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BULLETIN OF NEVADA STATE BUREAU OF MINES AND
MACKAY SCHOOL OF MINES

JOHN A. FULTON, *Director*

# Geology of the Silver City District and the Southern Portion of the Comstock Lode, Nevada


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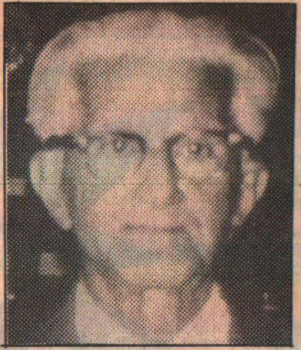
United States Geological Survey. In 1935 the Survey began a restudy of the region, and in order to avail itself of the benefits of Gianella's knowledge of the region, the Survey asked the State Bureau of Mines to cooperate with it, Gianella acting as the Bureau's geologist. A preliminary report of this resurvey will probably be published during 1937.

These two papers should have distinct economic and scientific value, and will bring out many important geologic features not covered by earlier reports.

JOHN A. FULTON,
*Director, Nevada State Bureau of Mines.*

7/10/83

# Noted Nevada professor dies



**VINCENT GIANELLA**
Professor emeritus

AUBURN, Calif. — Vincent P. Gianella, 97, emeritus professor of geology at the University of Nevada's Mackay School of Mines for 29 years, died Saturday at his residence in Auburn, Calif.

He retired in 1952 after serving 20 years as UNR's geology department chairman.

A funeral is scheduled for 2 p.m. Wednesday at Chapel of the Hills, Auburn.

Gianella was born Feb. 9, 1886 in Marysville, Calif. He received bachelor's degrees in electrical engineering and mining engineering from Oregon State College in 1910 and 1911. He held several positions with mining companies in Alaska, Arizona, Nevada and California. He entered UNR in 1919.

He was geologist for the State Bureau of Mines, 1929-1942, was on the Executive Committee of the American Association for the Advancement of Science; a fellow of the Geological Society of America, a member of the Society of Economic Geologists, the Mineralogical Society of America, the American Institute of Mining and Metallurgical Engineers, and the American Seismological Society.

In 1962, Gianella was awarded a Distinguished Nevadan citation in recognition of his scientific contributions to the state.

# OUTLINE OF REPORT

The Silver City district lies in the southern end of the Virginia Range, 12 miles northeast of Carson City, Nevada. The district includes the southern continuation of the Comstock Lode and, as the geologic formations and history of the two areas are closely related, a proper solution of the geology at Silver City involves an understanding of that of the Comstock itself.

The geology of the region is complex. There are numerous rock types of various ages which have been deformed by folding and by several periods of faulting. The rocks have been altered during deformation and also by the heat, and solutions, accompanying Mesozoic and Tertiary intrusions.

The Silver City district has been a continuous producer of gold and silver since 1850, and there is more mining activity at the present time (1935) than at any other period during the past twenty years. Most of the production has come from ores found within 300 feet of the surface. Some ore has been found below 400 feet, and in several mines exploration has been carried on to a depth of 800 feet or more. There is probably little likelihood that large quantities of ore will be discovered at depth, but the district gives promise of continuing production for many years.

The principal vein, a continuation of the Comstock vein system, paralleling Gold Canyon, has been traced to the southern part of the Silver City district. The wall rocks enclosing the veins are identical, except for the absence of diorite, with those enclosing the northern part of the Comstock Lode. The veins are along normal-fault contacts. Most of the veins are enclosed wholly within Tertiary lavas; some have pre-Tertiary rock forming the footwall; a few are entirely within the older rocks. The veins are relatively narrow and vary greatly in width within short distances. In general, their thickness is from less than a foot up to three or four feet. Even the broader portions seldom reach ten feet, although in several places ore has been stoped to a width of forty feet or more. In general, the veins are lenticular and pinch out laterally and in depth. The larger ore bodies, and the richer ores, in many instances occur at, or near, vein intersections. No evidence has been found to indicate that the nature of the wall rock has influenced the tenor, size, or continuity of ore shoots.

In most veins the chief gangue mineral is quartz, in others carbonate and quartz occur together. In places a vein may be entirely of carbonate. In many veins a change from quartz to carbonate, or vice versa, takes place within short distances. Some of the carbonate is calcite, and some is manganiferous calcite. Both may occur in the same vein. In some veins adularia is an important constituent.

The principal ore mineral is an alloy of gold and silver, in various proportions. Some argentite is present, and there are probably minor amounts of other silver minerals. Pyrite is found in practically all unoxidized ore, but seldom in great abundance. Galena and chalcopyrite are rare. The Silver City ores are much less complex than those from the northern part of the Comstock Lode, where there is a much greater variety of silver minerals, together with considerable quantities of copper, lead, and zinc. The veins were formed about middle Miocene time.

The important rocks of the district fall into two broad groups, pre-Cretaceous and Tertiary. A third natural division is the Quaternary rocks, but these play a minor part in the history of the region. The oldest rocks are Triassic(?) sediments and a series of meta-volcanics, presumably of Triassic age. The sediments consist of limestone, shale, schist, and some thin quartzites. A few tuffaceous beds are intercalated with the sediments. The thickness of these rocks, within the mapped area, is about 2,000 feet. The sediments have been folded and faulted; the shales have been in part rendered schistose, with abundant development of biotite and some andalusite, and the limestones have been recrystallized.

The old volcanics comprise a series of breccias, tuffs, and lavas. They probably contain some minor intrusives. These igneous rocks lie unconformably upon the sediments. They have been subjected to less deformation than have the underlying rocks. Their thickness probably exceeds 1,000 feet. These volcanics have undergone metamorphism with widespread development of chlorite and epidote. In a small area, they have been converted into an andalusite-sillimanite hornfels. The sediments and meta-volcanics were intruded by Sierran quartz monzonite. The sediments were metamorphosed during the deformation which preceded the outpouring of the old volcanics, and again, together with the volcanics, by the intrusion of the monzonite. Further alteration accompanied the Tertiary volcanism and mineralization.

Following a prolonged period of erosion, the older rocks were covered by Tertiary lavas. These volcanics are separable into two groups: (1) A series of volcanics, mostly Miocene, ranging from rhyolite to pyroxene andesites, with a thickness approximating 4,700 feet. (2) A group of Pliocene lavas, aggregating 1,200 feet thick. The earlier Tertiary lavas have been mineralized.



The earlier Tertiary volcanics, and older rocks, have been intruded by andesite dikes and a stock of diorite. The rocks were then displaced by normal fault movements, with throws as much as 2,000 feet. Along the faults veins were deposited. The earlier Tertiary volcanics have been tilted westward, with dips averaging 35°, throughout a considerable part of the district. They have a general northerly trend.

Faulting continued during mineralization, and further movement crushed many of the veins after the ore was deposited. All scarps, which may have been formed, were effaced by a long interval of erosion, which removed about 2,500 feet of rock. The region was reduced to one of moderate relief.

Lavas were extruded during the Pliocene, and these were largely removed by later erosion. Toward the close of the Pliocene, or in the early Pleistocene, faulting was renewed on a grand scale in the Basin and Range province. At this time the Virginia Range was uplifted, forming a scarp 1,500 to 2,000 feet high, along its eastern front. This scarp is the upward prolongation of the footwall of the Comstock Lode, at Virginia City, and forms the eastern slope of Mount Davidson, the most imposing topographic feature adjacent to the Silver City district.

Since the Basin and Range fault movements, rugged canyons and gulches have been eroded into the front of the range, and into the depressed fault block east of the Comstock Lode.

The latest volcanic activity was accompanied by flows of olivine basalt. A small flow of the basalt issued from a fissure on the eastern slope of McClellan Peak. The lava flowed down a canyon in the range front, across American Flat, and on through American Ravine. The lava overlies older Quaternary alluvium, and in some places it has been covered by later alluvium.

The last phase of the geologic history includes a rejuvenation of erosion enabling streams to cut sharp V-shaped gorges, to depths of 50 to 100 feet, through the basalt and into the underlying rocks. Late faults have made small scarps in the alluvium. The most prominent Recent scarp follows the projected trend of the vein along the south end of Spring Valley.

Among the more important features that have been disclosed during this investigation, and brought out for the first time, are the following:

The Tertiary lavas have been grouped into new lithologic units.

separable into an Eocene-Miocene series and a Pliocene series, and correlated with contemporaneous volcanics of the Sierra Nevada. Evidence is presented that indicates that the Davidson diorite is an intrusion of Miocene age.

The late Pliocene(?), Basin Range, faulting has been differentiated from the Miocene faulting. Heretofore, practically all investigators have regarded the faults as belonging to one period of Pleistocene deformation. Some Miocene faulting took place before mineralization and continued during vein formation. Further movements crushed the veins after ore deposition. The Miocene faults have throws as great as 2,000 feet; of greater magnitude than the Pliocene(?) displacement. The Miocene faults were not recognized by the earlier workers.

Several Tertiary intrusives, including the Davidson diorite, were recognized, and their probable relation to mineralization noted. The source of the ore-bearing solutions has heretofore received little attention or has been considered to be related to the post-mineral vulcanism. Vein formation followed the Miocene intrusive activity and preceded the outpouring of the Pliocene lavas. Many other features, not previously described, receive consideration in the body of this report.

# GEOLOGY OF THE SILVER CITY DISTRICT AND THE SOUTHERN PORTION OF THE COMSTOCK LODE, NEVADA

By VINCENT P. GIANELLA*

## INTRODUCTION

### PRELIMINARY STATEMENT

Historically, Silver City has been connected with the Comstock Lode since 1859, when lode mining began in the region. Although known as the Silver City mining district, the value of the gold production has greatly exceeded that of silver. Nor can the district be considered separately from the Comstock Lode, either geologically or from the standpoint of mining. The geological history of the two regions is closely interwoven, and some of the mines of the Silver City area are on veins that constitute a southern continuation of the Comstock vein system.

Geologically, the district presents a complex variety of rock types, ranging from Triassic (?) to Quaternary age. These are of wide extent and their correlatives are to be found in the nearby Sierra Nevada. Throughout this investigation both the main lode, to the north, and the Silver City area have been studied. The geology of the two areas are mutually supplementary, and some of the problems can be solved only by considering the region as a whole. In reality, the district is but a portion of a much larger area which was mineralized at the time of the formation of the Comstock Lode.

### LOCATION AND PHYSICAL FEATURES

The Silver City district (figure 1) lies upon the eastern slope of the Virginia Range, 12 miles north of Carson City, Nevada. The district, as described in this report, is a rectangular area measuring about three and one-half by four miles, containing approximately 13 square miles.

Silver City, three miles south of Virginia City, is situated just east of the center of the district. Gold Hill, an old mining town one mile south of Virginia City, lies just beyond the northern boundary of the area. Dayton, the site of the first gold discovery in Nevada, is situated at the junction of Gold Canyon with the Carson River, three and one-half miles southeast of Silver City.

The area is reached from Virginia City or Carson City by

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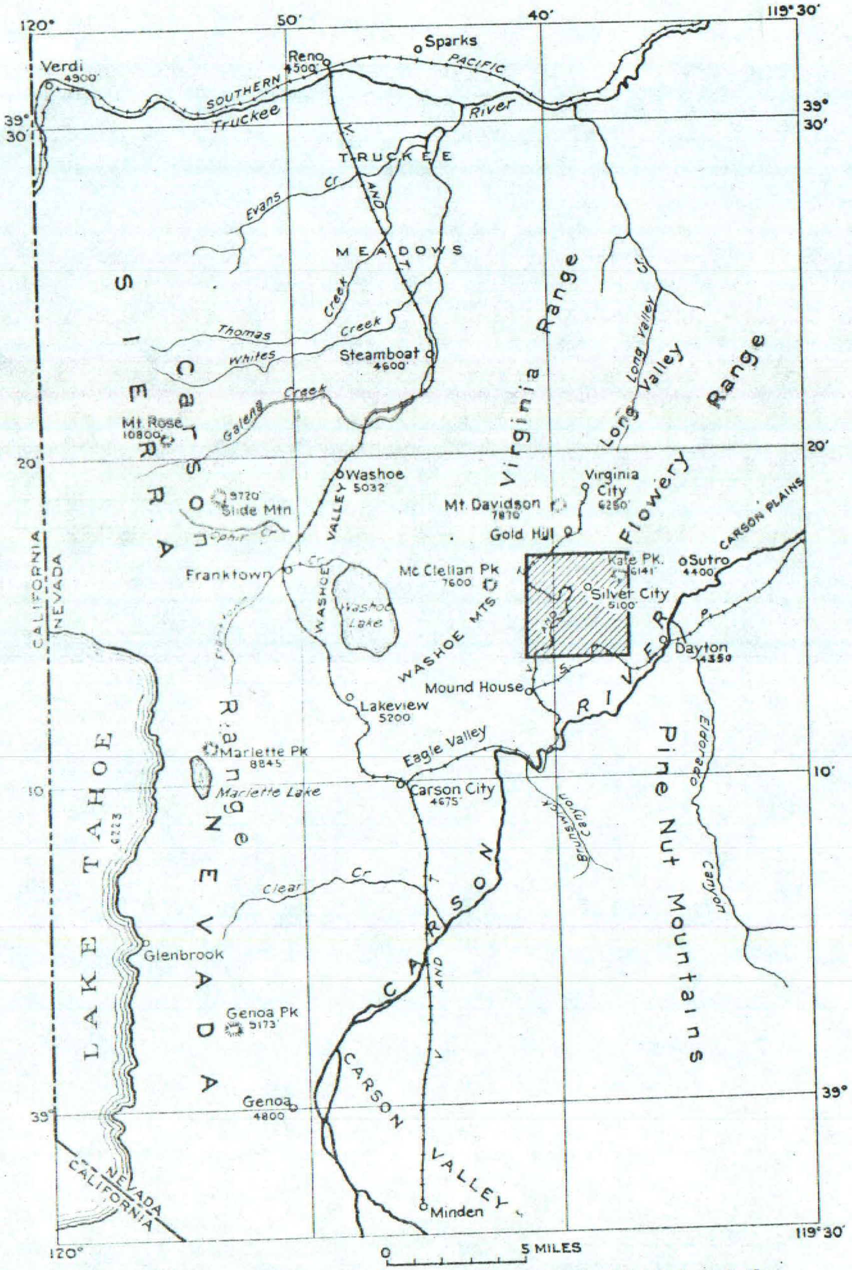


Figure 1. Index Map Showing the Silver City District and the Surrounding Region.

paved highway. Silver City is 42 miles from Reno, by way of Carson City, over a road with slight grades, and 25 miles from Reno, by way of Geiger grade, which ascends from Truckee Meadows to the summit of the Virginia Range. The Virginia and Truckee Railroad connects Virginia City with Carson City and Reno.

The mapped area, along its western and northwestern borders, includes part of the steep scarp of the Virginia Range; the eastern part is in the rough Flowery Range.[1] The rugged topography has a relief of 2,200 feet, culminating in Mount Davidson, 7,870 feet above sea level, a mile north of the area. McClellan Peak, 7,500 feet, the highest point in the Washoe Mountains, is half a mile beyond the western edge of the area. Within the district, altitudes range from 4,600 feet, in the southeast, to 6,700 feet along the western margin.

The Washoe Mountains form a spur connecting the Sierra Nevada and the Virginia Range. The Pine Nut Mountains and the Virginia Range form a single continuous mountain mass, the first of the desert ranges east of the Sierra Nevada. The gorge of the Carson River is considered as the boundary between the two ranges.

North of the Carson River gorge is a relatively flat area from which the surface rises gradually toward the north and, a short distance inside the area, the gentle slope steepens and gives way to a series of flat-topped hills with more or less open flats between. Farther on, these flats grade into rather sharp gorges which emerge into open areas covered with a veneer of alluvium, beyond which rises the steep scarp (figure 2) which forms the east front of the Washoe Mountains and Virginia Range. The scarp has had its outline softened by erosion, and has been trenched by streams which have cut deep gorges into the range front.

Gold Canyon heads on the south side of Mount Davidson and trends to the southeast diagonally through the center of the district. All but the southern part of the area is drained by Gold Canyon and its tributaries which spread out fan-like from the vicinity of Silver City. A small permanent stream flows from American Flat into American Ravine and thence to Gold Canyon. There are few springs, and the remainder of the area has no running water except during storms or when there is melting snow. The southwest corner of the district drains through ravines into the Carson River. The run-off from the

[1] See Carson Topographic sheet. U. S. Geol. Survey.

Figure 2. View Southward Along the Comstock Lode. To the right, in the foreground, is Cedar Hill. In the middle distance is Mount Davidson with McClellan Peak beyond. In the far distance is the Carson Range of the Sierra Nevada. At the foot of the Davidson scarp is the Comstock Lode and Virginia City. The larger dump, just above the town, marks the mouth of Ophir Ravine where the lode was discovered in 1859.



southern part enters the river just west of Dayton, below the Carson gorge.

The water supply for Virginia City, Gold Hill, and Silver City is obtained from the Sierra Nevada. The chief source of the water is the small streams flowing into Lake Tahoe on the western slope of the Carson Range. In 1873 a tunnel, flumes, and an inverted syphon were constructed to bring this water, a distance of about 40 miles, to Virginia City. The seven-mile syphon withstands a head of 1,720 feet where it passes under the Reno-Carson City highway three miles north of Carson City.

## FIELD WORK

During a period of years the writer has, from time to time, done field work in the general region and has been employed in a consulting capacity at many of the mines. During the summers of 1932, 1933, and 1934 the geologic map (Plate 1) was completed. The results of these studies have been summarized in published papers.[2] Further investigation has been carried on during the 1935 and 1936 field seasons, in cooperation with the U. S. Geological Survey.

In the district there are literally hundreds of pits, shafts, and tunnels. A relatively small proportion of these have been studied in detail. More attention has been devoted to the mines situated along the larger faults and to those in critical areas which would give additional information concerning the geologic structure and nature of the vein systems.

The map used as a base is, with minor modifications, that prepared by the Wheeler Survey in 1876 and 1877. Although far from ideal, it was the best map available when this study was made. The elevations, as given on this map, differ as much as 80 feet from those obtained by the latest surveys. Many names of abandoned and unimportant workings have been deleted and those of newer developments have been added. Because of the inaccuracies of the topography, as given on the base map, it has not been possible to indicate all of the numerous minor faults and smaller veins. It is believed, however, that a sufficient number of both faults and veins have been shown to bring out the vein pattern and the major structural features.

The many rock varieties have been grouped into eleven cartographic units for convenience in mapping.

[2]Gianella, V. P., New features of the geology of the Comstock Lode; Min. & Met., vol. 15, pp. 296–300, 1934. New features of the geology of the Comstock Lode; (Abstract) Proceed. Geol. Soc. America for 1934, p. 378, June 1935. Geology of the Comstock region; (Abstract) Proceed. Geol. Soc. America for 1935, pp. 339–340, 1936.

**ACKNOWLEDGMENTS**

It is a pleasure for the writer to express his appreciation of the kindly help and suggestions given by the many persons who have aided in this investigation. To list all who have been helpful would properly include practically all the operators and most of the other residents of the district.

To Professors Charles P. Berkey, R. J. Colony, and Paul F. Kerr, of Columbia University, the writer is especially indebted for helpful suggestions and criticism of the manuscript. Professors Colony and Kerr also visited the writer in the field during the progress of the work. Director J. A. Fulton of the Nevada State Bureau on Mines lent encouragement to this investigation. Mr. Theodore Overton assisted in the field during a period of two weeks.

Dr. W. D. Johnston, Jr., and Dr. Frank C. Calkins of the U. S. Geological Survey kindly offered the results of their studies, which enabled the writer to make important alterations and additions to the geologic map. To Dr. Philip Kreiger of Columbia University the writer is indebted for the photomicrographs. Mr. Grant H. Smith of San Francisco offered many valuable suggestions regarding the early history of the region.

## HISTORY OF THE DISTRICT AND PREVIOUS INVESTIGATIONS

### PRODUCTION OF THE SILVER CITY DISTRICT

Silver City, scene of the earliest mining in Nevada, has been a consistent producer of gold and silver. Because the great production of the region, over $400,000,000, came mostly from the northern part of the Comstock, the southern part has received but little mention in the literature. The value of the gold production far exceeds that of the silver, while for the whole Comstock region 57 percent of the value of the bullion was silver and 43 percent was gold. The total production of Silver City is indeterminable from the early records, and most of the later accounts have included its output with that of the Comstock. Smith[3] gives the production of the principal mines as $21,528,000, but states: "It is impossible to secure accurate figures giving the total past production of the mines * * *," and that this figure "should be regarded only as an estimate obtained from miscellaneous sources." This estimate is probably much too high.

[3]Smith, A. M., The Mines and Mills of Silver City, Nevada; Univ. Nev. Bull. vol. 29, No. 6, p. 21, 1932.



### EARLY HISTORY OF THE COMSTOCK REGION

The story of the discovery of the Comstock Lode, and of the feverish mining activity which followed, forms one of the most fascinating chapters in the development of the West. This history has been covered by various writers,[4] yet it is not amiss to give a résumé.

Early mining operations which finally led to the discovery of the lode centered about Silver City, and it is probable that the first discovery of ore-bearing veins in Nevada was made near where the town is now situated.

A party of Mormon immigrants, on their way from Great Salt Lake to California, stopped for lunch at the junction of a ravine with the Carson River near the present position of the town of Dayton. This region was then a part of Utah Territory. William Prouse, one of the young men of the party, took a milk pan and washed some of the gravel from the ravine and found a few specks of gold. To the ravine they gave the name of Gold Canyon. The discovery was made on May 15, 1849. The earliest recorded mention of finding gold within the boundaries of Nevada appears in a letter by Prouse[5] in which he says that he made a previous discovery of gold dust at the same place in the fall of 1848, while returning to Salt Lake from the American River in California. The finding of a few grains of gold was not considered of such importance as to warrant further investigation, and the party moved onward.

Deep snow still covered the summit of the Sierra Nevada, forcing the immigrants to spend some time in Carson Valley waiting for the melting of the snow to allow them to proceed upon their journey. But gold draws like a magnet, so some of the men returned to Gold Canyon and found a few small nuggets. Shortly the snow melted and the party left for California.

News of the strike spread rapidly, and before long miners were washing the gravels in Gold Canyon. They built a camp at Johnstown, a short distance down stream from where Silver City now stands. Nearly a decade was to pass, however, before the discovery of the Comstock Lode was to electrify the world, causing the great "Washoe Rush" and paving the way to the foundation of a new State east of the Sierra Nevada.

[4]Lord, Eliot, Comstock Mining and Miners; U. S. Geol. Survey Mon. vol. 4, 1883. De Quille, Dan, History of the Big Bonanza; 1876.

[5]Lord, Eliot. Quoted from a letter from William Prouse, December 14, 1880. U. S. Geol. Survey Mon. 4, footnote p. 11, 1883.

Figure 3. Silver City. View up Gold Canyon with Mount Davidson in the distance. American Ravine enters Gold Canyon from the left, opposite the mill buildings in the foreground.



Hosea B. and Edgar A. Grosh, who had a considerable knowledge of mineralogy and assaying, came to Gold Canyon in 1853 and engaged in placer mining. They possessed a good library and assay equipment in their small stone cabin in American Ravine. The brothers were continually prospecting in the hills for silver deposits, for by that time the return from the placers was poor. After a time ledges were found for on March 31, 1856, they wrote to their father informing him: "We found silver ore at the forks of the canyon,"[6] and in a letter, November 3, 1856,[7] "we found two veins of silver at the forks of Gold Canyon * * *. One of these veins is a perfect monster." The Groshs also reported having obtained assays as high as $3,500 per ton. Wright[8] states that he found their assay furnaces near the cabin which stood at the foot of a large mountain, on the side of which there was "a sort of sink." This description refers to the depression on the north side of Grizzly Hill which is just south of the junction of American Ravine with Gold Canyon.

It is commonly stated that the Grosh discovery was on the Comstock croppings near Gold Hill. Considering the topography of the district, it is improbable that the "forks of Gold Canyon" refers to any other place than its junction with American Ravine (figure 3). These letters tell of the first discovery of gold- and silver-bearing quartz veins within the Great Basin.

In the fall of 1857 Hosea Grosh died from an infection of a foot injury, and the following winter his brother died at the Last Chance mining camp in California, while attempting to cross the deep snow covering the Sierra Nevada. The knowledge of their discovery perished with them. Gold and silver ore was soon discovered again, for in January 1858 an arrastra was built near Devils Gate[9] and an unsuccessful attempt made to mill the ore.

