° and have an average pitch of about 60°. Consequently the movement must have had a considerable horizontal component. Observations of recent faulting in California show that horizontal movement may be very important and that in some cases there seems to have been very little vertical movement. Figure 16 shows beds that have been tilted and that are cut by a fissure of which the dip is opposed to that of the beds. The strike of the fissure makes an acute angle with the strike of the beds. The left half of the block is shown to move horizontally toward the reader. This results in an apparent normal displacement that, when seen only in cross section, appears to have been straight up or down the plane of the fault. This effect is not produced when the beds are flat or when the strike of the fault is parallel to the strike of the beds, provided the movement is entirely horizontal; but the vertical displacement and horizontal displacement increase as the angle between the strike of the fault and the strike of the beds increases and are greatest when this angle is 90°. As shown in figure 16, there is, after faulting, an overlap of strata in the plan and a gap in cross section. If the left half, on the other hand, had moved in a horizontal direction away from the reader (see fig. 17), the result would be an apparent reverse fault, or one in which the foot wall appears to have dropped with respect to the hanging wall. There is a gap in plan and an overlap in vertical section. With sufficient horizontal movement in the proper direction, such an apparent reverse fault might result even when some of the movement of the hanging wall was down the dip of the fault plane.

A study of the Bullfrog map shows that most of the offsets of strata due to faulting are such as could be produced by movement of the hanging-wall side down the dip, without horizontal displacement or heave. But nearly everywhere there is an offset with an overlap instead of a gap. This shows that the horizontal element of movement of the blocks, however great it may have been, was in the direction which increased the apparent vertical displacement, or else its offsetting effect on the tilted beds was less than that caused by vertical movement, for if it had been greater and in an opposite direction a gap would have resulted where the relations of beds to fault planes are like those shown in figure 17, and the fault, as shown in vertical sections, would have been reverse. Since in the Bullfrog district no clearly reverse faults are shown and since there are no gaps on the surface such as would indicate

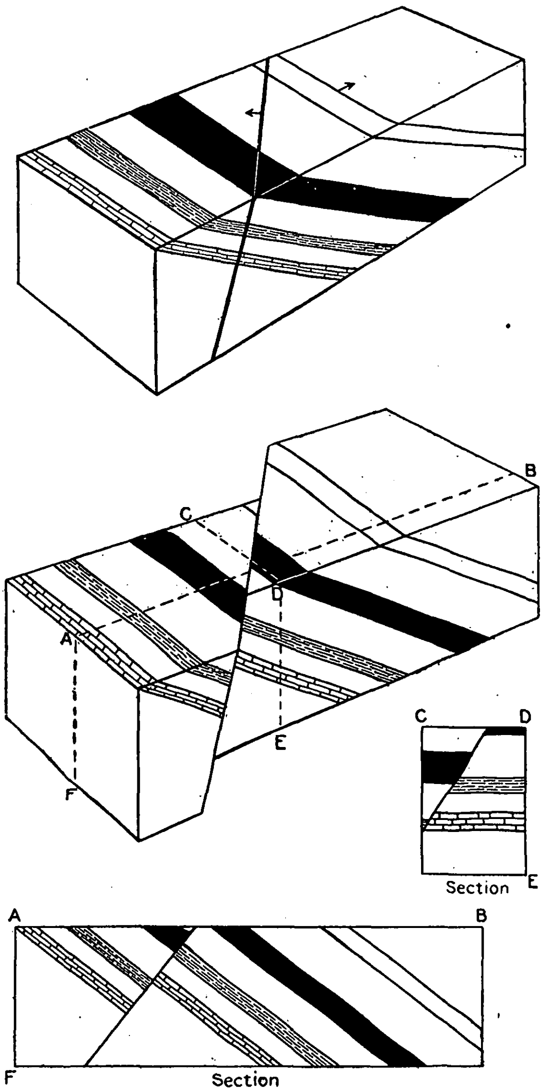


FIGURE 16.—Diagram illustrating some of the effects of heave along a fault in tilted beds. See text for explanation.

them, it seems very probable that forces causing horizontal movement always operated in one direction, and so as to increase the

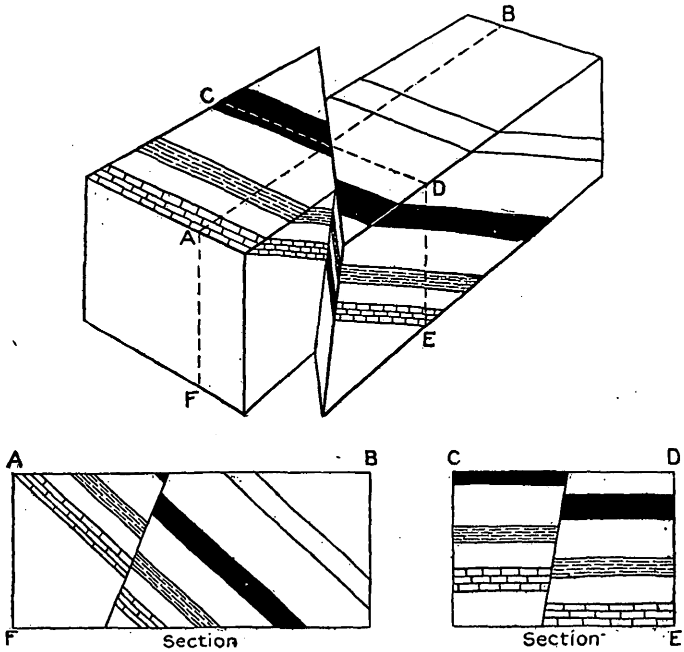


FIGURE 17.—Diagram illustrating some of the effects of heave along a fault in tilted beds.

apparent displacement. As already stated the directions of striæ observed, taken all together, show that, in the movement recorded, the vertical component was greater than the horizontal component.

DEFORMATION AND CHANGES IN AREA.

It is generally recognized that crustal shortening accompanies folding of strata. If a horizontal bed is tilted, without faulting, either it must be stretched or the rocks below must move or be compressed to meet the new conditions. The jointing of the rocks in the Bullfrog district shows that there has been some stretching, though certainly it is insufficient to meet the demands required by any considerable crustal shortening. On the other hand, tensional stress is commonly regarded as a condition for normal faulting and this appears to be necessary if the blocks move downward freely without crumpling the strata.

If the various sections of rhyolite No. 7, as represented in figure 10, were horizontal and placed end to end, the resulting section would be 33,600 feet long. The horizontal distance over which the small sections are now distributed is 42,240 feet. The difference is 8,640 feet, or 25.6 per cent of 33,600 feet, which, for this whole section, represents the apparent net crustal extension due to faulting and tilting. Sections making large angles with that of figure 10 also indicate an apparent extension, as is shown by section D–D′ of Plate I.

That horizontal displacement with gap, as shown in vertical section, does not always represent real extension of the earth's surface is apparent from inspection of figure 16, where both cross sections A–B and C–D show gaps, while the plan ABCD shows an overlap. The movement represented has been along the strike of the fault, and while the area itself has been unchanged the disposition of the surfaces of the individual blocks is different. Yet as seen in vertical cross sections A–B and C–D the faulting has resulted in horizontal displacement with gap. However, this extension is only apparent, for, as seen in plan, it is compensated by the offset with overlap. All three dimensions, length, breadth, and thickness, should be considered in the discussion of the problem. As there has been no appreciable change of density in the material of the rocks in consequence of deformation, it is evident that the thickness of a faulted block must decrease if the length or breadth increases. Part of the overlap shown in the map of the Bullfrog area may be regarded as the expression of the shortening in this vertical direction, as shown diagrammatically in figure 16. From an inspection of the diagrams above referred to, it appears that the whole truth is not to be gained by measurements of distances between points of separation of beds in a few cross sections. The operation serves to indicate the kind of effects produced, but it is not accurately quantitative. It shows only that extension has taken place along the line of section; it does not show how much of this is due to horizontal movements (heave) in the directions of strike of the faults. As already stated, the horizontal component of the movement is less, on the average, than the vertical component in those faults where the direction of movement is recorded by striæ. It is estimated that about one-third of the apparent crustal extension shown in figure 10 is due to horizontal displacement of blocks along the strike of fault planes by movement that does not effect a change of area, but only a change in position of certain blocks. In accordance with this estimate the extension of the surface approximately at right angles to the strike of the faults would be two-thirds of the 25.6 per cent extension calculated from that shown in figure 10, or about 16 per cent. Further, if the individual blocks retain their shapes and dimensions, it is evident that the combination of tilting and inclined faulting does not extend the area in a direction parallel to the strike of the faults, but only in a direction at right angles to this. If all the faults were strictly parallel, the areal extension would be the same as the linear extension in a direction at right angles to the faults. No correction for heave would be necessary and the general section of figure 10 would show directly an extension of about 16 per cent. In other words, an area of 1 square mile would be, after faulting and tilting, 1.16 square miles.

SUMMARY.

A study of the faults in the Bullfrog area leads to the following conclusions:

1. All the faults are normal, since the hanging walls appear to have been depressed with reference to the foot walls.

2. Tilting and faulting, in the main, followed the extrusion of all the lava flows now present.

3. As there is no record of sedimentation in the interval between faulting and tilting, the two processes probably operated at the same time, and if so the movement was to some extent a rotation of the blocks in a measure independent of one another, so that fault planes were tilted as well as strata.

4. The lateral or horizontal element of the movement (heave) along fault planes was considerable, though it was less than the vertical element.

5. The horizontal displacement with gap, which appears in all cross sections of faults and beds, does not indicate the actual extension of the surface. The apparent extension of 25.6 per cent, as shown in figure 10, is estimated to represent an actual extension of not more than 16 per cent.

PART II.—ECONOMIC GEOLOGY.

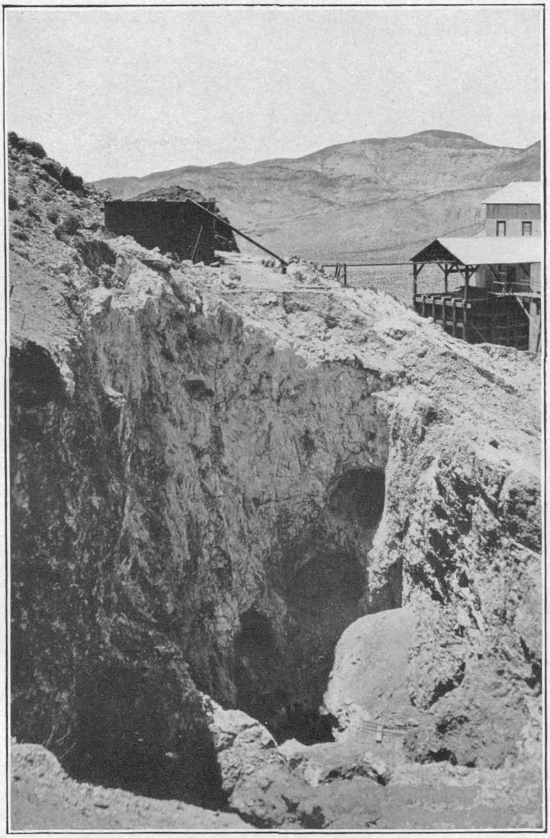
By F. L. RANSOME.

THE MINES; A GENERAL ACCOUNT OF THEIR DISTRIBUTION AND DEVELOPMENT.

By far the most important mine in the Bullfrog district is the Montgomery-Shoshone (Pl. X, *B*), situated 1½ miles northeast of Rhyolite, in the pass between Montgomery Mountain and Black Peak. The workings lie on the southeast side of the Montgomery-Shoshone fault and are mainly in rhyolite No. 10. The main shaft is 600 feet deep and is connected with about 9,000 feet of drifting. The ore as delivered to the company's mill at the mine in July, 1908, averaged from $10 to $15 a ton in assay value. The ratio of gold to silver in ounces is approximately as 1 to 17, but is not uniform. About 150 tons of ore are milled in twenty-four hours and the gross monthly output is from $50,000 to $70,000. Northeast of the Montgomery-Shoshone mine, on the same fault zone, are the Providence, Lucky Jack, and Red Oak mines, none of which has been productive. The Steinway shaft, about 2,300 feet west of the Montgomery-Shoshone, and the Yankee Girl shaft, in the flat just northeast of Rhyolite, are prospects which when visited in 1906 were about 200 feet deep. They were not being worked in 1908. The Amethyst, a prospect on a minor fissure north of the Montgomery-Shoshone mine and fault, was also idle at the time of last visit.

