UNITED STATES

DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

OUTLINE OF THE GEOLOGY

OF

THE COMSTOCK LODE DISTRICT, NEVADA

by

F. C. Calkins

Separate map filed in map drawer.

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ABSTRACT

The term Comstock Lode district is here applied to the mapped area, which includes parts of the Virginia and Flowery Ranges of Nevada.

The oldest rocks of the area are much altered sedimentary strata, probably Jurassic or older. These are overlain by metavolcanic rocks chiefly of basaltic composition, and both the sedimentary and the volcanic rocks have been invaded by quartz monzonite porphyry and granodiorite. These intrusive rocks may be contemporaneous with the great composite batholith of the Sierra Nevada and are certainly pre-Tertiary.

Upon the pre-Tertiary rocks, after a long interval of erosion and probably in Eocene time, several hundred feet of rhyolitic lava was poured out. The rhyolite is overlain in turn, with apparent conformity, by the Alta andesite, nearly 3,000 feet thick. The Alta consists mainly of pyroxene andesite and hornblende-pyroxene andesite, in the form of lava and pyroclastics, but it includes a sedimentary member, the Sutro, containing Miocene fossil leaves. Marked hydrothermal alteration has affected a large part of the formation.

Intrusive bodies of several kinds cut the Alta andesite. What may be the oldest of these are dome-like masses of the American Ravine andesite porphyry. The largest mass consists of the Davidson diorite, from which Mount Davidson was carved. There are also many dikes, andesitic or dioritic in composition, some of which are later than the Davidson diorite, some contemporaneous with it, and some perhaps earlier.

Another great body of andesite, the Kate Peak andesitic series, occurs mainly in the Flowery Range. The andesites of the Kate Peak are varied in composition, but are mostly characterized by the presence of biotite and hornblende. They are of upper Miocene or Pliocene age, and they probably were erupted after the Alta andesite had been tilted and faulted.

Still later, but probably Pliocene, are the Knickerbocker and Lousetown (?) andesites. These are chiefly dark pyroxene andesites locally passing into basalts.

Latest among the eruptive rocks is an olivine basalt.

Large areas of alluvium have been mapped, together with some landslides and some areas of made ground, which includes dumps and tailings.

The pre-Tertiary sedimentary and volcanic rocks have been crumpled and sheared; the pre-Tertiary intrusives are unaffected by shearing. The Tertiary rhyolite and the Alta andesite have been tilted, mostly to the northwest, and dislocated by many faults, the most important of which are the Comstock and Silver City faults, from both of which large ore bodies have been mined. The Silver City fault may be a branch of the Comstock. A fault similar to these but less extensively mineralized is the Occidental. There are many other faults having various directions, and some of the latest cut the Kate Peak andesitic series. This series and the latter Pliocene volcanic rocks may have been involved in some of the later movement on the Comstock fault and slightly tilted.

INTRODUCTION

This paper, together with accompanying geologic map, is intended to serve as an easily portable guide for those who wish to study the geology of the district in the field.

The geology of the Comstock Lode has been studied and written about by geologists almost from the date of its discovery, but only two of the many resulting publications deal effectively with the general geology of the district. The first is Monograph 3 of the U. S. Geological Survey, based on studies made in 1880 and 1881 by G. F. Becker and his associates. 1/ The tract that was mapped by these men coincides in large part with that shown in plate 1. Becker's report has been of great value; its presentation of the facts is in large part sound, and it distinguishes most of the geologic formations that are recognized at the present day; but it reflects in many particulars the immature state of geology at the time it was written, and neither the topographic nor the geologic mapping are up to modern standards. The outstanding modern report is V. P. Gianella's bulletin on the geology of the Silver City area.2/ This report deals with only a minor part of the area described by Becker, but it contains descriptions of all the formations recognized by Becker, and also of other stratigraphic units that were first distinguished by Gianella. It has the advantage of being based on modern concepts, and it corrects some of Becker's misconceptions, but it is handicapped by being plotted on the same inadequate topographic base that Becker used.

1/ Becker, G. F., Geology of the Comstock Lode and the Washoe district: U. S. Geol. Survey Mon. 3, 1882.

2/ Gianella, Vincent P., Geology of the Silver City district and the southern portion of the Comstock Lode, Nevada: Nevada Univ. Bull., vol. 30, no. 9, 1936.

The field work upon which the present report is based was done chiefly in 1935 and 1936, but the district was re-visited for a few weeks in 1939. A topographic map, on the scale of 1:24000, of an area considered large enough to illustrate the geology of the district and to include all mineral-bearing ground related to the Comstock Lode was made by R. C. Seitz and Lloyd Allen, Jr., in 1935. Most of the area mapped lies between the parallels 39° 13' and 39° 20' N. and the meridians 119° 37' and 119° 42' W., but the outline of the map is somewhat irregular, the most marked irregularity being a projection from the eastern border to include the portal of the Sutro Tunnel. The area shown on this map will be called, in the following pages, the Comstock Lode district.

The mapping of the geologic features that are visible on the surface and a detailed examination of the straight part of the Sutro Tunnel were done mainly by F. C. Calkins and T. P. Thayer. The accessible mine workings and the laterals of the Sutro Tunnel were studied by W. D. Johnston, Jr., and V. P. Gianella. Although Gianella and Thayer have had no direct part in the authorship of this report, their contributions to the field work deserve cordial acknowledgment. Gianella, who had become familiar with the geology of the district as a student and consultant, gave guidance to the others which was of great value, especially in the early stages of the work. Valuable aid and cooperation were given by many mine operators and others.

GEOGRAPHY

Topography

The Comstock Lode district has a moderately rugged topography. Its highest point, the summit of Mount Davidson, is 7,853 feet above sea-level; the lowest, near the southeast corner of the area, is a little less than 4,475 feet.

The western part of the district lies in what is now officially designated the Virginia Range, though it has sometimes been called the Washoe Range. This range abuts against the base of the Carson Range--a part of the Sierra Nevada--at a pass about 4 miles northwest of Carson City. The irregular western slope of the southern part of the Virginia Range is bounded by Washoe Valley and the Truckee Meadows. The higher part of the range within the district has on the east a steep north-south slope at the foot of which lies Virginia City, at an average altitude of about 6,200 feet. The foot of the slope roughly coincides, as will be seen later, with the trace of the Comstock fault. The top of the range is not marked by a distinct crest but is an undulating plateau. The only named summits on the divide in the area mapped are Mount Abbie and Ophir Hill. Mount McClellan, which is about 2 miles south of the crossing of the Ophir grade and is not included in the mapped area, is the most prominent mountain in or near the district that is on the crest-line of the range. Mount Davidson, which is higher than any of these, is nearly a mile east of the divide. Other high points near the east front of the range are Cedar Hill, Mount Butler, and the crag now called Suicide Rock, which appears to have been formerly known as Crown Point.

The extreme eastern part of the district is occupied by the ragged southern end of the Flowery Range. This range has a prominent crest extending for many miles north and northeast of Flowery Peak, and it is continued south of Six Mile Creek by the ridge on which Emma Peak (not shown on the map), Mt. Rose, Mount Grosh,3/ and Kate Peak are the main summits. Mount Grosh, the highest of these, is more than 1,500 feet lower than Mount Davidson. The Flowery Range ends just north of Dayton.

The hilly area which contains all the known ore bodies of the district is regarded as lying between the Flowery and Virginia Ranges without being part of either. Many of the hilltops appear to be remnants of a surface of low relief, which has an altitude of about 6,200 feet at Virginia City and is roughly 5,500 feet in average height southwest of Silver City. This surface is thought to be a part of the same surface that forms the top of the Virginia Range, and to have been let down by the Comstock fault.

Two large relatively flat areas lie lower than the Virginia City upland. One is American Flat, west of Silver City. The other, in the southern part of the district, is part of the former valley of Carson River, which now flows in a gorge southeast of it.

The district has no perennial stream except the one that rises in American Flat and flows through American Ravine. The west slope of the Virginia Range drains to the Truckee River, the deep hollows in the northwest corner of the district having been carved by tributaries of Steamboat Creek. The rest of the area drains to the Carson River, chiefly by way of Six Mile and Gold Creeks, the divide between which extends from the south end of Virginia City to Mount Grosh.

Climate and vegetation

The climate of the district is semi-arid, the precipitation coming mainly in winter snows and occasional summer showers. The summers are hot and the winters moderately cold. Conditions for field work are mostly favorable between May 15 and October 15.

The characteristic vegetation consists mainly of low, bushy pinon and juniper trees, interspersed with sage brush, though it includes many other shrubs and herbs. Small yellow pines grow in a few areas, all of them underlain by greatly altered and bleached volcanic rocks, upon which little vegetation except these trees will grow. The only considerable tracts bearing yellow pine are north of Cedar Hill Canyon and in the rugged ravines northwest of Ophir Hill. These are the largest areas of bleached rocks other than those immediately adjacent to Virginia City, where it seems likely that yellow pines once grew but were cut down for timber and fuel soon after the discovery of the Comstock Lode.

3/ This hitherto nameless though prominent summit has been named in memory of the brothers Allen and Hosea Grosh, who were the first to prove the existence of ore-bearing veins in the district. See Lord, Eliot, Comstock mining and miners: U. S. Geol. Survey Mon. 4, pp. 24-31, 1883.

Settlements, water supply, and mine openings

The only settlements in the district are the old mining camps Virginia City, Gold Hill, and Silver City. Virginia City, by far the largest, is the best preserved; visitors can still, with a little exercise of the imagination, visualize the appearance of its business district and some of its more substantial dwelling houses as they were when the town was rebuilt after the conflagration of 1875. Very little remains of Gold Hill and Silver City.

The water supply of the district comes from Marlette Lake, a reservoir that lies east of Lake Tahoe and about 8,000 feet above sea level, by way of an inverted siphon under Washoe Valley and a flume which is conspicuous along the eastern slope of the Virginia Range for about 3 miles south of Mount Davidson.

By far the most extensive mine opening now accessible in the district is the Sutro Tunnel, whose course is indicated on the map. This tunnel is kept open in order to maintain its franchise. The straight adit is about 20,000 feet long, and the aggregate length of the north and south laterals is about as much more. Together, these afford extensive exposures of the underground geology, which, however, are somewhat disappointing because the rocks that they penetrate are in large part severely altered and largely concealed by close timbering and lagging. The Hale & Norcross tunnel, the portal of which is in the Arizona-Comstock mill, near the south end of Virginia City, extends more than 6,000 feet westward, nearly in line with the Sutro adit, but unfortunately it is now caved. Specimens collected from this tunnel by the late J. A. Reid[4] were kindly given to the Survey by the Mackay School of Mines through the agency of Dr. Gianella.