Contrary to the general belief that the miners followed the gold-bearing gravel up Gold Canyon to the very outcrop of the lode, they found that the canyon above Devils Gate (figure 27) did not pay even poor wages. Toward the very end of the placer mining period, according to the early writers, the miners were continually troubled with "a superabundance of black sand and heavy pebbles of iron ore."[10] Iron ore is unknown in the rocks

[6] Lord, Eliot, loc. cit., pp. 26–27.
[7] Ibid. p. 27.
[8] De Quille, Dan (William Wright), History of the Big Bonanza; p. 34, 1876.
[9] Lord, Eliot, loc. cit., pp. 33–34.
[10] De Quille, Dan, History of the Big Bonanza; p. 55, 1876.

of upper Gold Canyon, but occurs in considerable quantity in the metamorphic rocks along the gulch which joins American Ravine from the south, a short distance west of Silver City. This iron ore finds its way down American Ravine into Gold Canyon. The evidence indicates that toward the end of the placer operations the miners were still working in this vicinity. It is quite certain that most of the placer gold came from the gold veins nearby rather than from the more argentiferous, baser ores two miles farther up the canyon.

The first discovery of the outcrop of the lode was made at Gold Hill (figures 2 and 26), January 1859, and on June 8 of that year another outcrop of the lode was uncovered in Ophir Ravine (figure 2), a mile to the north. The priority of the Gold Hill discovery is attested to by the early arrivals. One of these was Dr. Henry DeGroot who came to Virginia City in 1859. De Quille[11] in discussing this phase of the history says:

> In January 1859, James Finney, or Fennimore, * * * John Bishop, and a few others of the Johnstown miners, struck a rich deposit of free gold in placer diggings in a little hill at the head of Gold Canyon. From this hill the town of Gold Hill derives its name. * * * The gold was in a deposit of decomposed quartz mingled with soil, and the miners were really delving in a part of the Comstock Lode without at first knowing that they were at work on any quartz vein. These diggings yielded gold by the pound, at times.

An earlier quartz location was made, however, for De Quille[12] states:

> The Ophir claim was the first that was located, as a quartz claim, at any point on the Comstock Lode, though as early as February 22nd, 1858, Old Virginia made a location on a large vein lying to the westward of the Comstock. This vein is known as the Virginia lead or Virginia croppings. It has never yielded much ore, but contains vast quantities of base metal of various kinds.

The Gold Hill mines were worked for several years before it was positively known that they were on the same vein as the Ophir mine. There can be no doubt that the placer miners, who worked for ten years in Gold Canyon prior to the discovery of the Comstock, must have been familiar with the bold croppings for they spent much time hunting and prospecting in the hills. They were driven to search for other mines for, after a few years, the returns from working the gravels were very poor. By 1857 the miners obtained but two dollars a day for their hard

[11] De Quille, Dan (William Wright), A History of the Comstock Mines, etc.; pp. 34-35, F. Boegle, Virginia, Nevada, 1889.

[12] De Quille, Dan (William Wright), History of the Big Bonanza; p. 53, 1876.



work in Gold Canyon and this would scarcely provide them with food. In prospecting they found gold in Six Mile Canyon, about a mile below the outcrop of the Ophir bonanza, and in following up the ravine they came to the lode. It is not surprising that the vein was not discovered sooner for the croppings were generally of low grade, and only two rich ore bodies came near to the surface—the original Gold Hill strike and the Ophir bonanza. These places were masked by detritus and only exposed through placer operations at Gold Hill; and in digging to develop water at a spring, in the bottom of Ophir Ravine, Peter O'Riley and Patrick McLaughlin sank down directly upon the croppings of very rich ore. From the decomposed outcrop the miners washed free gold and a "heavy black stuff" which clogged their rockers. Not recognizing the value of this material they considered it a nuisance and threw it away.

Late in June 1859, J. F. Stone took a specimen of the black ore to Nevada City and Grass Valley, California, where it was assayed by J. J. Ott and Melville Atwood. It proved to be rich silver ore carrying free gold and returned $3,876 per ton. The news of the rich strike spread, and soon hundreds were leaving California for the Washoe Country, as the region was then known, and the great "Washoe Rush" followed. Henry Comstock happened along immediately following the discovery and, by a clever maneuver, obtained an interest in the claim. Through his loud boasting the great lode finally acquired his name.

The mines were rapidly developed and, because of the immense size of the ore shoots, new methods of supporting the wall rock were necessitated. It was on the Comstock that the square-set method of timbering was devised. Great quantities of hot water were encountered at depth, which not only required the installation of large and expensive pumping equipment, but made work difficult in the excessively hot workings.

To overcome the great expense of pumping, hoisting and ventilation, Adolf Sutro conceived the idea of driving a long tunnel to connect with the mines, 2,000 feet below the outcrop of the vein. After many years, fraught with determined opposition by many of the mine owners, he finally carried the project to completion. The Sutro Tunnel was driven from the Carson Plains to the Comstock Lode, crosscutting the formations for a distance of over 20,000 feet.[13] At the time the tunnel was started, drilling for blasting was done entirely by hand labor and little

[13] Becker, Geo. F., Atlas Sheets IV, VI, VIII, and IX, 1882.

progress could be made when hard rock was met, or when the temperature rose as the tunnel was driven deeper into the mountain. The invention of air-driven drills, which were soon after used in the tunnel, made its completion possible. The driving of the tunnel began October 19, 1869, and the connection was made with the Savage mine, on the 1640 level, July 8, 1878.[14] Laterals were driven northerly and southerly in the hanging wall and connected by crosscuts with the workings of the various mines.

The total length of the tunnel and its laterals exceeds 33,000 feet. One of the chief purposes of the tunnel was to drain water from the mines. This it has done well. At times, when water was being pumped from the lower levels, the tunnel carried large quantities. During 1880 the average flow was 3,500,000 gallons per day, although at times the volume reached almost 4,000,000 gallons. At present the tunnel still furnishes drainage and ventilation for the mines.

### RECENT MINING ACTIVITY

For many decades the Comstock yielded great wealth; Silver City, though never spectacular, has been a constant producer of bullion. During the past few years there has been a marked revival in mining along the lode. Silver City has enjoyed its share of prosperity and at present (1935) is one of the most active mining districts in Nevada.

Much of the renewed activity has been due to numerous lessees who have extracted ore principally from the shallow levels of the old mines. However, many of the old mines have been reopened, including the Milwaukee, Table Mountain, Hartford, Woodville, Dayton, and at Gold Hill, the Overman. Many of the old properties were operated for a short period but now are idle. The Silver Hill mine, which has long been a consistent producer, has increased its output. The Overland has produced rather steadily. The Dayton mine, idle for many decades, was unwatered to the 500-foot level. A mill was erected (1934) and has operated steadily.

Among the new developments was the sinking of a 100-foot shaft on the Montezuma ground, east of Spring Valley, but little ore was extracted. The Keystone mine, between the Justice and the Caledonia shafts, was opened on the Silver City branch vein and produced ore from several levels. The Spring Valley mine opened an ore shoot on the 100-foot level to a width of over forty feet. For some months the property gave promise of developing into a large mine but the ore terminated a short distance below the 100-foot level, against a flat-lying fault.

Many mines, other than those mentioned above, have been operated from time to time.

[14] Whitehall, H. R., Biennial report of the State Mineralogist of the State of Nevada for the years 1877 and 1878; pp. 80-85, 1879.



### PREVIOUS INVESTIGATIONS

The Comstock Lode was one of the first important gold-silver mining districts in western United States to receive extensive geologic study. Frequent references to the lode are found in the geologic literature, particularly that touching on mineral deposits. Little mention is made of Silver City, as the previous workers confined their labors almost entirely to the northern portion of the lode (figure 2), in the vicinity of Gold Hill and Virginia City. It is largely because of this concentration, upon the more productive part of the district, that much confusion exists regarding the geology. There, only a part of the story is revealed; it is there too that the rocks are most intensely altered and hence more difficult to identify. By studying the outlying parts of the region, where alteration is less intense, and carrying the investigation into the mineralized area, much of the confusion disappears. There is much difference of opinion among previous investigators on the character, age, and structural relations of the various rocks.

The earliest study of the Comstock is that of von Richthofen.[15] This work, performed in 1865, includes a discussion of the great vein and of the general geology of the surrounding region. He determined the Comstock to be a "true fissure vein" and concluded that the ores were deposited by hot waters ascending from great depth. Richthofen thought that the ores would extend far below the then shallow workings, and he suggested that the "bonanzas" were to be searched for in fissures rising into the hanging-wall country. This prophecy was borne out by the discovery of the "Big Bonanza" in the Consolidated Virginia and California mine a few years later. It was during this study that Richthofen introduced the term "propylite" as a new rock species. This later proved to be altered lava, but the term "propylitization" has been retained in the literature to specify a type

[15] von Richthofen, Baron Ferdinand, The Comstock Lode; its character and probable mode of continuance at depth; (November 22, 1865), San Francisco. Published by the Sutro Tunnel Co., Towne & Bacon, 1865. Republished by the Sutro Tunnel Company, in the Sutro Tunnel, etc.; John Murphy & Co., Baltimore, 1868. Extensively quoted by Becker in U. S. Geol. Survey Mon. 3, pp. 12-24, 1882.

of alternation. He grouped the rocks into a recent and an ancient series, as follows:[16]

| Recent series[17]— | Ancient series— |
|---|---|
| Trachyte. | Quartzose porphyry. |
| Propylite. | Syenite. |
| | Metamorphic rocks. |

He regarded the ancient series to be Triassic in age, and separated the metamorphic rocks into three groups, only two of which occur in the immediate district. One of these consists of "micaceous quartzose slates," the other is a "series of hornblendic (uralitic) rocks with interbedded layers of quartzite, slate, and crystalline limestone."

Of the relation of the syenite to the metamorphic rocks he stated:[18] "The latter rocks join the syenite to the north and south, and are intersected by dikes of that rock, thereby proving its later origin."

He classes the Davidson intrusive as syenite and considered it[19] as being "composed of two kinds of feldspar (orthoclase and oligoclase), hornblende in laminated prisms of greenish black color, some mica, and occasionally epidote, but no quartz." Richthofen thought that the present outcrops were essentially those existing at the time of vein formation and but little modified by erosion.

King[20] made a study of the mines, and a geologic map of the adjacent country. In his report King closely adheres to the petrologic terms proposed by Richthofen, but gave more detailed descriptions, and listed the rocks in their supposed order of occurrence.

King[21] gave the sequence of the rocks in the following order:

| Tertiary— | Jurassic or older— |
|---|---|
| Basalt. | Syenite. |
| Rhyolite. | Granite. |
| Trachyte. | Uralitic and mica schists, |
| Andesite. | and limestone. |
| Propylite. | |

King correctly placed the period of mineralization between

[16] von Richthofen, F. B. The Comstock Lode; its character and probable mode of continuance at depth; In the Sutro Tunnel, etc.; John Murphy & Co., Baltimore. pp. 100–105, 1868.

[17] All rock sequences are from the youngest to the oldest in descending order.

[18] Loc. cit., p. 101.

[19] Ibid., pp. 100–101.

[20] King, Clarence, The Comstock Lode; Fortieth Parallel Survey Reports, vol. 3, pp. 11–96, with atlas, 1870.

[21] Loc. cit., pp. 17–18.



the older andesite (propylite) and the later flows, for in discussing the alteration of the propylite he states:[22] "The andesites overlying them are untouched. The general thermal activity was confined to the interval between the outflow of propylite and that of the later andesite. To this period is assigned the Comstock Lode."

The numerous rock specimens collected by the Fortieth Parallel Survey were subjected to a petrographic study by Zirkel.[23] The collection contained several rocks from the Comstock region. He classified the Davidson intrusive as diorite, and that designation has been retained by most subsequent workers. Zirkel recognized propylite as a distinct rock species[24] and retained the term trachyte for the mica-hornblende andesite.

Church[25] described the occurrence of ore on the Comstock and contributed some valuable suggestions as to the veins, but added little to what was previously known of the kinds and sequence of the rocks. Church, however, mentions many occurrences of petrified wood and impure coal at various horizons in the Tertiary volcanics. Neither he nor later workers grasped the significance of this discovery. Of the diorite[26] he says: "Diorite is one of the fine grained, thin-running lavas, * * *" and (p. 59) "* * * streams of diorite were poured out upon a level country, covering it with a succession of thin layers." Such statements indicate a surprising lack of knowledge of the igneous rocks.

The most detailed and comprehensive investigation of the region is that of Becker.[27] He mapped all of the workings and constructed many sections to illustrate the geologic structure. The rocks were given careful microscopic study and were described in detail. Some errors of the earlier workers were corrected.

The sequence of the rocks was given in great detail for the first time. Many more rock formations were recognized and a geologic map was made of most of the mineralized area. The geologic map includes much of the Silver City district, as defined in the present report. This work is highly considered, and is frequently consulted by those engaged in mining in the Comstock district.

[22] Loc. cit. p. 19.

[23] Zirkel, Ferdinand, Microscopical Petrography; Fortieth Parallel Survey Reports. vol. 6, 1876.

[24] Loc. cit., pp. 110–113.

[25] Church, John A., The Comstock Lode; its formation and history; New York, 1879.

[26] Loc. cit., p. 153.

[27] Becker, Geo. F., Geology of the Comstock Lode and the Washoe District, with atlas; U. S. Geol. Survey Mon. 3, 1882.

Becker considered the order of rocks to be:[28]

| | |
|---|---|
| Basalt. | Quartz porphyry. |
| Later hornblende andesite. | Meta-diorite. |
| Augite andesite. | Porphyritic diorite. |
| Earlier hornblende andesite. | Granular diorite. |
| Later diabase (black dike). | Metamorphics. |
| Earlier diabase. | Granite. |

He was of the opinion that the lower group, from the granite to the earlier diabase, was of pre-Tertiary age;[29] and the later diabase, andesites, and basalt he regarded as Tertiary or later. Becker discussed the propylite in considerable detail and demonstrated it to be altered lava. The so-called trachyte was shown to be andesite. He was in doubt as to the "metamorphic origin" of the "granite" in American Ravine and he thought that the "meta-diorite" had been metamorphosed[30] by the later flows of quartz porphyry. Becker regarded the Davidson diorite as an intrusive body, but much older than the lavas of the hanging-wall country, and the period of mineralization to have taken place during Recent time, for he states:[31] "It is, of course, most unlikely that the Comstock is the only vein in which the deposition of ore is recent * * *."

Hague and Iddings[32] made an exhaustive petrographic study of the igneous rocks from the Comstock region. For this purpose they used the collections made by King and Becker and other specimens supplied by the operators.

Theirs was purely a laboratory study, and the authors made no claim to extensive field studies, in connection with their paper, for they clearly state in a footnote:[33] "One of the writers of the present article was geological assistant to Mr. Clarence King when he made his study of the Comstock mines in the winter of 1867–1868 and is quite familiar with the occurrence of the igneous rocks of the Washoe district."

Iddings made a brief visit to Virginia City in 1880,[34] while Becker was engaged in his investigation.

At the time of King's study, the deepest shaft was but 1,200 feet deep.[35] The Sutro Tunnel, the rocks of which enter so largely into Hague and Iddings discussions, was not available for study when Hague assisted King, nor for many years after King had completed his work on the Comstock.

The petrography and analyses of the rocks were discussed at considerable length and the conclusion was reached:[36] "that there are abundant geological and petrographic evidences in the Washoe district to show that the igneous rocks do not belong partly to Pre-Tertiary and partly to Tertiary eruptions, but are all of Tertiary age." And furthermore: "That the so-called granular diorite and diabase, augite-andesite are identical and belong to the same geological body."

All of the igneous rocks were determined to be Tertiary volcanics specifically including the Davidson diorite, of Zirkel and Becker, and the monzonite from the Lady Bryan shaft.[37] Their interpretation of the igneous history of the Comstock area is fairly well covered in the following paragraph:[38]

> After these eruptions of pyroxene and hornblende andesites there was a period of rest, during which there was more or less removal of the superficial material by denudation, a study of the surface geology presenting many arguments in favor of a time of comparative inaction. These older andesitic rocks have been broken through by numerous intrusive bodies of both acidic and basic lavas represented by hornblende-mica-andesites, dacites, rhyolites, and basalts. From masses of these later rocks offshoots were pushed out and forced upwards into the older rocks, in many cases failing to reach the surface, but now exposed by vertical shafts and horizontal workings.

They clearly state that the Davidson diorite, of the earlier workers, and augite-andesite are parts of the same rock mass, and they considered the rhyolite and dacite as intrusive into it. The olivine basalt and the "black dike" were thought to be identical and represented the latest manifestation of igneous activity. Their description of dacite corresponds to that of quartz latite, a term not in use at the time their paper was written.

Becker revisited the lode in 1886 and strongly defended his earlier conclusions except that he then decided that the augite-andesite, which he had previously considered as a unit, consisted of two andesites of different ages, and he stated:[39] "It is worth noting that most of the glassy pyroxene andesite, and perhaps

[28] Loc. cit., p. XV.
[29] Loc. cit., p. 372.
[30] Loc. cit., p. 34.
[31] Loc. cit., pp. 186 and 379.
[32] Hague, Arnold, and Iddings, J. P., On the development of crystallization in the igneous rocks of Washoe, Nevada, with notes on the geology of the district: U. S. Geol. Survey Bull. 17, 1885.
[33] Loc. cit., p. 26.
[34] Mathews, E. B., Memorial to Joseph Paxton Iddings; Bull. Geol. Soc. America, vol. 44, part 2, p. 356, 1933.
[35] King, Clarence, loc. cit., p. 37.
[36] Hague and Iddings, loc. cit., pp. 40–41.
[37] The Lady Bryan shaft is in Flowery Canyon, about three and one-half miles east of the north end of Virginia City, and just beyond the eastern edge of Becker's map.
[38] Hague and Iddings, loc. cit., p. 40.
[39] Becker, G. F., The Washoe Rocks; Calif. Acad. Sci., vol. 2, p. 101, 1886.

all of it, belongs to the eruption immediately preceding the later hornblende andesite."

In a paper on the structure of the Comstock Lode, Reid[40] discussed the rocks found in the Hale and Norcross tunnel which was driven, from the hanging wall westward through the lode, a distance of over 5,000 feet. The tunnel penetrates Mount Davidson a few hundred feet south of the peak. Reid[41] states: "The present writer, through late mining work, is in possession of the facts necessary to prove beyond the shadow of a doubt the conclusions of Hague and Iddings."

After presenting the various features of the rocks encountered in the tunnel he concluded that:[42] "The rocks of this section, when properly studied, will complete the work of Hague and Iddings east of the lode, and will serve to bring into greater relief the admirable work of these men."

This paper was confined principally to a discussion of the structure and genesis of the lode, and added very little information of the rocks and their structures.

After further work, in the Virginia and Pine Nut ranges and a portion of the Sierra Nevada, he found evidence which led him to consider the marked similarity between the Comstock rocks and those of the Sierra Nevada. In a later paper[43] Reid expresses doubt as to his previous conclusions on the Comstock rocks for he says: "From the field investigations of the writer, the diorite of Mt. Davidson is of indefinite relationship to the older lava rocks. If the Davidson plateau be the correlative of the plateau in the Sierra Nevada, that antedates the period of volcanism there, and if the various volcanics of the two ranges be of similar ages, we may need to reopen the Comstock question of ages and identities of the various eruptive rocks upon this new basis for final settlement."

The relationship of the Davidson diorite to the overlying andesites is clearly stated by Smith[44] who writes "that the diorite of Mt. Davidson projected into the overlying andesite in the form of tongues or apophyses; that it has assimilated the andesite around its border; and that large masses of andesite were suspended in it."

[40] Reid, J. A., The structure and genesis of the Comstock Lode; Univ. Calif. Pub. Bull. Dept. Geol., vol. 4, pp. 177–199, 1905.
[41] Loc. cit., p. 182.
[42] Loc. cit., p. 195.
[43] Reid, J. A., The geomorphogeny of the Sierra Nevada northeast of Lake Tahoe; Univ. Calif. Pub. Bull. Dept. Geol. vol 6, p. 141, 1911.
[44] Smith, D. T., Vein systems of the Comstock; Eng. & Min. Jour. vol. 94, pp. 895–896, 1912.

Hershey,[45] after a period of professional work in the region, wrote a paper on the geology in which, so far as the Silver City district was concerned, he closely followed the rock sequence as proposed by the present writer.[46] Hershey, however, considered the rhyolite as intrusive.

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[45] Hershey, O. H., Modern geology of the Comstock; Western Mining News, vol. 1, No. 6, pp. 13–14, 1934; Ibid., vol. 2, No. 6, pp. 13–15, 1934; Ibid., vol. 2, No. 7, pp. 10–12, 1934; Ibid., vol. 2, No. 8, pp. 19, 20, 30, 1934.
[46] Private reports, during 1932–33, to various mining companies operating in the district. Also address before the Nevada Section of the A. I. M. E., at Virginia City, Nevada, April 7, 1934.

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RICHTHOFEN, F. VON, The Comstock Lode: its character and probable mode of continuance at depth; San Francisco, November 22, 1865. Published by the Sutro Tunnel Company in The Sutro Tunnel, etc., John Murphy & Co., Baltimore, Md. 1868.[47] Also published by the Sutro Tunnel Company. Towne & Bacon, 1866. This publication is now difficult to obtain, but the more important portions are quoted at considerable length by Becker in U. S. Geol. Survey Mon. 3, pp. 12–24. 1882.

## GENERAL GEOLOGY OF THE DISTRICT

### CHARACTER OF THE FORMATIONS

In this part of the Virginia Range there is a considerable variety of rocks. These include sediments, meta-volcanics, intrusives of several ages, lava flows, breccias, tuffs, alluvium, and gypsite. For convenience of discussion, these rocks have been grouped, according to age, into three general classes — pre-Cretaceous, Tertiary, and Quaternary.[48]

The oldest rocks of the district comprise a series of sediments of probable Triassic age. These are composed, for the most part, of shales, schists, and limestone aggregating over 2,000 feet in thickness. The sediments have been folded and considerably deformed.

Unconformably overlying the sediments is a series of meta-volcanics which may have been extruded during the Triassic. The volcanics consist of both lavas and pyroclastics, probably with some intrusives. Their thickness is in the neighborhood of 1,000 feet.

The sediments and meta-volcanics have been intruded by quartz monzonite and accompanying dike rocks. This intrusive is similar to that which is prevalent in the Carson Range, the eastern ridge of the Sierra Nevada (figure 1), where it is intrusive into sediments and meta-volcanics, like those mentioned above. The quartz monzonite is a part of the plutonics which invaded the Sierra region during the late Jurassic.

[47] It is this edition that is cited in the present paper.

[48] For a discussion of the regional geology, see Jones, J C., and Gianella, V. P., Reno and Vicinity; 16th Internat. Geol. Congress Guidebook 16, pp. 96–101. 1933.



**SUMMARY OF ROCK FORMATIONS IN THE SILVER CITY DISTRICT**

| | | |
|---|---|---|
| Quaternary | Alluvium and gypsite | Gravels, sand, silt, and alluvial fan material. Some gypsite is deposited in the alluvium. |
| | American Flat basalt and alluvium | Flow of olivine basalt 25 feet thick. Underlain by alluvium. |
| | Unconformity | |
| Late Pliocene | Knickerbocker andesite | Pyroxene andesite. Thickness 200 feet. |
| | Unconformity | |
| Early Pliocene (?) | Kate Peak andesites | Pyroxene andesites, glassy lavas, tuffs, breccias, and agglomerates. Some flows with prominent biotite and hornblende phenocrysts. 1,200 feet. |
| | Unconformity | |
| Miocene | Intrusives<br>Alta andesites | Hornblende and pyroxene andesites, tuffs, and breccias, including water-laid Sutro tuff member, about 300 feet thick. Intrusions of various andesites and the Davidson diorite, followed by vein formation. Thickness, 3,600+ feet. |
| | Erosion interval | |
| Eocene | Hartford Hill rhyolite | Biotite rhyolite with some quartz latite. Occasional underlying lenses of dacite. In places the rhyolite overlies fanglomerate or auriferous gravels. Attains a thickness of 450 feet. |
| | Erosion interval | |
| | American Ravine andesite | Light gray, felsitic, hornblende andesite. Lies upon fanglomerate, monzonite, or the metamorphic rocks. Thickness, 500 feet. |
| | Unconformity | |
| Late Jurassic | Quartz monzonite | Biotite-hornblende quartz monzonite and associated dikes. Intrusive into sediments and meta-volcanics. |
| | Intrusive contact | |
| Triassic (?) | Meta-volcanics | Andesite and basalt lavas, tuffs, and breccias. Probably with minor intrusives. 1,000+ feet. |
| | Unconformity | |
| | Sedimentary rocks | Limestone, shale, and schists. Minor lenses of quartzite and pyroclastic material. Thickness over 2,000 feet. |

Overlying the pre-Cretaceous rocks, with marked uncomformity, is a thick series of Tertiary volcanics. At the base is andesite overlain by rhyolite and latite, of Eocene age; these in turn are overlain by a thick series of Miocene breccias containing lava flows and water-laid tuffs. These Tertiary volcanics attain a thickness of 4,600+ feet.