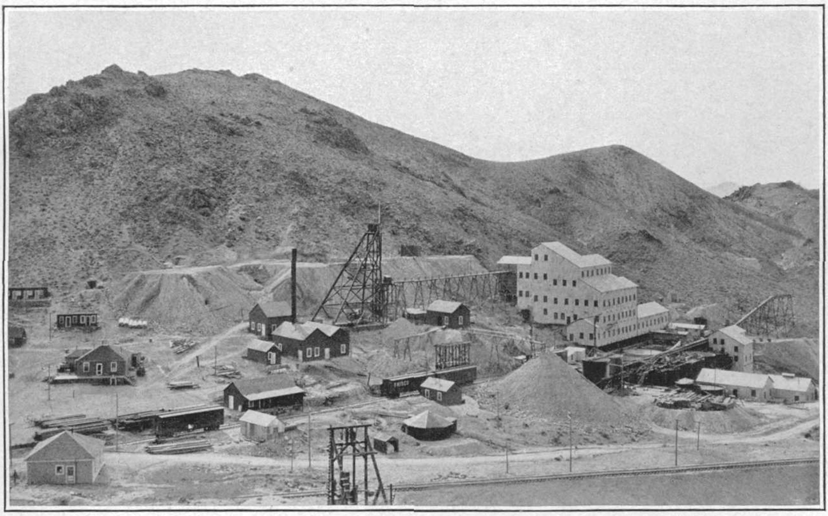
On Ladd Mountain (Pl. XI, *A*), east of Rhyolite, the principal workings are those of the National Bank mine in rhyolite No. 5. This shaft was 200 feet deep in 1906, with two levels. Although some ore has been found, the mine has not been profitable and was closed in 1908. The tunnel of the Bullfrog Mining Company has been driven into the west base of Ladd Mountain for over 550 feet, but has not opened workable ore bodies. At three or four places on the west slope of the hill lessees have discovered bunches of ore near the surface, in rhyolite No. 5, and shipments were being made from two such sets of shallow workings in 1908.

Due west of Rhyolite is Bonanza Mountain, in which are the workings of the Tramps Consolidated Mining Company, including



A. OPEN STOPE OR "GLORY HOLE" OF THE MONTGOMERY-SHOSHONE MINE.

Photograph by A. E. Holt.



B. MONTGOMERY-SHOSHONE MINE AND MONTGOMERY MOUNTAIN, FROM THE NORTH.

Photograph by A. E. Holt.

the Denver mine, and of the Gibraltar mine. The Denver, which has shipped considerable ore, is on a nearly north-south vein in rhyolite No. 5. The workings consist of four tunnels, mainly on the vein, with a winze about 300 feet deep below the No. 4 tunnel. There are levels at approximately 50, 150, 250, and 300 feet below the collar of the winze. The total length of the vein explored is about 700 feet and the total depth is about 500 feet. The Denver mine has no mill and the ore is hand sorted and shipped.

Southeast of the Denver mine are the Tramp, Eclipse, and Hobo workings of the same company. These are mainly in rhyolite No. 5 and consist of several tunnels and shallow shafts, which explore a block of ground about 1,700 feet long from north to south and about 900 feet wide. The principal tunnels or adits are the Tiger, which runs northeast and enters the vein zone at the north end of the explored area, and the Tramp, which runs northwest under the summit of Bonanza Mountain. The two tunnels are connected by a raise of 106 feet from the Tramp tunnel to a drift from the Tiger tunnel. The maximum vertical range of exploration is about 400 feet. Within this block are from eight to ten recognized veins, some of which accompany basaltic dikes. Their general trend is nearly north and south. Although considerable low-grade oxidized ore and some small bunches of rich ore have been discovered, the workings have not been productive.

On the southeast side of Bonanza Mountain are the workings of the Gibraltar mine on a series of nearly north-south veins, of which the productive parts are mainly in rhyolite No. 6. There are two tunnels that follow one of these veins and one crosscut tunnel. The mine has been irregularly worked on a small scale by lessees, who have sorted the ore by hand and shipped it out of the district. A shaft 300 feet deep was sunk by the Gibraltar Company through the alluvium south of Bonanza Mountain, but no ore was found and these workings were abandoned.

North of the summit of Bonanza Mountain the Scepter fault (see Pl. I) has been prospected unsuccessfully through the Golden Scepter shaft and tunnel and through the Great Eastern shaft. These shafts were closed at both times of visit.

At the south base of Bullfrog Mountain, 3 miles west of Rhyolite, are the Original Bullfrog and Bullfrog West Extension mines. These are on a large vein, in places fully 60 feet thick, which dips north at angles rarely exceeding 18°. The vein is a mass of much-shattered rhyolite that forms the hanging wall of the Original Bullfrog fault fissure (see Pl. I) and that has had its fractures and interstices filled with quartz and calcite. The vein material is of low grade as a whole, but the Original Bullfrog mine has shipped a little rich ore, which was found in bunches in the vein. The Bullfrog West Extension mine is 195 feet deep, with three levels, the lowest being entirely in limestone and shale in the foot wall of the vein. There have been no shipments of importance and the future of the mine depends upon the possibility of milling low-grade ore in quantity. The Big Bullfrog is a prospect in the schists south of the Original Bullfrog mine. No ore was found and the shaft had been abandoned in 1908.

About 4 miles northwest of Rhyolite and outside of the mapped area are the Gold Bar and Homestake-King mines. These are on a north-south zone of fissuring and mineralization in rhyolite. The Homestake-King, 500 feet deep, was the only one of these in operation in 1908. It has a modern 25-stamp mill, which at the time of visit had just begun running. The ore of both mines is generally of low grade.

About 7 miles north of Rhyolite is the Mayflower mine, 200 feet deep. The vein is a broad, low-grade zone of fissuring and mineralization in rhyolite. No work was in progress during the summer of 1908 and the mine has never been productive.

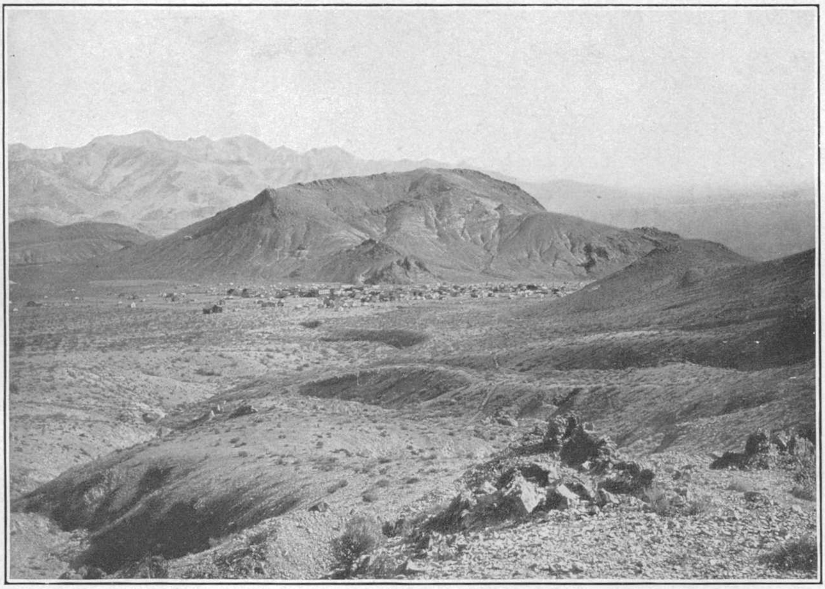
The Keane-Wonder mine, sometimes referred to as being in the Bullfrog district, lies on the Death Valley side of the Funeral Range, about 15 miles south-southwest from Rhyolite, which is its supply and shipping point. It is on a flat vein in rocks supposed to be of Cambrian age.[a] The mine was producing actively in 1908, but was not visited and lies entirely outside of the area with which this report is concerned.

From this summary it appears that the Bullfrog district contains only one mine of moderate size and of steady productiveness. The others are all small and up to the middle of 1908 no one of them could be said to have emerged from the prospecting and experimental stage. Whatever the expectations excited from time to time by the finding of superficial bunches of rich ore, there can be no doubt that the veins as a whole are to be classed as low grade when the conditions under which they must be exploited are taken into consideration. They are in no way comparable with the remarkable bonanzas that have brought fame to Goldfield and can not be successfully worked by the same methods.

MINERALOGY OF THE ORES.

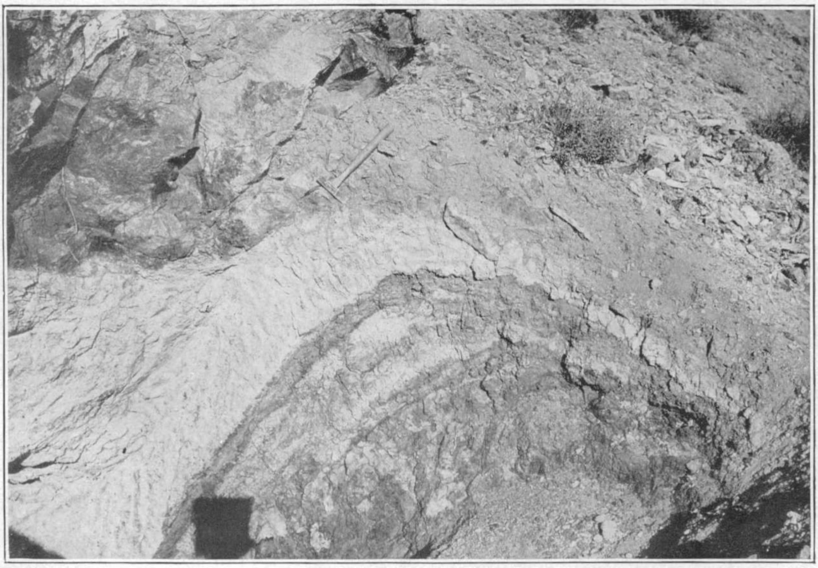
Introductory statement.—All of the ore thus far mined in the Bullfrog district is oxidized and consequently the deposits lack much of the mineralogical interest of those at Goldfield, where may be studied not only the products of oxidation but the original sulphides whence these have been derived. Moreover, the ores of the southern district, so far as can be judged from present exposures, do not in their original

[a] See Ball, S. H., A geologic reconnaissance in southwestern Nevada and eastern California: Bull. U. S. Geol. Survey No. 308, 1907, p. 174.



A. LADD MOUNTAIN AND THE TOWN OF RHYOLITE, FROM THE NORTHWEST.

Beyond Ladd Mountain, to the left, is Bare Mountain. To the right is the Amargosa Desert.



B. PIT ON HOBO VEIN AND FAULT FISSURE.

Shows superficial overturning of the soft, crushed material by downhill creep.

condition present the variety and complexity that render Goldfield so much more attractive a field for the mineralogist.

Gold.—The native gold of the Bullfrog district where visible in the ores has the form of small specks, which, as a rule, are in the center of a spot of limonite. Evidently the gold was once in pyrite, the oxidation of which has produced the limonite. Large crystalline or showy masses of gold are unknown. The native metal is generally pale and contains a considerable proportion of silver. In the Original Bullfrog mine the gold is in part embedded in chrysocolla, and from this source have come the only specimens from the district that have any pretension to mineralogical distinction.

In some ore from the Hobo shaft on Bonanza Mountain the gold is in nests of little hackly particles, associated with minute quantities of a dark metallic mineral, which may possibly be a telluride. Not enough of this could be obtained, however, for chemical tests.

Galena.—Galena is not known in any of the mines, but is present in small quantity in some quartz veins in the pre-Tertiary metamorphic rocks south of Beatty.

Chalcocite.—Chalcocite, cuprous sulphide, is sparingly present in some of the ore of the Original Bullfrog mine as small irregular particles peripherally altered to chrysocolla.

Pyrite.—Pyrite is not abundant in the ores now mined owing to its general alteration to limonite. Small crystals may be seen occasionally in some of the ore of the Denver mine, and the mineral makes up a small part of the concentrates of the Montgomery-Shoshone mill. None of the veins appear to have been originally rich in sulphides, and it is doubtful whether below the zone of oxidation pyrite will constitute more than a very small part of any deposit.

Cerargyrite.—Cerargyrite, or horn silver, is probably present in many of the veins but is not a conspicuous mineral. Even in the Bonanza ore of the Montgomery-Shoshone mine above the 200-foot level, much of which averaged over 600 ounces of silver to the ton, cerargyrite does not appear to have been a very noticeable constituent. The mineral has been detected by panning in a streak of oxidized ore near the mouth of the Tiger tunnel of the Tramps group, on Bonanza Mountain, and could probably be found elsewhere in the district by similar search.

Quartz.—The prevalent form of the primary quartz of the veins is that of irregular or xenomorphic aggregation with calcite. Much of it is cryptocrystalline and this variety has in part formed by silicification of fragments of rhyolite. Coarsely crystalline transparent quartz or quartz with well-developed crystal faces is not characteristic of the veins of Montgomery, Ladd, or Bonanza mountains.

Nearly all of the oxidized ore contains some secondary quartz, partly as the skeletal pseudomorphs after calcite described below and partly as thin crusts and druses lining cavities.

The quartz of the Original Bullfrog and Bullfrog West Extension mines and of the Ali Baba shaft south of Bonanza Mountain is of a different character from that of most veins in the district. It is coarsely crystalline and much of it is delicately amethystine. At the Original Bullfrog mine a large part of the vein material is beautifully banded, yellowish chalcedonic layers alternating with crusts of radially crystallized transparent quartz up to 4 or 5 inches in thickness. (See Pl. XII, *A*.) There is no constancy in the direction of this banding. It appears in most places to represent crustification around fragments of rhyolite and of shattered calcitic vein material previously deposited. The quartz also belongs to two or more periods of formation separated by movements which shattered the vein and produced open spaces to be filled by fresh deposition of quartz.