Little is accessible of the scores of miles of old underground mine workings at Virginia City. Those open in 1935-1936 included the Central Tunnel, connecting with the upper part of the Ophir mine and the Andes shaft, part of the Sierra Nevada workings, and a few minor tunnels; the Union shaft then gave access to the Sutro Tunnel level but has since been closed. A large open cut on the lode was being worked by the Arizona-Comstock Corporation. At Gold Hill there are open cuts at the mouth of Confidence Ravine and south of Crown Point Ravine, and the Overman shaft gave access to the lode within recent years. Farther down Gold Canyon a good many mining operations have accessible workings, the largest being the Dayton mine. Open cuts in the east slope of Hartford Hill are of geologic interest because they expose the actual walls of great faults. The Spring Valley mine has the most southerly extensive underground workings that are accessible. The old Daney mine, still farther south, is blocked by caving, but an open cut near it shows an exposure of a fault that is probably a southern continuation of the Silver City fault zone.

4/ Reid, J. A., The structure and genesis of the Comstock Lode: Calif. Univ., Dept. Geol., bull. 4, No. 10, pp. 193-195, 1905.

Routes of travel (in 1948)

Virginia City is connected by well-graded automobile roads with both Reno and Carson. The shortest route to Reno goes northward for a few miles on the old Geiger Grade, but departs from it before beginning to descend the west slope, to follow a broader road of easier gradient which was opened to traffic in 1936. An automobile bus travels daily to and from Reno. The most evenly graded route to Carson follows the old Occidental grade, widened and improved in 1936, down Long Canyon and continues southward until it joins Route U. S. 50 about 1½ miles east of its crossing, near Mound House, with the Virginia & Truckee Railroad. Other main roads are the one down Gold Creek from Silver City to Dayton; one down Six Mile Creek, which is the shortest route from Virginia City to the Sutro Tunnel; the old Ophir or Jumbo grade, which crosses the divide of the Virginia Range northwest of American Flat; and one that skirts the west side of American Flat, to join Route 50 at Mound House. The Virginia and Truckee Railroad, which was built in 1869 and served the district until about 1938, has been abandoned and torn up. The Carson and Colorado Railroad, which serves a considerable part of western Nevada, joined the Virginia and Truckee at Mound House.

FORMATIONS

General features

The oldest rocks of the district are metamorphosed sedimentary strata, which are overlain by dark metamorphosed lavas that are probably not much younger. Intruded into these rocks is a monzonite exposed in a few small outcrops. A granodiorite of a type common in the Sierra Nevada also has been intruded into the old sedimentary and volcanic rocks but is not exposed on the surface in the area mapped. All these rocks are pre-Tertiary, but their precise age is uncertain. They occur mainly in the southern part of the district, but fragments of granodiorite and associated older rocks may be seen on the dump of the Utah Shaft and that of a tunnel southwest of it.

The pre-Tertiary rocks are overlain by volcanic flows, thousands of feet in total thickness, which are mainly Tertiary. The oldest of the lavas are rhyolitic in character and probably Eocene. The rhyolites are overlain by the Alta andesite, of Miocene age, which is the thickest and most widely distributed unit shown on the map; it occurs mainly in the Virginia Range and the low hills to the east. The Alta andesite includes a stratum of water-laid tuff, called the Sutro member, which is distinguished on the map. The lower part of the Alta andesite, as well as the rhyolite and pre-Tertiary rocks, has been intruded by dome-like masses of what is called the American Ravine andesite porphyry. The Alta andesite is also cut by many dikes and has been invaded by an intrusion of diorite, from which the upper part of Mount Davidson has been carved. Some of the dikes may be older than the diorite or contemporaneous with it, but some are definitely younger. After the intrusion of the diorite the rocks were much faulted and were altered by hot solutions, and the deposition of the ores took place late in this time of disturbance and chemical activity. The greatest faults of the district are the Silver City and Comstock faults, in branching fissures of which the great ore bodies of the district were deposited.

Apparently after these activities had almost ceased, another series of volcanic eruptions, prevailingly andesitic, was poured forth. Its products, named by Gianella the Kate Peak andesitic series, are the dominant rocks of the Flowery Range. Volcanic rocks nearly if not quite contemporaneous with the Kate Peak andesitic series occur in the central and southern part of the district; and eruptions of lavas intermediate in character between typical basalt and typical pyroxene andesite--the Knickerbocker and Lousetown (?) andesites--were probably the latest products of Tertiary volcanic activity. A final eruption, clearly Quaternary, produced the basalt which forms a conspicuous mesa at the mouth of American Ravine. A dike injected along the Comstock Lode may consist of this same lava.

The principal formation later than the basalt consists of unconsolidated stream deposits, which are thick and widespread in the southern part of the district. A few landslides and some areas of talus are mapped. Dumps and other made ground wholly conceal the bedrock geology of large areas, especially in and near Virginia City, and they are in part shown on the map.

Pre-Tertiary rocks

Sedimentary rocks

The old sedimentary rocks are exposed in only one large area, on the east slope of the Virginia Range and southwest of American Flat. Small areas occur farther southeast, and others too small to show on the map may be seen in areas, prevailingly of old volcanic rocks, on the slopes northwest of American Flat. In places these old sediments form the footwall of the Comstock lode, and they have been seen in the Overman workings.

The most abundant material in the old sedimentary formation was originally dark mud, which has become hardened and metamorphosed in various degrees, so as to take on the character of shale, slate, or schist. The most intense alteration is probably due to the action of intrusive rocks, but all these sediments, and also the overlying pre-Tertiary volcanic rocks, are regionally metamorphosed. Some of the most altered rock, probably affected by igneous metamorphism, is a mica schist with a knotty appearance due to crystals of andalusite and cordierite. Sands and gravels formed part of the series, and are now represented by micaceous quartzites and by conglomerates in which the pebbles are welded, as it were, to their matrix, and elongated as a result of the pressure to which the rocks have been subjected. In some of these stretched conglomerates the pebbles are largely replaced by feldspar. Some limestone occurs in the formation, most of it, apparently, in its upper part. This rock supplied material for at least one lime-kiln, the ruins of which may be seen on the west side of the road south of American Flat. A large deposit of anhydrite, altering to gypsum where it is exposed, occurs northwest of Mound House, outside the mapped area, where it was formerly quarried. It is the source of the white "gypsite"--impure gypsum--abundant in the alluvium near Mound House.

As these old strata have not yielded any identifiable fossils, their age is uncertain. They resemble rocks of the Mariposa and Calaveras formations (Jurassic and older) in the Sierra Nevada. Triassic and Lower Jurassic fossils have been collected in Eldorado Canyon, about 7 miles southeast of Mound House, from rocks that are somewhat similar in composition to those near American Flat,5/ but these fossiliferous rocks are so little altered that they are thought to be younger than the strata in question. It thus appears fairly safe to say that the pre-Tertiary rocks in the Comstock district are not younger than Jurassic.

Volcanic rocks

The pre-Tertiary volcanic rocks are much more extensively exposed than the sedimentary rocks, and they occupy several large areas in the southern part of the district. Some altered volcanic rock that appears to be andesitic is interbedded with the old sediments, especially west of American Flat, but the main body of pre-Tertiary volcanic rock consists of metabasalt overlying the sediments. Perhaps the best, as well as the most accessible, exposures of the metabasalt are in the area crossed by American Ravine, especially along the railway southeast of American Flat.

In general appearance these old volcanic rocks are remarkably uniform. Their outcrops are rugged and bouldery and more or less discolored with red and yellow iron oxide. On fresh fractures the rocks are very dark and greenish, and they contain a large proportion of sparkling greenish-black amphibole, which is the mineral most readily identified with the naked eye. Under the microscope, however, it is seen that their most abundant mineral is albite or oligoclase, which contains a far higher proportion of soda than the plagioclase that would normally occur in an unaltered rock in which dark minerals were so abundant. Amphibole usually comes next in abundance, and one or more of the minerals quartz, chlorite, secondary biotite, sericite, and epidote is always present. The rocks have evidently been thoroughly recrystallized, but the only chemical analysis available6/ indicates a composition like that of a basalt or a pyroxene andesite. The rocks in the formation are judged to be volcanic, largely because of their fine texture and a lack of evidence that they are intrusive. Although the structural characteristics of volcanic rocks are largely obliterated by thoroughgoing alteration, tuffaceous textures are visible in places, and a spotted rock has been identified by Gianella7/ as an amygdaloid--a lava that once contained gas bubbles, which have been filled with minerals. The filling of a specimen collected for the Survey consists of albite and epidote.

5/ Gianella, Vincent P., op. cit., p. 37.

6/ Becker, G. F., op. cit., p. 152, table, "metamorphic diorite".

7/ Gianella, V. P., op. cit., p. 40.

Intrusive rocks

Quartz monzonite porphyry.--A granite-like rock (called granite by Becker) intrusive into the pre-Tertiary sedimentary and volcanic rocks is well exposed in American Ravine, where its intrusive relation to the old rocks is well shown, and near the south base of Basalt Hill. It is mostly light gray but is tinged in places with dull red. Feldspars and quartz are the most abundant minerals, and a moderate amount of biotite and of prismatic augite and hornblende are visible. The texture would on casual inspection be taken for granular, but, as can best be seen under the microscope, it is really porphyritic, though the phenocrysts are crowded together and the groundmass is relatively coarse. The most abundant phenocrysts are of oligoclase, but there are some of orthoclase, of augite altering to pale-green amphibole, and of deep-green hornblende. The goundmass consists of orthoclase and quartz. The orthoclase is less abundant, on the whole, than the plagioclase but not definitely subordinate; quartz is more abundant than the ferromagnesian minerals.

Granodiorite.--A granular rock of a type that is widespread not only in the Sierra Nevada but in many other western mountain ranges forms a small part of the dump of the Utah shaft, where it is clearly shown to be older than an andesitic porphyry similar to some of the Alta rocks; small fragments of granodiorite are enclosed in blocks of the andesitic rock, dikelets of which penetrate the granodiorite. Still stronger evidence that the granodiorite is pre-Tertiary may be seen on the south slope of Hartford Hill, where boulders of granodiorite occur in a coarse conglomerate underlying the base of the rhyolite.