The earlier Tertiary volcanics, together with the older rocks,

Figure 4. Breccia of the Kate Peak Series. Some of the blocks are four to five feet in diameter and occasional blocks are ten to fifteen feet long.

have been tilted, faulted, mineralized, and subjected to a long period of erosion.

Upon the erosion surface, Pliocene(?) volcanics were erupted to a thickness of 1,600 feet. The late Tertiary volcanics contain lavas, breccias, and agglomerates as shown in figure 4. These rocks are pyroxenic, but some are rich in biotite and hornblende phenocrysts. In general, they have undergone little alteration.

Small areas of Pleistocene olivine basalt occur within the mapped area, and large flows cover the mountain slopes to the southwest. A columnar section is shown on page 33.

The Tertiary andesitic volcanics have some features in common which makes their identification difficult even with careful tracing of contacts. There is much variation among the rocks of a single group, and some of the lavas of the two Tertiary series strongly resemble each other. The mineralizing solutions, together with subsequent weathering, have considerably altered the Miocene lavas over wide areas. The alteration makes their specific identification difficult; this condition, however, precludes confusing them with the Pliocene volcanics.

## PRE CRETACEOUS ROCKS

### TRIASSIC(?) SEDIMENTS

#### GENERAL FEATURES

A series of sediments, in the northern and western parts of the district, are the oldest rocks in the area. They consist of shales, schists, and limestone with minor amounts of quartzite and tuff. Locally the sediments are much distorted, but in general have a northerly strike and easterly dip. Dips as high as 60° were determined.

The limestone is commonly marbleized and usually is massive. Near the Florida shaft it is made up of alternating, light and dark, thin beds. The shales are usually carbonaceous, especially in the vicinity of Gold Hill. Mica and andalusite schists are present along the western edge of the American Flat, and are traversed by occasional irregular masses of quartz containing biotite and tourmaline. Some of the quartz masses attain a thickness of several feet. Minor beds of quartzite, graywacke, and lenses of tuff, are found in the westernmost exposures.

The sediments extend northward under the later rocks, as limestone was found at the north end of the Comstock Lode on the 1,450-foot level of the Sierra Nevada mine. About 1921, limestone was cut by a crosscut driven northwesterly from the 2,000-foot station of the Union shaft into the footwall of the lode.

A black carbonaceous shale is found in the mine dumps north of American Flat and at Gold Hill. In the Gold Hill mines (figure 26) the black shale was encountered in the footwall of the Comstock Lode. A southwest crosscut from the 1,100-foot level of the Overman shaft penetrated the footwall shale for a distance of 200 feet. A footwall drift was then driven northerly for several hundred feet in the black shale. Becker[49] mentions its occurrence in other Gold Hill mines. As the attitude of the underground exposures is similar to that of the outcrops of the other sediments, it is probable that the shale is an upper member of that series. Neither the top nor the bottom of the sediments is exposed, within the mapped area, and therefore their total thickness is not known. In the Washoe Mountains (figure 2), northwest of the Florida shaft, these rocks are exposed (measuring across the strike) for a distance of half a mile. From this section the thickness is estimated at over 2,000 feet. The total thickness must be much greater than this figure.

The area mapped as sediments, north of American Flat, also contains meta-volcanics and some small areas of Tertiary volcanics. A long period of erosion truncated the folded sediments before the outpouring of the meta-volcanics and thus the contact marks a major unconformity.

Similar sedimentary rocks are exposed in the Carson Range (see figure 1), west of Carson City; at Carson Hot Springs, and in the north end of the Pine Nut Mountains. At Lakeview summit, two miles northwest of Carson City, and along the Carson River gorge in the Pine Nut Mountains, the sediments are unconformably overlain by meta-volcanics. At Lakeview summit the lavas and sediments are intruded by the Sierra Nevada plutonics.

### AGE OF THE SEDIMENTS

Fragmentary fossils were found in the hills northwest of American Flat. These are too poorly preserved for identification and therefore we have no direct evidence as to the age of these rocks.

The sediments extend southerly beyond the mapped area into the Sierran region described by Lindgren.[50] Four miles southwest of Silver City, and west of Mound House, the limestone contains beds of gypsum. These rocks were considered by Louderback[51] and Jones[52] to be Triassic because of their resemblance to the known Triassic rocks of western Nevada.

[49] Becker, G. F., Geology of the Comstock Lode and the Washoe district; U. S. Geol. Survey Mon. 3, p. 191, 1882.

[50] Lindgren, Waldemar, The Tertiary gravels of the Sierra Nevada of California; U. S. Geol. Survey, Prof. Paper 73, p. 192, 1911.

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At Ludwig, Nevada, 25 miles southeast of Silver City, Jones[53] and Knopf[54] found Triassic fossils in sediments containing a deposit of gypsum. In Eldorado Canyon, six miles southeast of Silver City, Whitney[55] collected fossils which, though too poorly preserved for close identification, were regarded as indicating Triassic age. Spurr[56] found fossils in Eldorado Canyon, probably from the same locality referred to by Whitney. Spurr's collection was studied by Stanton who says:[57] "The collection * * * yielded only fragments and impressions of a *Pecten* and a specimen that appears to be part of an *Ammonite*. These are Mesozoic and probably Triassic."

In 1930 the writer visited the Eldorado locality, three miles south of Dayton. The sediments[58] trend nearly east and west and in general dip north at angles from 30° to 80°. The lesser dips are toward the top of the section. The upper part of the section consists of arenaceous and calcareous shales containing some thin limestone members. The stratigraphically lower, upstream, portion is black carbonaceous slate. These sediments are intruded by granitic rocks and are unconformably overlain by Tertiary volcanics. Fossils from this locality were submitted to Muller[59] for examination and he reported as follows:

> The stratigraphically lower assemblage consists of a good number of specimens of "*Pseudomonotis*" *subcircularis* Gabb and a few indeterminate, badly deformed, cephalopods. "*Pseudomonotis*" *subcircularis* alone, however, is quite sufficient to date the strata from which it was obtained as late Triassic (late Noric). The "*Pseudomonotis*" slates of Eldorado Canyon can be correlated with the "*Pseudomonotis*" slates of Muttlebery Canyon, Humboldt Range, Nevada; * * *. The assemblage obtained stratigraphically several hundred feet above the "*Pseudomonotis*" *subcircularis* consists of numerous but poorly preserved "Arietites"-like ammonites. Because of the poor state of preservation of the material the species and even the genera cannot be determined with certainty. Still I am reasonably sure that these fossils represent the Lower Jura, Lias.

Muller and Ferguson[60] described Jurassic and Triassic sediments from the Mina, Nevada, region. The "Arietites" beds of

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[54] Knopf, Adolph, Geology and ore deposits of the Yerington district, Nevada; U. S. Geol. Survey, Prof. Paper 114, pp. 12–13, 1918.

[55] Whitney, J. D., Geological Survey of California; vol. 1, pp. 21–22, 1864.

[56] Spurr, J. E., Descriptive geology of Nevada south of the fortieth parallel and adjacent portions of California; U. S. Geol. Survey Bull. 208, p. 123, 1905.

[57] In Spurr, J. E., loc. cit., p. 123.

[58] Jones, J C., and Gianella, V. P., Reno and vicinity; 16th Int. Geol. Congress Guidebook 16, Excursion C–1, p. 98, 1933.

[59] Muller, S. W., Personal communication, December 19, 1932.

[60] Muller S. W., and Ferguson, H. G., Triassic and Lower Jurassic formations of west central Nevada; Geol. Soc. Am., Bull., vol. 47, pp. 241–252, 1936.

Eldorado Canyon correlate with the Sunrise formation, while the "*Pseudomonotis*" slates are probably referable to the Gabbs formation.

The "*Pseudomonotis*"-bearing strata are highly carbonaceous slates, while the "*Arietites*" are found in sandy shales. The carbonaceous slates strongly resemble the carbonaceous shales at Gold Hill which are also probably Upper Triassic. The sediments west of American Flat appear to be lower in the section, and therefore older, than the Gold Hill shales. The lower sediments are more metamorphosed than those apparently higher in the section. It is probable that the metamorphosed sediments, exposed west of American Flat, may be Paleozoic, although no evidence has been found which substantiates such a conclusion. From what is now known of these rocks they might well be regarded as Triassic.

## MESOZOIC META-VOLCANICS

### GENERAL CHARACTER OF THE META-VOLCANICS

Overlying the tilted and eroded sediments is a series of old volcanic rocks. The volcanics have been extruded upon a surface, apparently of considerable relief. They consist of porphyries, breccias, and occasional tuffs and felsites. The volcanics are andesites, basalts, and minor amounts of siliceous lavas. Intrusives are probably present, although none were identified with certainty. These old volcanics have undergone alteration with widespread chloritization and epidotization. Tremolite and tourmaline occur in these rocks west of the Oest mine, and also southwest of the Haywood shaft.

The porphyritic nature of some facies is best seen on the weathered surface where the feldspars contrast strongly with the groundmass. Where the feldspars are numerous, the rock has a granular appearance which no doubt led Becker[61] to regard these rocks as meta-diorite. The porphyritic varieties frequently have conspicuous phenocrysts of feldspar and augite, or hornblende. The ferromagnesian minerals are usually altered to uralite or chlorite.

In some areas, shearing has developed schistosity. Just west of the South End shaft the volcanics, probably a tuffaceous facies, have been converted to a hornfels with the development of andalusite and sillimanite. Much epidote occurs in the meta-volcanics along the road south of the Florida shaft, and also in the

[61] Becker, G. F., op. cit., p. 43.



vicinity of the Haywood and Amazon mines. South of the Amazon mine is an amygdaloidal variety in which the vesicles have been filled with epidote. (See figure 6.)

The meta-volcanics are exposed along the western boundary of the mapped area, and also to the west of Silver City. Good exposures for study occur along Amazon Gulch and also to the west of the Oest mine. These rocks are not found in the area east of Gold Canyon, either on the surface or in the mine workings. They extend southward to the Mound House gypsum quarry and into the Sierra Nevada at Lakeview. Similar lavas overlie sediments in the northern end of the Pine Nut Mountains.

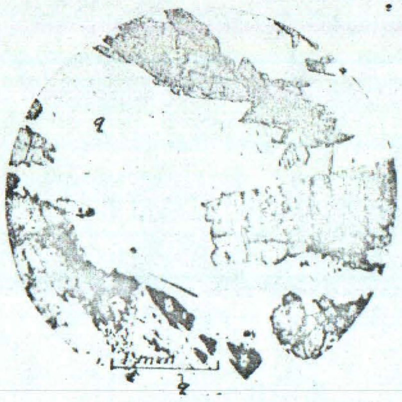



FIGURE 5.

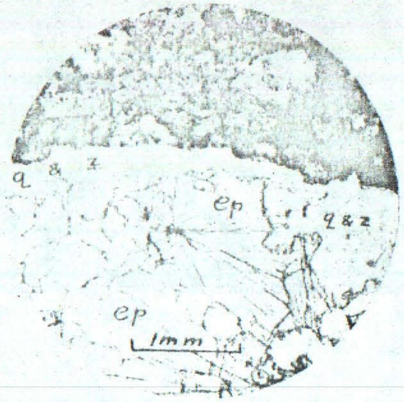



FIGURE 6.

**Figure 5. Quartz Vein Near the South End Shaft (SC 50). A pre-Tertiary quartz vein containing tourmaline (t) and epidote (ep) in quartz (q) which encloses many small tourmaline needles. (Photomicrograph.)**

**Figure 6. Amygdaloidal Meta-andesite (SC 55). The dark area is meta-andesite. The lighter portion is part of an amygdule composed of epidote (ep), bordered by quartz and a zeolite (q and z). (Photomicrograph.)**

In the northern and western part of the district the volcanics overlie the sediments unconformably. The contact between the overlying rocks and the steeply dipping sediments suggests deposition upon an irregular erosion surface. In the Sierra Nevada, south of Lakeview, and along the Carson River gorge through the Pine Nut Mountains, the relation between the sediments and the meta-volcanics is similar to that described above.

Near the South End shaft dikes of andesite and rhyolite cut the meta-volcanics, and in American Ravine they are intruded by monzonite and aplite. Immediately southeast of the monzonite area, the meta-volcanics contain small lenses of epidote and tourmaline-bearing quartz veins as illustrated in figure 5.

There are many places where the contact with the overlying unaltered Tertiary volcanics may be observed. The meta-volcanics are overlain by rhyolite at the south end of Hartford Hill, also along the northern boundary of the map, and north of the Haywood mine. Along the southwest wall of American Ravine, and also west of the Oest mine, the old volcanics are covered by Tertiary andesite.

The meta-volcanics had been largely removed by erosion prior to the eruption of the Tertiary lavas and therefore the thickness varies throughout the district. The greatest observed thickness occurs just beyond the western limit of the mapped area. Here the sediments underlie the old volcanics which in turn are overlain by the rhyolite, which extends to the top of McClellan Peak (figure 2). The vertical distance between the two contacts is about 1,000 feet, suggesting at least that thickness for the meta-volcanics.

### PETROGRAPHY

In thin section the meta-volcanics, from the hill west of the Oest mine, show large crystals of plagioclase with uralitized augite and hornblende in a confused groundmass. The groundmass consists of fragmented feldspars which have been rehealed by the development of cloudy plagioclase, crowded with fine, slender needles of pale green amphibole. These rocks appear to be metamorphosed crystal tuffs. A specimen from near the Amazon mine contains abundant large crystals of plagioclase and hornblende. Numerous small hornblende crystals penetrate the groundmass in every direction. This rock is similar to that described above. Some of the large hornblende crystals have been converted to chlorite, while blotches of chlorite, and grains of epidote and magnetite, occur throughout the groundmass.

The amygdaloidal lava south of the Amazon shaft is an andesite with a felsitic groundmass set with small crystals of hornblende and plagioclase. The amygdules are composed principally of epidote, with minor amounts of quartz and a zeolite of low birefringence. The quartz and zeolite line the walls, as shown in figure 6, while the center is filled with epidote. Similar quartz-epidote amygdules were described by Knopf [62] from the meta-andesites of Spenceville, California.

Under the microscope, the hornfels from the South End shaft is found to be made up largely of andalusite meta-crysts with numerous inclusions of ilmenite, biotite, sillimanite, and chlorite.

[62] Knopf, Adolph, Notes on the foothill copper belt of the Sierra Nevada; Univ. Calif. Publ. Bull. Dept. Geol., vol. 4, p. 413, 1906.



The sillimanite penetrates the andalusite in slender needles; frequently in radiating groups. Much of the sillimanite is faintly pleochroic, colorless to pale-yellowish and pale-bluish tones. It appears to be of later origin than, and to replace, the andalusite. The original rock was fragmental and quite probably a tuff. Between the South End shaft and the railroad there is a light colored felsitic rock. In thin section it is seen to be composed almost entirely of white chlorite. Ghosts of rock fragments suggest that this rock was originally a very fine-grained volcanic tuff. West of the north end of American Flat, there is a schistose phase of the volcanics containing residual quartz, orthoclase, plagioclase, and felsitic fragments. These minerals, and rock fragments, are held in a fine-grained matrix of chlorite, biotite, and muscovite. There are a few needles and prisms of tourmaline. The tourmaline is pleochroic, colorless parallel to its elongation, and dark murky-blue transverse to the prisms, and is therefore the variety indicolite.

### AGE

The relationship of the meta-volcanics to the other rocks of the district indicates that they are younger than the sediments and older than the late Jurassic quartz monzonite (p. 43). They are similar to the Triassic lavas of the Yerington district, described by Knopf,[63] twenty-five miles to the southeast of Silver City. With no further evidence these rocks are best referred to the Triassic.

## PLUTONIC ROCKS

### QUARTZ MONZONITE

The only plutonic rock mapped in the district is the quartz monzonite exposed for about a half mile along the bottom of American Ravine, and the smaller body to the south of Basalt Hill. Monzonite float was found north of American Flat and also in the southwestern part of the mapped area, suggesting other smaller bodies. That its distribution is even more extensive is indicated by the finding of this rock on the waste dumps of the Rock Island and Baltimore mines (figure 28) in American Flat, and at the Lady Bryan mine in Flowery Canyon, about three miles east of Virginia City. The Sierra Nevada plutonics are exposed along the west side of the Virginia Range, east of Washoe Valley, and also in the western part of the Washoe Mountains. The granitic mass in the Washoe Mountains continues across to connect with the Sierra Nevada at Lakeview.

[63] Knopf, Adolph, Geology and ore deposits of the Yerington District, Nevada; U. S. Geol. Survey Prof. Paper 114, pp. 13-16, 1918.

The monzonite of American Ravine is a light-gray, granular, rock with orthoclase and plagioclase, quartz, biotite, and hornblende. In hand specimens it is indistinguishable from that found in the mine dumps mentioned above, and is quite similar to the monzonite on the east shore of Lake Tahoe, seven miles west of Lakeview.

The monzonite is intrusive into the meta-volcanics in American Ravine, and dikes of monzonite and aplite penetrate the surrounding rocks. West of American Flat, opposite the Rock Island shaft, aplite dikes cut the meta-volcanics suggesting the presence of a nearby intrusive.

In American Ravine the monzonite is in part overlain by the meta-volcanics and, where these have been removed by erosion, the American Ravine (Tertiary) andesite rests upon the eroded surface of the monzonite.

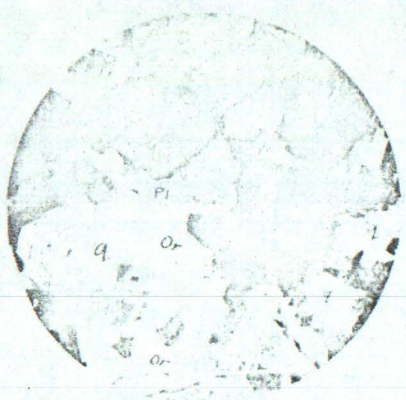


FIGURE 7.

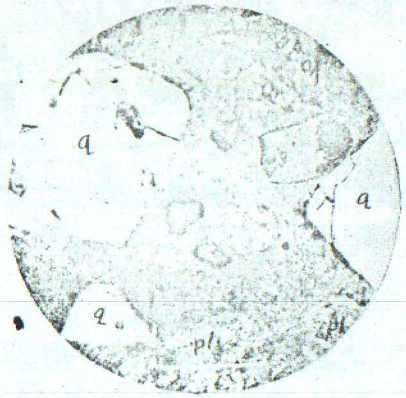


FIGURE 8.

Figure 7. **Quartz Monzonite from American Ravine (SC 8). Plagioclase (pl) with albite borders, and orthoclase (or) are present in about equal amounts. Quartz (q), biotite (b), and titanite (ti). (Photomicrograph, crossed nicols.)**

Figure 8. **Quartz Latite from Hartford Hill (SC 19). A fluidal, glassy groundmass contains phenocrysts of quartz (q), orthoclase (or), plagioclase (pl), and biotite (b). (Photomicrograph.)**

PETROGRAPHY

In thin section (figure 7) the rock is seen to be completely granular with hypidiomorphic texture. Orthoclase and plagioclase are present in equal quantity, together with abundant quartz. Biotite is the principal ferromagnesian mineral and there is a small amount of hornblende. The plagioclase is near oligoclase in composition. Microcline appears in a few small grains. Some of the feldspars, particularly the orthoclase, have



opaque areas due to fine dustlike inclusions and partial alteration to sericite and carbonate. The biotite is commonly intergrown with chlorite. Hornblende, somewhat chloritized, occurs sparingly. Numerous grains of magnetite and epidote form clusters throughout the section. There are a considerable number of small garnets and fine crystals of zircon. Titanite is plentiful in crystals and irregular grains, and is usually associated with biotite and magnetite.

AGE OF THE QUARTZ MONZONITE

The monzonite is identical with some facies of the Sierra Nevada batholithic intrusions which are exposed over large areas several miles to the southwest of the Silver City district. A portion of this batholith makes up the western flank of the Virginia Range along the eastern side of Washoe Valley (figure 1). The Sierran intrusives bear the same relationship to the metamorphic rocks and Tertiary lavas as does the monzonite in American Ravine. From the similarity in composition and texture, and relation to older and younger rocks, the Silver City and Sierran intrusives are regarded as parts of the same batholithic mass.

The Sierra Nevada batholith has received long and careful study by many geologists and the consensus of opinion places the period of intrusion in the late Jurassic.[64]

## TERTIARY ROCKS

### GENERAL STATEMENT

In the Silver City district the Tertiary volcanics fall naturally into two general divisions. The age of the older series ranges from Eocene to Miocene; the younger series is Pliocene(?).

The older lavas may be assigned to several volcanic epochs separated by periods of erosion. Andesite forms the base of this series. Above the andesite is rhyolite, with some quartz latite and a minor amount of dacite, followed by a thick accumulation of andesites and andesite breccias. The lower part of the andesite series has been intruded by dikes and sills of hornblende-pyroxene andesite. About 500 feet above the base of the series are beds of water-laid tuffs.

This older division of Tertiary rocks has been tilted, faulted, and intruded by andesite dikes and diorite. These volcanics have dips ranging from 10° to 55°; in general their inclination is

[64] Jenkins, O. P., Report accompanying geologic map of northern Sierra Nevada; Calif. Div. of Mines Rept., vol. 28, p. 285, 1932.

about 35° westerly. The period of vein formation followed closely upon the period of intrusion, and practically all of the veins lie wholly within this group of lavas, or have Tertiary lavas on the hanging wall and pre-Tertiary rocks on the footwall. The aggregate thickness of the older Tertiary volcanics is over 4,600 feet.

The younger Tertiary series of lavas consists of hornblende-pyroxene andesites, tuffs, breccias, and agglomerates. They are separated from the older series by a marked unconformity. These rocks are not so disturbed as the older Tertiary rocks, their average westerly dip probably not exceeding 15°. In places, these lavas cover the eroded outcrops of ore-bearing veins. Their maximum thickness appears to be about 1,200 feet.

In the district there are several small areas of a pyroxene andesite of still younger age.

## EARLIER TERTIARY VOLCANICS

### AMERICAN RAVINE ANDESITE

At the base of the Tertiary volcanics is a light gray andesite lying upon the eroded surfaces of the monzonite and meta-volcanics. This andesite is well exposed along American Ravine, west of the quartz monzonite. Several areas along Gold Canyon were mapped as this andesite, but it is probable that these are of later age.

The American Ravine andesite is generally felsitic and commonly exhibits a platy structure. The weathered surface of the porphyritic facies shows conspicuous phenocrysts of hornblende. In American Ravine it appears to lie directly upon the monzonite, and contains many fragments of that rock. Along the railroad, west of the South End shaft, the andesite overlies meta-volcanics and is capped by rhyolite. In one of the railroad cuts in this vicinity, about six feet of alluvial material intervenes between the Tertiary andesite and the meta-volcanics. This alluvium is made up largely of angular to sub-rounded boulders of meta-volcanics, and contains fragments of quartz. The quartz fragments range from the smallest pieces up to those one and one-half feet in diameter. This quartz is quite similar to that which forms a vein, in the meta-volcanics, a short distance to the south. The writer is of the opinion that these fragments were derived from the outcrop of this vein.

This andesite has a thickness of 500 feet just west of the monzonite in American Ravine, but on Hartford Hill, about 1,000 feet to the northeast, the rhyolite rests upon the meta-volcanics.



A similar loss of thickness is suggested by its relations south of American Ravine. The great decrease in thickness, in short distances from the center of the mass, suggests considerable erosion during the time which elapsed between the andesite and rhyolite flows.

No American Ravine andesite was found in the northern and western part of the district. However, the base of the rhyolite flow on McClellan Peak contains numerous inclusions of this andesite. The andesite was probably present in the area where the rhyolite flow had its source. A similar andesite overlies the meta-volcanic rocks in the Sierra Nevada a mile south of Lakeview.