Limonite.—The common hydrous oxide of iron is a constituent of all of the oxidized ores and gives them their rusty appearance. It has been formed by the weathering of pyrite and presents no features of special interest.

Wad.—Under the name of wad are included various earthy, impure, hydrous oxides of manganese, which are not crystalline and which probably do not have a definite chemical composition. Such dark, manganiferous material is very common in the oxidized veins of Bonanza and Montgomery mountains and is the principal residual product from the solution and removal of the calcite from the veins. (See Calcite.)

Calcite.—Calcite is a common gangue mineral in most of the veins, usually crystallized with quartz in rather fine grained, dull white aggregates. In many veins or parts of veins, however, the calcite is coarsely crystalline and forms bands or bunches in the finer-textured vein filling. It has not been found in large, well-formed crystals. Calcite is abundant in the veins of Bonanza and Montgomery mountains.

Under the action of oxidizing solutions the calcite in the veins succumbs before the quartz and is carried away, leaving behind an earthy residue, which consists largely of hydrous oxides of manganese and iron. Thus a cavernous structure and the presence of sooty, impure manganese oxide are very characteristic of the weathered portions of the calcitic veins. All steps of this process may be studied in the field, and specimens showing the uneven corrosion of masses of clear calcite and the deposition of the oxides are readily obtainable. The attack upon the anhedral crystals is not wholly peripheral, but takes advantage of cleaving planes and minute irregular cracks. By the study of cleavage blocks of the more coarsely crystalline forms of the calcite it may be seen that the first step in the process is a clouding of the mineral due to the separation of minute particles of manganese and iron oxides from the originally clear or milky spar. At a more advanced stage of the alteration the crystal is opaque and as seen under a lens is minutely porous. This dark, spongy material, which still contains calcite, grades in turn into a nearly black earthy mixture of oxides, from which all the calcium carbonate has been removed. A cleavage block of calcite from the Gibraltar mine on Bonanza Mountain was analyzed in the Survey laboratory by Dr. Chase Palmer with the following result:

Chemical analysis of calcite from the Gibraltar mine.

SiO_2	8.59
Al_2O_3, Fe_2O_3	.10
FeO	.13
CaO	50.50
CO_2	39.33
MnO	.93
	99.58

Approximately 10 per cent of the mineral was insoluble in hydrochloric acid and a considerable part of the manganese oxide was in this residue, although the material analyzed showed no perceptible alteration and it was supposed that whatever manganese was present would be in the form of carbonate. The quantity of silica found was greater than the appearance of the sample would suggest.

The weathering of the calcite is in many places accompanied by some silicification. The silica penetrates the calcite along cleavage cracks and when the calcium carbonate has all been removed the secondary quartz remains as fragile septa. Some of these are in parallel groups, others intersect at the angles of the rhombohedral cleavage, and still others at various angles dependent on the original juxtaposition of differently oriented calcite anhedrons. Between the septa are angular spaces whose walls are lined with minute quartz crystals and which are as a rule partly filled with impure wad. Such fragile, cellular, manganiferous material is highly characteristic of the oxidized portions of the veins in this district. The earthy oxides are in a few places lacking and the delicate pseudomorphous siliceous combs are there of snowy whiteness.

Parts of the oxidized zone in some veins show a late deposition of clear calcite as crusts on oxidized or partly oxidized material, as may be observed in the Tramp tunnel in Bonanza Mountain and in the Ali Baba shaft in the town of Bullfrog.

Malachite.—The green hydrous carbonate of copper has been found in small quantity at the Original Bullfrog mine associated with chrysocolla and gold.

Chrysocolla.—Chrysocolla, a hydrous silicate of copper, is moderately abundant at the Original Bullfrog and Bullfrog West Extension mines, where it forms bunches, streaks, and films in quartz. In most of the rich ore obtained from the Original Bullfrog mine native gold may be seen embedded in greenish-blue chrysocolla. It is the color of this ore that is reported to have suggested the name of the district. The chrysocolla appears to have been derived from chalcocite, which in turn may have formed from chalcopyrite.

STRUCTURAL FEATURES OF THE DEPOSITS.

In general the deposits of the Bullfrog district are fissure veins in rhyolite. The minor structures of those portions of the veins at present visible are more or less obscured by oxidation, but the fracturing that was followed by ore deposition appears largely to have taken the form of sheeting or brecciation of the brittle rhyolites, and to a less extent has resulted in simple open fissures. Consequently the larger veins contain numerous fragments of rhyolite, and the boundary between the vein proper and adjacent rhyolite, which in most places contains small irregular stringers of quartz, or quartz and calcite, is not in every case distinct.

Out of the twelve to fifteen veins that have been explored by other than by mere surface pits all but two strike nearly north and south and dip at angles greater than 50°. The exceptions are the Original Bullfrog vein, which strikes nearly east and west and dips north at angles generally less than 20°, and the contact vein in the Montgomery-Shoshone mine, which strikes and dips with the Montgomery-Shoshone fault zone. (See Pl. XIV.) The Mayflower vein, north of the area specially studied, strikes northwest and dips about 65° SW. Some of the approximately north-south veins, among which may be mentioned the Montgomery-Shoshone, Denver, and Eclipse lodes, while showing variation on different levels, are on the whole nearly vertical; others, like the Polaris, National Bank, Gibraltar, Hobo, and Lester veins dip west. Decided and persistent dip to the east is rare. The Eclipse, although very steep, might be classed as an eastward-dipping lode and the upper part of the Denver vein dips in the same direction.

Veins and faults are in this district very closely associated. The veins, like many of the basalt dikes, occupy for the most part fissures that were formed at the time the region received its present elaborate structural dissection. Out of the 100 or more faults of sufficient importance to be shown on a map of the scale of Plate I, certainly not over 15 per cent and probably not over 10 per cent are associated with veins of known or prospective value. Most of the fault fissures show no deposition of vein material whatever and the most promising veins occupy fissures that as elements of geologic structure have only slight importance. The Denver vein and the veins of Bonanza Mountain generally have been deposited in fissures along which the displacement probably does not exceed 100 feet and in most places is much less. As dislocations these are insignificant in comparison with the Rush fault west of Sutherland Mountain or with the Bullfrog Mountain and other faults that, although themselves concealed by alluvium, are evident enough in the structure of the district. The nearly north-south veins of the Montgomery-Shoshone mine appear to occupy fracture zones of very slight displacement, which converge southward into a fissure that corresponds to a minor fault crossing one of the tectonic blocks into which the region is dissected.

The great Montgomery-Shoshone fault, which Messrs. Emmons and Garrey estimate to have a throw of 2,000 feet, limits the ore of the mine on the north, as is described on page 109. The manner in which the north-south veins end at this fault zone, which is in part occupied by a strip of basalt No. 4, is shown in Plate I. The contact vein, which follows the southeast side of the zone, has already been referred to as exceptional, since it differs in trend from most of the veins and is associated with one of the great dislocations. It can scarcely, however, be said to constitute a mineralization of the fault zone itself. It is rather a mineralization of the fissured rhyolite of the foot wall and its ore bodies are in many places clearly related to the ending of north-south fissures at the fault zone. As explained on page 106, the main movement along the Montgomery-Shoshone fault appears to have been on the northwest side of the zone and to correspond to fissures not reached by the Montgomery-Shoshone workings. There is no evidence as yet that any important mineralization has taken place along these fissures.

Another exceptional vein is the Original Bullfrog, which is very closely associated with the fault of the same name. This remarkable dislocation, which (see p. 122 and Pl. I) if not identical is probably connected with the Amargosa fault to the east, is apparently of the normal type, since younger rocks in the hanging wall are brought against older rocks in the foot wall. The dip, however, is so low (20° or less) as to make necessary the supposition that movement along this fault was effected by some strong lateral thrust. As the rhyolitic flows were forced over the uneven foot wall of the pre-Tertiary rocks, they were extensively fractured, and this fractured rhyolite, cemented and in small part replaced by quartz and calcite, constitutes the vein.

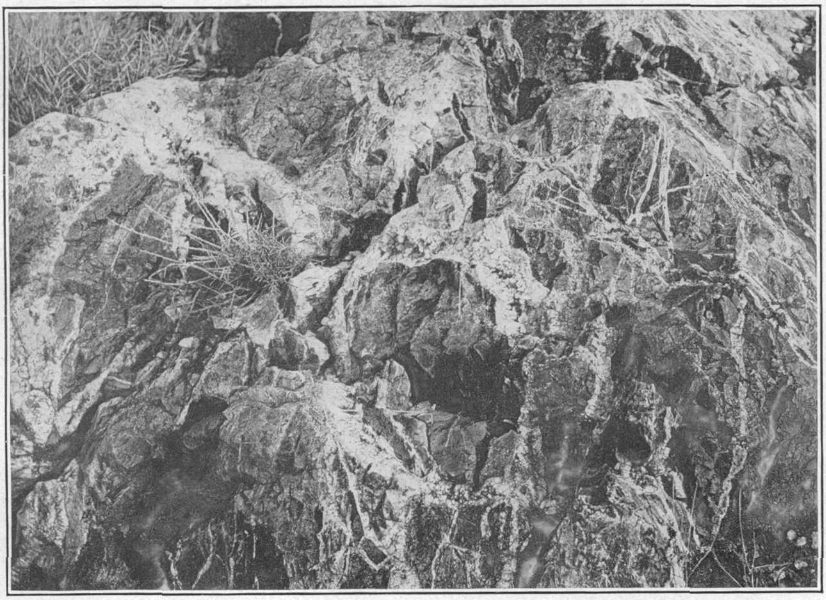
Many of the fault fissures, as shown in Plate I, are occupied in part by basaltic dikes. These are older than the veining, as may be well seen in the Tramps mine, where the Hobo vein at one place cuts obliquely across its accompanying dike. At other places veinlets and stringers of the same character as the larger veins have been noted in the dikes. So far as is known, however, no ore occurs in this rock.

Since the veins were formed movement along some of the fissures has continued. This is particularly true of the Hobo (Pl. XI, *B*), Eclipse, and Gold Bar veins. Such movement is recorded by seams of gouge, accompanied by slickensiding and striation, which in some places intervene between the vein and its walls and in other places are wholly within the vein. The low-angle faults of small throw that displace the Eclipse and Hobo veins (see p. 117 and fig. 19) and the Denver vein (see p. 121) belong to this class of movements subsequent to vein formation. These late slips apparently record relatively slight displacement.

The lode fissures, in brief, were formed at the time the region received its present faulted structure and were for the most part accessory or subordinate effects of the stresses to which that structure is due. Faulting was succeeded by intrusions of basalt that in many places ascended the fault fissures as narrow dikes. After the basaltic intrusions there was renewed movement along some of the fissures, with perhaps some fresh dislocation, followed by vein deposition.

The veins show various gradations between fairly regular sheeted zones in which parallel banded veinlets composed of alternating crusts of quartz and calcite are separated by thin slabs of rhyolite, through irregular stringer lodes, to veins made up in large part of angular fragments of rhyolite cemented together by quartz or calcite or both. As a rule there is very little replacement of the walls or of the larger rock fragments by vein minerals. Between the smaller fragments, however, and the fine-grained white quartz of the fissures there is in many places no definite boundary. Much of the finely crushed rhyolite that presumably once partly filled the interstices between the larger fragments has been transformed to cryptocrystalline quartz. Banded structure is well shown in some of the cuts on the Hobo vein on Bonanza Mountain, where oxidation has gone just far enough to accentuate the structure by partial decomposition of some of the calcite layers to black manganese oxide. The crusts range from less than a sixteenth to half an inch in thickness. Close inspection shows that they are not altogether due to alternate deposition of calcite and quartz on the walls of a fissure. The constituent crystals of some of the quartz layers point inward from both sides, giving typical comb and vug structure along the medial plane of the layer and showing that the quartz was deposited as a little veinlet along a crack in older calcite. In some parts of the lode also the banded portions have crystallized in fissures that cut an older and less regular deposit of calcite and quartz. It thus appears that the

A. BANDED QUARTZ OF THE ORIGINAL BULLFROG VEIN.



B. SHATTERED AND VEINED RHYOLITE, ORIGINAL BULLFROG MINE.

veins were probably filled in three or more stages and that the quartz is in part younger than the calcite.

Where oxidation is well advanced, as is the case in most of the underground workings, the original structure of the veins is obliterated, and those in which calcite was abundant become soft structureless masses in which stained fragments of rhyolite and quartz are confusedly mingled with earthy ferruginous and manganiferous material or are embedded in the friable pseudomorphous masses described on page 94.

The Original Bullfrog vein differs from the other veins in the district as much in structure as in mineralogy. It consists mainly of quartz with subordinate calcite. Part of the quartz is cryptocrystalline and represents silicified fragments of rhyolite. The greater part, however, is very conspicuously banded, as may be seen from Plate XII. Curved layers of clear vitreous quartz (Pl. XII, *A*), much of it amethystine, run in various directions and alternate with striped chalcedonic crusts. The structure is complex in detail. Some of the calcite is older than the quartz, and the chalcedonic layers are cut by many veinlets of pure vitreous quartz up to 6 inches in width. Finally the whole brittle mass has been fractured and, in places, shattered by movement subsequent to the last period of deposition. On the hanging-wall side the vein grades into much-altered shattered rhyolite, traversed by innumerable branching veinlets of quartz, as may be seen in Plate XII, *B*.