The granodiorite differs distinctly from the quartz monzonite porphyry in several respects; it contains more biotite and hornblende, less orthoclase, and no augite, and its texture is granular instead of porphyritic. Plagioclase, with the average composition of a calcic andesine, is the most abundant constituent of the granodiorite; orthoclase and quartz are subordinate though not scarce; hornblende and biotite are present in moderate and nearly equal quantity.

Tertiary rocks

Rhyolite

The oldest of the Tertiary volcanic formations is extensively exposed in the southern and west-central parts of the district, especially in the hills around American Flat and those bordering Spring Valley. Gianella[8] has named it the Hartford Hill rhyolite from its occurrence in that hill, where both its base and its top are exposed. Its thickness there is about 1000 feet.

8/ Gianella, V. P., op. cit., p. 45.

The base of the rhyolite, on the south slope of Hartford Hill and at some other places, is separated from the underlying old volcanic rocks by a few feet of conglomerate, which contains pebbles and boulders of these old volcanics and of the quartz monzonite porphyry and granodiorite already described. This conglomerate, and the fact that the base of the rhyolite northwest of Basalt Hill rests partly on the sedimentary pre-Tertiary rocks, indicate that a long period of erosion preceded the eruption of the rhyolite.

The rhyolite is one of the most readily distinguished rocks in the district. It is all rather light colored, mostly in various tints of pink or dull purple, less commonly in green or white. Nearly all has an irregular platy parting. It is one of the more resistant rocks and tends to form prominent hills. Its outcrops are rugged and usually a little stained with orange-colored oxide of iron. On examining a hand specimen closely one usually sees many whitish flakes of included pumice and abundant phenocrysts of quartz. Feldspars form numerous though less conspicuous phenocrysts, and a little altered biotite can be found in most specimens. A little decomposed hornblende occurs in a small proportion of the rock in the lower part of the formation.

Under the microscope, it is seen that the feldspar of every specimen is partly orthoclase and partly plagioclase. The proportion between the two varies widely. Where orthoclase is dominant, the plagioclase is albite; in some specimens where the plagioclase is abundant it is zoned and has the average composition of an oligoclase. Some of the flows containing such feldspars, together with hornblende, are dacites or quartz latites rather than rhyolite in the strict sense. The groundmasses all show flow structure and other details of texture that show them to have been originally glassy, but all the glass has now been replaced by crystalline matter.

Although the great body of the rhyolite underlies the Alta andesite, some rhyolite in the vicinity of the Daney mine overlies andesite. It seems probable that the eruptions of andesite began before the eruption of rhyolite, from a different center, had quite ceased.

The amount of rhyolite in the district is so great that it probably came from several volcanoes. The root of one of them may be represented by a plug of intrusive rhyolite occurring high on the slope west of American Flat.

Although there is no conclusive evidence of the age of the rhyolite, the relation of the main body of it to the Alta andesite, which, as will be shown, is mainly if not wholly Miocene, and the fact that rhyolites known to be Eocene are abundant in the Sierra Nevada, indicate that the rhyolite of the Comstock district also is mainly if not wholly Eocene.

Alta andesite

General features.

The Alta andesite, named by Gianella after the Alta shaft, which is entirely in that unit, occupies about half the mapped area of the Comstock Lode district. Its estimated thickness is about 2,700 feet, and it might be divided under favorable conditions into at least four members, which are, in descending order, as follows:

	Prevailing rock	Approximate thickness (feet)
A.	Hornblende-pyroxene andesite, mostly lava. . . .	1,000 +
B.	Pyroxene andesite, mostly lava	800
C.	(Sutro member) Water-laid sediments, shaly to conglomeratic in texture	300
D.	Hornblende-pyroxene andesite, lava and breccia .	600

Because of the complexity of the structure in some places and the degree to which much of the Alta is altered, it has seemed impracticable to do more than separate division C in mapping, and the boundaries of that division are in part only rough approximations. The question often arose, also, whether certain parts of the Alta andesite as mapped were extrusive or intrusive. Owing to the similarity of some of the intrusive to the extrusive rocks and the unsatisfactory character of the exposures over large areas, it was often impossible to decide whether a given mass elongated in the same direction as the flows was itself a flow or an intrusive sheet; and if it was known to be a sheet it would often be traceable for only a few yards before it disappeared under surface waste. The conclusion was reached, after several changes of opinion, that most of the massive rock in the area mapped as Alta is extrusive; but if that is so, the flows are remarkably lacking in the vesicular layers that afford the clearest evidence of extrusive origin.

Lower hornblende-pyroxene andesite.--

The lowest division (D) of the Alta is characterized by hornblende-pyroxene andesite, in the form of flows, tuff, and breccias. The typical lavas are medium dark gray, commonly tinged with green or purple. The most conspicuous phenocrysts are prisms of hornblende, ordinarily about 5 millimeters long, but far more numerous are small phenocrysts of plagioclase. These are mostly about 1 millimeter in diameter and without marked elongation, so that in the aggregate they remind one of fish-roe. In thin sections it is found that the rock contains phenocrysts of augite, which do not readily catch the eye in the hand specimen, and also phenocrysts of hypersthene, which have all been replaced, mainly by a green fibrous chlorite or serpentine. The phenocrysts of plagioclase are labradorite averaging about 55 or 60 percent anorthite. The groundmass is everywhere devitrified.

A large proportion of this lowest division of the Alta is in the form of tuff or breccia, which because of its permeability is more altered than most of the lava. Much of this material has a highly characteristic appearance: it consists of greenish-gray angular fragments in a reddish-purple matrix consisting of small grains of minerals and rocks. Rock of this character forms a large part of the Forman dump. Flow-breccia, formed by the breaking of the lava as it flowed, also is common.

A rock of very striking appearance occurs in the vicinity of the Overland mine, on the hill south of it, and on the 5,426-foot hill northeast of Silver City. Its character is that of the lava last described except that is it coarser and contains very large phenocrysts of hornblende, some of them 2 or 3 centimeters long. The character of this rock suggests that it is intrusive, and a fairly thick sheet of it may have been injected into the volcanic series. Somewhat similar rock forms a few dikes, but this has a lighter-colored and coarser groundmass and shows more obviously the character of an intrusive rock.

A very little rhyolite is found in the Alta andesite in the lower part of Crown Point Ravine.

Sutro member.--Although the upper limit of the lower hornblende-pyroxene andesite is somewhat indefinite, it roughly coincides with the base of the Sutro member of the Alta andesite (division C). This member, curiously neglected or misinterpreted by the earlier geologists, was first described by Gianella,9/ who recognized its importance as a horizon-marker that would be useful in working out structure. He gave it the name of Sutro Tuff member because of its extensive exposures in the Sutro tunnel. This member does not, however, consist wholly of tuff in the strict sense of the word, but seems more suitably described as sedimentary.

Among the best exposures of this unit on the surface are: (1) in a strip extending northeastward from the vicinity of the Overland mine to the slope south of the main tunnel of the Occidental mine, where it seems to taper out; (2) in several areas south of Crown Point Ravine -- the crag known as Suicide Rock consists of the upper part of the member, which here is coarse grained; (3) in a wash-out under the flume north of Crown Point Ravine; and (4) on the eastern end of the spur south of Confidence Ravine. Bleached sedimentary rock exposed in the east slope of Cedar Hill is believed to belong to the Sutro. The maximum thickness of the Sutro sediments, attained near Suicide Rock, is estimated to be between 300 and 500 feet, but it is somewhat uncertain because of the complexity of the structure. For the same reason, the boundaries in many places are no more than rough approximations.

9/ Gianella, V. P., op. cit. pp. 55-58

The most typical rock of the Sutro member is a regularly banded shale, prevailingly of sage-green color, breaking into smooth-faced slabs an inch or so in thickness. This grades into coarser material, well shown in Suicide Rock. All of the unit was clearly laid down in water, the fine-grained material doubtless in a lake. Some of the fragments in the coarser beds are fairly well rounded. The composition of the unit as a whole is varied and complex; some of it is rhyolitic, some is andesitic, and some contains pebbles of the pre-Tertiary sedimentary rocks. It is difficult to judge what proportion of it is truly tuff--a product of contemporaneous explosive eruptions--and how much was formed by erosion.

On the flume south of Crown Point Ravine, there seems to be a thin layer of lava--not shown on the map--between two strata of sedimentary rock at the general stratigraphic level of the Sutro member. There is, also, at least one unmapped shaly stratum at a higher stratigraphic level, interbedded with the uppermost division of the Alta andesite. This stratum is best exposed at the west brow of the hill a mile north of the Foreman shaft. Fragments of whitish hardened shale found on the slopes east of Gold Hill are thought to be derived from the same stratum.

Pyroxene andesite.--The middle part of the Alta andesite (division B) consists mainly of lava, the freshest of which is so dark as to resemble basalt. This dark lava, together with some belonging to later formations, was in part mapped by Becker as augite andesite, but it was later shown by Hague and Iddings[10] to be pyroxene andesite, containing hypersthene as well as augite. Good exposures of this rock in fairly fresh condition are to be seen in Six Mile Canyon, in Long Canyon, and on the ridge south of Crown Point Ravine.

This pyroxene andesite differs from typical basalt in containing abundant phenocrysts of sodic labradorite (about An_{50} in average composition), most of which are about 2 millimeters in average diameter. These are recognizable by the glitter of their cleavage faces, being so transparent that they are not distinct in color from their background. Much less conspicuous are dark phenocrysts of pyroxene. Here and there occurs a phenocryst of hornblende readily distinguished by its bright cleavage faces. Magnetite and apatite are ever present accessories, visible in all thin sections.

In thin sections from the freshest specimens of this rock, none of the minerals appear much altered except the hypersthene, which is partly replaced along cracks and margins by green fibrous secondary minerals. In most specimens the hypersthene is wholly replaced. The groundmass, though it probably once contained glass, is now entirely crystalline. In this alteration of the hypersthene and devitrification of the glass, the pyroxene andesite of the Alta differs from a later lava of similar character (the Knickerbocker andesite), in much of which the hypersthene and the original glass of the groundmass are entirely unaltered.

10/ Hague, Arnold, and Iddings, Joseph P., On the development of crystalization in the igneous rocks of Washoe, Nev.: U. S. Geol. Survey Bull. 17, p. 17, 1885.