Becker[65] mapped this rock as "felsitic quartz porphyry."

The age of this andesite is discussed, together with that of the Hartford Hill rhyolite on pages 50 to 52.

#### PETROGRAPHY

Under the microscope, a specimen of this lava from American Ravine, reveals a dense partly glassy groundmass with irregular small areas of carbonate. The plagioclase crystals are almost completely replaced by calcite, but the albite twinning is distinct. Slender hornblende phenocrysts have undergone resorption, leaving crystal outlines filled with fine, dusty magnetite. The groundmass of some specimens has a tuffaceous appearance, due to small fragmental inclusions, but the fluidal arrangement of microlites, around the plagioclase phenocrysts, demonstrates a flow rock. Partial devitrification is indicated by small areas of aggregate polarization.

### HARTFORD HILL RHYOLITE

Rhyolite covers much of the western and southern parts of the area. That shown in the northwestern corner of the map area can be traced, with but few breaks, southward along the Washoe Mountains and into the Sierra Nevada, northeast of Lake Tahoe. This flow appears to be principally rhyolite, but contains some quartz latite. To the north of American Flat, and also west of the Spring Valley mine, there are thin dacite members underlying the rhyolite, but their areal distribution is too small to be shown on the map.

Becker[66] referred to this rock as quartz porphyry, whereas

[65] Becker, G. F., Geology of the Comstock Lode and the Washoe District; Atlas Sheet IV. 1882.

[66] Becker, G. F., Geology of the Comstock Lode and the Washoe district, with atlas; U. S. Geol. Survey, Mon. 3, pp. 45-48, 1882.

Figure 9. Angular Conglomerate Underlying the Rhyolite. The conglomerate is composed of angular to rounded fragments. The fragments are granodiorite, metamorphic rocks, and occasionally pre-Tertiary vein quartz.



Zirkel[67] determined a specimen, collected near American Ravine, as rhyolite. Zirkel[68] described another rock from north of American Flat as dacite. This specimen probably was from the thin dacite member referred to above. Hague and Iddings[69] described the quartz-bearing lavas, and summed up their conclusions by stating: "We consider them as partly dacite and partly rhyolite, and, judging from the specimens in the collection, without any sharp line of demarcation between them."

The writer agrees with this statement with the substitution of the term "quartz latite" for "dacite." The rock which they describe as dacite was a quartz-bearing lava with about equal amounts of orthoclase and plagioclase which would now be classified as a quartz latite. It should be recalled that the term "latite" was introduced into the literature several years after the publication of their work.

The rhyolite exposures are commonly buff to reddish-brown in color, although some dense, glassy facies are lavender. In underground exposures the rock is usually light colored, commonly almost white. Rhyolite from the Forman shaft dump is light gray to pale lavender, glassy, and with strong flow structure. Quartz and biotite are usually conspicuous in the fresh rock, and the mica is frequently distinguishable even where the lava has been thoroughly silicified. Hornblende occurs sparingly.

There are many exposures of rhyolite in the underground workings. It occurs along the footwall of the Silver City vein on the 1,100-foot level of the Overman mine, in the Keystone, Woodville, Silver Hill, Dayton, Kossuth, Spring Valley, and other mines along Gold Canyon. Rhyolite was seen in the Pedroli mine, at the Milk Ranch, and was encountered on about the 400-foot level of the Succor mine according to Donovan.[70]

Its contact with the overlying Alta andesite is well exposed on the northern slope of Hartford Hill, on the east side of Basalt Hill, and north of American Flat.

On Hartford Hill (figure 28) the rhyolite has a thickness of about 450 feet. On the north end of Hartford Hill, and in the vicinity of the Milk Ranch, the topography of the rhyolite surface, under the Alta andesite, suggests considerable erosion before this period of volcanic activity.

[67] Zirkel, Ferdinand, Microscopical Petrography; U. S. Geol. Exp. of the 40th parallel, vol. VI, pp. 163–165, 1876.
[68] Ibid., p. 134.
[69] Hague, Arnold, and Iddings, J. P., On the development of crystallization in the igneous rocks of Washoe; U. S. Geol. Survey, Bull. 17, p. 27, 1885.
[70] Donovan, William, oral communication.

Figure 10. Large Boulders from the Conglomerate. The size of the granodiorite boulders is indicated by the field notebook leaning against the boulder in the foreground.



The rhyolite rests upon conglomeratic material at the south end of Hartford Hill. Under the fragmental rock is meta-andesite. The conglomerate (figure 9) consists chiefly of angular fragments of meta-andesite, hornblende granodiorite, quartz monzonite, and occasional pieces of quartz. The granodiorite ranges in size from small fragments to somewhat rounded boulders four feet in length. Some of the larger boulders are shown in figure 10. One small patch of rhyolite, in the extreme southwestern part of the map area, is underlain by fluvial conglomerate composed of angular to well-rounded boulders of blue and white limestone, shale, meta-andesite, coarse-grained quartz monzonite, and granodiorite. The granitic boulders are numerous, with some up to four or five feet in diameter. Occasional fragments are of a peculiar breccia in which fragments lie in a matrix of calcite and tourmaline. The replacing nature of the calcite and tourmaline is shown in figure 11.

The tourmalinized breccia caps a ridge a mile to the west. Granodiorite and quartz monzonite, like that in the conglomerate, is exposed in the Washoe Mountains three miles to the west, suggesting a land surface sloping east, or northeast, at the time of the rhyolite extrusion.

Becker[71] recognized the rhyolite as an extrusive while others, notably Hague and Iddings,[72] regarded it as an intrusive body. Its petrologic character, and the nature of both the upper and lower contacts, leaves no doubt as to its extrusive nature.

PETROGRAPHY

A quartz latite from a quarry on the west side of Hartford Hill is shown in figure 8. The groundmass is glass with strong flow structure. The section contains a few phenocrysts of plagioclase, near oligoclase in composition, and an equal amount of orthoclase largely replaced by calcite. The quartz phenocrysts are irregularly corroded and some have deep embayments filled with glass. Biotite is plentiful and is partly replaced by carbonates, or altered to a greenish, amorphous material. The biotite occasionally has dark borders apparently composed of fine magnetite dust. There are occasional crystals of hornblende. A single sharply-formed zircon crystal is present. A specimen from the Forman dump has abundant quartz, biotite, and feldspars in a glassy groundmass. Some of the feldspars are altered to carbonate and others contain green chloritic material. The

[71] Becker, G. F., loc. cit., p. 196.
[72] Hague, Arnold, and Iddings, J. P., loc. cit., p. 38.

orthoclase phenocrysts greatly exceed those of plagioclase. The rock is rhyolite.

Figure 12 illustrates a tuffaceous facies from the south end of Hartford Hill. This is a rhyolite vitric tuff with crystals of orthoclase, quartz, and biotite in a matrix of glass shards.

Sections of the rhyolite from the Spearhead (Succor) shaft, half a mile north of Silver City, exhibit beautiful flow structure in the glassy groundmass. The phenocrysts are quartz, biotite, and feldspars. The feldspars are predominantly orthoclase and the majority are quite fresh while others have been altered to carbonate. A single crystal, apparently titanite, has been altered to white, opaque, leucoxene.


FIGURE 11.

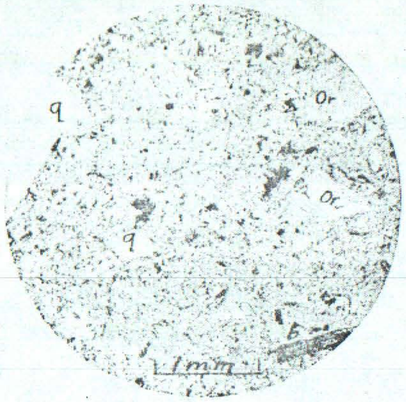



FIGURE 12.

Figure 11. **Tourmalinized Breccia (SC 80). The white tuff fragments are partially replaced by tourmaline (t) and carbonate (c). In the upper right, tourmaline is enclosed in flamboyant quartz (q), (of) is open field. (Photomicrograph.)**

Figure 12. **Rhyolite Tuff from the South End of Hartford Hill (SC 96). Glass shards enclose quartz (q), orthoclase (or), and biotite (b), in a tuffaceous facies of the rhyolite near the base of the flow. (Photomicrograph.)**

### AGE OF THE RHYOLITE AND AMERICAN RAVINE ANDESITE

The lower members of the older Tertiary lavas of the Silver City district is the American Ravine andesite and the overlying Hartford Hill rhyolite. The age of these rocks will be discussed together as, in all probability, they were extruded during the same geologic period.

The andesite occurs in isolated areas, while the rhyolite is quite extensive and has been traced, with but short breaks, from the Washoe Mountains, above American Flat, into the Sierra Nevada northwest of Carson City.

In the Sierra Nevada, northeast of Lake Tahoe, the rhyolite has been described by Reid[73] as overlying Tertiary auriferous

[73] Reid, J. A., The geomorphogeny of the Sierra Nevada northeast of Lake Tahoe; Univ. Calif. Publ., Bull. Dept. Geol., vol. 6, pp. 97-99, 1911.



river gravels. Reid mapped the river channel from Marlette Lake, overlooking Lake Tahoe, to Washoe Valley. The boulders were reported to be entirely of metamorphic material. The writer is familiar with this Tertiary channel, having traced it from Marlette Lake across the Carson Range to and beyond Washoe Valley. A continuation of the channel was found at the southeast side of Washoe Lake. At this locality the river deposits contain a small amount of gold, and are composed of rounded boulders, mostly of metamorphic rock. These range in size from small gravels to boulders three feet or more in length. Lenses of rhyolitic tuff, and rounded boulders of rhyolite, are interbedded with the upper gravels. Some of the rhyolite boulders are five feet or more in diameter. This deposit is covered in places by rhyolite lava. This evidence indicates that the river flowed for some time after the beginning of the rhyolitic eruption and formed boulders from that rock. Eventually the lava filled the channel and capped the river deposits. Farther east, on the summit of the Washoe Mountains, there is another occurrence of river gravels with interbedded rhyolite tuff. There is a small gravel area farther east.

The bouldery material found under the rhyolite, in the Silver City district, and described on page 49, lies four miles farther east. This has the appearance of a river deposit and may well be a continuation of the channel described above.

The Tertiary gravels of the Sierra Nevada, and their relation to the rhyolite flows, have been thoroughly investigated by Lindgren[74] and described in great detail. Dickerson[75] found rhyolite interstratified with the Ione formation and writes that: "These facts show that the Ione is the marine or estuarine equivalent of the Auriferous Gravels, stream laid deposits of the Sierra Nevada." Fossils found by Dickerson places the Ione in the Upper Eocene.

The contemporaneous deposition of the older Tertiary gravels and the Ione formation is clearly demonstrated by the evidence presented by Allen[76] who made an extensive study of this formation and its relation to the auriferous gravels, along the western flank of the Sierra Nevada. This evidence is clearly stated as follows:[77] "Not only have the Ione types been duplicated among the fine sediments of the white quartz gravels, but pebbles similar

[74] Lindgren, Waldemar, The Tertiary gravels of the Sierra Nevada of California; U. S. Geol. Survey Prof. Paper 73, 1911.

[75] Dickerson, R. E., The stratigraphy and faunas of the Tejon Eocene of California; Univ. Calif. Publ. Bull. Dept. Geol., vol. 9, p. 398, 1916.

[76] Allen, V. T., The Ione formation of California; Univ. Calif. Publ. Bull. Dept. Geol. Sci., vol. 18, pp. 347-419, 1929.

[77] Loc. cit., p. 395.

to those in the gravels have been found interbedded in the Ione, suggesting continuity that is supported by the field relations." And further that:[78] "As the deltas grew in size, the lower parts of the streams began to aggrade their channels headward, and the deposition of the white quartz gravels took place contemporaneously with the Ione."

Recently Chaney[79] has collected and studied fossil plants from the gold-bearing gravels in California and states: "The tuffs and shales in which fossil plants occur interbedded in the Auriferous Gravels range in age from lowermost Eocene to upper Miocene."

A review of Chaney's paper and Lindgren's[80] work indicates that Eocene fossils were associated with the rhyolite tuffs while Miocene plants were found in the overlying andesites.

The oldest Tertiary lava associated with the auriferous gravels, on the western slope of the Sierra Nevada, consists of rhyolite and quartz latite similar to the Hartford Hill rhyolite. In the Placerville quadrangle metamorphic gravels are interbedded with rhyolite tuff.[81] One of the largest eruptions of the Tertiary rhyolite occurred in the Truckee quadrangle,[82] near Donner Summit, and flowed down a valley near the present Middle Fork of the American River. Rhyolite covers a Tertiary channel at Echo,[83] four miles south of Lake Tahoe. Another river headed immediately west of the lake, near Barker Pass,[84] on the summit of the Sierra Nevada.

There can be little doubt that the Hartford Hill rhyolite was erupted during the same period of volcanic activity as the Eocene rhyolite associated with the Tertiary river channels in the Sierra Nevada. The American Ravine andesite, although somewhat older than the rhyolite, is also judged to be of Eocene age.

### ALTA ANDESITE SERIES

The most extensive formation is a thick series of andesitic rocks which overlie the Hartford Hill rhyolite. At the base, there is usually a coarse breccia which, due to disintegration upon weathering, commonly obscures the underlying contact. In the lower part of this series breccias predominate, although there are also flows of hornblende and pyroxene lavas. Toward the top of the series there are lavas and lesser amounts of breccia.

[78] Loc. cit., p. 405.
[79] Chaney, R. W., Notes on occurrence and age of fossil plants found in the auriferous gravels of the Sierra Nevada; State of Calif. Div. of Mines, vol. 28, p. 301. 1932.
[80] Lindgren, Waldemar, loc. cit.
[81] Lindgren, loc. cit., p. 168.
[82] Lindgren, ibid., p. 136.
[83] Lindgren, ibid., p. 183.
[84] Lindgren, ibid., p. 161.



The breccias are commonly composed of fragments of hornblende or pyroxene andesites in a fine matrix. A common variety has boulders of pyroxene andesite in a hornblende andesite matrix.

The fresh rock is light greenish gray to dark gray, and dark green. A characteristic breccia is mottled with blotches of green and red, producing an attractive appearance. Weathering produces various shades of gray, green, yellow, buff, and red.

Large areas of this rock are bleached almost white, particularly in the vicinity of the Comstock Lode. These bleached areas commonly grade downward into dark-colored rocks charged with pyrite. The pyritic rocks are hydrothermally altered. It is probable that the bleaching is due to the presence of the pyrite which, upon weathering, produces sulphuric acid and sulphates which readily attack the rock.

Several hundred feet above the base of the series is a bedded tuff which will be described in a later section.

It was not practicable, except for the bedded tuff just mentioned, to map separately the various members of this series. Together they constitute a related group of volcanic rocks which are apparently the products of the same period of volcanism. They are therefore mapped as a single unit.

This series was previously called the Forman andesites[85] but as a similar name is used for a formation in California[86] it was decided to substitute another term. This series of andesites will be referred to as the Alta andesite series from the excellent exposures, both on the surface and underground, in the neighborhood of the Alta shaft.

The breccias may be seen in numerous surface exposures, as well as in the underground workings of most of the mines northeast of Gold Canyon. Typical material occurs at the head of Nigger Ravine, northeast of Silver City, and coarse breccia crops on the east slope of the hill near the Forman shaft. Here, rounded pyroxene andesite fragments range from three to six inches across while some are more than a foot in diameter. Fine material, with poor stratification, has a trend of N. 30° E. and is inclined 50° to the west. A coarse tuff immediately north of the shaft has a similar appearance to some of the material in the Forman shaft dump. Here the stratification strikes N. 40° W. and dips 30° SW.

In Nigger Ravine a breccia grades from coarse tuff to a

[85] Gianella, V. P., New features of the geology of the Comstock Lode; Min. & Met., vol. 15, pp. 298-300, 1934.
[86] Diller, J. S., Geology of the Taylorsville region, California; U. S. Geol. Survey Bull. 353, pp. 53-57, 1908.

breccia with rounded boulders two feet in diameter. It is composed principally of pyroxene andesite, but many of the rounded fragments, particularly the larger ones, are strongly hornblendic with dark brilliant phenocrysts. The finely bedded material, occurring in lenses, strikes N. 20° W. and dips 55° to the west. The rock is greenish gray, weathering to very dark red.

A peculiar feature of some of the breccias of this series is that the lava fragments are quite well rounded and the rock could well be termed a volcanic conglomerate. The lenticular form of the finer material and frequent poor to good stratification suggests considerable water sorting during deposition.

Excellent exposures are accessible in the Sutro Tunnel and particularly in the south lateral from the Forman shaft connection to the Alta shaft.

The Forman shaft penetrated the Alta andesite series for 2,250 feet before entering the underlying rhyolite.[87] From surface and underground exposures the average dip is determined as averaging about 35° westerly. The section at the Forman shaft, if not repeated by faulting, indicates a thickness of 2,800 feet. An estimate of the maximum thickness was made from the position and attitude of the Sutro tuff member in the south lateral. Projecting the average dip downward to intersect the Comstock Lode, near the Yellow Jacket shaft, indicates that the base of the Alta series is 3,000 feet vertically below the surface. Considering the inclination, a thickness of over 3,600 feet is obtained. This figure is certainly but an approximation; however, it is probably not far from correct. From the available data no closer estimate is possible.

Contacts with the underlying rhyolite have been seen in many places. The contact is well exposed in the hills north of American Flat and also on the northwestern slope of Hartford Hill. Underground the contact is exposed at the bottom of the incline shaft at the Pedroli mine. One of the most interesting contacts between the Alta andesite and the rhyolite may be seen along the railroad cut on the eastern slope of Basalt Hill south of American Flat. The base of the Alta consists of fine to coarse fragments of hornblende-pyroxene andesite together with many other varieties of rock. There are large, somewhat rounded, masses of metamorphic rock, rhyolite, and granodiorite. A few of these blocks have diameters of 10 to 15 feet. Large boulders of the rhyolite are common in the Alta breccia west of the Kossuth shaft.

[87] Becker, op. cit., Atlas Sheet VI.



SUTRO TUFF MEMBER

At the head of Nigger Ravine, northeast of Silver City, is a finely bedded tuff about 500 feet, stratigraphically, above the base of the Alta andesites. From here it was traced northward to Long Canyon where the tuff appears to abut against the footwall of the Occidental lode. In the west fork of Nigger Ravine a normal fault displaces the tuff about 800 feet. From this point it continues southwesterly toward the Alta shaft. No outcrop was found in this direction farther than shown on the map. The lack of surface exposures at this place is probably due to the tuff weathering so readily as to be obscured by more resistant surface detritus. It is known that the tuff continues to the vein, along Gold Canyon, as this formation was encountered in the mine workings at the Lady Washington and Overman shafts.

This formation is named the Sutro tuff from the good exposures in the Sutro tunnel.

In general the tuff is composed of fine volcanic dust and ash (figure 23), with particles up to one-fourth of an inch, while occasional lenses are much coarser. The coarser facies may be seen in Long Canyon. The color is usually creamy-yellow to light buff. There are occasional layers which contain flat, oval-shaped pellets from one-fourth to three-fourths of an inch in length. These are made up of the finer material.

The fine-textured tuff is uniformly well stratified, and in some places is finely laminated. The persistent stratification of the finer material indicates that the tuff was deposited in water, probably in a lake. A few small fault-segments of tuff occur north of the Vivian shaft. In general the strike of the tuff is about N. 30° E. with a dip of 40° to the northwest.

Good exposures of the tuff may be seen in the Sutro Tunnel,[88] especially between 11,000[89] and 16,000 feet. Particularly well-banded tuffs are exposed at 12,800 and 13,800 feet. The tunnel section was not mapped; nor was it studied in sufficient detail to determine the structural relations between the various tuff occurrences. The tunnel passes through alternate masses of tuff and andesite which probably represent blocks produced by normal faults, transverse to the trend of the tunnel.

In general the tuffs dip westerly with an average inclination of about 35°. This attitude is similar to that of the surface exposures. The tuffs in the tunnel section are commonly well

[88] For map see Becker, G. F., loc. cit., Atlas Sheet VI.
[89] Figures indicate distance from the tunnel portal.

stratified with the finer and coarser bands easily seen in the hand specimens. On fresh surfaces the color is white to pale green or gray. The finer-grained tuffs are sometimes highly silicified so that they closely resemble dense white chert.

In the south lateral of the Sutro Tunnel excellent exposures may be seen between the Yellow Jacket and Forman shafts. Here the lateral was driven through tuffs for several hundred feet. The average strike of the formation is about N. 25° E. and the dip is 30° to 40° westerly. The tuffs are well stratified and consist mostly of fine material. Some beds are composed of coarse fragments. The color is generally white, but occasionally has a greenish or grayish tint. The tuff overlies the Alta andesite breccia and, in turn, is overlain by the upper part of this series.

The Sutro tuff was penetrated by the northeast crosscut, and by the northwest drift, on the 1,100-foot level of the Overman mine. In the northwest drift the tuffs strike N. 10° E. to N. 10° W., and the dip averages about 35° west. Here the tuffs are composed of white, fine-bedded volcanic dust with occasional layers of coarse fragments. In the northeast crosscut the tuffs are quite well stratified. In this mine the tuffs have been silicified and have the appearance of replacement quartz or, in places, like banded cherts or siliceous shales.

Above the Ophir grade the tuffs are exposed for several thousand feet. The general strike is northerly, and dips up to 60° westerly have been observed. Here the tuff lies within the Alta andesite series, about 600 feet stratigraphically above the base. The Alta andesites rest upon the rhyolite. Suicide Rock, a prominence rising above the Ophir grade, is a mass of a coarse facies of the tuff like that in Long Canyon.

The persistent and pronounced western dip of the Sutro tuff on both sides of the Comstock Lode suggests a period of deformation preceding the normal-fault movements.

In Long Canyon and in Nigger Ravine the tuffs have a thickness of 250 to 300 feet. North of the mapped area, and above the Ophir grade, it is probably somewhat greater. In the south lateral of the Sutro Tunnel the apparent thickness is in excess of this figure, probably reaching 800 feet, and might well be the result of minor faulting. It is probable that the thickness of these bedded deposits is quite variable; such a condition, however, is not indicated in the surface exposures.

The general nature and attitude of the underground occurrences, as well as their stratigraphic position, clearly indicate [illegible] tuffs exposed on the surface.



The recognition of the Sutro tuff and its position in the geologic column gives the most valuable key horizon to be found in the district. The tuff makes possible the determination of the attitude, and approximate thickness, of the Alta andesite series, and serves as a marker for these volcanics in the footwall country. The tuffs also furnish a horizon from which to estimate the Miocene fault displacement.

PETROGRAPHY

The tuff from the head of Nigger Ravine is composed of minute lithic fragments, broken crystals of plagioclase and orthoclase, and occasional quartz fragments in a matrix of fine dust. There are occasional shreds of biotite. The feldspars are much altered.

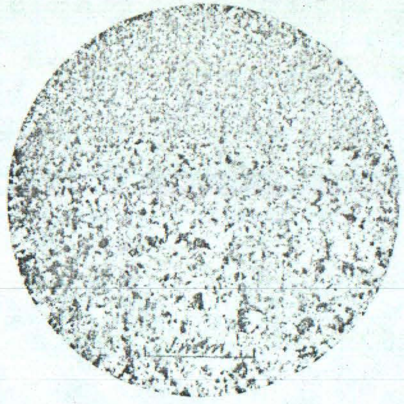



FIGURE 13.

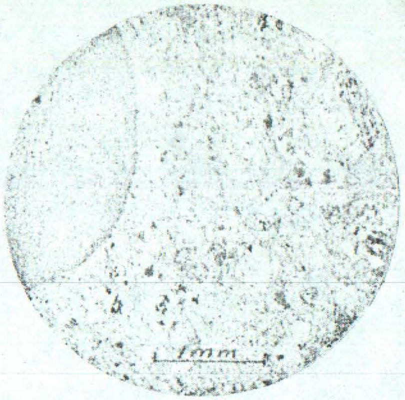



FIGURE 14.

Figure 13. Sutro Tuff from the Sutro Tunnel (SC 109). Specimen was collected 13,700 feet from the portal of the tunnel. Shows the fine- and coarser-grained laminae. (Photomicrograph.)