The vein was originally a mass of shattered rhyolite that appears to have been first cemented by the deposition of quartz and calcite. This was again fissured and quartz was deposited abundantly in the open spaces and to a large extent replaced the fragments of rhyolite and the earlier-deposited calcite.

ACTION OF VEIN-FORMING SOLUTIONS ON THE WALL ROCKS.

The depth of oxidation and the shallowness of most of the mines make it impossible at this time to carry out any thorough study of metasomatic processes in connection with the deposition of the veins. It is safe to say, however, that the solutions which rose through or filled the fissures have left scarcely any trace of their chemical activity outside of the actual channels through which they moved. The rocks of the district as a whole are fairly fresh and show only the effects of normal weathering. Pyritization, sericitization, alunitization, or other kinds of alteration such as in most regions traversed by ore-bearing veins have affected the rocks over considerable areas are noticeably absent and the sole secondary change discernible in most of the rhyolites is the devitrification of the originally glassy groundmass into the usual fine-grained aggregate in which quartz is the only mineral identifiable under the microscope. This change takes place so readily in siliceous glassy rocks that it is difficult in some cases to distinguish sharply between such devitrification and original crystallization from the molten state. It has no necessary connection with ore deposition.

To some extent small particles of rhyolite lying in the fissures have been replaced by fine-grained aggregates of vein quartz or of quartz and calcite. In a few places also the walls of fissures have been slightly modified by the same process, as is shown by the irregular character of the contact between vein and wall rock, seen in thin section under the microscope. On the other hand, the feldspar phenocrysts in specimens of rhyolite taken from mine workings within an inch or two of a vein show as a rule no alteration that can be ascribed to the vein solutions. They may be slightly turbid near their surfaces and along cleavage planes, but the same turbidity is visible in specimens collected from most parts of the district. Many thin sections show vein quartz in actual contact with feldspar phenocrysts that are almost wholly fresh. In a few specimens of rhyolite collected from the 300-foot level of the Montgomery-Shoshone mine the microscope shows that some calcite has developed in the rock by replacement of orthoclase and plagioclase phenocrysts and of parts of the groundmass. Sericite is rare, even in the rhyolite fragments in the veins.

At the Original Bullfrog mine the rather heterogeneous and in part thin-layered flow breccias making up rhyolites No. 1 and No. 2 are more thoroughly altered by vein-forming agencies than are the rocks exposed in the other mines. The shattered material has been actively replaced by both quartz and calcite. Even here, however, the chemical action of the vein solutions appears to have been confined to the fractured portions of the rhyolite and there is no extensive alteration of the country rock. Specimens taken from the transition zone between the vein and the hanging-wall rhyolite, that, under the microscope, show extensive enlargement of the quartz phenocrysts by vein quartz and complete recrystallization of the groundmass into a quartz mosaic, still retain some unaltered phenocrysts of feldspar.

On the whole the chemical activity of the ore-depositing solutions has been comparatively slight, being confined to the deposition of quartz and calcite with a little pyrite and associated gold and silver in and immediately adjacent to fissures. A large number of the fissures, it should be remembered, show practically no vein deposition. Results so slight suggest that the vein solutions were dilute, cool, and under no heavy pressure.

GENESIS OF THE DEPOSITS.

It should be clear from the foregoing description that the Bullfrog district, in its present stage of mining development, is not likely to contribute greatly to the rather meager knowledge of how ore deposits are formed. Nevertheless the work has not been wholly fruitless of suggestion and has led to one or two inferences that may have some value.

Any consideration of the genesis of the ores reverts to the origin of the faults, concerning which Messrs. Emmons and Garrey have concluded that they are normal and that in general the horizontal component of the movement, although large, was less than the vertical component. They have confined their discussion to the description of facts and to an interpretation of the mechanics of the faulting and have conservatively refrained from suggesting even a proximate cause for the elaborate dislocation that is the most interesting structural feature of the district.

As pointed out on page 16 and shown in Plate I, the volcanic series of the Bullfrog Hills is bounded on the south by a fault or zone of faults that separates it from the pre-Tertiary rocks. These older rocks are exposed only in the southwest and southeast corners of the district, but they have been found at a depth of 300 feet under the town of Bullfrog and probably continue beneath the wash along the entire south edge of the area mapped. On the west the Original Bullfrog fault has a general dip of about 18° N. On the east the dip of the Amargosa fault is not known, but it also appears to be low. The relations to each other of the rocks on opposite sides of these fault planes are those generally considered as indicative of normal faulting. If these are normal faults the pre-Tertiary rocks south of them presumably were covered at one time with the entire volcanic series, over 6,000 feet in thickness, and have since been laid bare by erosion during Quaternary or late Tertiary and Quaternary time.

There are difficulties in the way of this supposition. Bare Mountain, whose summit, 6 miles southeast of Beatty, attains an elevation of over 6,200 feet above sea level, is composed of pre-Tertiary rocks upon which there are no remnants of the Tertiary lavas south of the eastward continuation of the fault zone. The mountain appears never to have been covered by the volcanic series. The dip of the fault is certainly too low to have permitted the material on the hanging-wall side to slide down by gravity alone. If it moved in this direction at all it must have been pushed down by material set in motion from the south on a part of the fault fissure steeper than that now visible. All of this impelling mass of volcanic rocks, if it ever existed, has been wholly removed.

Another hypothesis is that the volcanic rocks were poured out in a basin that extended far to the north of the Bullfrog district[a] and was bounded on the south by hills of pre-Tertiary rocks; that the entire mass of volcanic material was subsequently crowded against these older rocks and was thrust over them for an unknown distance along the Original Bullfrog and Amargosa faults. In other words, the foot wall of these fissures may be in part an old topographic surface.

An extensive thrust movement of the kind suggested is not incompatible with normal faulting of the rocks in the hanging wall, even under the supposition that normal faulting is always due to settling after the failure of an underlying support. When a mass of rock overrides an uneven surface it must adjust itself to the inequalities of that surface unless its rigidity is so great that the mass is competent to support its own weight over the depressions in the foot wall and can rest without deformation on only a few protuberances. In general the rocks in the hanging wall will be competent (to use the expressive term introduced by Willis) only over small inequalities and will collapse over large ones, either during the thrust or when the compression relaxes. Such collapse will take place by flexure and flowage or by fracture and faulting according to circumstances. Slight settling, soft, thinly laminated rocks, and heavy load will favor flexure and flowage; extensive settling, brittle massive rocks, and light load will favor normal faulting. Two of the conditions favorable to faulting, namely, brittle rocks and light load, were undoubtedly present when the rocks of the district underwent deformation. The third condition, irregularity of foot wall, is indicated by the exposures along the Original Bullfrog and Amargosa faults and accords better with the hypothesis of overthrust over a prevolcanic topography than with the supposition of normal faulting along a fissure that cuts across the rock formations irrespective of older contacts.

Of the two hypotheses discussed, the second, that of overthrust, appears to have most in its favor. Proof, however, is not obtainable and it is doubtful whether mine workings in the northern part of the district will ever be carried deep enough to decide this question. Should a shaft at any time show that the Original Bullfrog and Amargosa fault zone continues under the northern part of the district with a low dip and with pre-Tertiary rocks in the foot wall, the second hypothesis will be supported by much more substantial evidence than can now be adduced for it.

Whichever hypothesis may be true, it is probable that the volcanic series as a whole rests on Paleozoic or older rocks, comprising limestone, shale, and schist, and that the contact is a surface of

[a] See Ball, S. H., A geologic reconnaissance in southwestern Nevada and eastern California: Bull. U. S. Geol. Survey No. 308, 1907, Pl. I.

faulting. It is probable also that most of the normal faults that cut the lavas do not extend below this contact, although some of the more extensive dislocations presumably do so. The fact that a fault fissure is occupied by a basalt dike does not prove that it itself extends to profound depths. The magma may have come up through other channels and have found its way into the fault fissure comparatively near the surface.

One of the most interesting features of the veins in view of the siliceous character of their walls is the abundance of calcite they contain. This mineral has clearly not been derived from the rhyolites, for these would have to be extensively leached and altered over wide areas to furnish so large a supply of calcite from rocks originally so deficient in calcium; whereas, as has been shown, the rhyolite near the veins is fresh, or shows the introduction of calcite. Nor do the basalt flows and dikes appear to have supplied the calcite to the veins; for these have undergone only the ordinary decomposition due to weathering, in which the calcium of the silicates, changed to the carbonate form, remains in the rock, in part as the filling of vesicles. There is apparently no significant relationship between abundance of calcite in the veins and the proximity of basalt. The veins in the Montgomery-Shoshone mine, for example, become more calcitic with increasing distance from the basalt in the main fault zone. It is probable that the calcite in the veins was derived from the Paleozoic limestone, which without much doubt underlies the volcanic series over a considerable part of the area studied. It follows that the solutions by which the ores were deposited ascended from the pre-Tertiary rocks.

It does not appear possible to connect the ores genetically with any particular one of the many magmas that solidified as the lavas now exposed in the district. Their deposition may have closely followed the intrusion of the basalt dikes, but this sequence would perhaps have more significance were it not that basalt was erupted several times during the volcanic history of the region and were it known that the dikes are younger than the quartz basalt, dacite, and some of the later rhyolites, which are not, so far as known, cut by basaltic intrusions.

As already pointed out, the solutions that deposited the ores were neither hot nor concentrated and evidences of solfataric action are wanting. They contained, in combined or ionized condition, calcium bicarbonate, silica, disulphide of iron, manganese, silver, gold, and in some places a little copper.

The comparative recency of the lavas, the lack of any evidence to suggest that they have ever been deeply buried under still younger formations, and the character of the faulting all indicate that the parts of the veins now visible were formed within a few hundred feet of the surface. At the most, the overlying rock probably did not exceed 3,000 feet in thickness.

FUTURE OF THE DISTRICT.

It must be admitted that the sanguine expectations aroused by the discovery of the rich oxidized ore of the Montgomery-Shoshone mine in 1905 have not been realized. No other bodies of equal size and richness have been found and it is now known that even this mass does not maintain its high tenor to great depth. Other oxidized deposits, although they have proved to contain small bunches of rich ore, are as a whole of too low grade to ship, and few of them have been shown to possess such size as would warrant the installation of mills capable of treating them profitably on a large scale. The character of the ore below the zone of oxidation is still problematic. The chances are, however, that little of it will average over $10 a ton.

On the whole, the deposits in the Bullfrog district, unlike those at Goldfield, are not likely to yield quick and large profits with a moderate outlay of capital, although small masses of superficial ore may for some time reward a few fortunate lessees.

The question whether the sulphide ores can be successfully mined under present conditions in this region will undoubtedly soon be answered by the experience of the Montgomery-Shoshone company. The likelihood of others succeeding if this mine can not be worked below the zone of oxidation is small. It is certain that unless the sulphide ores are so abundant as to justify extensive and economical operations the district has little promise. The chances for such abundance would be greater were there more indications of strong chemical action by ore-bearing solutions than are to be found in the rocks now visible.

DESCRIPTIONS OF INDIVIDUAL MINES.

MONTGOMERY-SHOSHONE MINE.

INTRODUCTORY STATEMENT.

The Montgomery-Shoshone Consolidated Mining Company, with offices in New York, owns most of the issued stock of the Montgomery-Shoshone Mines Company, the Shoshone-Polaris Mining Company, and the Crystal-Bullfrog Mining Company. The property comprises fourteen contiguous claims, covering in all about 178 acres. The consolidation includes also the Bullfrog Reduction and Water Company and the Goss and Davis ranches, north of Beatty, with their water rights.

By the end of the year 1905 the Montgomery-Shoshone mine had been developed to a depth of 150 feet and a large body of rich silver-gold ore had been blocked out. The property at this time was in litigation and no large production had been made. The present consolidation was effected early in 1906, and a report made by the president to the stockholders in November, 1907, estimated the

PLAN OF THE PRINCIPAL WORKINGS OF THE MONTGOMERY-SHOSHONE MINE

total value of ore blocked out and on the dump at $5,000,000. Mr. Henry Krumb's report, made in March, 1908, gave the probable operating profit of the mine as about $400,000. The Montgomery-Shoshone, when visited in 1908, was 600 feet deep, with about 9,000 linear feet of drifts and crosscuts. The mill, which was constructed to have a daily capacity of 300 tons, is limited by the slow percolation of the cyanide solution to about 160 tons a day of ore averaging from $10 to $15 a ton. It is equipped with a jaw crusher and three sets of rolls. The pulp, carried in weak cyanide solution, passes to classifiers, whence the sands go over Wilfley tables and the slimes over vanners. There are no amalgamating plates. The Wilfley tailings are cyanided by percolation and the vanner tailings by agitation. The percentage of extraction was not ascertained, but is known to be rather unsatisfactory; the slimes are particularly troublesome and require the addition of considerable lime to neutralize the sulphuric acid present.