Most of this hypersthene andesite is decidedly altered. The most obvious evidence of alteration is a lightening and greening of the color. Porphyritic texture is more conspicuous in the moderately altered rock than in the freshest, because the white of the plagioclase phenocrysts and the dull greenish black of the pyroxene both stand out in contrast with the light greenish gray of the groundmass.

Upper hornblende-pyroxene andesite.--The middle part of the Alta grades into the upper part, the transition being marked by an increase in the size of the phenocrysts of feldspar and by increasingly frequent appearance of hornblende. Transitional rocks illustrating these characteristics may be seen in the two conical hills east of the town of Gold Hill. A mass of exceptionally coarse-grained hornblende-bearing pyroxene andesite or andesite porphyry exposed west and southwest of the Overman shaft is within the stratigraphic limits of this division, but this mass may be intrusive. Other exposures of the transitional rocks occur near Sutro No. 4 shaft, and in Long Canyon on the east side of the most prominent outcrop of the Occidental lode, which is on a fault with downthrow to the east.

It is in the northwestern part of the quadrangle--on the ridge connecting Mounts Butler and Bullion, in the vicinity of Ophir Hill, and in the basin containing Jumbo Falls--that the youngest lavas assigned to the Alta are best seen. A characteristic type occurring here is a light-gray rock with glistening black phenocrysts of hornblende and moderate-sized phenocrysts of feldspar, which are very distinct in character from the small "fish-roe" feldspars of the lower hornblende-pyroxene andesite. In the Jumbo Falls Basin there are large areas of relatively coarse-grained dull-gray andesite whose texture suggests intrusive origin, but in at least one place these grade into what seem to be flow breccias, so that they are probably extrusive. Some of the lava of the Alta in the Jumbo Falls Basin is black, and is much like that of the division below except that it contains more hornblende. Like the other andesites of the Alta, the andesites of the upper division contain both augite and hypersthene, or did contain them originally; but both minerals are inconspicuous, and the hypersthene in the specimens examined microscopically is all replaced. The feldspars are sodic labradorite or calcic andesine, and the groundmasses are devitrified--a point of distinction between the youngest lavas mapped as Alta and those regarded as younger than Alta.

The Alta andesite is of Miocene age. A small collection of leaves from the Sutro member obtained in a cut on the new highway in the lower part of Long Canyon, southwest of the 5,229-foot hill, is judged by Roland W. Brown to be middle or upper Miocene; and, as will be shown later, the overlying Kate Peak andesitic series is upper Miocene or lower Pliocene.

The Alta andesite appears to be essentially conformable with the underlying rhyolite, with which, as already noted, it is regarded as interfingering.

Some intrusive rocks cutting the Alta andesite

General statement.--Several kinds of intrusive rock cut the Alta andesite, but the age relation of these rocks to each other and to some of the volcanic rocks later than the Alta is uncertain.

The larger bodies of these intrusives consist of two sharply different kinds of rock, the American Ravine andesite porphyry and the Davidson diorite. The American Ravine andesite porphyry cuts the rhyolite and almost certainly penetrates the lower part of the Alta, but is not known to have risen higher. The Davidson diorite cuts across all divisions of the Alta, which may be regarded as presumptive evidence that it is younger than the American Ravine rock.

Other intrusive rocks cutting the Alta form dikes and other small intrusive bodies, including sills. There are doubtless more sills than have been mapped, because of the difficulty of distinguishing sills from flows. The age relation of many of the dikes to the Davidson diorite is uncertain. As the dikes are similar to the diorite in composition as well as in their relation to the Alta andesite, it would seem probable that some of them are contemporaneous with the diorite and that some of them are offshoots from it. This relation has not in any instance been proved, but that fact may be due to concealment of the junctions of dikes with diorite masses by the talus which almost everywhere covers the margins of the diorite. Some of the dikes were regarded by Thayer as being earlier than the diorite. Some, however, are demonstrably later.

A few intrusive bodies that cut the Alta are described in connection with extrusive rocks later than the Alta, because of their close relationships with those rocks.

American Ravine andesite porphyry.--The part of American Ravine immediately below American Flat crosses a dome-like mass of fine-grained igneous rock, called by Becker[11] a felsitic quartz porphyry, and regarded by Gianella, who called it the American Ravine andesite, as the earliest of the Tertiary lavas.[12] This mass, however, is certainly intrusive into the rhyolite and probably into the lower part of the Alta andesite. The mass in American Ravine is in contact only with rhyolite and pre-Tertiary rocks. Some of the several bodies of similar rock in Gold Canyon at and below Silver City are in contact with Alta andesite.

The best evidence that the American Ravine andesite porphyry was intruded into the rhyolite may be observed in the southernmost area, on Gold Creek. A tunnel northwest of the 5170-foot hill shows a "frozen" contact between the two rocks. The andesite porphyry has a distinct flow structure near the contacts, marked by approximate parallelism of the hornblende crystals, and all around the border of the porphyry these crystals tend to lie parallel to the contact. This fact is especially

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11/ Becker, G. F., op. cit., p. 47.

12/ Gianella, V. P., op. cit., pp. 44, 50.

well shown on the north side of Gold Creek, where the contact can be seen in places to cut across the lamination of the rhyolite, though the rhyolite has to some extent been pushed up by the intrusive magma, which appears to have been unusually viscous. High viscosity may account for the lack of dikes of the andesite porphyry in the rhyolite.

In American Ravine the relations around the border of the porphyry are obscure, but there is indirect evidence that the porphyry is intrusive. The dominant rock in American ravine almost surrounds a body of coarser porphyry. The relation of these two rocks is none too clear, but careful scrutiny of contacts exposed on the "shoo-fly", or abandoned railroad-bed, north of the tunnel led to a decision that the coarser facies is the older. A dike of this coarser porphyry cuts the rhyolite just north of the creek near the upper end of the ravine, and since the finer-grained porphyry is still younger it also must be younger than the rhyolite. In road cuts and a few natural exposures near the lower part of Long Canyon, the American Ravine andesite porphyry is seen in contact with Alta andesite, and although the relation is obscured by weathering the American Ravine is apparently the younger rock: the contact is wavy and apparently "frozen", and cuts across the dip of the Alta. Near the Dayton shaft, the American Ravine is overlain by the Alta, but the actual contact is not exposed. The fact that the Alta is here a breccia and the American Ravine is also somewhat brecciated suggests that the two rocks intergrade, but it really proves nothing.

The finer-grained rock that forms the greater part of the American Ravine mass and the whole of the others is very distinct in appearance from both the rhyolite and the Alta andesite. Its color varies from medium to light gray, and it is characterized by a peculiar silky luster. The only mineral ordinarily identifiable with the naked eye is hornblende, in slender prisms that are not very abundant, but in much of the rock the hornblende is replaced by a dull-gray mixture of secondary minerals. Relatively large grains of quartz occur here and there. In thin sections of the freshest specimens, prisms of greenish-brown hornblende appear as the only numerous phenocrysts, but occasional phenocrysts of augite are seen. The grains of quartz, and some of sodic plagioclase, are probably inclusions derived from the rhyolite. The groundmass consists mainly of minute laths of plagioclase (labradorite), prisms of augite, and granules of magnetite. The feldspar laths tend to lie nearly parallel, and it is to this fact that the silky luster of the rock is due. No glass is found, and all specimens contain a little calcite, chlorite, and epidote. The rock is cut, also, by many veins of quartz. It is therefore distinctly more altered than the Lousetown (?) andesite, which it resembles in some respects.

Davidson diorite.--The top of Mount Davidson is near the middle of the largest area of a diorite, named by Gianella13/ the Davidson diorite, that has been intruded into the Alta andesite. This area is about a mile long from north to south and less than half a mile in average width from east to west. The

13/ Gianella, V. P., op. cit. pp. 64-68.

diorite is exposed in many smaller areas lying northward and westward from Mount Davidson. Its extent is much exaggerated on Becker's map. The intrusive relation of the diorite to the Alta, though not recorded in print until 1912,14/ is clearly shown by intricate frozen contacts, by inclusions of andesite in diorite, and by metamorphism of volcanic and sedimentary rocks in the Alta.

In surface exposures this diorite is rather light gray, but specimens taken underground are much darker, the difference of color being all in the feldspar. Plagioclase is by far the most abundant constituent; irregular dark-green clusters of ferromagnesian minerals, not readily distinguished from one another, are thickly sprinkled through the rock; and a little quartz and orthoclase are discernible though inconspicuous. Under the microscope it is found that the plagioclase is zoned and has the average composition of an andesine. Augite was originally second in abundance, but in all specimens it is more or less altered, and in some it is completely replaced by fibrous amphibole and other minerals. Biotite likewise is partly or wholly replaced by chlorite. A few altered grains of hypersthene have been found in one of the specimens taken by Reid in the Hale and Norcross tunnel, 4,150 feet from the portal. In all the other specimens from the main mass that have been examined microscopically, hypersthene is represented by pseudomorphs consisting mainly of serpentine or fibrous chlorite. Some specimens contain a little primary hornblende. Quartz and orthoclase are subordinate but essential constituents; they fill irregular spaces between the other minerals. Both petrographic study and chemical analysis indicate that this diorite is rather closely related to the andesites of the Alta but contains a higher proportion of silica and alkalies.

The Davidson diorite is almost certainly of Miocene age, being younger than the Alta and apparently older than the Kate Peak andesitic series.

Dikes and other small bodies.--Some of the small irregular bodies cutting the Alta andesite are so evidently facies of the Davidson diorite that they have been mapped in the same color. One of these, on the north side of Ophir Ravine, is noteworthy for containing hypersthene. One dike, traceable for only a short distance, in the ridge north of Spanish Ravine is so similar petrographically to the diorite--from which it differs only in texture, being finer-grained and obscurely porphyritic--that it is undoubtedly an offshoot from the main mass forming Mount Davidson.

Dikes whose relation to the Davidson diorite is uncertain appear to have about the same range of composition as the Alta andesites themselves. Like the lavas, they contain phenocrysts of andesine or labradorite. They are in general more altered than the freshest of the lavas, so that the pyroxenes which all of them probably contained have been almost wholly replaced. No specimen from a dike contains hypersthene, though one contains unmistakable pseudomorphs after hypersthene, associated with fresh augite. In all others, whatever pyroxene was originally present has been replaced,

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14/ Smith, D. T., Vein systems of the Comstock: Eng. and Min. Jour., vol. 94, pp. 895-896, 1912.

mainly by chlorites, epidote, and calcite. Some of these dikes contain fresh hornblende, accompanied by pseudomorphs after pyroxenes. But in some of them even the hornblende is replaced, mainly by chlorite, the origin of the pseudomorphs being indicated only by their form. These are accompanied by smaller pseudomorphs presumably derived from pyroxenes.