Figure 14. Sutro Tuff from the Forman Shaft (SC 30). Contains many lithic fragments with quartz, orthoclase, plagioclase, and biotite. The dark area is part of an ovoid pellet composed of the finer material. (Photomicrograph.)

A thin section from a specimen collected in the Sutro Tunnel at 13,700 feet is shown in the photomicrograph, figure 13. The tuff is made up of thin bands of volcanic dust, of which two are shown in the illustration. The coarser layers are composed of broken crystals of orthoclase, plagioclase, and quartz in a base largely made up of fragmented glass. Chlorite is common, as are also small grains of a mineral of high index, and high birefringence, which appears to be titanite. Epidote is plentiful. The orthoclase is more plentiful than plagioclase. Except for occasional grains, the finer material is composed of particles too small for determination. Much of this material appears to be glass. The rock is a rhyolite tuff.

A thin section of tuff from the Forman dump is shown in figure 14. It contains much orthoclase with lesser amounts of plagioclase and quartz. There are many lithic fragments and a few shreds of chlorite. Much of the feldspar is altered to carbonate; some of it is sericitized. The base contains many blotches of chlorite. There are irregular grains of titanite, occasional zircon crystals, minute slender apatite prisms, and devitrified shards of glass.

This section contains part of a pellet which is composed of fine grains, like those of the enclosing tuff. The material in the center is fine, grading into even finer particles until, at the border, the individual grains are indistinguishable. A few shreds of biotite give the outer zone a rude lamination.

The character of the tuffs indicates that, somewhere in this region, there was explosive activity of rhyolitic volcanoes. The source of this material, like that of most of the other volcanics, is unknown.

### AGE OF THE ALTA ANDESITES

Volcanics, petrographically similar to the Alta andesites, make up the low hills immediately north of Reno. These lavas are hydrothermally altered and contain minor ore deposits. Louderback[90] in discussing these volcanics states: "The lavas have often suffered alteration by solfataric action or mineralization." And further[91] that "The best known deposits in these rocks are along the Comstock Lode * * *."

The Alta andesites resemble the labradorite andesites of the western Cascade Range, as described by Callaghan.[92] His description of the western Cascade andesites indicates their close similarity to the older Tertiary andesites of the Silver City district, and also agree closely in their place in the geologic column. Of the age of these andesites, Callaghan writes:[93] "In southern Oregon they rest upon an arkosic formation of Eocene age, and the paleobotanical work of Chaney on intercalated sediments indicated that they range in age from Eocene to middle Miocene."

The Alta andesites rest upon rhyolite of Eocene age (page 52). They have undergone a complex history, including intrusion, faulting, mineralization, and prolonged erosion prior to the early Pliocene volcanism. No paleontologic evidence of the age of these lavas has been found in the district. In the Sierra Nevada, Chaney (see page 52) found Miocene fossils in the andesites which overlie the rhyolite. From the similarity of the sequence of the lavas in the Sierra Nevada and in the Silver City district, it is the writer's opinion that the Alta andesites are Miocene. They possibly range from Eocene to Miocene.

[90] Louderback, G. L., General geological features of the Truckee region east of the Sierra Nevada; Geol. Soc. America Bull., vol. 18, p. 664, 1908.

[91] Ibid., p. 665.

[92] Callaghan, Eugene, Some features of the volcanic sequence in the Cascade Range in Oregon; Am. Geophys. Union Trans; Fourteenth Ann. Meeting, [illegible] 243-249, 1933.

[93] Ibid., pp. 243 244.



## TERTIARY INTRUSIVES

### GENERAL STATEMENT

In the Comstock region dikes are plentiful in the neighborhood of the ore-bearing veins. In an area which has had such a varied igneous history it would be surprising if there was a lack of intrusive phenomena. Dikes are particularly numerous from Silver City to Virginia City and in the footwall of the Comstock Lode in the vicinity of Mount Davidson and Cedar Hill. Of the various intrusives only the Mount Davidson diorite, and associated dikes, have a granular texture. Dikes have been encountered in the mine workings in the Sutro Tunnel, and especially in the north lateral. Some of the intrusions are certainly closely related in time of occurrence with faulting and vein formation.

Becker[94] who has made the most exhaustive study of the Comstock, recognized but few dikes in the region, and in discussing the "black dike," which follows along the footwall of the Comstock Lode, remarks:[95] "This is the only dike known in the district, excepting one of diorite in diorite, in spite of the prevalence of eruptive rocks." The "black dike" is recognized as intrusive by all who have written on the Comstock. In several of the geologic sections of Becker,[96] structural relations strongly suggest intrusive phenomena.

The more important intrusions will be discussed in the following section.

### MICA ANDESITE PORPHYRY

The most conspicuous dikes in the area are those to the north and east of Silver City. Four of these dikes are shown on the map. They are from 50 to 150 feet wide, trend roughly parallel to the vein along Gold Canyon, and usually dip northeasterly at high angles. The rock is light colored, ranging from light gray to greenish gray, and weathers to a yellowish tint, due to oxidation of the contained iron. There are conspicuous phenocrysts of white plagioclase, biotite, and lesser amounts of hornblende. The texture is decidedly porphyritic and, when the

[94] Becker, G. F., Geology of the Comstock Lode and the Washoe District; [illegible] Atlas. U. S. Geol. Survey Mon. 3, 1882.

[95] [illegible] cit., p. 382.

[96] [illegible] Atlas Sheets V and VII.

phenocrysts are present in considerable amount, the rock closely resembles diorite porphyry. The phenocrysts are usually small, seldom reaching a quarter of an inch in their greatest dimension. This rock will be referred to as mica andesite porphyry.

In addition to the dikes referred to above, the mica andesite porphyry is exposed in many underground workings. The long dike trending from Nigger Ravine to the Milk Ranch has been penetrated by several tunnels near its northern end, and by many prospect pits, and the Pedroli mine, near the Milk Ranch.

The mica andesite porphyry intrudes the carbonaceous shales in the footwall of the Comstock Lode at Gold Hill. On the 1,100 foot level of the Overman mine a drift to the southwest entered and followed a post-mineral fault for several hundred feet. A crosscut was driven through the fault into mica andesite. After driving a distance of over 175 feet through this rock the shale-andesite contact was passed through. This is an intrusive contact. The andesite has a chilled border and contains inclusions of shale fragments. The chilled border is of interest as, at the time of intrusion, there was a cover of more than 4,000 feet of rock. The andesite shale contact trends N. 30° W. and dips 75° northeasterly. As the attitude of the intrusive conforms to that of the sediments, the andesite mass is a sill. On the 900-foot level of this mine the mica andesite is intrusive into the Alta andesites of the hanging wall, near the Comstock vein. Intrusions of the mica andesite porphyry were observed in the Sutro Tunnel, particularly in the section within 3,000 feet of its junction with the north lateral. Becker[97] mentions an occurrence at 20,424 to 20,434 feet from the tunnel portal, containing quartz phenocrysts. Other similar intrusions were found in a connection driven, within the past 15 years, from the north lateral to the Union shaft.

A large mass of "mica diorite" is shown by Becker[98] between the Alta and Forman shafts on the Sutro Tunnel level. A drift has since been driven through this ground and exposes Alta andesite for most of this distance.

*Petrography.* Thin sections from the dike in Long Canyon, east of the Forman shaft, show phenocrysts of plagioclase, biotite, and hornblende in a micro-crystalline groundmass. The feldspars are andesine. The phenocrysts and groundmass are much altered ... epidote, calcite, and other secondary ...



The dike of the Woodville shaft has a fine groundmass with conspicuous feldspar phenocrysts. Biotite is much more abundant than hornblende. In thin section, figure 15, the groundmass is seen to be very finely crystalline. Biotite is commonly chloritized while the hornblende is largely replaced by chlorite. Some of the biotite crystals contain numerous small grains of magnetite. Stubby crystals of apatite are rather plentiful.

In driving a connection between the Union shaft and the north lateral[99] of the Sutro Tunnel a coarsely porphyritic intrusive was exposed. Because of its granular appearance it was indicated on some of the mine maps as diorite. This occurrence is

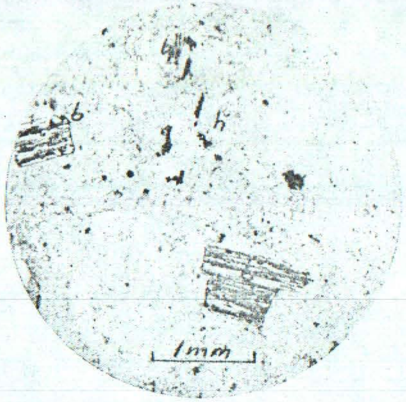



FIGURE 15.


FIGURE 16.

**Figure 15. Biotite Andesite Porphyry (SC 41). Specimen from a dike at the Woodville shaft. Phenocrysts are plagioclase (pl), hornblende (h), and biotite (b), set in a partially devitrified groundmass. (Photomicrograph.)**

**Figure 16. Contact of Andesite Porphyry with Carbonaceous Shale (SC 124). Specimen from a sill in shale on the 1,100 level of the Overman mine, and in the footwall of the Davidson fault. The porphyry has a glassy border near the contact. There are phenocrysts of plagioclase (pl), biotite (b), and hornblende (h). The shale is rendered opaque by carbonaceous material. (Photomicrograph.)**

approximately 1,800 feet north and 300 feet east (magnetic) of the C. and C. shaft.

Thin sections show a partially devitrified groundmass with plentiful plagioclase and biotite phenocrysts. Hornblende occurs sparingly. The plagioclase proves to be calcic andesine. Green chlorite and carbonates have largely replaced the biotite and hornblende. The texture is distinctly that of andesite with the phenocrysts making up considerably less than half of the rock. ...ll irregular patches of the groundmass has been replaced by ...nate. The rock is a biotite-hornblende andesite porphyry.

...p of the Sutro Tunnel see Becker, loc. cit., Atlas Sheets VIII and IX.

Figure 16 shows a photomicrograph of the andesite-shale contact from the 1,100-foot level of the Overman mine. This occurrence is described on page 60. The andesite has a chilled margin of glass with strong flow structure. A short distance from the margin are phenocrysts of plagioclase, biotite, and hornblende in a groundmass showing incipient crystallization. The andesite contains many shale inclusions. The carbonaceous shale is opaque, except for the presence of calcite and minute mineral fragments.

Some of the dikes have a microcrystalline groundmass with numerous phenocrysts and are diorite porphyries; others are andesite porphyries. The latter type appears to be dominant and the rock is referred to as biotite-andesite porphyry.

MINOR INTRUSIVES

In the lower part of the Alta andesite series, northeast of Gold Canyon, there are dikes, sills, and possibly flows of a dark, almost black, augite-hornblende andesite porphyry. Exposures of this rock are plentiful from Devils Gate to the east branch of Nigger Ravine, northeast of Silver City. A few small dikes were found southeast of the town and also in the vicinity of the Kossuth shaft.

The unaltered rock is dark gray, to almost black, with splendent jet-black phenocrysts of hornblende. The phenocrysts are unusually large, commonly attaining a length of one-half to three-fourths of an inch. Occasional crystals were one and one-half inches long and one-fourth of an inch wide. Becker[100] mentions hornblende, from this area, with a length of several inches. With weathering, the groundmass becomes blue and purple which, contrasting with the brilliant black hornblende, gives the rock a striking appearance.

This andesite porphyry appears to be confined to the rocks below the Sutro tuff and no dikes were seen above this horizon. This relationship suggests that the intrusions were earlier than the deposition of the tuff. Evidence to warrant a definite conclusion on this point was not obtained.

The microscope reveals a groundmass consisting of glass, highly charged with magnetite dust, minute slender feldspar microlites, and numerous small crystals of labradorite and augite. Hornblende crystals are not so numerous as those of augite but because of their large size, make up a larger portion of the [illegible] The hornblende is strongly pleochroic in yellow and brown [illegible] The extinction angle is 20 [illegible]. Most of the hornblende has [illegible] borders of magnetite, while many of the crystals [illegible]



entirely resorbed. The resorbed hornblende usually has its outline indicated by a rim of magnetite surrounding an area charged with magnetite dust and small grains of augite and plagioclase.

The large hornblende phenocryst, illustrated in figure 17, has been almost completely resorbed with the formation of an aggregate of plagioclase and augite. Irregular remnants of the hornblende remain unaltered. Surrounding the plagioclase-augite aggregate is the magnetite border and a reaction-rim composed of small clear crystals of augite.

Becker[101] found evidence which indicated that some of the magnetite borders were formed before, and others after, the extrusion of hornblende lavas. He was of the opinion that variation in pressure, equivalent to lowered temperature, induced the precipitation of magnetite.

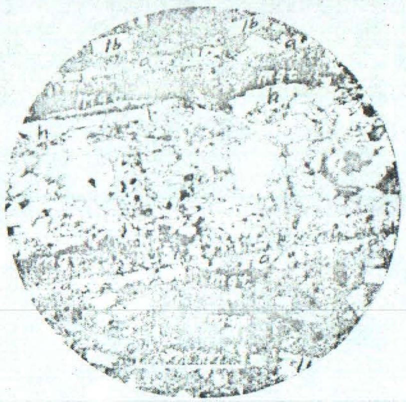


**Figure 17. Hornblende Andesite from Nigger Ravine (SC 32). The phenocrysts are labradorite (lb), and hornblende, charged with magnetite dust (mgt). The central band is a portion of a large hornblende crystal partially recrystallized to an aggregate of plagioclase and augite. Ragged fragments of hornblende (h) remain unaltered. A zone of magnetite is enclosed by a border of augite (a). (Photomicrograph.)**

It appears to the writer that both the liberation of magnetite and formation of augite and feldspar are probably due to the same causes. Frequently hornblende was observed to be completely resorbed, leaving the crystal outlined by an aggregate of finely divided magnetite. Less complete resorption leaves remnants of the original hornblende associated with small crystals of augite and plagioclase, together with numerous magnetite grains. It is suggested that at high temperature liberation of water from the magma caused a reversion to minerals stable under a more anhydrous environment. This condition resulted in the formation of pyroxene and plagioclase with the liberation of magnetite.

Narrow dikes of augite andesite, some but a few inches wide, [illegible] the rhyolite which makes up the hill immediately south of [illegible] Milk Ranch. Plagioclase phenocrysts are numerous. The [illegible] crystals are very slender and are generally arranged [illegible] to the walls of the dikes. This orientation of the plagio- [illegible] the rock a peculiar and interesting texture. Similar [illegible] with slender plagioclase phenocrysts, occurs as a dike which trends across the saddle of the ridge east of the Woodville shaft. Another of these dikes, about one foot wide, intruded the meta-volcanics in the railroad cut west of the South End shaft.

A mass of rhyolite, apparently a narrow dike, is exposed in shallow workings on the ridge north of the South End shaft.

Many other examples of intrusions could be cited, but those described above indicate their abundance.

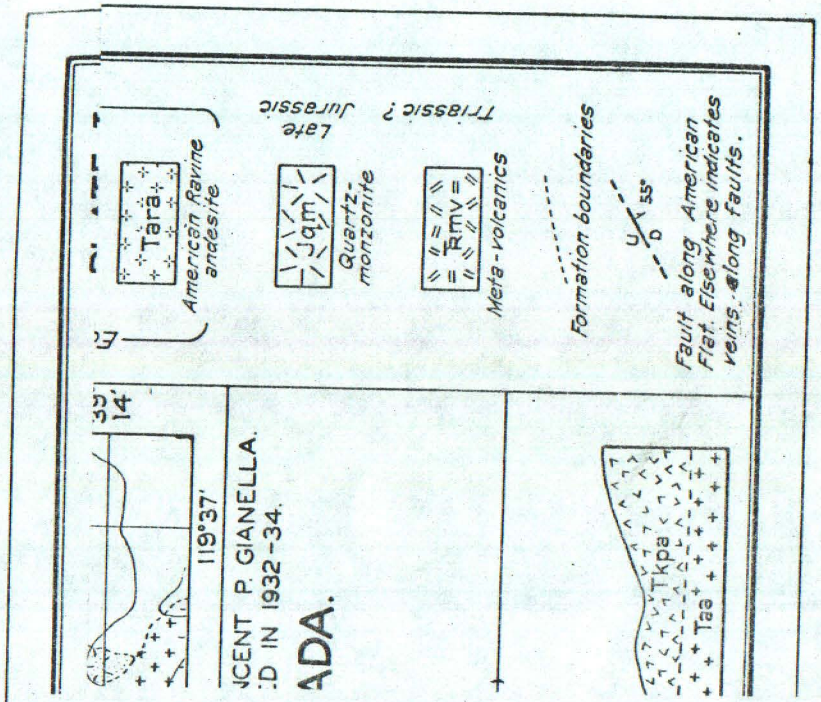
### DAVIDSON DIORITE

Probably the most interesting intrusive of the Comstock region is the diorite which makes up the bulk of Mount Davidson (figures 2, 3, and 26). Although this rock is not known to occur in the Silver City area, it is of importance in this study because of its prominent place in the geologic history of the region and its probable relation to ore deposition. Furthermore, the Davidson diorite is the first granular Tertiary intrusive so far recognized from western Nevada. The diorite is a medium-grained granular rock of light gray color. It differs but little in appearance from certain facies of the Sierra Nevada plutonics. Hornblende, plagioclase, and occasionally biotite, are readily recognized in hand specimens.

The diorite is clearly intrusive into the surrounding rocks as indicated by its many dikes and apophyses penetrating the adjacent volcanics. A specimen of andesite from above the Ophir grade, and immediately south of Bullion Ravine, contains thin intricately branching injections of granular diorite. Some of these sheets are but one-eight of an inch thick. The main mass of the diorite, particularly in the vicinity of the summit of Mount Davidson, contains many inclusions which may readily be recognized as andesite. Along the south side of Spanish Ravine, immediately north of Mount Davidson, is a small mass of andesite near the northern margin of the diorite. This andesite contains numerous dikes of diorite. Some of the andesite inclusions near the summit of Davidson have been so thoroughly assimilated as to form irregular, indistinct, ghost-like blotches.

The Hale and Norcross tunnel penetrated the footwall country for a distance of about 5,000 feet and, as it passed almost directly under Mount Davidson, gives a good cross section of the mountain. Reid[102] has described the tunnel, and the formations passed through, in considerable detail. The tunnel dump contains material which shows diorite and pegmatite penetrating andesite.

[102] Reid, J. A., The structure and genesis of the Comstock Lode; Univ. Cal. Publ. Bull. Dept. Geol., vol. 4, pp. 186-187, 193-195, 1905.



Diorite forms the footwall of the Comstock Lode in the neighborhood of Virginia City, and dikes cut the hanging wall andesite on the Sutro Tunnel level, near the Consolidated Virginia and California shaft. Intrusions of the diorite may be seen near the connection to the Mint shaft, in the crosscut to the Ophir incline, and in the north lateral near the crosscut to the lode in the Mexican mine. Becker[103] indicates an intrusion of diorite below the bonanza, but expressed the opinion[104] that the mass had been "separated from the west wall" during the eruption of the "diabase."

*Petrographic Description.* A specimen from the summit of

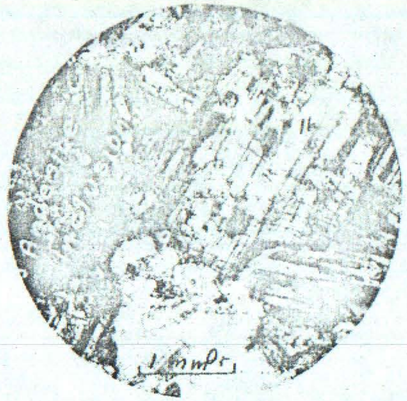


FIGURE 18.

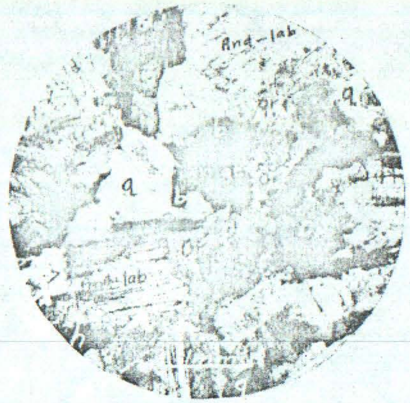



FIGURE 19.

Figure 18. Diorite from Summit of Mount Davidson (SC 114). The texture of the diorite contrasts strongly with that of the inclusion of augite andesite. The andesite has been thoroughly recrystallized, producing a fine-grained texture. The diorite contains plentiful labradorite (lb), with a small quantity of orthoclase (or). Quartz (q) occurs sparingly. (Photomicrograph, crossed nicols.)

Figure 19. Diorite from the Hale and Norcross Tunnel (Com. 141). Andesite-labradorite (and-lab), orthoclase (or), and quartz (q), are the principal constituents. Other minerals are biotite (b), hornblende (h), and magnetite (mgt). (Photomicrograph, crossed nicols.)

Mount Davidson is a light-gray, medium-grained rock. Under the microscope (figure 18) it is seen to have a hypidiomorphic texture. The texture of the augite andesite inclusion contrasts strongly with that of the diorite. The principal minerals are plagioclase, orthoclase, and hornblende. There is about 10% of orthoclase, 5% of quartz, and 15% of hornblende, and an occasional crystal of biotite. Granulated areas occur between the plagioclase crystals and are filled largely by orthoclase and quartz. The orthoclase commonly contains inclusions of plagio-

…Sheet V. Section through C. & C. shaft.

The plagioclase is near andesite-labradorite in composition. It is relatively clear and fresh, though occasionally shows some sericitization. Granules of augite are common inclusions. The orthoclase is somewhat sericitized and charged with dust-like inclusions. The hornblende is pleochroic in light greenish-blue and greenish-yellow tones. Extinction angles as high as 22° were measured. Some of the hornblende is quite fibrous and some has altered to fibrous green chlorite. Apatite and magnetite are plentiful while titanite and zircon occur sparingly. Minor amounts of epidote is present in small grains. The rock is diorite approaching granodiorite in composition, although much lower in quartz content than is usual for that rock. Another specimen from about 100 feet east of the summit shows features identical with those of the thin section described above. The hornblende shows partial alteration to fibrous chlorite. A gradual change from fresh to altered hornblende may be seen in some crystals. A single small crystal appeared to be hypersthene, but identification was not certain.

An intrusion of hornblende-mica diorite was seen in the Ophir crosscut (not shown on Becker's map) from the north lateral to the Ophir incline. The locality is about 300 feet east of the Ophir shaft. The rock is holocrystalline, with andesine, hornblende, mica, and but little quartz. Alteration products are epidote and calcite. This diorite is similar to some facies of the Davidson intrusive.

Other intrusions were cut in the north lateral. One is about 200 feet south of the north endline of the Ophir mine, and another at the crosscut driven from the lateral to the vein along the Ophir-Mexican property line. The latter intrusive is exposed for about 50 feet.

Thin sections show andesine feldspar and numerous biotite and hornblende crystals surrounded by fragmented mineral grains. Quartz and orthoclase are present in minor amounts. The principal accessory minerals are apatite and magnetite. The ferromagnesian minerals show considerable alteration to pale green chlorite. Quartz and pyrite have been introduced and epidote and carbonates have developed. The plagioclase contains many shreds of biotite and hornblende. This rock is a sheared diorite.

The granular rock from the Hale and Norcross tunnel dump is a light-gray, medium-grained rock, with plagioclase, hornblende, and some biotite. Neither orthoclase nor quartz were recognized in the hand specimen.



Under the microscope the rock is seen to be holocrystalline (figure 19) and composed essentially of calcic-andesine, orthoclase, hornblende, biotite, and quartz. The plagioclase is quite fresh and some of the crystals show beautiful zoning. Slight alteration to sericite was noted. Hornblende comprised about 15% of the rock and basal sections of the crystals have the characteristic, prismatic, amphibole cleavage. The extinction angle is 21°, birefringence is near .024, and pleochroic colors are light green, bluish-green, and pale light yellow. Some of the hornblende is altered to finely-fibrous chlorite. Biotite appears in occasional ragged crystals and is pleochroic in rich green and pale yellow tones. It is partially chloritized. Titanite occurs throughout the section in small crystals and irregular grains.

The rock had undergone shearing, with some granulation, after the crystallization of the plagioclase. The quartz and orthoclase crystallized in the fracture areas, sealing the rock. However, the quartz and orthoclase grains are of the usual size and appearance of normal orthotectic minerals and are apparently but little later than the plagioclase, as is the usual sequence. The rock is a granodiorite.

A shaft was sunk in the hanging wall of the lode in Ophir Ravine and evidently passed through the vein into the footwall, as there is a quantity of fresh granular rock on the dump. This shaft has long since been abandoned. This rock differs somewhat from those described above.