A microscopical examination of a sample of Wilfley concentrates, which yielded on assay 16.78 ounces of gold and 278.06 ounces of silver to the ton, showed that about half the material is quartz. With this are pyrite, particles of limonite, little pellets of a soft yellowish kaolin-like material, and a little cerargyrite. No gold could be seen.

UNDERGROUND DEVELOPMENT.

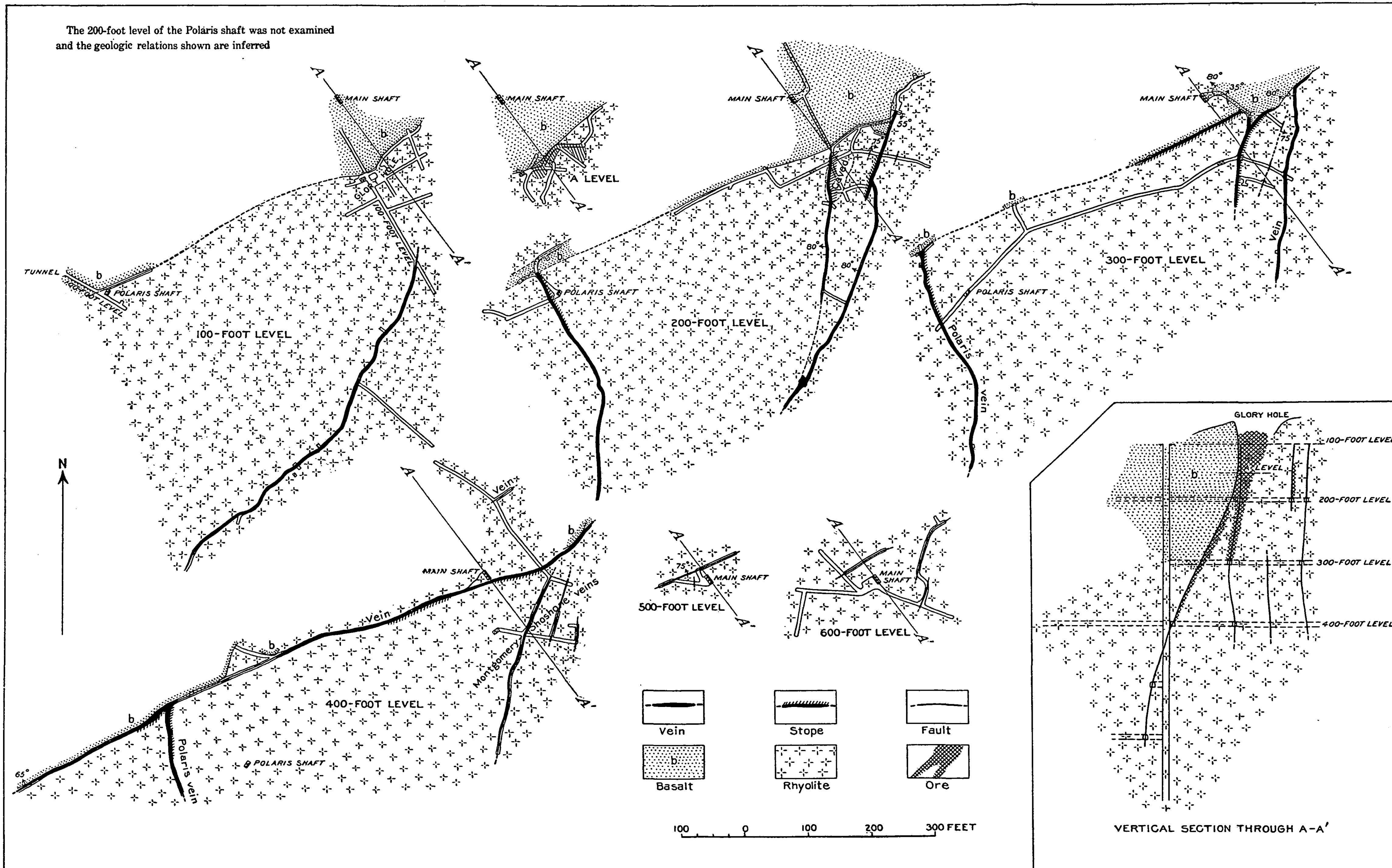
A general plan of the underground workings of the Montgomery-Shoshone mine is shown in Plate XIII. The old 100-foot level is at the same elevation as the collar of the new shaft and the levels below this are all about 100 feet nearer the surface than their names indicate. Thus the level at the bottom of the 600-foot shaft is called the 700-foot level. The position of the main ore body is indicated by the close tangle of drifts and crosscuts a hundred feet southeast of the main shaft. The drifts running south-southwest from this ore body follow the two main branches of the Montgomery-Shoshone vein zone, which apparently coalesce about 500 feet south of the shaft. The drifts running southwest from the vicinity of the main shaft to the Polaris shaft are in general parallel with the Montgomery-Shoshone fault and lie on the southeast side of the basalt strip that occupies part of the fault zone. The nearly north-south drifts near the Polaris shaft are on the Polaris vein. At the time of visit, in July, 1908, no stopes had been opened below the 400-foot level and the 700-foot level comprised merely the shaft station. The drifts and stopes above the 200-foot level had in part been obliterated in the formation of an open pit or "glory hole" (see Pl. X, *A*) and in part obstructed by the caving of the unsupported walls of this irregular opening. A portion also of the 200-foot level directly under the large stope had been crushed in by the weight of loose rock and ore and could not be examined in 1908.

GEOLOGIC FEATURES.

The general country rock of the workings, at least on the upper levels, is rhyolite No. 10. This is separated from rhyolite No. 16, northwest of the mine, by the Montgomery-Shoshone fault zone and by a dikelike strip of basalt along this zone. This basaltic strip was supposed at the time the general geologic mapping was done to be a dike, although it was recognized that the partly amygdaloidal character of the material was suggestive of a narrow down-faulted portion of a flow. At that time the linear and fairly persistent exposures of the rock and the fact that other similar masses are clearly dikes were held to overweigh the alternative suggestion. Later developments in the Montgomery-Shoshone mine have shown beyond reasonable question that the basalt is not a dike, but is a slender prismatic block of extrusive material bounded on two sides by faults and resting on rhyolite No. 10.

The general relations of the basalt to the rhyolite and to the veins may be best understood by reference to the geologic plans of the mine levels and the section shown in Plate XIV. At the surface the basalt is not very satisfactorily exposed. Being decomposed and soft, it has no prominent outcrops, and it is partly concealed by rhyolitic detritus. On the 100-foot level it is cut in the original Montgomery-Shoshone and Polaris adits, as shown in Plate XIV. On the 200-foot level the basalt is known to be nearly 200 feet wide near the main shaft; its northwest side had not been reached at the time of visit. Near the Polaris shaft it is narrower, the width here being probably less than 25 feet. Near the 300-foot level the main shaft, at a depth of about 200 feet, unexpectedly went through the bottom of the supposed dike into rhyolite that appears to belong to flow No. 10. (See Pl. XIV.) At the station on this level the bottom of the basalt is a curved, irregular surface, which dips in general to the northeast and is accompanied by some gouge. A narrow strip of basalt appears to continue southwest past the Polaris shaft, as shown on the plan of this level. On the 400-foot level a northwest crosscut near the main shaft, about 250 feet in length, is all in rhyolite. A little basalt is exposed in the northwest side of a drift about 150 feet northeast of the shaft, and some masses are known north of the Polaris shaft. The 500-foot, 600-foot, and 700-foot levels are all in rhyolite.

The mine workings, as is evident from Plate XIV, throw very little light on the northwest contact of the basalt, which is probably the plane along which most of the movement of the Montgomery-Shoshone fault zone has taken place. (See description of the Providence mine on p. 111.) The crosscuts northwest of the main shaft on the 200-foot and 400-foot levels would probably cut this branch



GEOLOGIC PLANS AND SECTION, MONTGOMERY-SHOSHONE MINE.

of the fault if extended a little farther. The fissure that bounds the basalt on the southeast and that continues below this rock into the rhyolite (see Pl. XIV) is in part ore bearing and has been much better explored. As a rule the basalt and rhyolite are separated by a thin sheet of gouge, which would not ordinarily be taken as indicating more than slight movement of one rock past the other. In some places this seam of gouge is not thicker than a sheet of stout cardboard, yet, as shown by the cross section (Pl. XIV), the minimum displacement along this one fissure can not be less than 200 feet. Moreover, southeast of the main shaft, on the 200-foot level, the contact surfaces of the two rocks show deep, rounded corrugations with parallel striæ, all of which pitch about 10° E. This shows that the latest movement along the fault zone at this place was nearly horizontal and that the total displacement therefore was considerably greater than the 200 feet required on the supposition of movement in vertical planes alone.

The basalt is generally more or less decomposed, and much of it is traversed by many irregular curved fissures with slickensided walls. It has undergone much internal movement, and this fact and the resulting plasticity of the mass as a whole accounts in great part for the absence of conspicuous brecciation of the rhyolite in contact with it. In the progress of faulting the comparatively soft basalt, with its innumerable fractures and polished slipping surfaces, was able to adjust itself readily to change of form and to slide smoothly over inequalities in the rhyolite walls without shattering them to fault breccia.

Petrographically, the basalt is an ordinary feldspathic, olivinitic variety, in which few of the mineral constituents are visible to the naked eye. The most compact and freshest specimens collected underground show under the microscope small porphyritic crystals of augite and olivine, the latter almost wholly altered to serpentine, in a microlitic groundmass consisting chiefly of plagioclase, augite, magnetite, and a large proportion of glass. The small crystals are arranged so that the longer axes of most of them approach parallelism, and they sweep in curved trains around the larger crystals in the manner characteristic of lavas that have congealed rapidly as flows in contradistinction to magmas that have consolidated more slowly as dikes. The abundance of glass suggests also that we have here to do with an extrusive and not an intrusive rock. Additional evidence for the same conclusion is presented at the bottom of the basaltic mass where it is penetrated by the main shaft on the 300-foot level. The basalt at this place is a dull, reddish, earthy-looking rock, with lighter mottling. It is clearly much decomposed and contains a large proportion of calcite. The microscope shows that the material was originally a very spongy or scoriaceous glassy basalt and that the mottled appearance is due to the filling of the irregular vesicular cavities with impure calcite. This variety represents the frothy lower part of a lava flow that once spread over a surface composed of rhyolite No. 10. Similar mottled basalt is exposed northeast of the shaft on the 400-foot level, where, also, it probably indicates proximity to the base of the flow. An amygdaloidal facies was noted also by Mr. Emmons in the excavation for the mine boarding house. It thus appears that the basalt of the Montgomery-Shoshone mine is a down-faulted portion of plagioclase basalt No. 4, which is a flow overlying rhyolite No. 10 and is extensively exposed between Montgomery Mountain and Beatty. (See Pl. I.)

There are some notable irregularities of the southeast contact of the basalt with rhyolite No. 10 in the Montgomery-Shoshone mine, particularly on the 200-foot and 300-foot levels, southeast of the shaft. (See Pl. XIV.) These are due to displacement of the main fault contact by minor slips, which appear to be connected with movements along the veins in the rhyolite.

The total thickness of rhyolite No. 10, according to Messrs. Emmons and Garrey, is about 400 feet. At many places in the district it has a distinct glassy facies at its base, which serves to mark the division between it and the underlying rhyolite No. 9, which is about 250 feet thick. It thus appears that the Montgomery-Shoshone workings, with a depth of 600 feet, should go through rhyolite No. 10 into rhyolite No. 9. I have been unable to detect this change underground. The specimens of rhyolite from levels below the 300-foot are slightly more porphyritic than those collected above, but the microscope shows no essential difference in the rocks. As stated by Messrs. Emmons and Garrey, on page 45, certain varieties of rhyolite No. 9 are very similar to rhyolite No. 10, and where the base of No. 10 is not glassy positive distinction between the two rocks is probably not possible in ordinary underground exposures. If a continuous vertical section, such as that afforded by the main shaft during sinking and before timbering, could be carefully examined and specimens collected at intervals, it might be possible to determine the contact between the two flows. The present levels and accessible stopes, however, are not adequate for this purpose. The rhyolite exposed in them is practically and lithologically uniform and presents only such color variations as are due to changes connected with mineralization and weathering.

VEINS.