That some dikes of porphyry cut the Davidson diorite is best shown in the lower part of Bullion Ravine. A dike crosses the ravine and the flume, and is readily traceable northwestward up the steep side of the canyon nearly to the crest of the southeast spur of Mount Davidson. Similar dikes, less well exposed but undoubtedly later than the diorite, extend along the eastern slopes of Mount Davidson. In Ophir Ravine an irregular porphyry dike crosses a small outlier of the diorite. The relation between the two rocks is not obvious, but thorough scrutiny of the contacts led to the conclusion that the porphyry is the younger.

It is the outcrops in Ophir Ravine that have yielded the freshest specimen of the post-Davidson porphyry. This specimen shows conspicuous phenocrysts of plagioclase (calcic andesine) and of glittering black hornblende in a dark-gray, very fine-grained groundmass. There are also other small, inconspicuous, dark phenocrysts, which the microscope shows to be pseudomorphs, presumably after pyroxene; these consist mainly of chlorite and epidote. Sparse phenocrysts of quartz occur in the rock. The dike in Bullion Ravine is much more thoroughly altered. The feldspar has been converted to albite. Even the prominent ferromagnesian phenocrysts, which, to judge from their form, represent hornblende, have been wholly replaced by chlorite, epidote, and other minerals, and the same is true of smaller ones that probably represent pyroxenes. Sporadic crystals of chlorite derived from biotite occur in specimens from this dike.

Such extreme alteration of the dikes, contrasting with the comparatively slight alteration of their dioritic wall rocks, is rather surprising. It seems to indicate that the porphyry was intruded shortly after the solidification of the diorite, and that it was acted upon by emanations rising from underlying, perhaps not yet solidified, parts of the diorite magma. These emanations, we may imagine, had a relatively easy passage upward along the walls of the dikes, which they therefore altered more thoroughly than the massive diorite. Intrusion of these dikes may have been closely followed by the formation of the Comstock fault and that of the lode, the northern part of which largely follows dikes.

What may be one of these later dikes is crossed by the Geiger grade near Cedar Hill Canyon and is cut by another similar dike in the spur to the north. The rock exposed on the Geiger grade is as thoroughly altered as the one in Bullion Ravine, the plagioclase being altered to albite and the ferromagnesian minerals completely replaced. Alteration has gone farther in the dike than in the Alta andesite that it cuts.

Probably late, also, are some dikes in the eastern part of the district, the most prominent of which is known as the Milk Ranch dike, because it is well exposed near a house in Long Canyon on what was once a dairy farm. At this locality the rock is much decomposed, but fresher material was obtained on the ridge east of Gold Creek, from what is probably the same dike. Here the prominent phenocrysts are of andesine and biotite, but the microscope reveals pseudomorphs after smaller phenocrysts probably of hornblende and pyroxene. The proximity of part of this dike to the Kate Peak andesitic series suggests that it may be contemporaneous with them. The fact that it is more altered than the lavas would not prove that it is older, in view of what has been shown regarding the alteration of the post-Davidson dikes farther west.

Alterations in the Alta andesite

Certain extensive and conspicuous alterations have taken place in the Alta andesite and are almost confined to it. These alterations include (1) typical contact metamorphism caused by the Davidson diorite, (2) less pronounced changes of a sort sometimes called propylitization, which are believed also to have been caused by the intrusion of the diorite, and (3) a more thorough-going change, due to hydrothermal alteration followed by weathering, the end-products of which are bleached rocks irregularly stained with iron oxide.

Contact metamorphism is best shown in the ridge extending northwest from the summit of Mount Davidson. Close to the contacts it produces rocks that are visibly crystalline and show little of the texture of the andesitic lavas and tuffs from which they were derived. Crystals of magnetite and, more rarely, of garnet are visible in places. More common are secondary biotite and feldspars of such fine texture that they are not identifiable except under the microscope. Farther from the contact the original textures are clearly recognizable, though the sparkle of disseminated biotite suggests metamorphism. Replacement of ferro-magnesian minerals by biotite, and reduction of the lime content of the feldspars, are characteristic effects at this stage. In the Sutro member, along Bullion Ravine, chloritic spots are developed in shale and tourmaline crystals deposited in joint fissures, clearly as a result of contact metamorphism. At the eastern base of Mount Davidson, the dump of a caved shaft consists in part of hornfels containing poikilitic secondary hypersthene. This rock was presumably derived from some part of the Alta andesite.

The term propylite was coined by von Richthofen for what he regarded as an independent species of volcanic rock, especially well exemplified in this district. Becker15/ showed that propylite was merely altered andesite, and the noun "propylite" has consequently fallen into disuse, but the adjective derived from it is still applied to a certain sort of alteration that has never been very clearly defined. As the Comstock district is the type locality for propylitization, the term is probably applicable to changes that are well exemplified on the Ophir grade and the adjacent flume.

15/ Becker, G. F., op. cit., pp. 81-90.

The more evident effects of this alteration are the acquisition of greenish hues and a thorough cementation of porous rocks, such as tuffs and breccias, which makes them compact and hard. In detail the changes in the minerals are complex and irregular, but the commonest alteration products are chlorite, epidote, and calcite. The area in which the changes have occurred appears to center in the Davidson diorite, and it is believed that the propylitization in this district is essentially a low-grade igneous metamorphism.

A more thorough hydrothermal alteration, resulting in the formation of much albite and pyrite, has occurred in some areas, the largest of which are roughly delineated on the map. As a result of weathering, the rocks thus altered have been bleached and irregularly stained with limonite, so that they are not always readily recognized as altered andesite. They are in fact called propylite on an early map of the district, but the term does not seem to be applied, here, in the sense that Von Richthofen intended. The effects of the hydrothermal alteration, uncomplicated by weathering, are best observed underground, especially in the Sutro tunnel. Large masses of such unweathered rock are pale-green in color and are peppered with tiny crystals of pyrite. Where these rocks are long exposed to the atmosphere, the oxidation of the pyrite produces both sulphuric acid, which further attacks the rock, and ferric oxide, which becomes irregularly disseminated through it. The bleached lavas, for the most part, still retain a porphyritic texture, but the feldspars are altered to albite and the ferromagnesian minerals so completely destroyed that pseudomorphs after them are rarely distinguishable. Although albite is the commonest product of the hydrothermal alteration, replacement by quartz takes place locally. A specimen taken about 1,000 feet southwest of the Scorpion shaft is found under the microscope to be at least 90 percent quartz. The quartz replacing the feldspar phenocrysts is coarser than the rest and forms pseudomorphs closely similar in outline to the replaced crystals.

The bleached rock forms many prominent, rusty ledges that resemble some outcrops of mineral deposits. These have naturally invited the attention of prospectors and have been prospected in many places, but without revealing any workable ore deposits.

Kate Peak andesitic series

The Kate Peak andesitic series makes up most of the Flowery Range. It is magnificently exposed in the steep eastern slope of Mt. Rose, and much of its western boundary lies just above the road in Long Canyon. Other extensive exposures occur north of the western part of the district, and a small isolated area lies west of the Sierra Nevada shaft.

The series, as is best seen in the face of Mt. Rose, consists in great part of coarse breccia, with some boulders more than 10 feet in diameter, but it comprises lava flows and possibly some intrusive sheets that have not been distinguished. Several bodies of rock similar in character to some of the flows and intrusive into the earlier part of the series are considered to be products of the same general episode of vulcanism as the Kate Peak andesitic series and are mapped in a slightly different pattern.

Two of these intrusive bodies, both in the northeastern part of the district, are thick dikes, one of which is interpreted as mushrooming into a sill at the top. Four larger masses lie near a northwesterly-trending line in the northern part of the district. One, from which Mount Abbie is carved, is regarded as an intrusive plug, and a second, near the Utah shaft, is more doubtfully regarded as another. The third is exposed in the 6229-foot hill 1½ miles south-southeast of Virginia City. A quarry on the northeast side of this hill supplied, in former days, most of the gray coarsely porphyritic rock that was used for engine-bases at the mine shafts. This mass is regarded as part of an intrusive sheet or laccolith, its lower boundary being the outcrop of its base. The bulkier mass that forms the top of Mount Grosh consists of rock similar in texture and general appearance, but largely reddish rather than gray. It seems most probable that the main body of this mass is an intrusive plug, with a sill-like extension to the north which forms the capping of a small plateau. It is even possible that this extension once connected with the mass in the 6229-foot hill. Sugarloaf, which is a little east of the mapped area, is clearly an intrusive plug, and possibly the root of a volcano from which some of the later flows of the series were erupted.

The rocks that constitute the lava flows, the intrusive bodies, and the fragments in the pyroclastic beds of this great volcanic series have in general a much fresher appearance than those of the older formations, and they are further distinguished by an abundance of large and conspicuous feldspar phenocrysts, a porous texture, and a harsh feel. Largely because of this last characteristic, they were called trachyte by the pioneer geologists. The series was mapped by Becker partly as "augite andesite" and partly as "later hornblende andesite."

Though obviously produced by a long series of eruptions unbroken by any long intervals of rest, the Kate Peak andesitic series is remarkably varied in composition and appearance. Some of its rocks are whitish, light gray, or light red, others almost black. The minerals that occur as phenocrysts, apart from the plagioclase that dominates in all, are hornblende, biotite, augite, hypersthene, olivine, and all the other minerals named, though the quartz grains are scarce and may be inclusions. Extremes of variation are fairly well represented by two specimens, one from the 6229-foot hill already mentioned, the other from the 5812-foot shoulder three-fourths of a mile south of Kate Peak. The first is medium light gray and is crowded with large white phenocrysts of feldspar (calcic andesine), some nearly half an inch long. It contains many phenocrysts of hornblende, a few of biotite, and a few inconspicuous ones of augite and quartz. The groundmass contains much cristobalite. The silica percentage is 63.49. The other rock is rather dark gray and andesitic in habit; it contains conspicuous phenocrysts of labradorite about 5 millimeters in greatest length, and smaller ones of augite, hornblende, hypersthene, and olivine. Much magnetite and both cristobalite and tridymite are present. The silica percentage is 58.51.