Thin sections show the rock to be holocrystalline with hypidimorphic texture. The principal mineral is well-twinned acid labradorite ($An_{52}$). Quartz makes up about 5%, while orthoclase occurs sparingly. Hornblende is present to the extent of about 10% of the rock. It is pleochroic in bluish-green, yellowish-green, and pale yellow. The section contains one crystal of faintly pleochroic hypersthene. The rock might well be termed a quartz diorite-gabbro.

*Relation to Surrounding Rocks.* Hague and Iddings[105] regarded Mount Davidson to be composed of hornblende and pyroxene andesites and as a part of the andesites of the hanging wall. One of the rocks discussed by these authors was from the summit of Mount Davidson. As the summit area of the mountain is very small, their specimen came from very near the one described above (page 65). They considered the hornblende as [illegible] augite and hypersthene. No mention was made of orthoclase or biotite. Orthoclase is not present in the Miocene

[illegible] pp. 39-40.

hornblende-pyroxene andesites of the hanging wall adjacent to the vein, and biotite is rare. Hague and Iddings are clearly in error here.

Becker[106] discussed the Sutro tuff-diorite intrusive contact phenomena, south of Bullion Ravine, but unfortunately decided that the finely laminated tuff, and coarser breccia, were but peculiar facies of the diorite. He failed to grasp the significance of this, and similar evidence elsewhere, and thereby lost the opportunity of determining the relative ages of the two rock masses.

The nearness of the diorite dikes, in the hanging wall, to the Davidson pluton of the footwall country suggests a common origin. Their mineralogical and textural similarity, and intrusive nature, indicates they were derived from the same magmatic source. There can be no doubt that these dikes were injected into the surrounding rocks during the intrusion of the main mass. The abundant evidence decisively demonstrates that the Davidson diorite intruded the Alta andesites.

#### AGE OF THE TERTIARY INTRUSIVES

The Tertiary intrusives have clearly been shown to cut the Miocene Alta andesites and are therefore younger than these rocks. King[107] considered the diorite to be Jurassic like that of the Sierra Nevada, while Becker[108] states that it is pre-Tertiary. Hague and Iddings[109] thought that it was Tertiary and a part of the Alta andesite. The mica andesite porphyry (mica diorite of Becker) they regarded as identical with the Kate Peak andesite (later hornblende andesite of Becker).[110] These two rocks, mineralogically, have little in common. The andesite porphyry dikes have intruded a rock which has since been subjected to a long period of erosion before the extrusion of the later lava flows.

The major intrusives cut Miocene lavas and are overlain by lower Pliocene volcanics, and are therefore of Miocene age. They probably were intruded about the middle of that period.

### LATER TERTIARY VOLCANICS

#### KATE PEAK ANDESITE SERIES

A series of Tertiary volcanics differing in character, and decidedly later in age than the Alta andesites, has been mapped as

[106] Loc. cit., p. 41.
[107] Loc. cit., pp. 13-14; 23-24.
[108] Loc. cit., p. 372.
[109] Hague and Iddings, Loc. cit., pp. 21-22; 40.
[110] Loc. cit., p. 41.



the Kate Peak andesites. They constitute the mass of lavas which makes up the high ridge, the Flowery Range (figure 28), along the eastern part of the map area, culminating in Kate Peak. The series is composed of hornblende-pyroxene lavas, breccias, and agglomerates. The uppermost member is a coarsely porphyritic lava with large phenocrysts of plagioclase, biotite, and hornblende.

There is much variety in the rocks along the western slope of Kate Peak. There are agglomerates, coarse and fine breccias, and tuff. A coarse agglomerate is shown in figure 4. There are also dark glass, scoria, coarsely porphyritic and felsitic varieties. Near the base is a bed of light gray, almost white, biotite-hornblende andesite breccia. This breccia is about 30 feet thick and several hundred feet long.

These volcanics are identical in appearance and general character to those exposed along the gorge where the Truckee River cuts across the Carson Range east of Truckee, California, and also those about Donner Pass on the summit of the Sierra Nevada.

The uppermost member of the Kate Peak series, at Rose Peak and along the ridge of the Flowery Range to the northeast of the map area, is one of the most individualistic lavas of the region. This is a coarsely porphyritic andesite, light- to dark-gray in color, generally with large phenocrysts of plagioclase, and either biotite and hornblende. In some specimens biotite is prominent while in others hornblende is conspicuous. The dark brilliant hornblende and biotite phenocrysts contrast strongly with the feldspar crystals. Pyroxene was not detected in the hand specimens. Locally this lava contains fragments of a very light-gray andesite with numerous slender, brilliant, hornblende phenocrysts. In general appearance these inclusions are quite like the andesite fragments in the breccia near the base of the series.

This porphyritic lava was mapped by Becker[111] as "later hornblende andesite." Later Becker[112] recognized the lower part of the Kate Peak andesites, west of Kate Peak, as distinct from, and younger than, his "augite andesite." He had originally mapped these two lavas as a unit. The "augite andesite" of Becker is here considered as a part of the Alta andesite series. Reid[113] described occurrences of andesite east of Glenbrook, Lake Tahoe, which he regarded as identical with the "later hornblende andesite" of the Comstock region. The mica andesite,

[111] Atlas Sheet IV.
[112] [illegible] F. The Washoe Rocks; Calif. Acad. Sci., vol. 2, Bull. 6, pp. [illegible]
[113] [illegible] The Geomorphogeny of the Sierra Nevada northeast of Lake [illegible] Bull. Dept. Geol., vol. 6, pp. 89-161, 1905.

referred to by Reid, may be observed along the Clear Creek highway between Carson City and Lake Tahoe. Just west of the summit of the Carson Range this andesite stands out as bold reefs which add a scenic effect to the region. The mica andesite occurs as dikes cutting through an older Tertiary lava much like the Alta andesite of Silver City. Further south, along the shore of the lake, a highway tunnel passes through a mass of mica andesite, known as Cave Rock, which is identical with the porphyritic variety of the Kate Peak series.

The thickness of the series is estimated to be about 1,200 feet.

### PETROGRAPHY

The lowest exposed member of the Kate Peak series, near Long Canyon, is a light-gray porous rock with pronounced flow structure. Slender jet-black, splendent, hornblende crystals up to three-eighths of an inch in length are conspicuous phenocrysts in the felsitic groundmass.

In thin section the rock has a dark-gray, glassy groundmass with numerous feldspar laths which have a fluidal arrangement about the plagioclase and hornblende phenocrysts. The large plagioclase crystals are well-twinned labradorite ($An_{53}$); zonal banding is common. Hornblende is the dominant ferromagnesian mineral and there are minor amounts of pyroxene. The hornblende is the basaltic variety with an extinction angle of about 9°, but occasionally somewhat greater than this figure. Pleochroism is quite strong in brown and yellow tones. (X-greenish-yellow, Y-yellowish-brown, Z-dark, yellowish-brown).

The pyroxene is colorless with weak pleochroism and parallel extinction, with birefringence (.012), and pleochroism in faint green and red tints. It is optically negative. The mineral is hypersthene, but is less strongly pleochroic than is usual with the hypersthene of the other lavas of this area. There are also a few phenocrysts of strongly pleochroic biotite. The groundmass is rich in tridymite.

Another characteristic member is an almost black, glassy, hornblende-pyroxene andesite. Under the microscope the groundmass is seen to be largely a grayish glass containing slender plagioclase crystals, a few grains of augite, and an abundance of magnetite dust. The principal phenocrysts are andesine-labradorite ($An_{50}$), hypersthene and augite, in about equal amounts, a few crystals of basaltic hornblende, and occasional biotite. Many of the hornblende crystals have been completely resorbed, leaving their crystal outlines solidly filled with magnetite dust, while others show



a narrow border of magnetite surrounded by a broader zone of minute crystals of plagioclase and augite. The reaction rim indicates that the hornblende was dissolved in the magma and reprecipitated as augite and plagioclase. This reaction feature is also common to other lavas of the region. There are a few apatite crystals with black borders. The remainder of the mineral is usually brown, occasionally lavender, and exhibits pleochroism in dark brown and grayish-blue. The usual needle-like colorless apatite microlites are plentiful.

The rock which forms the summit of Kate Peak is petrographically much like the lowest exposed member of the series. A characteristic of this series is the association of pyroxene, basaltic hornblende and biotite.

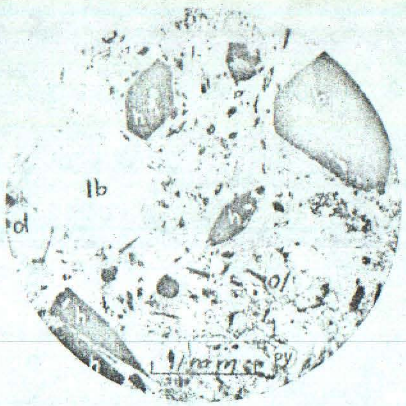



Figure 20. Biotite-Hornblende Andesite of the Kate Peak Series (SC 36). Phenocrysts of biotite (b), hornblende (h), labradorite (lb), pyroxene (py), and olivine (ol), are set in a glassy groundmass. The biotite is dark red and barely translucent. The hornblende is charged with magnetite grains. (Photomicrograph.)

In the rock which caps the Kate Peak series there is found a surprising variety of ferromagnesian minerals and other peculiar features. A photomicrograph is shown in figure 20. The groundmass is chiefly of clouded glass. The plagioclase is labradorite, strongly zoned, and contains inclusions of small, pleochroic, apatite crystals and dusty mineral particles. The hornblende is the basaltic variety and has black borders. Some of the hornblende crystals have been entirely resorbed, leaving a fine dust of magnetite grains or an aggregate of small plagioclase and augite crystals. Augite occurs, usually in clusters of small colorless crystals. The biotite is dark brownish red and barely translucent. Some of the biotite crystals are so highly charged with magnetite as to be opaque and easily overlooked because of their resemblance to the magnetite-charged hornblende.

A peculiar feature of the porphyritic andesite is the presence of an occasional large crystal, or cluster of small crystals, of [illegible] clear, glassy-appearing olivine; fragments and crystals of quartz, and rounded plagioclase. The rounded and embayed [illegible] and plagioclase indicate that they are xenocrysts caught [illegible] lava and partially digested in the magma.

There is a considerable variation in the mineralogic content of this lava as some facies contain no olivine or quartz.

The andesite at Cave Rock, on the eastern shore of Lake Tahoe, is like the rock just described. The two rocks are so similar that the petrographic description given above serves equally well for both. Cave Rock is thirty miles southwest of Silver City. The widely separated intrusions and flows of this rock suggests that the magma from which they came was of considerable lateral extent.

### AGE OF THE KATE PEAK ANDESITES

The later Tertiary lavas are quite unaltered in contrast to the mineralized Miocene lavas. In the field this difference is rather striking, especially along Long Canyon, where the contact between the two formations sets off the mineralized and non-mineralized areas. On the west side of this canyon there are many mines and numerous prospect pits, while on the east, covered by the younger lavas, there is a conspicuous lack of prospect workings. Evidence that these lavas are later than the period of vein formation was demonstrated by the finding of a boulder (figure 24), weighing about 15 tons, resting upon, and entirely surrounded by, hornblende-pyroxene andesite breccia. The boulder is highly silicified vein material containing minor amounts of gold and silver. After digging about the margin of the boulder, miners drove a tunnel, from down the hillside, to intercept the supposed vein at depth. Unfortunately this outcrop is far removed from the vein from which it was a part.

About one mile beyond the northern corner of the map area the porphyritic andesite extends to within a hundred feet of the outcrop of the Occidental lode. The field relations indicate that the younger lavas once covered the vein, but have since been removed by erosion.

Becker[114] shows this lava, later hornblende andesite, lying upon the eroded outcrop of the Comstock Lode at the Sierra Nevada mine. This interpretation is probably correct, as the Kate Peak andesites were accumulated upon an erosion surface which truncates the Alta andesites and the ore-bearing veins of the district.

A thick series of similar lavas occur in the Sierra Nevada, to the north and west, covering the older rocks to a depth of several thousand feet. These rocks have been mapped by Lindgren[115] and described in considerable detail. Lindgren's description of

[114] Loc. cit., Atlas Sheets IV and V.

[115] Lindgren, Waldemar, The Tertiary gravels of the Sierra Nevada of California; U. S. Geol. Survey Prof. Paper 73, p. 30, 1911.



the younger lavas of the Truckee quadrangle, and their study in the field, leaves no doubt that they are identical with the Kate Peak series. In the vicinity of Verdi, Nevada, the Sierran lavas grade upward into, and are interstratified with, the lower part of the Truckee formation. In the Virginia Range, six miles northeast of Virginia City, is an area of the Truckee formation, locally called the Chalk Hills. This area was briefly described by Hill.[116]

At the Nosi ranch, on their southern margin, the lake beds grade into the Kate Peak andesite. About a mile northeast of this ranch the lacustrine deposits are made up of thin-bedded shales and diatomite beds, which alternate with tuffs and breccias. At this particular locality the tuff and breccia beds range from six inches to four feet thick, while those of interstratified lake-bed material are generally from one to four inches thick. Higher in the section lacustrine material appears to predominate. Here the strata strike N. 60° E. and dip 30° to 50° southwest. Elsewhere in the area a great variation of strike and dip may be observed. In the finely-laminated shale, fossil leaves are abundant. The interstratified relationship between the pyroclastic material and the Truckee formation at Verdi and at Chalk Hills demonstrates the comtemporaniety of the top of the late Tertiary lavas of the Sierra Nevada, and of the Kate Peak series, with the base of the Truckee formation.

A critical review of the literature by Louderback[117] would indicate that the Truckee formation is either Upper Miocene or Lower Pliocene. Fossil leaves, collected by the writer, were submitted to Chaney[118] for study and he reported that "from the general generic content of this flora and the absence of certain Miocene elements, I am of the opinion that it is Lower Pliocene."

The fossil evidence thus places the upper portion of Kate Peak andesites in the Lower Pliocene. It is possible that the lower part of this series was extruded in late Miocene time.

### KNICKERBOCKER ANDESITE

A still younger pyroxene andesite is mapped in a number of isolated areas. This lava is a dark, almost black, massive rock, which is quite fresh. A typical occurrence of this lava may be

[116] Hill, J. M., Notes on the economic geology of the Ramsey, Talapoosa, and White Horse mining districts, Nevada; U. S. Geol. Survey Bull. 470, p. 108, 1911.

[117] Louderback, G. D., Period of scarp production in the Great Basin; Univ. Calif. Publ. Bull. Dept. Geol. Sci., vol. 15, p. 20, 1924.

[118] Chaney, R. W., personal communication.

seen in the vicinity of the Knickerbocker shaft and another about 1,500 feet further to the west. Other areas are near the Forman shaft, at the railroad cut northwest of American Flat, and on Basalt Hill. A small mass of the Knickerbocker andesite lies along the western edge of the map area, west of the railroad cut mentioned above. This body of rock continues westward beyond the map area and, at one time, was probably connected with the small mass of lava along the railroad. There are several other smaller areas. Many of the occurrences of the Knickerbocker andesite are close to the fault which lies immediately under the Comstock Lode and continues along the north and west sides of American Flat.

In general, this andesite lies upon the Alta andesite breccias, but the small patch, 1,500 feet west of the Knickerbocker shaft, and the larger area south of Basalt Hill, rests directly upon rhyolite and sediments. In these areas practically all of the older Tertiary lavas had been removed by erosion before the extrusion of the Knickerbocker andesite.

PETROGRAPHY

A specimen from Basalt Hill contains many phenocrysts of labradorite ($An_{58}$), as illustrated in figure 21, and lesser amounts of pyroxene in a brownish glassy groundmass. The phenocrysts comprise about 60 percent and the groundmass 40 percent of the rock. About three-fifths of these are labradorite and the remainder hypersthene and augite, with occasional olivine. The olivine is partially serpentinized. A few apatite crystals are pleochroic; bluish-gray parallel to the $c$ axis and clear, or light brown parallel to the $a$ axis. A crystal of fractured, and partially resorbed, quartz is surrounded by brown glass which also fills the spaces between the fragments. A border of clear augite crystals surrounds the xenocryst. The glass of the groundmass has an index less than that of balsam.

The andesite from near the Forman shaft is like that from Basalt Hill, but contains somewhat more olivine, and the hypersthene exceeds the quantity of augite. The plagioclase is labra[illegible] There is [illegible] pleochroic apatite. Small areas of [illegible] in part altered to greenish chlorite. [illegible] Knickerbocker shaft. The groundmass is of light brown [illegible] containing many crystals of augite and [illegible] Two-thirds of the phenocry[illegible]



labradorite and one-third is equally divided between hypersthene and augite. The few olivine crystals are usually associated with clusters of pyroxene. A single crystal of hornblende has been almost entirely resorbed, leaving but a small fragment of the original mineral. The fragment is surrounded by magnetite bordered by a narrow zone of small grains of augite and plagioclase.

This lava is a pyroxene andesite, but might well be designated basaltic-andesite.

The Knickerbocker andesite may be related to the "black dike" which is indicated on Becker's maps [119] as extending along

**FIGURE 21.**

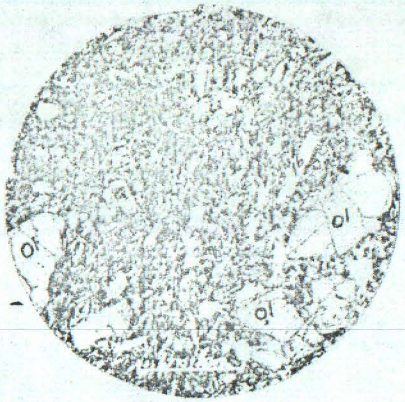


**FIGURE 22.**

**Figure 21. Knickerbocker Andesite from Basalt Hill (SC 24). Phenocrysts of labradorite (lb) are plentiful. The dark areas are altered pyroxene. The glassy groundmass contains small grains of pyroxene and plagioclase laths. A xenocryst of quartz (q) is surrounded by glass, which also penetrates along cracks in the crystal. The glass is bordered by an augite reaction rim. (Photomicrograph.)**

**Figure 22. American Ravine Basalt (SC 42). The larger crystals are olivine (ol), labradorite (lb), and augite (a). The groundmass has an intergranular texture with drop-like grains of augite between the plagioclase microlites. (Photomicrograph.)**

the footwall of the Comstock vein from Virginia City southward to the vicinity of the Knickerbocker shaft.

A thin section from a specimen of the "black dike" collected by Reid [120] from the Hale and Norcross tunnel, just west of the Comstock Lode, shows plagioclase, pyroxenes, and an occasional decomposed olivine, in a partially devitrified glassy groundmass. The rock is considerably altered with the formation of carbonate. [illegible]xture and mineral content is like that of the Knickerbocker [illegible] The alteration is probably due to the hot waters which

[illegible] IX and XIX.
[illegible] collections.

still circulate along the lode. It is not silicified, as is common to the wall rocks near the vein, indicating that the intrusion is post mineral. The dike is unlike the basalt in American Ravine with which it was correlated by Hague and Iddings.[121]

The position of the Knickerbocker andesite areas, near to the fault followed by the dike, and the similar nature of the two rocks suggest that they are from the same source. It is quite possible that some of the surface flows were fed through the fissure now occupied by the "black dike."

### AGE

Field evidence indicates that the Kate Peak, early Pliocene(?), lava was stripped from a considerable area before the Basin Range (Davidson) scarp was formed. This scarp had been subjected to considerable erosion before the extrusion of the Knickerbocker andesite as this lava lies upon a surface, somewhat displaced, extending across the fault. Some displacement has occurred since the extrusion. It is apparent that much of American Flat has been lowered by erosion since the Knickerbocker extrusion and before the flow of American Flat basalt.

Knopf[122] described a similar lava (basalt) downfaulted along the east side of the Singatsee Range. He regarded the lava as Pliocene. The scarp appears to be much later than that which bounds the range a few miles farther north and is not eroded to the same extent as the Davidson scarp.

The only criteria as to the age of the Knickerbocker andesite is that it is considerably later than the early Pliocene and somewhat later than most of the Davidson faulting. In this part of the Great Basin the faults appear to be in part late Pliocene and in part early Pleistocene.[123] Until a closer dating of the Basin and Range periods of faulting is possible, the writer prefers to regard the Knickerbocker andesite as late Pliocene.

## QUATERNARY ROCKS

### AMERICAN FLAT BASALT

The last volcanic activity of the region is represented by remnants of a basalt flow which once extended from American Flat, down through American Ravine, to and beyond Silver City. The largest body of the basalt is in the extreme southeastern part of American Flat. Several other patches are to be seen on terraces along the ravine, the most conspicuous being that which caps the terrace (Basalt Mesa, figure 25) immediately west of Silver City. About midway of the ravine is a terrace, cut in monzonite, about 50 feet above the bottom of the gorge. Scattered basalt boulders remain upon the terrace while numerous blocks of this lava are to be found on the lower slope of the steep canyon wall, between the terrace and the creek. Evidently the terrace was once covered by basalt which now has been all but removed by erosion.

Near the west end of American Ravine the basalt lies upon a surface eroded upon rhyolite and felsitic andesite. Under the large patch in American Flat, and the capping of Basalt Mesa, is alluvium consisting of angular and rounded boulders of all of the pre-basaltic rocks of the American Flat region.

No dikes were observed in the vicinity of these basalt areas, but on the eastern slope of McClellan Peak, west of the American Flat (figure 2), basalt broke through the meta-volcanics and flowed down the wall of the canyon, west of the snowshed. It is quite probable this flow once was continuous down the canyon, across American Flat (figure 28), and through American Ravine to, and probably beyond, Silver City. Erosion has dismembered this flow until only a few small patches remain along American Ravine. Just west of Silver City the basalt is 25 feet thick. The larger mass at the southeastern edge of American Flat is probably somewhat thicker.

### PETROGRAPHY

The basalt is dark gray to almost black. It is commonly somewhat porous and occasionally vesicular and scoraceous. The lava is quite fresh, and nowhere in the district is it found weathered. Olivine and plagioclase are readily identified in hand specimens.

In thin sections phenocrysts of plagioclase, olivine, and augite may be observed in a groundmass rich in slender plagioclase crystals. Grains of augite and magnetite fill the interstices between the plagioclase laths giving the typical intergranular texture. The plagioclase phenocrysts are calcic labradorite.

The augite is usually clear and colorless, but occasional phenocrysts are light yellowish-brown and slightly pleochroic. Some of the colored augite crystals exhibit well-developed hour-glass structure; others have a peculiar zonary extinction. Olivine crystals are conspicuous, as shown in figure 22. Some of the olivine has undergone resorption, with the groundmass penetrating the embayments. The olivine of this rock is unusually free from alteration.

[121] Loc. cit., pp. 27, 28.
[122] Knopf, Adolph, Geology and ore deposits of the Yerington district, Nevada; U. S. Prof. Paper 114, pp. 27; 29–30, 1918.
[123] Louderback, G. D., The period of scarp production in the Great Basin; Univ. Calif. Publ. Bull. Dept. Geol. Sci., vol. 15, p. 38, 1924.

### RELATION TO OTHER BASALT FLOWS

Olivine basalt is found throughout the western part of the Great Basin. Many small flows are to be seen in the Virginia Range and in the Sierra Nevada.

A basalt flow covers the southern slope of McClellan Peak down to Eagle Valley, north of Carson City (figure 1). The basalt at Steamboat Springs issued from fissures west of the springs.

In the Sierra Nevada, west of Steamboat Springs, a small flow may be seen in Thomas Creek. Flows are also found in the canyons of the Virginia Range east of Steamboat Springs. Numerous other flows in this region might be referred to. All of these basalts are rich in olivine and are similar to that at American Ravine. Becker[124] remarked the similarity of the Steamboat and American Flat basalts.

Lindgren[125] in summarizing the volcanic history of the northern Sierra Nevada, and the sequence of the lavas, remarked: "Almost all recorded successions agree, however, in one point, namely, that the eruptions close with the outpouring of basalts." The sequence of the Tertiary lavas of the Comstock closely parallels that of the Sierra Nevada, and the basalt flow marks the close of the volcanic activity.

### ALLUVIUM

Alluvial deposits of considerable difference in age occur in the region. An older alluvium is found along the lower slopes of the hills bordering the valleys. The younger alluvium is found along the stream courses and underlies the valley floors. All of the alluvium in the district was mapped as a unit.