The veins worked in the Montgomery-Shoshone mine are filled fissures in rhyolite. As a rule, the fissuring is rather irregular with a tendency toward sheeting and brecciation. Consequently, most of the veins contain many fragments of rhyolite embedded in the materials deposited from solution. The walls in general are rough and indefinite and there has not been much slipping along them since the veins were formed. The general plan of the veins is apparent from Plate XIV. In the neighborhood of the main shaft is what may conveniently be designated the Montgomery-Shoshone vein zone. This has a course ranging from north to northeast and as a whole is practically vertical. There are two main branches in this zone, which converge southward and which inclose between their northern portions numerous less persistent fissures. On the north they terminate against the basalt. On the 100-foot and A levels the rhyolite between the two main branches of the veins for distances ranging from 50 to 150 feet south of the basalt was all irregularly fissured and constituted the large body of rich oxidized ore worked in 1906 and 1907, of which only the outer shell now remains. A large proportion of this ore was a soft crumbling mass, consisting largely of kaolinite irregularly streaked with stains of iron oxide. Within this soft material could be detected residual fragments of less-altered rhyolite, loose quartz phenocrysts, and small anastomosing veinlets of quartz. Native gold and cerargyrite were both visible in the best ore. The whole clearly represented the alteration, within the belt of weathering, of a mass of thoroughly shattered rhyolite which had been veined and cemented by quartz. This ore was said to carry as much as $700 per ton, nearly half of the value being in silver. According to Mr. Ralph I. Johnson, who assayed much of the Montgomery-Shoshone ore for the original owners, the average ratio of gold to silver in 160 samples was 1 ounce of gold to 25.44 ounces of silver. This ratio suggests much secondary concentration within the zone of oxidation. At the present time the 100-foot and A levels are not used; and since much of the structure has been obliterated by stoping and caving, it has not been practicable to trace the veins up to the basalt, as has been done on the 200-foot and 300-foot levels shown in Plate XIV. As may be seen on the 400-foot level, the veins in some places are deflected at the basalt and continue for some distance along its contact.

The same vein zone appears on the 400-foot level, but the veins are smaller and are of too low grade (under $5 a ton) to work. On the 500-foot level this zone has not been explored and on the 600-foot level the veins, so far as opened in 1908, are narrow, of no value, and apparently less persistent than on the levels above.

The Polaris vein lies from 300 to 500 feet west of the zone just described and has been explored for a length of about 400 feet on the 200-foot and 300-foot levels. As shown in Plate XIV, its course is curved and varies from north to north-northwest. It dips 60° W. Like the veins east of it, the Polaris ends abruptly at the basalt.

Another important vein is one that may be designated the contact vein, since it follows the contact between the basalt and the rhyolite. On the 200-foot and higher levels the contact shows very little vein material. On the 300-foot level, however, the rhyolite alongside the basalt in the vicinity of the main shaft has been fissured and mineralized to a width of 4 to 6 feet and has been stoped for a distance of about 160 feet along the level and nearly up to the level above. A stope on the same ore body, from 40 to 60 feet long, extends down to the 400-foot level, where the vein is only in part accompanied by basalt. On this level, also, there is another stope on the same vein east of the main shaft. The contact vein is not continuous all along the contact and in many places contracts to one or more close fissures. Some of the widest and best parts of the vein are at places where minor north-south fissures end at the basalt, as may be well seen on the 400-foot level west of the Polaris vein. On the 500-foot and 600-foot levels the contact vein is wholly below the basalt. There were no stopes on these levels in 1908 and none of the material exposed in the drifts was ore.

The primary filling of all the veins was mineralogically similar, consisting of quartz, calcite, and comparatively small quantities of pyrite. The precious metals were probably originally contained in the pyrite, although it is possible that other sulphides were present also. The quartz and calcite appear to have been irregularly intercrystallized, partly as the filling of simple open fissures and partly in zones of shattered rhyolite where the filling served as the cement for a loose breccia. In general, the veins were originally most siliceous near the basalt and became more calcareous toward the south.

None of the vein material visible in the workings in 1908 retains its original character; it has all been modified by oxidation and solution. In the course of this alteration most of the pyrite has been changed to limonite, the gold has been set free, and the silver has combined with chlorine as cerargyrite. The resulting sulphuric acid, with the carbon dioxide introduced by percolating atmospheric water, has kaolinized the neighboring rhyolite and has helped to dissolve the calcite, leaving behind dark-brown or black mixtures of hydrous oxides of manganese and iron. During the process some silica has gone into solution and has formed fragile, lamellar pseudomorphs after calcite of the kind described on page 94. There is some question, however, whether this pseudomorphic replacement is altogether the work of oxidizing solutions. The structure is found in some of the veins on the 600-foot level, where the quantity of quartz deposited in and around the pseudomorphic skeletons is so abundant as to suggest rather more active transportation of silica than is usually credited to cold descending water. Unfortunately the workings were not deep enough in 1908 to afford a conclusive answer to this question. However deposited, this later quartz appears to contain no pyrite and no gold or silver. This, so far as it goes, is suggestive of deposition by water from the surface.

The veins of the Montgomery-Shoshone zone and the Polaris vein, particularly those parts distant 200 feet or more from the basalt, are composed of dark, friable, cavernous material, which is largely pseudomorphous quartz and earthy manganese and iron oxides. Such vein matter is as a rule not ore. The only parts of the north-south veins that have proved profitable are within a distance of 150 feet from the basalt and are those portions in which the filling originally contained much more quartz than calcite. All the drifts on these veins when driven south beyond this distance show a decrease in the tenor of the material, accompanied by an increased prominence of those features that indicate a vein originally composed mainly of calcite. In this respect the long drifts to the south have proved uniformly disappointing. Assay plans of the principal levels are given in Krumb's report. The highest assay recorded by him was 27.45 ounces of gold and 426.2 ounces of silver, or $783.41 a ton. This sample came from the main ore body, 17 feet below the 100-foot level.

Oxidation of the veins extends to the 600-foot level but is not quite complete, as is shown by the presence of some pyrite in concentrates from the ore of the 400-foot level. Water was first found at a depth of 545 feet (45 feet below the 600-foot level) and for a time the shaft is reported to have made 30,000 gallons in twenty-four hours. About 20,000 gallons a day was pumped during the cutting of the 700-foot station. This level is expected to throw light on the size and value of the ore bodies below the zone of oxidation.

PROVIDENCE MINE.

The Providence is a prospect on the Montgomery-Shoshone fault zone, northeast of the Montgomery-Shoshone mine. No ore has been found, but the workings are of interest in connection with the fault and its associated strip of basalt. A geologic plan of the levels is shown in figure 18. The new shaft is about 870 feet northeast of the main shaft of the Montgomery-Shoshone mine and is in rhyolite No. 10. The shaft had been abandoned in 1908 and the 50-foot level was the only one examined. The crosscut northwest from the shaft goes through a foot or two of crushed and squeezed basalt into rhyolite No. 16, showing that the fault zone has at this point narrowed to practically a single fissure. In the drift northeast of this crosscut the two rhyolites are separated merely by a seam of gouge which dips 53° NW. West of the shaft the basalt widens to 30 feet and has gouge seams on both sides.

The old shaft, also abandoned, is 400 feet northeast of the new. It started in basalt but went through the foot wall of this into rhyolite No. 10. A curved crosscut northwest from the shaft exposes the section shown in figure 18. About 100 feet north of the shaft is what appears to be a small basaltic dike, 4 feet wide, in rhyolite No. 10. This dips 50° NW. and appears to be generally parallel with the fault zone. It is not vesicular and the contacts are so close as to support the conclusion that this is not a fault slice but is intrusive. The main basalt strip is about 30 feet wide on this level. The rock, which is all soft and decomposed, is partly vesicular and is full of curved

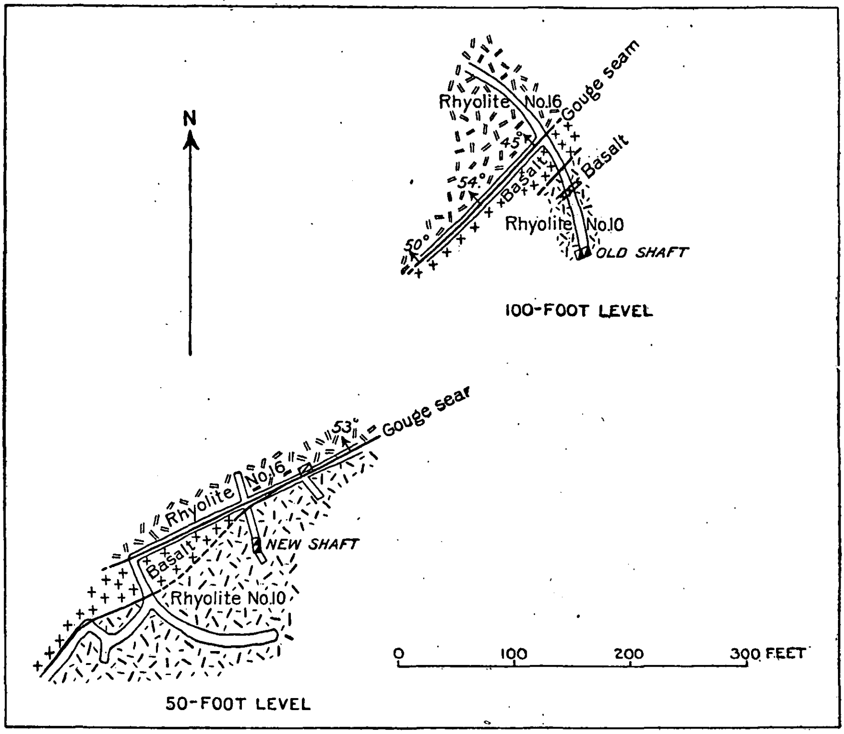


FIGURE 18.—Geologic plan of the Providence mine.

and polished surfaces of slipping, the basalt being squeezed into lenticular fragments of all sizes up to 2 or 3 feet in diameter. The hanging wall is remarkably smooth and consists of slickensided rhyolite No. 16, with numerous grooves and striæ, which pitch 65° NE., showing that the last movement along the fault was more nearly vertical than horizontal. The average dip of this wall is about 50°. The rhyolite of the hanging wall is very little disturbed and most of the movement of faulting was evidently concentrated along the yielding basalt.

If the surveys from which figure 18 was compiled are accurate it is evident, even when the dip and the difference in depth of the two levels is taken into consideration, that the strike of the Montgomery-Shoshone fault is far from being a straight line.

NATIONAL BANK MINE.

The National Bank is a prospect situated on the west side of Ladd Mountain, close to the town of Rhyolite. (See Pl. XI, *A*.) When first visited in January, 1906, the mine was operated through a vertical shaft 200 feet deep and had two short levels. No work was in progress in 1908 and the workings were not again examined.

As exposed at the surface and on the 100-foot level, the National Bank vein is a rather indefinite zone of fissuring in rhyolite No. 5. It strikes about N. 15° E. and dips west at 60°. The hanging wall is a basalt dike with an average width of 3 to 4 feet. The lode has no recognizable foot wall and consists of somewhat silicified rhyolite cut by many small and inconspicuous veinlets of quartz. The gold is not confined to the veinlets, but occurs also in the rhyolite, particularly where the latter shows little limonitic specks, representing oxidized pyrite crystals.

The ore is bunchy and good assays are sometimes obtained from the rhyolite at a distance of 30 or 40 feet from what is considered the main lode. The best assays obtained prior to the date of visit were about $230 a ton, mostly in gold. In the lower-grade ore the silver may exceed the gold, in one case there being about 5 ounces of silver to 3 of gold.

Considerable work has been done on the 200-foot level, mainly on a narrow seam which dips eastward at an angle of 45° to 50°, and which is probably the contact between two rhyolitic flows. The workings show that rhyolite No. 5 is, at this locality at least, made up of many layers or flows, some of which are only about an inch thick. These are separated by close regular partings that, as a rule, carry a little gouge and exhibit evidence of movement. The seam followed on the 200-foot level is such a plane of division between constituent parts of what is regarded as a single rhyolitic formation. The rhyolite below it is softer and a little more micaceous than that above, but is supposed to be a portion of rhyolite No. 5.

The dip of the National Bank lode from the surface to the 100-foot level would, if continued to the 200-foot level, carry the vein from 50 to 60 feet west of the shaft, or from 15 to 20 feet west of any crosscut in existence on this level at the time of visit.

A little ore has been shipped from near the surface but the mine has not been profitable.

GIBRALTAR MINE.

On the steep south slope of Bonanza Mountain is the Gibraltar mine, opened by three tunnels a few hundred feet in length. The upper tunnel (No. 3) is on what is known as No. 4 vein, the one below it (No. 2) is partly a crosscut and partly on the same vein, and the lowest (No. 1) tunnel is a crosscut. No. 1 tunnel enters the east slope of Bonanza Mountain only a few feet above the alluvium, No. 2 tunnel is about 85 feet higher, and No. 3 about 60 feet above No. 2. Six veins are recognized in the Gibraltar property. Their strikes range from N. 15° W. to N. 20° E. and they dip to the west. The veins are numbered from east to west. No. 4, on which most work has been done, strikes about N. 10° W. and dips west at angles varying from 45° to 55°. No. 2 vein is the most nearly vertical, its dip at the surface being about 80°. The croppings of the veins are spaced at various distances apart, ranging from 50 to 150 feet.

The general country rock of the mine is a rhyolitic flow breccia, containing occasional inclusions of basalt up to 3 feet in diameter. It has been correlated with rhyolite No. 6, though the many faults in Bonanza Mountain render the interpretation of the structure less satisfactory than in other parts of the district. The rock is considerably altered and contains much secondary quartz.

The veins are small and occupy fault fissures of slight throw. Vein No. 4, which has been opened by two tunnels and has supplied all the ore so far found, is in most places less than a foot wide, although locally it widens to 3 or 4 feet. It consists of quartz and a soft, dark, earthy material, which is in part oxide of manganese. A cavernous and platy structure, due to the solution of carbonates from an originally banded vein, is common. The best ore lies near the foot wall and usually includes a little of the rhyolite. The gold, which contains so much silver as to constitute electrum, occurs in the mode characteristic of the district, usually in little limonitic specks in quartz or silicified rhyolite. These rusty specks in rare instances show small residual grains of pyrite.