The best indication of the age of the Kate Peak andesitic series is given by fossil leaves and diatoms found in lake deposits interbedded with tuffs of the series, at and near the diatomite quarries in Long Valley, about 7 miles northeast of Virginia City. K. E. Lohman, who studied the diatoms, and Roland W. Brown and Ralph W. Chaney, who studied the leaves, all agree in placing the age of these beds near the passage from Miocene to Pliocene.

Some volcanic rocks underlying the Knickerbocker andesite at the west base of Basalt Hill and in the 5604-foot hill southeast of it are doubtfully assigned to the Kate Peak andesitic series. They overlie rocks that are correlated with the Alta andesite, and they are less altered than any that are known to be Alta. They are especially well exposed in railway cuts on the east side of the 5604-foot hill. The material is heterogeneous. The greater part is breccia, in which boulders of pyroxene andesite with conspicuous phenocrysts of augite are abundant. A hornblende-pyroxene andesite is exposed at the southeast side of this hill and in the west base of Basalt Hill, in which the most conspicuous phenocrysts are of hornblende. This lava bears some resemblance to that characteristic of the lowest division of the Alta, but it contains glass and cristobalite and is so fresh that it must be younger than the Alta.

The testimony of the fossil leaves and diatoms does not prove in itself that there was a long time interval between the eruption of the latest Alta andesites and that of the earliest Kate Peak andesitic rocks. The petrographic and structural relationships, however, indicate a distinct break. The lavas of the Kate Peak are on the whole much less altered than those of the Alta, and they rest on lavas of widely different stratigraphic position. In Long Canyon they rest on the bevelled edges of west-dipping Alta andesite. They are underlain by pyroxene andesite in Long Canyon, and by the later hornblende-pyroxene andesite near the northwest corner of the district. On the north side of the Jumbo Falls basin, lava of the Kate Peak with gentle westerly dip overlies lava, probably of the Alta andesitic series, that dips westward more steeply. South of American Flat, if the correlations there made are correct, volcanics of the Kate Peak andesitic series are in contact with division A (see p. 12) of the Alta in some places and with division B in others.

The relation of the Kate Peak andesitic series to the faulting is not altogether clear. Gianella16/ describes a block of vein material in breccia of this series, which he interprets as evidence that this andesite is younger than the period of vein formation--younger, apparently, than the Comstock Lode. It is clear on the other hand, from evidence in the Sutro Tunnel and on the south slope of Flowery Ridge, that the andesites of the Kate Peak andesitic series have been displaced by faults of large throw. It may be remarked that no evidence bearing on this point is afforded by the exposures near the 6229-foot hill, for the andesite blocks which there lie on the trace of the Occidental fault vein are not in place but form part of a landslide. The Kate Peak is believed, however, to be faulted down against the Alta along the canyon west of Mt. Rose.

16/ Gianella, V. P., op. cit., p. 72, and pl. 25.

Knickerbocker andesite

The Knickerbocker andesite was so named by Gianella[17] because of its occurrence at and near the Knickerbocker shaft, 1,000 feet northeast of the Baltimore shaft. Its petrographic character, however, is not so typically shown there as at some other localities. The best exposures are on Basalt Hill and on two hills south and southeast of it. Others are found along the railway on the west side of American Flat and at the top of the 6,625-foot hill still farther west, and a dike of Knickerbocker andesite occurs in the basin of Six Mile Creek, in the eastern part of the district.

The Knickerbocker andesite exposed in Basalt Hill is very similar in general appearance to the pyroxene andesite in the Alta. The main difference observable in the hand specimen is that the Knickerbocker looks fresher; and on close examination it is found to contain a thin sprinkling of little bright-green grains. On weathered surfaces it has a thin, well-defined, buff-colored rind, such as is never seen in the Alta. Microscopic study bears out the impression of general similarity with minor differences. The phenocrysts are of plagioclase, augite, and hypersthene. The plagioclase is labradorite, slightly more calcic than that in the Alta rock, its average composition being about An_{55} to An_{60}. The green particles noted are pseudomorphs after olivine and consist of a micaceous mineral with high double refraction and very low refractive indices. The rock is distinctly fresher than any in the Alta; the groundmass contains a good deal of glass showing no trace of devitrification, and the hypersthene is entirely unaltered. The rock is indeed so extremely fresh that the replacement of olivine is believed to have been caused by gases in the magma rather than by weathering. The rock is a little nearer to basalt than the pyroxene andesite of the Alta.

Specimens from some of the other localities differ in one direction or the other from this type. In some places the rock contains a few crystals of hornblende. Specimens from the hill southeast of Basalt Hill contain no pseudomorphs after olivine. The rock of the area adjacent to the Knickerbocker shaft is very like the pyroxene andesite in the Alta; it contains no olivine or pseudomorphs after olivine, the hypersthene in it is all more or less decomposed, and the glass is devitrified. The mass would be regarded as part of the Alta andesite were it not that it apparently overlaps the trace of the Silver City fault, though it seems to be cut off by the Comstock fault. In the spur west of B. M. 5733, on the edge of American Flat, the Knickerbocker andesite seems to have been faulted, being several hundred feet lower than the capping on the 6625-foot hill to the west, with which it presumably was once continuous. Some of the faulting there is regarded as earlier, and some of it later, than the eruption of the Knickerbocker andesite.

These relations of the Knickerbocker andesite to faults are somewhat similar to those of the Kate Peak andesitic series, and the age of the two is probably not greatly different. If the Tertiary rocks in Basalt Hill

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17/ Gianella, V. P., op. cit., pp. 73-76.

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and the 5604-foot hill southeast of it are rightly correlated, the Knickerbocker is later than the Kate Peak. In that case its most probable age appears to be Pliocene.

Later lavas north of Mount Grosh

Several areas of volcanic rock north of Mount Grosh, near Sutro No. 2 shaft, are represented on the geologic map by the same color as the Knickerbocker andesite. None of this rock is, indeed, precisely similar to typical Knickerbocker except the dike 3,000 feet north-northwest of No. 2 shaft, which resembles the rock of Basalt Hill in every detail, including the presence of tiny bright-green pseudomorphs after olivine. The other rocks are roughly correlated with Knickerbocker, for the present, because they resemble it somewhat in character and relations, and because the differences between them seem too little understood to justify their being represented, on a preliminary map, in several distinct patterns.

The largest area, which includes the hill northwest of the shaft, is occupied by andesitic-looking rocks, as dark as the Knickerbocker but more obviously porphyritic. All specimens contain augite and either hypersthene or pseudomorphs after hypersthene. Some contain olivine and some do not; some contain glass and some do not. Olivine-bearing rock at the eastern base of the mass may be intrusive into the rock that does not contain olivine. Both the appearance and relations of the mass as a whole indicate that it is younger than the Alta andesite upon which it lies, though it is not altogether fresh, being largely characterized by diffusion bands of bright-red iron oxide.

Dark andesite of still younger appearance occurs just west of the shaft, where it has a columnar structure, and in the valley both north and south of the shaft. This lava appears to be younger than a fault that brings andesite of the Kate Peak against Alta andesite. It is a pyroxene andesite containing fresh hypersthene and a little glass.

The knob about 4,000 feet north-northwest of the shaft appears to have been carved from a volcanic plug. The rock of which it consists resembles some pyroxene andesite of the Alta, though coarser than most and not so definitely porphyritic. It contains augite, but the hypersthene which it originally contained is all replaced. This mass may represent a feeder for some flows of Alta andesite.

Lousetown (?) andesite

In the southern part of the district there occurs a dark-gray fine-grained pyroxene andesite which may be of nearly the same age as the Knickerbocker andesite but is of distinctly different appearance. Its most interesting exposure is in a small butte, carved from an intrusive plug, west of the southern part of Grizzly Hill. Other masses, probably extrusive, occur east of Mound House, and extensive flows mantle the southwest slope of the Virginia Range near its southern end. This lava is provisionally correlated with extensive flows that have been seen north of the district,

on and near Lousetown Creek, and on both sides of Long Valley, which have been named by Thayer[18] the Lousetown series. Similar lava caps the Flowery Range near Tallapoosa, about 15 miles northeast of Virginia City. In Long Valley and near Tallapoosa this lava clearly overlies the Kate Peak rocks.

The tentative correlation of the lava in the Comstock Lode district with that farther north is based mainly on lithologic similarity, which, however, is incomplete in one respect: the lavas to the north all contain olivine, whereas those in the district do not. The lava in the butte west of Grizzly Hill is medium to dark-gray. The coarsest, which is intrusive, is distinctly porphyritic, with readily visible phenocrysts of plagioclase (medium labradorite), hypersthene, and augite, and a groundmass of plagioclase, magnetite, cristobalite, and cryptocrystalline material. Finer-grained lava in this butte and farther south is not definitely porphyritic. It has a peculiar silky luster, very like that of the American Ravine andesite porphyry, which some of it resembles, moreover, in containing "ghosts" of hornblende crystals. The body of the rock consists of laths of plagioclase, prisms and grains of augite and hypersthene, and a good deal of magnetite, glass, and cristobalite. The presence of the two last-named constituents, together with the extreme freshness of the rock, indicates that it is much younger than the American Ravine andesite porphyry.

In their relations to other rocks the lavas of the Lousetown (?) resemble the Knickerbocker andesite, but these two formations have not been found in contact and their relative age is not definitely known. In texture the rocks of the two formations are consistently different, and the difference in composition between the analyzed specimens of the one and of the other, though not large, is distinct, the lavas of the Lousetown (?) being less silicic and otherwise nearer to the basalts. It is conjectured from their apparent relative degree of erosion that the Lousetown (?) is a little younger than the Knickerbocker, perhaps very late Pliocene. The situation of the plug west of Grizzly Hill, near the intersection of two great faults, suggests a connection between the eruption and the faulting.

Pleistocene volcanic and intrusive rocks

Olivine basalt

On the north side of American Ravine, near its mouth, there is a small plateau capped with columnar basalt, which is underlain by a thin layer of gravel. Farther up the ravine and at the east side of American Flat there are other remnants of this lava; and there is a relatively large and rugged mass of it high on the slope west of American Flat. The lava evidently flowed down a valley that had about the same location as the present American

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18/ Thayer, T. P., Petrology of later Tertiary and Quaternary rocks of the north-central Cascade Mountains in Oregon, with notes on similar rocks in western Nevada: Geol. Soc. America Bull., vol. 48, pp. 1648-1650, 1937.