The older alluvium underlies the basalt along American Ravine. The large area in the southwestern part of the district contains thin deposits of gypsite. These deposits are intermingled with bouldery alluvium and range in thickness from a thin mantle to a depth of several feet. Because of their small extent, and their gradational boundaries, they were not differentiated on the map. A large deposit of gypsite, containing alluvial fan material, lies in the neighborhood of Mound House. Some years ago this material was used for the production of plaster.

Gypsum and anhydrite are associated with the limestone in the Mesozoic(?) sediments.[126] A quarry one and one-half miles west of Mound House for several years was the source of the raw material used for the manufacture of plaster. Along the edges of the alluvial terraces are the light-colored gypsite deposits, formed through the solution, transportation, and redeposition of gypsum derived from the beds in the Washoe Mountains.[127]

The alluvium in the southeastern part of the map area consists of a thin mantle of bouldery soil overlying deep gravels. These gravels are, for the most part, well rounded. This deposit, as well as the gravels in nearby Gold Creek, are auriferous. It was the discovery of gold in the gravels of Gold Creek that led to the finding of the veins of the Silver City district and then the discovery of the Comstock Lode.

Gold Canyon follows along one of the principal veins for about three miles and its tributaries drain the ore-bearing region about Silver City. Gold Creek thus received material from numerous veins and the gold was concentrated in the stream gravels. About one mile below Silver City, the gradient lessened and gravel was deposited to considerable depth. The Davidson diorite is very resistant to disintegration and hence is a prominent constituent of the gravels of Gold Creek from its source near Gold Hill (see figure 26) to its junction with the Carson River at Dayton.

## GEOLOGIC STRUCTURES

### PRELIMINARY STATEMENT

The rocks of the Comstock region have been subjected to several periods of deformation. The sediments were folded to steep inclinations and beveled by erosion, before the deposition of the pre-Cretaceous volcanic rocks. These old rocks were intruded by quartz monzonite during the late Jurassic. Erosion laid bare the intrusive prior to the extrusion of the earlier Tertiary volcanic rocks.

The earlier Tertiary lavas in the eastern part of the district have a general northerly strike and dip westerly from 40° to 60°. In the western part of the area the dips are more gentle. These rocks were displaced in pre-Pliocene time during two, and possibly more, periods of faulting. Between periods of diastrophic activity there were intervals of quiescence, during which many hundreds of feet of rock were removed by erosion.

The faulting which displaced the earlier Tertiary lavas occurred probably during middle Miocene. Along the fractures formed at this time, the ore-bearing veins of the district were deposited.

[124] Becker, G. F., Geology of the quicksilver deposits of the Pacific Slope, with atlas: U. S. Geol. Survey Mon. 13, p. 156, 1888.

[125] Lindgren, Waldemar, The igneous geology of the Cordilleras and its problems. Problems of North American Geology, Yale Univ. Press. New Haven, p. 271, 1915.

[126] Jones, J. C., In R. W. Stone and others. Gypsum deposits of the United States: U. S. Geol. Survey Bull. 697, pp. 153-155, 1920.

[127] Gianella, V. P., Itinerary, Reno to Walley Hot Springs and return: 16th Internat. Geol. Congress. Guidebook 16, Excursion C-1 pp. 110-111, 1933.

Figure 23. Sutro Tuff Outcrop in Long Canyon. View is south along the strike of the formation. The tuffs are well stratified, and dip westerly with an inclination of 40°.



The veins were crushed during later movements. These faults are referred to as Comstock pre-mineral, and Comstock post-mineral faults. Before the extrusion of early Pliocene(?) volcanic rocks, erosion removed all scarps which might have been formed by this faulting.

The later Tertiary lavas were, to a large extent, stripped from the old erosion surface prior to the late Pliocene, Basin Range, fault movements. The late faulting was completed sufficiently long ago that the scarps were considerably eroded and trenched by canyons before the extrusion of Pleistocene basalt. Recent scarps, along the lines of earlier faults, have displaced the alluvium in a few places.

Normal-type faults predominate in the region, only occasional minor reverse faulting being observed in the mines. The dips of the principal faults usually range from 40° to 60°, although greater and lesser dips have been measured. The major faults have throws exceeding 1,500 feet. The principal faults have been mapped to bring out the major lines of dislocation and the fracture pattern. Lack of an accurate base made it impractical to indicate many of the lesser faults.

Becker[128] stressed an hypothesis that the faulting along the Comstock Lode resulted from minor displacements between numerous parallel sheets, distributed over a broad zone. During this study the writer not only was unable to find evidence supporting such an hypothesis, but, on the contrary, noted that the fault movement was confined within fairly sharply-defined limits. The foregoing statement does not imply that there are no parallel fractures in the vicinity of faults, but that the displacement is usually confined to a narrow belt; not distributed throughout a broad-sheeted zone. It is true that in many instances the wall rocks are greatly crushed in the nieghborhood of large displacements. Crosscuts into the wall rocks commonly reveal massive rock within a relatively short distance from the vein.

### TERTIARY FAULTS

#### COMSTOCK PRE-MINERAL FAULTS

The great thickness of earlier Tertiary volcanics was subjected to deformation with the production of northwest-trending faults. There is some indication that sheeting, with a northerly trend and eastward dip preceded this faulting. This structure is particularly conspicuous along the north wall of Gold Canyon a few hundred feet northeast of Devils Gate (figure 27). Some

[128] Becker, G. F., op. cit., chapter 4.

of the sheeting, with this trend, no doubt accompanied a later period of deformation. The lavas appear to have steep eastward dips and were so considered by Church.[129] The volcanics, however, dip westward with an inclination of about 40°. This period of faulting was accompanied with, or followed by, the intrusion of dikes of biotite andesite porphyry. The dikes followed northwest fractures and commonly terminate abruptly against the sheeted zones. This behavior of the dikes suggests that some of the sheeting was earlier than the intrusions.

Northeasterly-trending faults, nearly parallel to the sheeting, displaced the dikes. Mineralization occurred along these faults and the veins contain blocks of dike rock. The Silver City branch vein, along Gold Canyon, and the Alamo vein, south of the Forman shaft, are along the northwest faults. The fault along Gold Canyon no doubt was active during both fault movements. It is probable that both the northwest and the northeast faulting, the intrusion of andesite porphyry, and also the mineralization, occurred within a relatively short interval of time. The veins of the Silver City district, and those of the Comstock area to the north, were formed at this time. The major fault of this period is that along which the Comstock Lode was deposited. This fault may be traced throughout most of its length by the quartz-vein croppings. Even where the veins do not crop out prominently, the vein has been followed in mine workings. The line of fracture parallels the front of Mount Davidson, at the foot of the Basin Range scarp, through Virginia City to Gold Hill. This fault enters the map area about a thousand feet west of the Overman shaft. At Gold Hill, footwall branch-faults extend toward American Flat, while the main fault turns southeasterly along Gold Canyon, passes through Silver City, and continues southerly along the west side of Spring Valley. The course of this fault cannot be traced with certainty beyond the southern limits of the map area. The total known length of this fracture system is over five miles.

In addition to the branching of the fault at Gold Hill, it again branches at the Silver Hill mine, where there are several distinct veins. West of Devils Gate (figure 27) the main line of fracturing is not well defined, but there are a series of step faults in a zone several hundred feet wide. These faults are occupied by quartz veins. It is possible that one of these veins continues across American Ravine to the Oest mine. South of Devils Gate

[129] Church, J. A., The Comstock Lode, its formation and history; p. 138, 1879.



the fracture zone again becomes restricted and, at the Dayton and Kossuth mines, is filled with a wide quartz vein.

At the Dayton mine the main vein continues to the south; footwall and hanging wall fractures diverge at slight angles and continue southward for a considerable distance. These fractures are now occupied by quartz veins. Branch veins are present also in the vicinity of the Spring Valley mine.

The strike of the fault is N. 45° W., near the Overman shaft, and about N. 30° W. from the Justice to the Dayton mine, where the trend is northerly, and beyond to Spring Valley the strike changes to somewhat west of north. The dip of the fault is constantly to the east, or northeast, with an inclination usually above 40°, and reaches 60° in the Overman mine.

South of Spring Valley, beyond the map area, is the Daney mine near the old, now abandoned, Carson-Dayton highway. This mine appears to be on the main line of fracturing, The Daney vein strikes N. 50° W., and dips 45° northeasterly. The strike aligns with a recent scarp which displaces the alluvium from this mine to within a few hundred feet of the Spring Valley mine. It is quite probable that this fault followed a line of earlier fracturing as is common with Recent scarps throughout the Great Basin.

Another area in which pre-mineral faults are prominent is in a belt trending northeasterly through Silver City. This zone is evidenced on the map (plate 1) by the numerous veins northeast of the town and a lesser number to the southwest. Some of the veins in the northeastern part of the map area trend toward the Occidental vein, which is just beyond the northern boundary of the district. These veins are wholly within the Tertiary volcanic rocks. The Oest vein, southwest of Gold Canyon, has both walls in pre-Tertiary meta-volcanics. Other veins in that area, as the Haywood, have meta-andesite on the footwall and Tertiary lavas make up the hanging wall.

So far as known the northeast-trending veins do not offset the main vein which parallels Gold Canyon. Displacement along these faults evidently was accompanied by lateral movement along the stronger fracture zone. The rock masses affected by the combined movements appear to have been displaced to the southeast, at the intersection of the faults, much like the movement of snow down the valley of a roof. The mineralization within the quartz veins indicates that throughout the region there were recurring fault movements during ore deposition.

### COMSTOCK POST-MINERAL FAULTS

Faulting continued, or again became active, after the cessation of vein deposition. Many of the veins carry gouge which was formed by post-mineral movement. The gouge may be along either or both walls. Many of the veins have been fractured, or even crushed. The ore in the Alamo vein, parallel to the west fork of Nigger Ravine, has been crushed and intermingled with gouge. Beautifully polished and grooved vein-material is exposed in the outcrop of the Occidental vein, just beyond the northern limit of the map area, and on the vein east of hill 5020, southeast of Silver City.

### MAGNITUDE OF COMSTOCK FAULT DISPLACEMENTS

The first, and so far as the writer is aware, the only estimate of displacement in the Comstock region is that made by Becker,[130] who measured the displacement of the Pliocene erosion surface which is preserved on the summit area of Mount Davidson and also on the hanging wall block which abuts against the foot of the Davidson scarp. This displacement is that of the Basin Range period of faulting. No writer has discussed the earlier faults.

No method was found by which the displacements due to the Comstock pre- and post-mineral strike faults could be distinguished. In a few instances post-mineral faults have offset the veins, but these cross faults offer no information relative to the displacements in the plane of the lode.

The Sutro tuff and the Hartford Hill rhyolite, because of their distinctive natures, serve as key horizons by which the throw of the earlier faults can be estimated. These are the only formations in the area which are suited to the purpose.

At Gold Hill, a short distance north of the map area, conditions are favorable for determining the combined throw of the Comstock (Miocene) and the Davidson (Pliocene) fault movements. Here the Sutro tuff occurs on both sides of the major fault.

The Sutro tuff is exposed along the south lateral of the Sutro Tunnel (page 56), about 800 feet east and 1,000 feet south of the east shaft of the Yellow Jacket mine. The tuffs projected down, westward, on their average dip of 35°, should contact the Comstock Lode at the 2,700-foot level of the Yellow Jacket shaft. Here the base of the tuffs would be 3,350 feet above sea level. In the footwall of the lode, above the Ophir Grade and directly west of the Yellow Jacket shaft, the tuff rests upon the Alta andesite at an elevation of 6,800 feet. The difference in elevation between the two exposures gives 3,450 feet as the total displacement across the vein. The throw of the Davidson fault is 1,500 feet (see page 87) leaving about 2,000 feet for the throw of the Comstock faulting. The footwall beds dip westerly but, as the footwall country has not been mapped in detail, no allowance has been made for this factor which would increase the above figure. It is evident that the vertical displacement due to the Comstock faulting is greater than 2,000 feet. NO!

But—DE's. initial thrust—disrupts this projection

[130] Becker, G. F., Geology of the Comstock Lode and the Washoe district with atlas; U. S. Geol. Survey Mon. 3, p. 180, 1882.



It might be suggested that much of this displacement is due to distributive faulting between the exposure of the tuffs, in the south lateral, and their projected position on the vein. However, in describing the rocks of this locality Becker[131] writes: "In a few places, as for example the 2,700-foot level of the Yellow Jacket, there are limited occurrences of excessively fine-grained, closely laminated diabase resembling slate."

This statement indicates that the tuffs are actually present on the 2,700-foot level, as this description is much like that given of the Sutro tuff exposure, referred to above, in the footwall of the lode. Becker[132] considered this occurrence as a facies of the Davidson diorite "with a closely laminated structure, not unlike a calcareous slate."

No determination of the displacement is possible further south along the lode, because of lack of recognizable horizons across the line of faulting. However, from the position of the rhyolite on opposite sides of the line of faulting, it is probable that the throw is about 800 to 900 feet at the Silver Hill mine, and from 500 to 700 feet at the Dayton mine.

### DAVIDSON PERIOD OF FAULTING

Within, or immediately adjoining, the map area is the high scarp forming the bold eastern slope of McClellan Peak and the even steeper eastern face of Mount Davidson at Virginia City (figure 2). Mount Davidson is the most conspicuous topographic feature of the region, and the movement responsible for its uplift is here referred to as the Davidson period of faulting. This fault movement is a part of the great disturbance which produced the Basin and Range structure.

This scarp was formed by a fault along the footwall of the Comstock Lode at Virginia City and Gold Hill. Beyond Gold Hill the fault continues along the western side of American Flat (figure 28) to the pass west of Basalt Hill. Beyond this pass the

[131] Loc. cit., p. 51.
[132] Loc. cit., p. 41.

Figure 24. Boulder of Vein Material in Kate Peak Andesite Breccia. This boulder, of 15 to 20 tons weight, lies in unaltered breccia a short distance northwest of Kate Peak.



scarp becomes less prominent and the southward continuation of the fault has not been determined.

The scarp along the west side of Spring Valley, and that forming the east front of the rhyolite hill in the southeast corner of the map area, was probably formed during this period of faulting.

South of Gold Hill the Knickerbocker andesite lies on both the footwall and hanging wall sides of the fault. The Davidson scarp appears to have undergone considerable erosion before the extrusion of this lava, and but little movement has occurred since this period of volcanism.

Becker[133] determined the throw of the Davidson fault at Virginia City to be 2,005 feet. The throw at Gold Hill, estimated from the displacement of the Pliocene surface, is about 1,500 feet. The faulting appears to have elevated the footwall block.

Since the formation of the scarp it has been trenched by deep canyons and its outlines have been softened by erosion. The scarp along the eastern front of the Carson Range, comprising the eastern summit of the Sierra Nevada, has been eroded to about the same extent as has the Davidson scarp. It is the writer's opinion that these two scarps are of the same age.

Since the Carson Range acquired its present form, deep canyons have been eroded into it, to about their present depth, before the flows of olivine basalt. After the basalt eruption the canyons have been eroded by ice during three glacial epochs. Because of the events which have taken place since the formation of these Basin Range scarps they are regarded as at least as old as late Pliocene.

### RECENT FAULTS

A series of small scarps displace the alluvium at the foot of the Davidson scarp west of American Flat. These scarps are but a few feet in height and a few hundred feet in length.

The largest Recent scarp is that extending for 4,000 feet southeasterly across the wash at the south end of Spring Valley. This scarp continues from the southern end of Grizzly Hill to the old Daney mine, beyond the southern limit of the map area. This scarp trends directly across the drainage from the southwestern part of the district. This fault displaces the alluvium between the south end of the Spring Valley mine vein and the north end of the vein at the Daney mine. From its position between these veins, it is thought that the scarp has been formed by recurrent movement along an older fault which has been beveled by erosion and covered by alluvium. The displacement

[133] Loc. cit., p. 180.

along this fault reaches a maximum of over 30 feet. The slight erosion of these scarps in alluvium indicates their recency.

Many similar Recent scarps may be seen along the eastern front of the Sierra Nevada. The most conspicuous of these is at Genoa, and has been described in detail by Lawson.[134] Other scarps near Carson City[135] displace early Pleistocene and late Quaternary alluvium. One of these scarps trends through Carson City and northward to the Carson Hot Springs.

In the western part of the Great Basin scarps have been formed during the past several decades,[136] and as recently as 1934.[137]

## VEINS AND ORE DEPOSITS

### DISTRIBUTION AND CHARACTER OF VEINS

This investigation was principally confined to mapping the formations and determining the sequence and major structural relations of the rocks. Some time was devoted to the study of many of the mines. Some comment will be given here on the veins and ore deposits.

Of the numerous veins in the region, only a sufficient number have been mapped that would give an adequate idea of their distribution and relationship. The veins occupy fissures, and some are along faults of considerable displacement. The veins of economic interest are characteristic of the Tertiary epithermal type as classified by Lindgren.[138]

The few pre-Tertiary veins of the district are closely associated with the granitic period of intrusion. They have produced but little ore. Of particular interest is a vein, of this period, exposed in the railroad cut west of the South End shaft. The vein, less than a foot wide, is enclosed by the meta-volcanics and has an attitude of N. 60° W. 73° SW. Quartz from the outcrop of the vein, and the early Tertiary erosion surface, is overlain by the American Ravine andesite, thus clearly demonstrating its pre-Tertiary age. The veins of this period are not numerous and are not of economic importance.

The two-mile-long north-south portion of the Comstock Lode has had many producing mines. The main lode appears to terminate at Gold Hill, and the ore-bearing Silver City vein continues southeast along Gold Canyon. Exploration along the western side of American Flat failed to reveal a continuation of the lode. The Silver City line of fracturing extends from the Overman mine, in Gold Hill, to the old Daney mine on the old Carson-Dayton highway. This vein system has produced ore from many mines along its length of over 22,000 feet, and productive mines, at the ends, are separated by a distance of over four miles. With the northern part of the lode, it forms a productive vein system six miles long.

The footwall of the Comstock Lode is diorite at Virginia City, metamorphic sediments at Gold Hill, rhyolite and Alta andesite at, and south of, the Overman shaft; and meta-andesite, or rhyolite, from the Justice to the limit of the map area. The footwall branches from the Justice southward may have both walls of rhyolite, near the surface, but at slight depth they pass into the underlying meta-andesite. The Occidental vein, so far as known, has both walls of Alta andesite. The hanging wall consists of Tertiary lavas in all mine workings that are now accessible. Some of the veins southwest of Silver City are entirely in meta-andesite.

The principal vein of the Silver City district, the Silver City branch of the Comstock Lode, was deposited in a fault closely paralleling Gold Canyon. This vein diverges from the strike of the Comstock Lode, at Gold Hill, and trends southeasterly to Silver City and then southward along the west side of Spring Valley. In places quartz may be absent, with only gouge between the wall rocks, so that the vein is not continuous throughout the extent of the fault.

Just south of the Justice mine the main vein bends westward into the footwall, while several smaller veins continue on the trend of the principal line of fracturing. The widest and best defined vein is 20 feet or more in width, but it is from the lesser veins, and on intersections, that the principal ore bodies occur. Some of the footwall veins appear to cross American Ravine and one probably continues to the Oest mine. The Oest vein may be a footwall fracture to the northeast-trending Santiago vein, or possibly these are but parts of one and the same vein.

[134] Lawson, A. C., The Recent fault scarps at Genoa, Nevada; Seismol. Soc. America Bull., vol. 2, pp. 193–200, 1912.

[135] Gianella, V. P., Itinerary, Reno to Walley Hot Springs and return; 16th Internat. Geol. Cong. Guidebook 16, p. 111, 1933.

[136] Hobbs, W. H., The earthquake of 1872 in the Owens River Valley, California; Beitrage zur Geophysik, Band 10, pp. 352–385, 1910. Jones, J. C., the Pleasant Valley, Nevada, earthquake of October 2, 1915. Seismol. Soc. America Bull., vol. 5, pp. 190–205, 1915.

[137] Gianella, V. P., and Callaghan, Eugene, The earthquake of December 20, 1932, at Cedar Mountain, Nevada, and its bearing on the genesis of Basin Range structure; Jour. Geology, vol. 42. pp. 1–22, 1934. Gianella, V. P., and Callaghan, Eugene, The Cedar Mountain, Nevada, earthquake of December 20, 1932; Seismol. Soc. America Bull., vol. 24, pp. 345–384, 1934. Callaghan, Eugene, and Gianella, V. P., the Earthquake of January 30, 1934, at Excelsior Mountains, Nevada; Seismol. Soc. America Bull. 25, pp. 161–168, 1935.

[138] Lindgren, Waldemar, Mineral deposits; pp. 516–530. 1928.

At the Justice mine (figure 26) the Woodville vein lies in the hanging wall, almost perpendicular to the trend of the Silver City vein. It dips to the southeast. This vein contains both quartz and calcite and has produced much ore. In places it is a stringer lode, differing in that respect from most of the other veins of the district. The Woodville vein is unique in that it is but little affected by post-mineral movement, while the nearby Silver City vein is accompanied by a heavy gouge and is usually greatly crushed. The crushed and dragged ore is conspicuous in the Keystone mine, north of the Justice shaft. South of the Woodville shaft, in the vicinity of Devils Gate (figure 27), the faulting is distributed, while at the Dayton mine it is confined to a narrow zone, and a strong well-defined quartz vein continues southerly through the Kossuth mine workings.

South of the Kossuth the main vein continues southward along the west side of Spring Valley. Veins continue through the Spring Valley mine, and in all probability beyond the south limit of the map area to the old Daney mine.

The Occidental lode is a large vein, sometimes referred to as the Brunswick lode. The Occidental vein is one and one-half miles east of, and parallel to, the Comstock Lode. Its southern end barely enters the northeastern corner of the map area. This vein could not be traced southward beyond Long Canyon. Most of the veins northeast of Silver City converge toward the Occidental vein, and appear therefore to be related to the same fault zone.

As indicated above, branching of the veins is quite common. It is probably more correct to state that many veins trend from the principal lines of mineralization into the footwall or hanging wall. It is seldom that these branch veins actually contact and merge into the larger vein. Whether the branch veins originally were continuous with, or approached close to, but did not actually join the main vein, is difficult to determine because post-mineral movement commonly obscures their relationship.

The distribution of the veins clearly indicates two systems of fracturing. One group of veins trends northwesterly, roughly paralleling Gold Canyon. The other group is northeasterly, diagonally across the map area.

### GANGUE MINERALS

According to early reports, the vein at Virginia City and Gold Hill is composed of quartz and included rock fragments, with but little calcite.

Southeasterly from Gold Hill much calcite is found in some



of the veins. In the Justice, Silver Hill, Woodville, Oest, Occidental, and many other mines, the veins may be either of quartz or calcite. In the same vein one may find either, or both, of these types of gangue. In the early days of the district a kiln produced lime from the calcite portion of the Occidental lode.

Reid was of the opinion that the Silver City branch was not the same age as the Comstock Lode because of the difference in the minerals of the two veins. In discussing these features he says:[139] "The gangue in the Silver City portion of the 'fork,' as of a few of the east-west veins east of Bullion Ravine, is largely calcite. Granting the identity of the rocks as set forth in the work of Hague and Iddings, this difference in gangue mineral from the silica of the lode proper can be accounted for, in the most probable way, by assuming a difference of age."

However, the Silver City vein is not predominately composed of calcite. In the Overman and Justice mines there is much quartz, and long reaches of the vein are almost exclusively quartz. In the Dayton, Kossuth, and Spring Valley mines the veins are chiefly quartz with but little calcite. There are many places, northerly from Silver City, where this and other veins are composed of calcite.

A comparison of the ores of Gold Hill with those of the Silver City area is of interest. The average ore from Crown Point mine, on the Comstock Lode at Gold Hill, is much like that of the average vein of the Silver City district, but has a higher silver-gold ratio. Some of the ores of Gold Hill were like that from the Silver Hill mine, but locally the latter contains much calcite. The Silver Hill mine has a higher silver-gold ratio than most of the other veins of the district. The Woodville vein also contains much calcite. King,[140] in describing the rich ore from the bonanzas at Virginia City, wrote: "From the Gould and Curry to the north line of the Central the quartz bodies continue; but instead of being charged with characteristic silver ore, contain bonanzas of the base metals; galena, blende, and iron pyrites predominating. The 600 feet lying directly north of the South Ophir mine was at one time the richest and most productive portion of the Comstock."