The veins in general cut two older structures in the rhyolite. One of these is a set of planes dipping east at angles ranging from 30° to 35° parallel to the flow bands in the rhyolite. These may be partings between separate flows or may possibly be cracks formed by the cooling of the rhyolite. The other structure is a fairly regular sheeting striking N. 30° W. and dipping southwest at an angle of 60°. When the lode fissures were formed they appear to have occasionally followed one or the other of these earlier fissures for short distances, so that the lodes are unusually crooked, as may be well seen in No. 3 tunnel on No. 4 vein.

The Gibraltar mine has been an intermittent producer of hand-sorted shipping ore obtained from small bunchy pay shoots. No work was in progress during the second visit to the district in 1908.

TRAMPS MINE.

UNDERGROUND WORKINGS.

A general plan of the principal underground workings of the Tramps mine is shown in figure 19. The Hobo inclined shaft is in the saddle of Bonanza Mountain, through which passes the trail from Rhyolite to the Denver mine. The Tramp tunnel enters the mountain at its south end and the other shafts and tunnels are on the west slope. There are no stopes and all the work, which has an extreme vertical range of about 500 feet, is exploratory.

The portal of the Tramp tunnel is at an elevation of about 3,740 feet, just below the track of the Las Vegas and Tonopah Railroad. About 200 feet from the portal the tunnel cuts obliquely a small vein, and a crosscut at this point connects with the Nelson shaft and with a curved drift on the Nelson vein. Another vein has been drifted on about 400 feet farther north. Thence the tunnel turns northwest to the Eclipse vein, which it follows for a little over 100 feet to a raise of 106 feet up to the level of the Eclipse tunnel. A short west crosscut from the head of this raise reaches the Eclipse vein again, which has been drifted on for over 800 feet, past the Tramp and Eclipse shafts. Near the latter shaft, which does not, however, extend down to the Eclipse tunnel, an east crosscut of 140 feet reaches the Hobo vein at a point 167 feet below the workings on the same vein in the Manganese tunnel and Hobo shaft. The Eclipse tunnel follows the unimportant Tiger vein for about 150 feet from the portal and then turns as an oblique crosscut toward the Eclipse shaft.

GEOLOGIC FEATURES.

As shown by the work of Messrs. Emmons and Garrey, the southern spur of Bonanza Mountain is minutely dissected by north-south to northwest-southeast faults of small throw. The top and much of the east slope of the mountain are occupied by rhyolites Nos. 6, 7, and 8, with the thin flow of basalt No. 2 between rhyolites Nos. 6 and 7. The four formations together are probably not over 200 feet thick at this place and, as shown in Plate I, they dip to the east at an angle not very different from the slope of the hill. The mass of the mountain and most of the western slope is composed of rhyolite No. 5, which is the prevailing rock in the workings of the Tramps mine. The Hobo shaft is partly in rhyolite No. 8 and the Tramp tunnel is for some distance from the portal in rhyolite No. 6. The different rhyolites are distinguishable only with much difficulty underground, especially where, as in this mine, many of the drifts follow thoroughly oxidized veins. It would perhaps be possible to determine the approximate position of some of the underground contacts with the help of numerous microscopical sections, but the present state of the workings appears

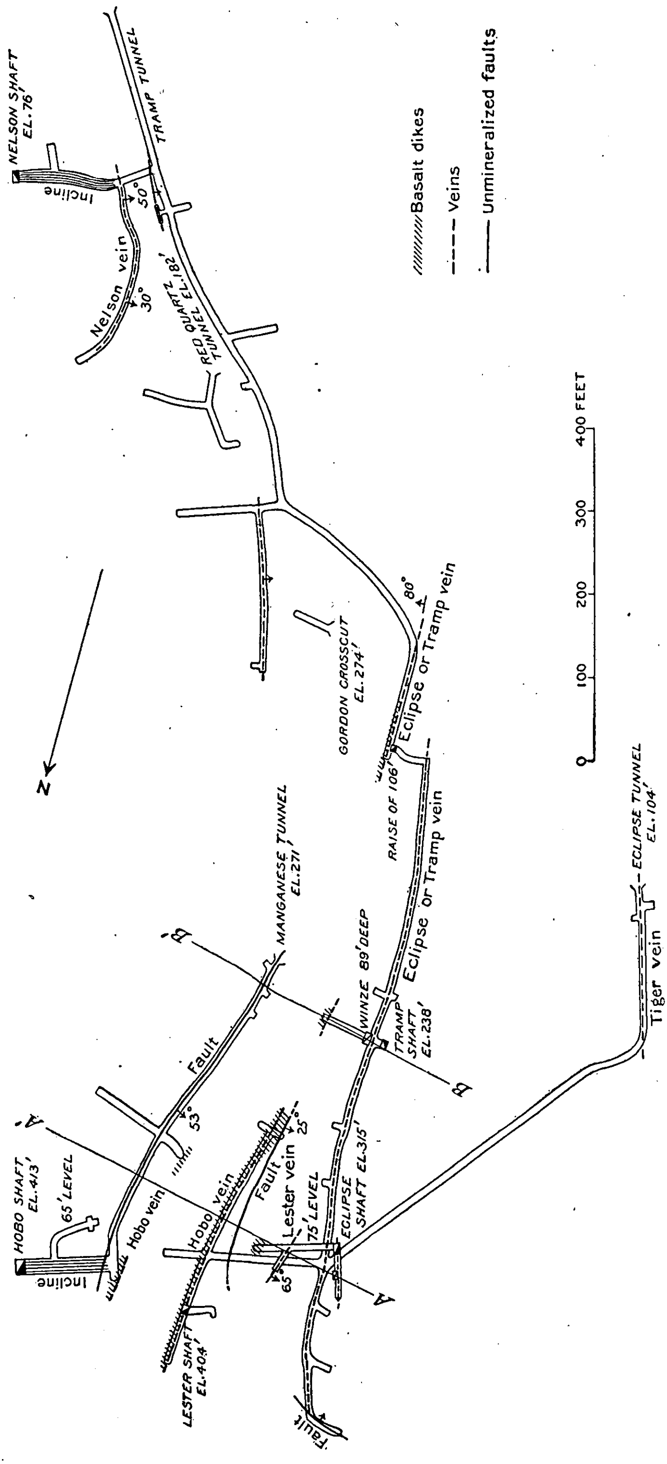


FIGURE 19.—General plan of the workings of the Tramps mine.

hardly to warrant the expenditure of time and labor that this would entail. There is no perceptible change in the veins at the passage from one rhyolite to another, and should the mine prove productive these superficial contacts will have no bearing on future development, which must be in rhyolite No. 5 and in underlying formations.

The only other rock found in the workings is basalt. This has the form of dikes, which run generally nearly north and south and which are as a rule accompanied by veins. The dikes vary considerably in width, the observed maximum being about 25 feet. The most regular and persistent is the one followed by the Hobo vein. The basalt is everywhere decomposed and in many places has been crushed and faulted by recent movement.

VEIN SYSTEM.

The vein system of the Tramps group is represented in slightly generalized form on Plate I, as the western half of the group of nearly north-south faults that cut Bonanza Mountain, the eastern half comprising the veins of the Gibraltar mine. At this place these faults are structurally unimportant, although the Scepter and Hobo faults are associated with increased displacement farther north. It is probable that none of the faults in the Tramps ground has a throw of over 100 feet and the displacement effected along most of them is certainly much less than this. The fissures shown on Plate I are not all mineralized and they represent the net result of movement at different periods, some prior to and some subsequent to ore deposition.

The veins as explored underground are shown in figure 19. The two principal ones are the Hobo and the Eclipse or Tramp vein. The Hobo vein outcrops at the collar of the Hobo shaft and can be traced down the steep hillside to the mouth of the Manganese (or Lester) tunnel. Thence the outcrop runs south, passes through the Gordon crosscut, and extends down the south slope of Bonanza Mountain west of the portal of the Tramp tunnel. The Eclipse vein outcrops along a line connecting the Eclipse and Tramp shafts. Although it can be traced for some distance south of the latter shaft its outcrop near the south end of the mountain is obscure and the vein is partly covered by detrital material. To the north the Eclipse fissure branches, one branch being the Saddle fault and the other the Scepter fault. (See p. 79.) The Hobo vein dips west at 53°; the Eclipse dips east at about 85°. Other veins, which are neither important nor persistent, are the Lester and Nelson, shown in figure 19. The Lester dips west at 65° and, as shown in figure 20, probably joins the Eclipse vein at a depth between 200 and 300 feet. The Nelson vein, as exposed on the Tramp tunnel level, near the Nelson shaft, dips west at 50° and is a fairly well defined streak of low-grade oxidized manganiferous material. As it is followed north the vein curves to the east and becomes more nearly horizontal. Finally, at the end of the drift, the fissure dies out in generally fractured rhyolite. The Tiger vein, followed for about 150 feet in the Eclipse tunnel, is a nearly vertical zone of fissuring in the rhyolite with no well-defined walls. It is not very persistent and although some good ore has been found in it the quantity was too small to encourage further prospecting.

A feature of much interest is a fault that appears in the crosscut between the Eclipse and Hobo veins in the Eclipse tunnel and in a short crosscut at the south end of the drift on the Hobo vein. (See fig. 19.) The fault fissure dips 25° W. and is filled with 1 to 2 feet of soft, crushed rhyolite. The same fissure is exposed at a point 33 feet below the Eclipse tunnel in a winze near the Tramp shaft. Here it cuts off the Eclipse vein, as shown in figure 20. From the bottom of the winze, which is 89 feet deep, an east crosscut of 60 feet

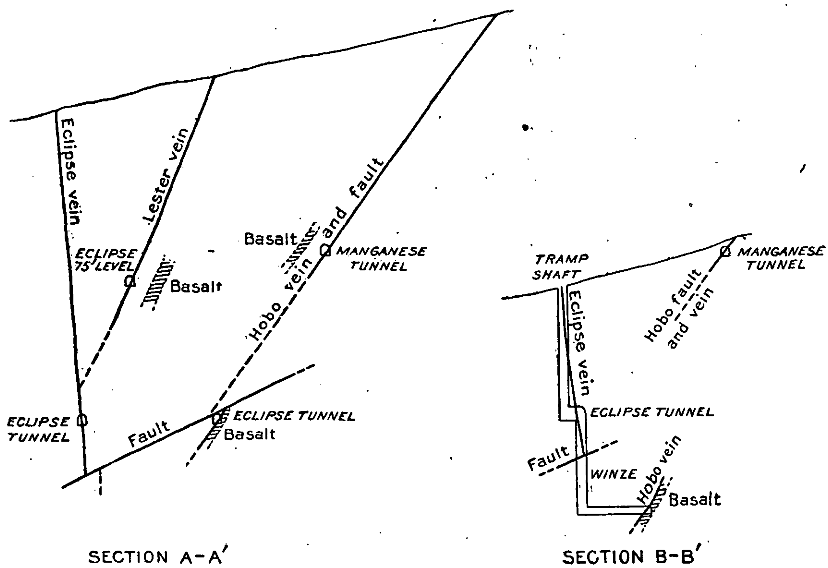


FIGURE 20.—Sections through the Tramps mine.

exposes a vein which is supposed to be the Hobo. This, however, is not certain and a glance at figure 20, where the known data are plotted in cross section, shows that more development is necessary before the hypothetical displacement, indicated by the dotted lines, may be accepted as a fact. The Hobo and Eclipse veins converge downward. What takes place where they come together is not known. There has been postmineral movement along both fissures and it is yet to be ascertained whether, as seems more likely, the final result of the movements has been the displacement of the Eclipse by the Hobo, or vice versa.

The vein followed near the end of the Tramp tunnel is supposed by those working the mine to be the Eclipse vein, and therefore the same as the vein opened in the Eclipse tunnel 106 feet above. It has the proper course and dip for this vein, but is about 35 feet east of its expected position on the Tramp level, as calculated from the average dip of the lode in the upper tunnel. The low-angle fault shown in figure 20 may pass through the connecting raise, which was not open at the time of visit, and so account for this discrepancy, the 35 feet being the measure of the horizontal separation at this place.

CHARACTER OF THE VEINS.

As the workings nowhere penetrate below the zone of oxidation the original character of the veins must be inferred from observations on weathered material. One of the best places for such study is the Gordon crosscut in the Hobo vein, on the west slope of the mountain, which exposes over 25 feet of vein material. The rhyolite was fissured to fully that width, the fracturing partaking in part of the nature of a sheeted zone but passing also into irregular rupture and brecciation. In the spaces thus provided were deposited quartz and calcite. The larger veinlets conform generally to the dip and strike of the lode as a whole, but the intervening plates of rhyolite are full of smaller stringers running in all directions. Many of these, particularly those in which calcite predominates, are regularly banded. This original structure of deposition is accentuated by partial weathering, which affects differently the various layers. The quartz is fine grained and much of it is almost porcelane in texture. It is, in part, irregularly crystallized, and in part interbanded with calcite. Both calcite and quartz, especially the latter, have to some extent replaced the fragments of rhyolite in the fissures. Such sulphides as may have been present in the parts of the Hobo vein exposed to view have mostly oxidized and it does not appear that they were ever abundant in the vein at this place. In richer portions of the vein a few minute crystals of pyrite can be detected in some of the hard residual fragments of quartz.