Ravine but that has been deepened about 200 feet since the eruption of the basalt. The highest outcrop may cover a small vent from which the eruption emanated.

The greater part of the basalt is very dark iron-gray and has a strikingly fresh appearance. All of it is somewhat porous, and the top of the flow is full of round bubbles formed by gases escaping from the lava when it was liquid. In rock from the main body of the flow, phenocrysts of greenish-yellow olivine are conspicuous. Other minerals are not easily distinguished, as a rule, with the naked eye, though one or two large crystals of feldspar may be seen in some specimens. Under the microscope it is seen that phenocrysts of augite are about as abundant as those of olivine. The groundmass consists essentially of plagioclase laths, augite granules, magnetite, and usually a little glass. A little red-brown biotite has formed later than these minerals, in small cavities. The larger plagioclase laths have the average composition of calcic labradorite or sodic bytownite (about An_{70}). They have a peculiar type of twin-structure; many crystals consist of three or four Carlsbad twins instead of the usual two. Specimens of the rock can be taken from almost any exposure that are as fresh as if erupted yesterday, even the olivine being entirely unaltered.

"Black dike"

A dike of dark rock injected into the fissure of the Comstock fault was called by Becker the "later diabase", but it was generally known to the miners as the "black dike." It cannot now be seen in place, for it is not exposed on the surface and the workings in which it was exposed are inaccessible; but specimens taken underground by Becker and others, by John Reid in the Hale & Norcross tunnel 1,070 feet from its portal, and by Gianella from the dump of the Bullion shaft, at the mouth of Bullion Ravine, have been examined and are all evidently of the same rock.

When freshly broken, specimens of this rock are of a dark-gray color like that of the basalt, but on exposure the surface of the rock assumes a brownish hue, the change becoming noticeable within a few weeks or days. Becker 19/ says that a visible change takes place within a few hours, but this probably is the case only in the hot, humid atmosphere of the mines. Dark specks that prove to be pseudomorphs after olivine, and less conspicuous phenocrysts of augite and olivine, are observable in hand specimens. Under the microscope, the feldspar of most sections is seen to be entirely unaltered. It is closely similar, not only in composition but in the peculiar character of its twinning, to that in the olivine basalt. The groundmass consists of plagioclase, augite, and magnetite. No hypersthene nor any mineral apparently derived from it has been found. The augite, like the feldspar, is perfectly fresh. The only secondary material present is mainly in pseudomorphs having forms characteristic of olivine. In the darker, unweathered part of the rock this material is deep green and similar to the mineral that has replaced olivine in the lavas of the Knickerbocker. All has an average refractive index lower than 1.54; some is apparently isotropic, but some has a fairly high double refraction and resembles green biotite in polarized light. In the part of the rock showing the brownish discoloration, this mineral has a

19/ Becker, G. F., op. cit., p. 52.

reddish-brown color and slightly higher refractive indices but is otherwise similar in optical properties to the green variety. The change in hue of the rock on exposure is evidently due to the oxidation of disseminated particles of this secondary mineral, which is perhaps hisingerite.

The basalt flow was described before the "black dike" not because the flow is known to be older, but rather for convenience in comparing the rock of the dike with the more abundant extrusive basalt. This lava and the Knickerbocker andesite are the only lavas in the district that the dike rock much resembles, and comparison with both may give some indication of the age of the dike.

Hague and Iddings,20/ who recognized the pseudomorphs after olivine, considered the dike rock so like the basalt that they failed to see any petrographic distinction between the two. Gianella,21/ on the other hand, correlates the dike with the Knickerbocker andesite. In my opinion, the dike rock is intermediate in character between the two lavas but resembles the basalt more closely than the andesite. Points of resemblance to the basalt are (1) the composition and peculiar twinning of the feldspar, (2) the former presence of much more olivine than occurs in the Knickerbocker flows, and (3) the absence of hypersthene. Chemical analysis points the same way: in a single specimen of each rock recently analyzed the approximate silica percentage of the Knickerbocker is 57, that of the black dike 50, and that of the basalt 48.

It therefore seems unlikely that the dike was a feeder for the Knickerbocker flows, even though the distribution of the Knickerbocker may be consistent with such a source. The distribution of the basalt, on the contrary, indicates a source west of the Comstock fault and independent of the black dike. It is thought probable that the black dike is a little older than the basalt, and intermediate in age as well as in character between the Knickerbocker and the basalt. Evidently, however, it was injected after the main movement on the Comstock fault, for none of the rock in specimens has been sheared. The complete alteration of the olivine could have been effected by hot solutions rising in the fissure while the dike was being intruded or immediately thereafter.

The basalt flow shows no evidence of having been faulted, and the small degree of erosion to which it has been subjected indicates a Pleistocene age. Similar basalt occurs in the canyon of the Truckee River below Reno.

Surficial deposits

Classification

The Virginia Range was never glaciated, and the district contains no glacial deposits. The surficial deposits mapped are mainly stream gravels. Some of the larger areas of talus and landslide, and some of the areas

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20/ Hague, Arnold, and Iddings, J. P., op. cit., p. 28.
21/ Gianella, V. P., op. cit., pp. 75-76.

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covered with dumps and other made ground, also have been mapped. On the present preliminary map, however, made ground, landslide material, and alluvium have not been distinguished in the vicinity of Virginia City. Made ground predominates on the flat ground in and near the town, and landslide material on the slopes just west of it.

Stream deposits

Some of the stream deposits of the district are much older than others. The very oldest, of which only scattered boulders and pebbles remain, are not represented on the map. One of the highest areas in which these meager remnants lie is in the head of the ravine just north of Mount Grosh. The mapped stream deposits are represented by a single color pattern, without distinction of age. Some of those obviously older than the Recent epoch are the terrace-cappings that occur west and south of Basalt Hill and on Gold Creek below Gold Hill. Most of the alluvial material on American Flat may be Pleistocene rather than Recent, for the present streams have been cut through it in places, and near the schoolhouse it has been stripped from the gently sloping eroded bedrock surface on which it was laid.

By far the largest area of stream deposits in the district occupies the lowland near its southern margin, which is thought to be part of an old valley of the Carson River. The great bulk of the gravel underlying this area was presumably deposited by this river when it held its ancient course. The gravel that makes up the great terrace just south of Gold Creek on the eastern border of the district is so well rounded and, as shown by numerous prospect pits, so deep that it could hardly have been laid down altogether by Gold Creek and other small mountain streams, though boulders of Davidson diorite and other rocks were brought down the ancient valley of Gold Creek. Gold Creek has cut its channel far below the upper surface of this gravel, and erosion has exposed the underlying bed rocks near the Daney mine and immediately north of Dayton.

Other considerations indicate that some of this gravel, especially southwest of the Daney mine, is much older than the Recent deposits. The most probable explanation for the gorge southeast of the 4901-foot hill, through which the Carson River now flows, is that the old broad valley was once occupied by a lake, in which deposits accumulated to a depth of at least 500 feet. These deposits, no remnant of which has been found in the Comstock Lode district, may have been an extension of those so remarkably displayed within the State Prison near Carson City, where they preserve the footprints of extinct elephants, horses, giant sloths, and birds. The river, having for some reason swung to the east side of its valley, incised its channel into the bed rock when the lake was drained. The subsequent removal of the lake beds in the Comstock district was presumably effected by small streams. The gravel reaches the crest of the ridge overlooking the gorge, and contains boulders of lava that probably came from the hills rising to the southeast.

According to Russell,22/ Lake Lahontan at its highest stage extended up

22/ Russell, I. C., Geological history of Lake Lahontan: U. S. Geol. Survey Mon. 11, p. 137, 1885.

the Carson River Valley as far as Dayton, and it therefore seems possible that a small body of silt exposed at the east edge of the district, half a mile south of Route 50, was deposited in Lake Lahontan.

The recent stream deposits may for the most part be recognized on the map by their relation to the topography. One of their few noteworthy features is the abundance, in alluvial fans near Mound House, of impure gypsum derived from the anhydrite deposit in the hills to the west. This alluvial "gypsite" was mined and used for plaster in former times.23/ Gold was discovered in the gravels of Gold Creek as early as 1848 or 1849, 24/ and later on Six Mile Creek, and the resultant placer mining led, about 10 years later, to the discovery of the Comstock Lode.

Talus and landslides

The question whether to map talus and landslides, and if so how thoroughly, arises in this as in other mountainous districts. Only some areas of both that are especially large or that conceal geologic boundaries have been mapped.

The only talus mapped is in areas adjacent to Davidson diorite, where talus is not only abundant and conspicuous but conceals a large part of an intrusive contact which, to judge from the better exposed parts of it, is very intricate. It was sometimes wished that even surface waste, or colluvium, could be mapped on the slopes of the ridge extending westward from Mount Davidson, where isolated crags of complexly intermingled diorite and andesite stand forth from smooth waste-covered slopes. Here only the bedrock that is conjectured to predominate is shown on the map.

Some of the largest areas of talus mantle the slopes of Basalt Hill, but they are not mapped because they do not interfere with the mapping of the bedrock geology.

Four areas of landslide have been mapped. Two of them adjoin the body of coarse andesite on the hill a mile and a half southeast of Virginia City. This rock is massive and relatively fresh, and some of it has slidden on the much more decomposed Alta andesite surrounding or underlying it. Another is on the slope north of American Flat, where there is a tongue-shaped mass, half a mile long, of loose rubble consisting mainly of pyroxene andesite of the Alta and intrusive pyroxene and andesite porphyry. The only other landslide mapped is a small one immediately south of the mouth of American Ravine. The benchlike top, the hollow left in the slope above from which the material slid, and the jumble of rock fragments in the slidden mass illustrate the typical features of a landslide in small compass. This slide occurred at the intersection of two of the largest faults in the district.

23/ Gianella, V. P., op. cit., p. 78.

24/ Lord, Eliot, Comstock mining and miners: U. S. Geol. Survey Mon. 4, p. 11, 1883.

Dumps and other made ground

The dumps of the shafts along the Comstock Lode are of enormous bulk and considerable extent, and, together with the made ground on which Virginia City is built, they doubtless conceal important details of the geology in the main fault zone. It was therefore almost necessary to map them, and, for the sake of consistency, some other comparatively large areas of these materials have also been mapped, including the broad sheet of fine tailings in the bed of Gold Creek below the Dayton mine. Though these materials were distinguished from alluvium in field mapping, for the sake of simplicity they are shown on the preliminary map with the same pattern as alluvium.