King, therefore, noted the great difference in the ore from adjacent portions of the same vein. Similar base ores were later found in the "Big Bonanza," on the East vein, and also in the Gold Hill mines. The differences in mineral content of the Silver

[139] Reid, J. A., The structure and genesis of the Comstock Lode: Univ. Calif. Pub. Bull. Dept. Geol., vol. 4, pp. 182-183, 1905.

[140] King, loc. cit., p. 61.

City vein is not so marked as that occurring in the Comstock Lode from Gold Hill to Virginia City.

In the Dayton and Overman mines small veins of barren calcite traverse gouge on faults which have disturbed the ore bodies. It is apparent that much of the barren calcite was introduced after the solutions ceased to deposit ore minerals.

Some of the carbonate gangue is manganiferous and, upon weathering, stains the outcrops black with manganese oxides. Some of this gangue is probably ankerite. The Cosmopolitan vein, and parts of the Occidental vein, is a light buff color instead of white as are most of the other quartz veins of the district. Examination, in thin section, shows the buff vein material to be composed of quartz, calcite, and adularia. Occasional grains of adularia have been detected in the other veins. In the buff-colored parts of the Occidental, and other veins, the adularia may constitute ten to fifteen percent of the vein material.

### ORE MINERALS

In general, the mineralogy of the veins of the Silver City district is simple. Among the ore minerals noted by the writer are pyrite, gold, silver, electrum, occasionally argentite, and rarely chalcopyrite. Molybdenite occurs in a small vein near Devils Gate. The Silver Hill mine has produced beautiful specimens of native silver in calcite. The quantity of sulphide minerals is rather small, usually not more than one or two percent of the vein material. In this respect they differ from the bonanza ores of Virginia City, which contained large quantities, and considerable variety, of ore minerals.[141] In that part of the lode base-metal sulphides were quite prevalent. Galena, sphalerite, and chalcopyrite may now be seen in the near-surface workings of the Ophir mine. Base-metal sulphides are generally conspicuously absent from the Tertiary veins of the Silver City district. In some of the small pre-Tertiary veins west of Silver City galena and chalcopyrite are common.

In some of the mines pyrite occurs, in considerable abundance, in the wall rocks and in post-mineral gouge. Rarely does this material constitute ore. In some mines the gouge is mined as ore, but only where it contains crushed, ore-bearing parts of veins. Pyrite was probably deposited in the gouge after the ore-forming period had come to a close, as the gold and silver is usually confined to the quartz, or calcite, veins.

[141] King, Clarence, The Comstock Lode; U. S. Geol. Expl. of the Fortieth Parallel, vol. 3, pp. 11-96, 1870. Bastin, E. S., Bonanza ores of the Comstock Lode, Virginia City, Nevada; U. S. Geol. Survey Bull. 731-C, pp. 40-63, 1922.



### ORE SHOOTS

Most of the ore now being milled, other than that from the Dayton mine, is produced by lessees. There is but little ore "blocked-out," and therefore one seldom has the opportunity of examining ore exposures except at the working faces.

The ore bodies are in the form of shoots, or lenses, and much of the vein is barren. The ore shoots commonly are at, or near to, vein intersections. Many of the larger ore bodies were found near intersections, and especially where there is a branching of the main vein. The Oest ore body was near the junction of two veins. At the Silver Hill and Dayton mines, and at Gold Hill, there is much branching of the veins. Valuable ore bodies were found at these places. From the vicinity of the Silver Hill mine many veins trend to the northeast into the hanging wall country.

The Woodville vein, a northeast trending vein in the hanging wall, proved to be one of the most productive veins of the district. The Spring Valley mine shaft was lately sunk near the junction of several veins and a good ore body was discovered.

### DEPTH OF ORE OCCURRENCE

In the Silver City district all ore being extracted at present comes from shallow workings; usually from depths of less than three hundred feet. In the past a few shafts were sunk to much greater depth, but then, as now, production was confined to within a few hundred feet of the surface. All of the deeper workings are now inaccessible, so that the conditions encountered at depth cannot be studied. Quartz was found in the deeper levels in some of the old workings, but the ore was reported to have been quite low grade or in small quantities. The values of some of the near-surface ore bodies are undoubtedly due to secondary enrichment, but many of the ores now being mined contain much pyrite, and the precious metal occurs in the form of light-yellow gold, or rather an alloy of gold and silver, and apparently is primary.

Most of the production from the mines of Virginia City, Gold Hill, and also from the Justice mine, came from above 4,600 feet above sea level.[142] In fact, up to the time of Becker's report, in 1882, only small ore shoots reached that depth, although much exploration has been carried on to 3,600 feet (2,500 level) and even down to 3,200 feet above sea level. Since that time deeper ore bodies have been discovered, especially on the East vein, in the Ophir, Mexican, and Union mines, and good ore was extracted down to 3,200 feet above sea level. The production from these deeper levels was not large, and amounted to

[142] See Becker, G. F., loc. cit., Atlas Sheets X, XI, XII.

not more than two percent of the total production of the Comstock district. Does the 4,600 feet elevation then constitute the "dead line" for ore bodies in this district? As the known ore shoots of the Silver City district have terminated well above that level, such a conclusion may be justified.

It might be suggested, however, that the ore occurs in short shoots or lenses, and only those lying relatively close to the surface have been discovered, and other lenses might be found by deeper exploration. Deeper exploration has so far failed to find other ore bodies. It is probable that the ores reach downward only to the bottom of the zone of enrichment. One property, now mining 250 feet or more below the permanent water

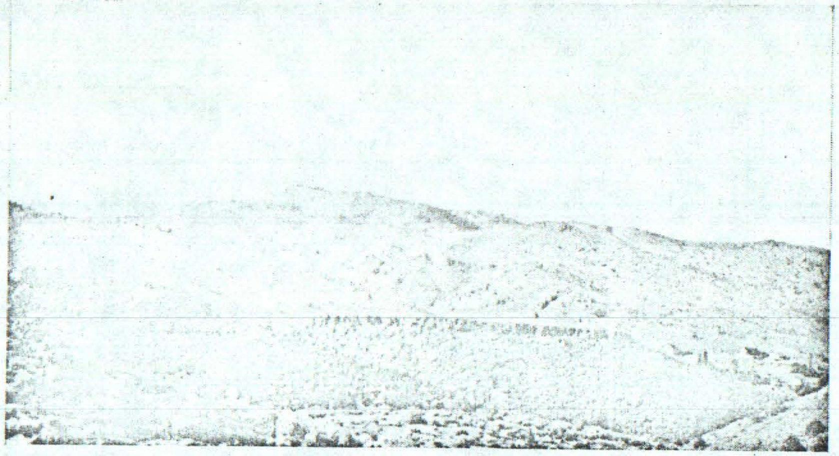


**Figure 25. Basalt Mesa at the Mouth of American Ravine. In the middle distance is a capping of basalt lying on meta-andesite. American Ravine crosses the line of view, in front of the mesa, and joins Gold Canyon a short distance to the right. Beyond the mesa, to the right, may be seen a portion of Silver City.**

level, is producing unoxidized ore. This is apparently primary ore.

Ore bodies indubitably were secondarily enriched during the long and deep erosion which reduced the region to one of low relief. Bastin,[143] in an instructive paper, reported the results of a microscopic study of ores from the Comstock Lode, on specimens from depths of 2,500 feet to within a few hundred feet of the surface. He concluded that supergene (surficial) enrichment was notable in some mines down to 350 feet in depth. The enrichment was by silver and copper, while no enrichment of

[143] Bastin, E. S., Bonanza ores of the Comstock Lode, Virginia City, Nevada: U. S. Geol. Survey Bull. 735-C, pp. 40-63, 1922.



**Figure 26. View of Gold Canyon, northward from Hartford Hill. In the left foreground is the eastern slope of Hartford Hill. Along the bottom of the canyon are the waste dumps of the Justice (left), and Woodville (right) shafts. At the head of the canyon are the mine dumps at Gold Hill. Mount Davidson is the peak in the center distance. At the extreme right, in the mid-distance, is the Alta shaft, and beyond, in the far distance, is the dump at the east shaft of the Yellow Jacket mine.**

gold was noted. In summing up the results of his investigations, Bastin[144] says: "Enrichment on a scale sufficient to exert any notable influence on the tenor of the ore was therefore noted only in ores obtained less than 500 feet below the surface, and some ores from these slight depths showed no enrichment phenomena."

These silver ores were between the surface and the ground-water level. The ground-water level is probably less than 300 feet from the surface in any of the Silver City mines, and, in most of them, it is much less than this figure. In the Spring Valley mine the water stood less than 60 feet below the surface, and in the Dayton mine, when recently reopened, water was flowing through a tunnel from the vein into Gold Creek.

It is unlikely that silver enrichment would extend much below ground-water. Enrichment of the gold, even where ground-water is deep, would probably extend to but slight depth. Evidently the ore bodies of the Comstock owed but little of their value to secondary enrichment. Most of the ore shoots were below the ground-water level. This condition applies even more forcibly in the Silver City area where the gold value greatly predominates over that of silver.

In this district, not only the ore shoots, but many of the veins, terminate at shallow depth. It is not uncommon for the veins to decrease in width downward and pass into clay seams. In some cases the veins persist, but become too low in value to be profitable. It would appear that the evidence, accumulated during the long period of mining, indicates that deeper exploration would be unprofitable.

During this study no geological evidence was found which indicated that deeper exploration would not reveal other ore deposits. Lord,[145] in discussing the probable occurrence of deeper-seated ore deposits on the Comstock Lode, wrote: "No valid argument against their occurrence has been presented, but positive evidence of their existence is lacking." This shrewd observation, made in 1883, appears to apply with equal force to the Silver City area.

### ALTERATION OF THE WALL ROCKS

The chief effect of the ore-bearing solutions upon the wall rocks was the introduction of silica, which rendered the rocks quite hard and imparted to them a dark, rather fresh, appearance. The silicified rock, because of this appearance, has been mistaken for

[144] Idem., p. 47.
[145] Op. cit., p. 410.



intrusions. In the neighborhood of the Comstock Lode, at Virginia City, much carbonate and some sericite has been introduced with the silica. It was this altered andesite which Becker[146] referred to as the "earlier diabase."

On the 1,100 level of the Overman mine the Sutro tuffs have been silicified and have the appearance of siliceous shales. These tuffs also contain considerable fine-grained pyrite. Other rocks in this mine show similar alteration. Black shale from the footwall of the Davidson fault, on the 1,100 level, contains veinlets of quartz, pyrite, calcite, and minor amounts of sericite. The veinlets consist of fine, interlocking grains which are predominantly quartz. Dark carbonaceous material is present in slender lenses and streaks.

Andesite in the southeast drift, 300 feet from the 1,100 station, contains much epidote and calcite. Thin sections reveal areas of radiating, fibrous chlorite. Pyrite is present in considerable quantity. The rhyolite in the footwall of the vein, and 600 feet southeast of the 1,100 station, has been bleached by the ore solutions. Thin sections, from a specimen taken within a few feet of the vein, show the rock to have a glassy groundmass with distinct flow structure. The glass has undergone incipient devitrification. The feldspars are partially altered to sericite and the biotite is bleached and colorless. No epidote is present. The alteration of this rock is slight, considering its position close to a 20-foot vein of quartz.

A specimen of porphyritic, dark-gray hornblende andesite from the 900-foot level west crosscut was collected within 50 feet of the vein. Study under the microscope reveals much introduced quartz, and the feldspars largely altered to calcite and sericite. The hornblende phenocrysts contain much calcite and chlorite.

Sections from rocks adjoining other veins of the district indicate that the alteration described above is general. The principal effect of the ore solutions consists of the introduction of quartz, calcite, epidote, and pyrite, alteration of the feldspars to calcite and sericite, and the ferromagnesian minerals to calcite and chlorite. The epidote is confined principally to the ferromagnesian phenocrysts, but occasionally is found in the groundmass of the lavas.

Large areas have been altered by the mineralizing solutions and the rocks are now bleached to the light buff to white color

[146] Becker, G. F., Geology of the Comstock Lode and the Washoe district: U. S. Geol. Survey Mon. 3, pp. 48–52, 1882.

Figure 27. Devils Gate. To the right is the south end of Hartford Hill and in the far distance are the Pine Nut Mountains. Gold Canyon passes through Devils Gate in a sharp notch, cut in rhyolite, leaving remnants of a terrace on either side. It was probably in this vicinity that the first veins were found in the Comstock region.



one may see extensively displayed at the surface. These light-colored areas are due to weathering of the hydrothermally altered rocks and are common throughout the Virginia Range and neighboring mountains, even where no known ore deposits occur. Lavas containing small amounts of pyrite weather in this manner, although they are of dark color where exposed by relatively shallow workings.

## LATE TERTIARY EROSION

Practically all of the earlier investigators were of the opinion that but slight erosion had occurred since the deposition of the ores. Richthofen,[147] Becker,[148] and Reid,[149] believed that the outcrop of the lode had been subjected to but slight erosion.

Deep erosion during the Miocene is evidenced by the beveling of the Miocene fault scarps. The region was reduced to an area of low relief before the extrusion of the early Pliocene(?) lavas which, in places, once covered the eroded vein outcrops.

Great depth of erosion is indicated by the removal of the rock which once covered the granular mass of the Davidson pluton. It is not evident that all of this erosion is post-mineral, but it is known that the mineralization is post-Davidson. The ore deposition is thought to be related to, and the ores deposited shortly after, this period of igneous activity. It is probable that most of this erosion followed the period of ore deposition.

The total depth of rock removed is suggested by the differences found in the thickness of the Tertiary lavas adjacent to the footwall and hanging-wall of the major lines of displacement. The base of the Tertiary lavas in the Yellow Jacket mine, at the east shaft, is 3,200 feet below the surface. The collar of the shaft is 400 feet below the outcrop of the vein, indicating a vertical thickness of 3,600 feet of volcanics. There is, in this vicinity, but 1,500 feet of lava now remaining in the footwall block; about 2,100 feet less than the thickness east of the lode.

The extent to which the earlier Tertiary lavas have been removed suggests a considerable depth of erosion. It is estimated that the late Tertiary erosion in the Comstock region is not less than 2,500 to 3,000 feet, and probably exceeds the latter figure. It is quite probable that most of this erosion is later than the period of ore formation. Graton[150] states: "that the Comstock

[147] Richthofen, F. B., loc. cit., p. 119.

[148] Becker, G. F., loc. cit., p. 185.

[149] Reid, J. A., The structure and genesis of the Comstock Lode; Univ. Calif. Publ. Bull. Dept. Geol., vol. 4, p. 150, 1905.

[150] Graton, L. C., The hydrothermal depth zones; Ore deposits of the Western United States, p. 191, 1933.

veins initially extended two or three or even more thousands of feet above their present outcrops."

The early Pliocene (?) lavas have been eroded from a considerable area which they once covered. During this stripping the older lavas were not deeply eroded and the Miocene and Pliocene erosion surfaces appear to be essentially parallel. Deep gorges have been eroded in the relatively depressed hanging-wall block, indicating an elevation of the Virginia Range during, or probably following, the Basin and Range period of faulting.

### POST-BASALT EROSION

Gold Canyon and American Ravine each head in relatively open, alluvium-covered flats at the foot of the Davidson scarp. These areas contrast strongly with the deep gorges through which their drainage escapes to the Carson River.

The olivine basalt flowed from American Flat (figure 28) into and through American Ravine when this outlet was relatively flat-floored. The gradient of the pre-basalt ravine, as shown by the elevation of the gravels underlying the small patches of basalt, is 125 feet to the mile. The present cycle of erosion has just reached into American Flat, where the basalt has been trenched to a depth of about 30 feet, and a short distance further west of the Creek channel is but a few feet below the general level of the flat. At Silver City the ravine has been eroded to a "V"-shaped gorge 200 feet below the top of the basalt-capped mesa (figure 25). American Ravine has steeper walls than the old valley, and the stream is confined to a narrow channel in contrast to the broad flat floor over which the lava flowed. The present gradient is 275 feet to the mile.

The post-basalt erosion suggests rejuvenation of the drainage by an uplift of the region.

### DEPTH AT WHICH THE ORES WERE DEPOSITED

The depth at which ore deposition occurred is not determinable from evidence available in the Silver City district. At Virginia City, just north of the map area, most of the production came from above the Sutro Tunnel level. This level is about 1,900 feet below the lode outcrop. Allowing 2,500 feet as a minimum of erosion indicates that the bulk of the ore was deposited to a depth of 4,400 feet below the surface. Some ore was recovered from the lower levels, 3,300 feet below the outcrop or 5,800 feet below the pre-erosion surface. It is of interest to



note here that Graton,[151] through the use of other evidence, arrived at a similar figure. In discussing the depth at which the epithermal ores were deposited, he wrote: "Such an indicated total of, say 6,000 feet, at Comstock is doubtless greater than the average for this zone."

The difficulties experienced in deeper mining, due to heavy ground and large quantities of hot water, prevented deeper exploration which might well have discovered ore bodies at still greater depth.

### PERIOD OF MINERALIZATION

#### EARLIER VIEWS

A study of the earlier reports reveals a wide diversity of opinion as to the nature and age of the rocks of the Comstock. However, most of the earlier workers agreed that the period of vein formation was late in the geologic history of the region.

Richthofen[152] believed that the veins were of recent origin, for he states that "the surface has undergone but slight changes" since the formation of the Comstock vein. King,[153] however, recognized that the veins were formed prior to the extrusion of the later andesites and that these lavas were not altered by the ore-bearing solutions. He was of the opinion that all of the lavas were post-Miocene in age, and hence that the ore deposits were still younger.

Becker[154] considered the veins to have been deposited in late geologic time and he states: "It is, of course, most unlikely that the Comstock is the only vein in which the deposition of ore is recent." Six years later, in comparing the ore deposits of Steamboat Springs with those of the Comstock, Becker[155] wrote: "Nevertheless the thermal action in each of the districts must be approximately of the same age, as are also the basalt eruptions of the two areas; * * *." He thought that the Pleistocene basalt was the source of the thermal activity at the Comstock as well as at Steamboat Springs.

Reid[156] made a study of the geology of the Comstock, and concluded that the ore was deposited since the Davidson faulting. Erosion, since vein formation, was considered to be negligible,

[151] Graton, L. C., loc. cit., p. 191.
[152] Loc. cit., p. 119.
[153] Loc. cit., p. 32.
[154] Loc. cit., pp. 186, 379.
[155] Becker, G. F., Geology of the quicksilver deposits of the Pacific Slope, with atlas; U. S. Geol. Survey Mon. 13, p. 339, 1888.
[156] Reid, J. A., The structure and genesis of the Comstock Lode; Univ. Calif. Publ. Bull. Dept. Geol., vol. 4, p. 180, 1905.

Figure 28. View to the Southeast Toward American Ravine. In the left foreground is the Baltimore mine dump. In the middle distance is Hartford Hill (left) and beyond is the southern end of the Flowery Range. In the center of the view is the west end of the gorge of American Ravine. In the far distance are the Pine Nut Mountains.



as he states that: "the present apex of the lode, or its outcrop, is that of the original lode apex, formed under practically no pressure from above and not yet removed by atmospheric agencies."

### AGE OF MINERALIZATION

The time at which the ores were formed is suggested by the geologic events which have transpired since their deposition. The thick series of Tertiary volcanics was intruded by diorite and biotite andesite porphyry dikes. Following these intrusions the rocks were displaced by faults, of large throw, along which solutions arose and deposited ore-bearing veins. The dikes were also mineralized, particularly where intersected by faults.

The biotite andesite porphyry and diorite constitute the last igneous activity preceding the period of vein formation. It is suggested that the magma, from which these intrusions came, is the probable source of the ore-bearing solutions. The period of intrusion is thought to antedate ore deposition by but a short interval. The earlier Tertiary lavas and the veins were beveled by erosion, which removed 2,500 to 3,000 feet of material. Early Pliocene (?) lavas were extruded upon the mature erosion surface.

The extent of the erosion indicates a considerable lapse of time between ore deposition and the extrusion of the later lavas. About middle Miocene is indicated as the probable period of vein formation in the Comstock-Silver City region.

## PLACER DEPOSITS

Placer mining operations played an important role in the early history of the district. The discovery of gold in the gravels of Gold Canyon, near its junction with the Carson River, led to the discovery of ore-bearing veins at Silver City, and later the Comstock Lode at Gold Hill and Virginia City.

It is improbable that there were no rich ore bodies in the large amount of vein material removed during the pre-Pliocene erosion. Remnants of placer deposits, which presumably were formed during that time, may yet be found under the later lava flows. The Miocene placers were, however, probably confined to regions near to the outcrop, as were the later ones. The older placer deposits may have been destroyed by erosion.

The present drainage system had penetrated productive portions of the Comstock Lode at two places. Six Mile Canyon cuts the vein at Ophir Ravine; Gold Canyon, and its tributaries, crosses the lode at Gold Hill. At these places bonanza ores came to the surface and rich placers resulted. The ores here contained a very high ratio, about 20 to 1, of silver to gold which, probably, is the cause of the placer deposits not migrating far from the outcrops.

The ore-bearing area at Silver City is drained by Gold Canyon and its tributaries, American Ravine and Long Canyon. In this area the silver-gold ratio is much lower than at Gold Hill and Virginia City, with the result that more extensive placers were formed. Due to late rejuvenation of the region, erosion is much more active in the Silver City area than at the northern end of the lode. The Gold Hill and Ophir Ravine placers were found to extend but a short distance from the outcrop, whereas the Gold Canyon placers were productive for a considerable distance below Silver City.

With the discovery of gold in 1849, the pioneers worked the Gold Canyon placers, but in a few years the richer gravels were exhausted.

After the discovery of the rich croppings at the foot of Mount Davidson, placer mining practically ceased. At that time the returns were so low as to hardly support the miners. Lord[157] states that in 1857 the miners recovered, on the average, but two dollars worth of gold for each day's labor. In an attempt to estimate the gold production from the placers of Gold Canyon, Lord obtained a total of $607,400.

During 1922–1923 an electrically operated dredge[158] of 5,000 cubic yards capacity worked the gravel deposits along the lower reaches of Gold Canyon in the southeastern part of the map area. Apparently the venture proved unprofitable for, after treating but a small part of the deposit, the operations were discontinued. Sporadic small-scale operations have been attempted during the past few years, but the production from this source has been negligible. There yet remains much gravel of low gold content, and it is probable that some of this gravel may eventually be worked at a profit.

## FUTURE OF THE DISTRICT

The production of the Silver City district has come chiefly from workings within a few hundred feet of the surface. No geologic evidence has been found, however, which indicates that there are no deeper ore bodies.

[157] Lord, Eliot, Comstock mining and miners; U. S. Geol. Survey Mon. 4, p. 24, 1883.

[158] Lincoln, F. C., Mining districts and mineral resources of Nevada, p. 132, Nevada News Letter Pub. Co., Reno, 1923.



In the earlier years of exploration of the Comstock, at Virginia City, many bonanza ore shoots were worked out within a few hundred feet of the surface and the deeper explorations gave little promise of other ore bodies. Within a few years rich ores were found at greater depth in mines which had been disappointing in the upper part of the vein. The great production of the northern mines came from these later discoveries. Some of the Virginia City mines produced ore, although from small bodies, from the very deepest levels. It is possible that deeper development will disclose other ore bodies in the Silver City veins.

Ore shoots commonly occur on, or near, vein intersections, and other such junctions should be favorable for prospecting. The ore bodies recently found in the Spring Valley and the Silver Hill mines came from regions with intersecting, or branching, veins. Other unexplored vein junctions should be sought for.

It is probable that ore-bearing veins may exist under the Pliocene(?) lavas in the eastern part of the district, as these lavas were extruded long after the period of ore deposition.

The Silver City district was the scene of the first discovery of gold-silver veins within the boundaries now embraced by the State of Nevada. Since the early discovery, production, though small, has been rather continuous. It is probable that its future will be largely a repetition of the past, as conditions at Silver City are now much as they were half a century ago when De Quille,[159] in describing the region wrote: "About the town are an immense number of small veins of gold-bearing quartz that pay from the surface down. Nearly every head of a family in the town has his own mine, and when he wants money he shoulders his pick, goes out to his mine, and digs it, as a farmer in the East digs a 'mess' of potatoes. Of late some large veins have been opened up in and about the town—as the Oest, Haywood and others—and Silver City bids fair to soon become a busy mining center. The people have lived off their home mines for thirty years, and constitute the most thoroughly independent mining community to be found in Nevada."

[159] De Quille, Dan. A history of the Comstock Lode mines; F. Boegle, Virginia, Nevada. pp. 101–102, 1889.