In the course of oxidation the calcite is attacked, calcium carbonate being removed and manganese oxide with silica being left behind. The vein becomes carious, the cavities being partly filled with sooty, impure wad, accompanied in places by the fragile skeletal pseudomorphs of silica after calcite described on page 94. In some of the banded veinlets the alteration to manganese oxide begins along certain planes of deposition so that the banding of the vein, as seen in section, is thereby accentuated by the presence of narrow, black parallel lines. As the weathering proceeds the coherence of the vein is destroyed and slight postmineral movements may transform the originally firm banded vein into a soft, structureless mass of stained quartz fragments mixed with dark, earthy hydrous oxides of iron and manganese and in some places coated with crusts of secondary calcite crystals. In the richer parts of the vein the gold is partly in the soft, earthy material and partly in the cryptocrystalline quartz, as minute particles associated with small spots of rust that have resulted from the oxidation of crystals of pyrite. A very large part of the vein material in all of the lodes opened in the Tramps workings is of this soft, structureless character.

The Hobo vein generally accompanies a decomposed basalt dike, the dike being, as a rule, on the east or foot-wall side. In one place at least, however, on the Eclipse level, the Hobo vein is within the basalt. In other places some rhyolite intervenes between vein and dike. The vein is clearly younger than the dike and was deposited in fissures which followed in a general way the line of the dike without conforming accurately to either contact. The basalt does not appear to be continuous along the whole course of the Hobo vein and is found only here and there along the Eclipse vein. Other veins, such as the Tiger and Nelson, are not accompanied by basalt and some dikes cut in the workings are not accompanied by veins.

Both the Eclipse and Hobo veins have been affected by postdepositional movements within the plane of the lode. A good part of the displacement along the Hobo fault appears to be referable to this later movement, which has crushed both dike and vein (see Pl. XI, *B*) and produced a fissure not strictly nor continuously accordant with either.

Both the Hobo and Eclipse veins contain bunches of oxidized ore that will yield on assay over $100 a ton, but these bodies are too small for profitable exploitation. There is probably a considerable quantity of ore ranging from $20 to $30 a ton in gross value, but this is not workable as the mine is at present equipped, although it could of course be profitably milled if there proves to be enough of this ore to warrant the construction of a mill. A very large part of the vein material in the present workings probably will not assay over $10 a ton, which is probably too low for profit under the average conditions likely to prevail for some time in this district.

DENVER MINE.

The Denver mine, belonging to the Tramps Consolidated Company, is about one-third mile north-northwest of the workings described as the Tramps mine, on the Denver fault. (See Pl. I.) The country rock is rhyolite No. 5. The vein strikes generally north and south. For the first hundred feet in depth it dips about 70° E.; below it changes to the west, so that the vein as a whole is practically vertical. It is not, however, a single fissure, but is rather a narrow zone of fissures that depart from parallelism in strike and dip by small angles. The best bunches of ore occur here in one fissure, there in another.

The underground workings comprise four tunnels from 50 to 100 feet apart and a winze from the lowest tunnel connects with levels at

50, 200, and 300 feet below its collar. The combined depth of the workings is about 500 feet and the vein has been explored for a total length of 1,000 feet. Most of the levels, however, are much shorter than this, the bottom level being 350 feet in length.

The Denver claims were located in September, 1904, and the mine has been worked steadily on a small scale since that time, making shipments of hand-sorted ore from time to time. In July, 1908, stoping was in progress between the lowest tunnel and the 50-foot level of the winze. In other words, the stopes have been carried to a depth of 250 to 300 feet. Below this no shipping ore in stoping quantities has yet been found. The ore thus far extracted has all been oxidized and has occurred in comparatively small shoots, few of them having a continuous stope length of over 50 feet. The 300-foot level of the winze shows slight dampness and some pyrite, indicating that the bottom of the oxidized zone has practically been reached.

Prior to oxidation the Denver vein apparently consisted of quartz and calcite, carrying auriferous pyrite. This filling was in general less than a foot in width and appears nowhere to have exceeded 18 inches. As in most of the veins in the district, there was considerable sheeting and irregular fracturing of the brittle rhyolite and the fissures were partly filled with rock fragments before vein deposition began. The boundary between vein material and fissured and veined wall rock is not everywhere definite. In a few places, where the vein is distinct from its hard siliceous walls, these show strong slickensided corrugations, which in every case observed are more nearly horizontal than vertical. These are not mere gouge markings such as often record recent movement, but were channeled in the hard rhyolite under great pressure before the vein-forming solutions had completed their work.

In the course of oxidation the calcite, less abundant in this vein than in some others in the district, was dissolved or partly replaced by pseudomorphous silica and the usual sooty manganiferous residue left behind. The pyrite was changed to little specks of limonite in which are now embedded particles of native gold. As usual, the gold is more closely associated with the quartz than with the calcite, and the best ore is a fine-crystalline quartz consisting in part of small silicified fragments of rhyolite and being spotted with limonite. The limonite is partly in irregular stains or blotches and partly in distinct pseudomorphs after small crystals of pyrite. Small hackly particles of native gold are generally visible in these brown spots.

In a few places the vein is faulted by nearly horizontal fissures, the part of the vein above each fissure being displaced to the west. The greatest displacement observed is about 7 feet; and so far as is known the faulting, which is probably younger than the original ore deposition, has had no influence on the formation of the ore bodies.

ORIGINAL BULLFROG MINE.

The Original Bullfrog mine is 3 miles west of Rhyolite, at the south base of Bullfrog Mountain. The principal workings comprise a tunnel with several hundred feet of branching drifts and crosscuts and two shafts, one of which was 140 feet in depth in 1906. The only work in progress in 1908 was on a small scale by lessees, near the surface.

The Original Bullfrog lode outcrops more conspicuously than the other deposits in the district. It is a huge mass of nearly solid quartz which, as a whole, dips north at 18° to 20° and is at least 60 feet thick. The quartz is partly chalcedonic and banded and partly coarsely crystalline. Much of the latter variety is amethystine. The quartz rests in most places upon a much-sheared shaly material, greenish or reddish in color, which is so decomposed as to leave its original character in doubt. It is supposed to be a shale that belongs, with the underlying limestone, to the Paleozoic series. The shale is not of great thickness and in some places the quartz rests directly upon the limestone.

The lode has no definite hanging wall, but is overlain by rhyolite No. 2, which is fissured and contains stringers of quartz for some distance above the mass of the lode. The deposit represents a mass of rhyolite that has been greatly fissured and shattered. The fissures have been filled with quartz and with minor amounts of calcite and ore minerals; and to a considerable extent the shattered rhyolite has been completely silicified.

Some bunches of rich ore have been found, but the mass as a whole is of very low grade. The fissuring that provided opportunity for the deposition of so much silica was probably caused by movement along the Original Bullfrog fault (see Pl. I), which has here brought the rhyolites against the pre-Tertiary rocks.

The shipping ore consists of quartz that originally contained chalcocite, but the latter mineral has been nearly all changed to green, blue, and brown chrysocolla with a little malachite. Native gold occurs in visible particles embedded both in quartz and chrysocolla. There is generally some calcite with the ore and with the quartz throughout the vein.

BULLFROG WEST EXTENSION MINE.

The Bullfrog West Extension mine lies just west of the Original Bullfrog mine and is on the same large, nearly horizontal vein. The mine is opened by a vertical shaft with levels at approximately 115, 139, and 195 feet in depth.

The vein appears in general to have a slight dip to the north but is irregularly rolling. It rests partly on much-sheared and slickensided red shale and partly on limestone, both rocks having been faulted before the rhyolitic eruptions and consequently before the vein was formed. The bottom level is entirely in these older rocks and is under the vein. The hanging wall is rhyolite No. 1 and the vein consists of a portion of this flow that has been shattered by movement along the Original Bullfrog fault and has been cemented and partly replaced by quartz.

The work at the time of visit in 1908 had been confined to exploration. It was reported by Mr. Leonard P. McGarry, the superintendent, that a considerable quantity of $50 to $60 ore had been blocked out, but that freight and treatment charges under conditions then prevailing amounted to about $35 a ton. The ore is similar to that of the Original Bullfrog in mineralogical character.

GOLD BAR MINE.

The Gold Bar mine is about 4 miles northwest of Rhyolite and is outside of the area covered by the detailed map (Pl. I) of the Bullfrog district. When it was visited in 1906 the main shaft, a 64° incline, was 150 feet deep and connected with several hundred feet of drifts on two levels. Mr. W. H. Emmons visited the mine in February, 1907, at which time new levels had been run at depths of 250 and 350 feet. His notes are made use of in the following description. About this time a 10-stamp mill was built, but the mine soon became financially involved and was idle in 1908.

The Gold Bar lode is a zone of irregularly fissured and brecciated rhyolite fully 100 feet wide. The hanging wall is generally a fairly regular and persistent slip along which some displacement has occurred since the vein was formed. On the foot-wall side there is no definite boundary between vein matter and more or less disturbed rhyolite. The general strike of the lode near the shaft varies from N. 55° E. to N. 65° E. and the average dip is about 65° NW. About 100 feet northeast of the shaft the fissure zone turns and runs due northeast for about 150 feet, beyond which it strikes nearly north toward the Homestake-King mine. The total length of the lode explored on the 150-foot level is about 1,000 feet. The other levels are much shorter.

In general the country rock of the mine is rhyolite, although some vesicular basalt appears on the two lower levels. This is probably part of an intercalated flow, but its relations are not clearly shown. The fissuring and shattering of the rhyolite and the fact that all of the workings are in oxidized ground render any study of detailed geologic relations unsatisfactory.

Although a little rich ore has been found, it is evident that the deposit is to be regarded as a large mass of low-grade material, such as can be worked, if at all, only on a considerable scale and by the most economical methods possible in this district. The rhyolite has been greatly fissured along a wide zone and the fissures have been filled with quartz and calcite carrying some auriferous pyrite and perhaps free gold. The mass has been disturbed by subsequent movements; the vein material has oxidized to the usual products; and there has probably been some migration and reconcentration of the gold and silver into isolated bunches of richer ore.

HOMESTAKE-KING MINE.

The Homestake-King mine adjoins the Gold Bar on the north and is on the same lode. It is opened by a 63° inclined shaft 500 feet deep, with levels at 200, 300, 400, and 500 feet below the collar.

The vein is the northern continuation of the Gold Bar vein and is of the same general character. Considerable stoping has been done on a pay shoot over 100 feet in stope length and up to 40 feet in width. This extends from a point above the 200-foot level to the 400-foot level and pitches to the north. The ore, which is oxidized, shows no mineralization to the eye, but carries native gold and is tested by panning. No ore had been found on the 500-foot level at the date of visit in August, 1908. The deposit as a whole, like that of the Gold Bar, is of low grade.

A north drift on the 300-foot level, about 1,100 feet long, connects the main shaft with the King shaft, sunk to reach the same vein, but not now used. The Daisy, another abandoned shaft, about 1,100 feet northeast of the Homestake shaft, is on a nearly east-west fissure in rhyolite and is 200 feet deep.

The Homestake-King mine is equipped with a well-constructed 25-stamp mill, completed in the summer of 1908. The ore is treated by amalgamation and cyanidation, no concentration being attempted.

MAYFLOWER MINE.

The Mayflower mine is situated about 7 miles north of Rhyolite on a vein that strikes N. 50° W. and dips from 60° to 65° SW. The country rock is rhyolite, in part a flow breccia, and two or three flows appear to be exposed in the workings. The main shaft when first visited in 1906 was 100 feet deep. Mr. Emmons examined the mine again early in 1907 and found the main shaft 200 feet deep, with two additional shafts, the Combination and Starlight, on the same lode, northwest of the main shaft. His notes were used in connection with my own in preparing the following brief description. The property, after attracting a good deal of attention in 1907, was idle in 1908 and has never been productive.[a]

[a] There was some revival of activity in the vicinity of the Mayflower mine in 1909, the locality being known as the Pioneer district.

The lode is a zone of sheeting and shattering which averages from 4 to 5 feet in width. The hanging wall is generally regular and well defined, but the foot wall is less definite and the width of the vein in many places is not readily ascertained. It is claimed that the ore is in some places 40 feet wide. The fissures in the sheeted zone and the irregular fractures in the rhyolite of the foot wall were originally filled with quartz and calcite. This material has been oxidized to a depth greater than that reached in the shafts, and part of the calcite has been dissolved, leaving behind the usual manganiferous residue. Neither quartz nor calcite form solid veins but have been deposited rather as a cement to angular fragments of rhyolite and have in part replaced the smaller rock particles. The lode appears never to have contained much pyrite and as a rule the valuable constituents are not visible.

Mr. Emmons was informed that considerable bodies of ore averaged $20 a ton, but that the usual grade was from $8 to $12 a ton, nearly all of the value being in gold.

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