STRUCTURE

General features

What seems worth saying in this brief text with regard to the geologic structure relates chiefly to the Tertiary rocks, especially to the rhyolite and the Alta andesite.

In the pre-Tertiary sedimentary rocks, which are in part well bedded, there has been extremely intricate crumpling and shearing, of a sort that must have taken place under extremely heavy load. Similar deformation has occurred in the metavolcanics, where, however, it is less evident than in the sedimentary rocks, because of the relatively massive character of the material. No faults have been recognized within the areas occupied by these old rocks, although some doubtless exist; and almost nothing has been done by way of tracing large folds. The distribution of the pre-Tertiary rocks in the southwestern part of the district indicates that they form a broad dome-like structure, the middle of which consists of the large mass of sedimentary rock exposed west of Basalt Hill. The overlying metavolcanic rocks cap this mass at the west, where they form the crest of the range, and they flank it on the north and southeast. The quartz monzonite porphyry and the granodiorite are free from any shearing, so that they probably were intruded after most of the deformation of the older rocks had been accomplished.

The Quaternary rocks have not been perceptibly deformed, except that there is some evidence of faulting in the large alluvial area in the southern part of the district.

Deformation of Tertiary rocks

Tilting

The rhyolite and the Alta andesite, being essentially conformable, have been deformed to virtually the same extent. Almost everywhere they are tilted, as is indicated on the map by numerous dip-and-strike symbols. In the Sutro member of the Alta, sharply laminated sedimentary beds afford opportunities for accurately measuring dip and strike in beds that once

were strictly horizontal. So much accuracy cannot of course be claimed for observations made in the lavas. The propriety of using dip-and-strike symbols in lavas may indeed be open to question. It is believed, however, that their use is justified even though their accuracy is subject to discount. In a lava flow of large extent, a platy parting usually develops on cooling that is prevailingly parallel to the top and bottom of the flow. Locally, of course, especially along the edge of a flow, the partings may have any attitude whatever; but where, over an area of many hundreds of square feet, the platy partings have a nearly uniform dip, it seems fair to assume that they represent the attitude of the flow as a whole, and that they give some indication of the extent to which the flow has been tilted. But at best they are subject to a correction representing original dip, for lavas must flow downhill, and at a considerably steeper gradient than water.

The original dip of tilted lavas can only be estimated and must vary considerably. If the tilting was toward the source, the original dip should be added to the present dip; if the tilting was away from the source, the original dip should be subtracted. If the Eocene and Miocene lavas of the Comstock district came from volcanoes farther east, negative corrections should be applied; the westerly tilting would have been less than the present dip. But even in that case, it seems clear that the rhyolite and the lavas of the Alta have been considerably tilted since they were poured out -- a conclusion strengthened by the fact that the beds in the Sutro member have nearly the same dips as the volcanic rocks with which they are associated.

The dips in the rhyolite and the Alta andesite are mainly westward to northwestward, but north of American Flat they form part of a broad north-pitching anticline.

The Kate Peak andesite series, in the Flowery Range, dips eastward and southeastward, but so gently that its dips may represent the gradient of flow and not the effect of tilting. In its other areas, the dips of the Kate Peak rocks are not easily measured, but there appear to be no persistent well marked dips such as would indicate that the formation has been tilted. They have, however, been faulted. No tilting has been proved in the Knickerbocker and Lousetown (?) andesites, although the Knickerbocker, and perhaps the Lousetown, appears to have been faulted in places.

Faulting

The structural features that are most conspicuous on the map, and of most economic significance, are faults affecting the rhyolite and the Alta andesite. Outstanding among these are the Comstock and Silver City faults. Use of the two names implies that these are two distinct faults, which is not quite certain; what will here be called the Silver City fault may be a branch of the Comstock fault. I am inclined, however, to believe that the southern part of the Comstock fault proper passes along the west side of American Flat, and that movement began on the Silver City fault a little earlier than it did on what is here called the Comstock fault. There are several reasons for believing that movement on these and probably other faults took place at two or more periods.

Comstock fault.--At the south end of Virginia City the Comstock fault, though covered with made ground, has a striking effect on the areal distribution of the rocks; it marks the eastern limit of the Davidson diorite, none of which appears on the surface farther east. Drag on the fault has here produced in the diorite a sheeting slightly steeper than the eastern slope of the mountain. The Sutro tunnel crosses the fault near its inner end, which is not now accessible; and the dip of the fault between the surface and the tunnel, which is about 1,500 feet lower, is approximately 45°. It is in this fault, of course, that the famous Comstock lode was formed.

The best and perhaps the only mode of measuring the movement on this fault along the line of the Sutro tunnel was recognized by Gianella.25/ This method consists in calculating the displacement of the Sutro member of the Alta, as exposed in the hanging wall on the tunnel level and in the foot-wall on the slope south of Crown Point Ravine. In this way the total vertical throw on the fault is estimated to be about 3,450 feet. As Gianella, again, has pointed out, a part of this movement probably occurred after an erosion surface of low relief had been formed that is represented in part by the undulating plateau west of Mount Davidson and in part by the bench upon which Virginia City was built. The vertical extent of this later movement, as measured by the displacement of the erosion surface, would be roughly 1,500 feet.

Northward from Virginia City, the Comstock fault becomes relatively obscure and its throw probably diminishes somewhat rapidly.

South of Virginia City the evidence of faulting is more obvious in some places than in others. On the bench southwest of the Overman shaft, both footwall and hanging-wall consist of Alta andesite; but the rock in the foot-wall belongs to the division below the Sutro member while that in the hanging-wall belongs higher in the formation. In the Overman workings, rhyolite and Alta andesite in the hanging-wall are in contact with pre-Tertiary sedimentary rocks in the foot-wall. Along the northwest side of American Ravine there is rather complex faulting with downthrow on the southeast, but it is not certain whether any one of the faults exposed is the main Comstock fault, which may be concealed by the alluvium along the border of the flat. South of the flat, the best evidence of faulting consists in the proximity of Alta andesite on the east to pre-Tertiary sedimentary rocks on the west about a mile south of the summit of Basalt Hill.

In this same vicinity, Knickerbocker andesite, some extremely fresh lava tentatively assigned to the Kate Peak, and Lousetown (?) andesite occur immediately east of the fault, but what this fact signifies is somewhat uncertain. Knickerbocker andesite has probably been faulted: west of American Flat, for example, the typical Knickerbocker exposed in railway cuts appears to be a segment of the flow that caps the 6625-foot hill half a mile farther west, thrown down on a fault that, although it cannot be the main Comstock fault, probably belongs to the Comstock fault zone. Near the Knickerbocker shaft, on the other hand, a tongue of Knickerbocker andesite appears to overlap the

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25/ Gianella, V. P., op. cit., p. 85.

Comstock fault. It thus appears likely that the eruption of the Knickerbocker andesite occurred in part during, and in part after, the period in which recurrent movements along the Comstock fault zone were taking place. The Lousetown (?) andesite may have had a similar history. The fact that all the mapped areas of rock lie close to the line of the Comstock fault suggests that its eruption may have been connected with the faulting; while the fact that a large area of the rocks occurs on the south end of the Virginia Range, west of the fault, would seem to indicate that it has been affected by some of the later movement in the Comstock fault zone.

In the open cut west of Gold Hill there is clear evidence that a small reverse fault of moderate westward dip cuts the Comstock fault; and there is less clear evidence to the same effect in the Arizona-Comstock open cut farther north.

Silver City fault.--The Silver City fault joins the Comstock fault about half a mile southwest of Gold Hill. It can be accurately located in the gulch, partly filled with impounded tailings, south of the Overman mine, for the rock on the southwest side of the gulch consists of breccia typical of the lowest part of the Alta, while that on the northeast side is hornblende-pyroxene andesite of the uppermost division. Its junction with the Comstock fault is concealed and may not be quite accurately located on the map. The relation of the two faults as mapped suggests a cutting off of the Silver City fault by the Comstock fault, rather than a gradual merging of the two; and if the Silver City fault is indeed the earlier, its continuation beyond the Comstock fault may be represented by the Bright Star fault.

From its junction with the Comstock fault, which trends on the average a little north of east, the Silver City fault extends southeastward. It is not everywhere easily identified, being associated with many other faults that strike in various directions, but it probably passes close to the Dayton mine and extends southward past the Daney mine.

The Silver City fault resembles the northern part of the Comstock fault in having a moderate dip to the east, which is the side of downthrow, and in being extensively mineralized.

Occidental fault.--Another fault resembling the Comstock fault in all these respects--though the production from it has been far less than that from even the Silver City fault--is the Occidental. This fault is best exposed on the surface near the Occidental tunnel in Long Canyon, and it is crossed by the Sutro tunnel. Its dip is about 35° E., and it has a downthrow of several hundred feet on the east; the rock on the west is pyroxene andesite of the middle part of the Alta, and that on the east is hornblende-pyroxene andesite of the upper part.

Faults of northeasterly strike.--In the middle part of the district and somewhat farther south, there are several faults that strike nearly northeast. These have various dips; some have the downthrow on the north, some on the south. Nearly all of those that intersect with the Silver City fault displace it. The longest is the Oest fault, which near the Oest mine brings Alta

andesite on the southeast against pre-Tertiary metavolcanic rocks on the northwest. At the ravine to the east the fault becomes obscure, but it is believed to intersect and displace the Silver City fault north of the Dayton mine and to continue into Long Canyon.

A fault along the southeast base of Grizzly Hill is intersected by a short tunnel, where it is seen to be a reverse fault with a dip of 37° NW. The fault on the opposite side of the hill appears to be about parallel to this one but is normal.

Associated with these northeasterly-striking faults are faults of other strikes, and all these together make up a very complex pattern southwest and northeast of the Dayton mine. The vicinity of Suicide Rock, also, is characterized by complex faulting.

Faults cutting the Kate Peak andesitic series.--The ravine north of Mount Grosh follows, in part, a fault between the Alta andesite on the west, and Kate Peak andesitic series on the east. This fault, which may be called the Mount Grosh fault, is intersected by the Sutro tunnel at or near the foot of the Sutro No. 2 shaft. It is nearly vertical but may dip very steeply to the west, in which case it is a steep reverse fault. It is probably not of large throw.

Along the southwest base of the Flowery Range there is another fault, also probably of small throw, bringing lavas of the Kate Peak on the east against Alta andesite on the west.