Geology of the Virginia City Quadrangle, Nevada

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GEOLOGY OF THE VIRGINIA CITY QUADRANGLE, NEVADA

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ABSTRACT

Most of the Virginia City quadrangle, Nevada, is covered by a thick series of Tertiary and Quaternary volcanic deposits, but pre-Tertiary rocks are exposed in small patches. The pre-Tertiary rocks consist of metamorphosed sedimentary and volcanic rocks probably of Triassic age. They have been folded along axes whose average trend is a little east of north, and are intruded by granitic rocks of Cretaceous age.

The oldest of the Tertiary rocks are rhyolite pyroclastic rocks, which are tentatively considered to be of Oligocene age. Overlying these is a thick and complex sequence of andesitic flows and pyroclastic rocks, which have been divided into an older unit, the Alta formation, and a younger unit, the Kate Peak formation. The Davidson granodiorite is intruded into the Alta formation. Hypabyssal intrusions of andesite porphyry cut both the Alta and Kate Peak formations. The Alta formation and older rocks, and to a lesser extent the Kate Peak formation, were extensively altered. Much later, surficial weathering of the altered rocks that contain pyrite produced large areas of bleached rocks.

Stream and lake deposits of the Pliocene Truckee formation overlie and partly interfinger with the Kate Peak formation. The lake deposits were laid down in structural basins formed by warping and block faulting. Contemporaneous rhyolitic eruptions contributed pumice to the Truckee formation and also formed a large rhyolite dome at Washington Hill. The sediments of the Truckee formation were warped and faulted, and a surface of low relief was eroded on the soft sediments. Later, flows of basalt and basaltic andesite were erupted from several vents and covered large areas.

Still younger volcanic rocks, Quaternary in age, include andesite and olivine basalt. These are scattered and relatively small in volume. Quarternary stream and lake deposits were laid down in the intermontane basins and are still accumulating in parts of the basins. Extensive Quaternary hot-spring deposits have accumulated at Steamboat Springs. The Quarternary deposits have been warped and faulted like the older rocks, though to a lesser extent.

The pre-Tertiary structures, insofar as they are known, trend about north, and the Cenozoic folds and fault blocks, although divergent in detail, also trend generally north. The similarity between the older and younger structures is limited to their trend, however; for the older structures are compressional folds, like those of the Appalachians and other folded mountains. On the other hand, the Cenozoic (basin and range) structures are more diverse; they include many normal faults (exemplified by the Comstock fault), warped and tilted blocks

(well shown along the western side of the Virginia Range), and anticlinal folds (best illustrated by the anticline west of Virginia City). These Cenozoic structures are best interpreted as forming contemporaneously, or nearly so, over a long period of time beginning at least as early as Miocene and continuing, perhaps sporadically, to the present.

The present topography is the result of a long history of constructional volcanism, warping, block faulting, and differential erosion.

The best known metallic mineral deposits of the quadrangle are the famous silver-gold deposits of the Comstock lode. Similar deposits of quicksilver, gold, silver, and tungsten have been mined or prospected in several places.

INTRODUCTION AND ACKNOWLEDGMENTS

The Virginia City quadrangle comprises an area of 230 square miles in west-central Nevada just southeast of Reno. It includes parts of Washoe, Storey, and Lyon Counties, and also the old mining town of Virginia City on the Comstock lode. State Highway 17 connects Virginia City with U. S. 395 at the western edge of the quadrangle and with U. S. 50 2 miles south of the quadrangle. Most of the area is mountainous highland of the Virginia Range and the adjoining Flowery Range. The highest peak, Mount Davidson, rises precipitously above Virginia City to an altitude of 7,856 feet. The lowest point, about 4,270 feet, is on the Carson River near the southeast corner of the quadrangle. West of the Virginia Range is a chain of basins, including Steamboat Valley and Truckee Meadows, all drained by Steamboat Creek, a tributary of the Truckee River. Carson River and Steamboat Creek are the only permanent streams.

Geologic mapping of the Virginia City quadrangle and the Mount Rose quadrangle, which is adjacent to the west, was done in the field seasons 1948–52. The previous work of Calkins and Thayer (1945) in the Comstock lode district was an invaluable starting point, and their map has been incorporated with only minor modifications. (See index map.) V. P. Gianella's report on the geology of the Silver City area has also been especially helpful. D. E. White mapped the geology of Steamboat Hills and the Quaternary deposits of Steamboat Valley and Truckee Meadows. Efficient assistance was given in the field seasons of 1950–52 by J. G. Moore, in that of 1951 by R. A. Pomeroy, and for parts of field seasons by R. C. Horton, F. L. Campbell, R. G. Reeves and W. J. Carr. The present report is intended as a summary of the geology.

ROCK UNITS

The rock units are pre-Tertiary metamorphic and granitic rocks unconformably overlain by Tertiary and Quaternary volcanic rocks and sediments of streams and lakes.

PRE-TERTIARY SYSTEM

Pre-Tertiary sedimentary and volcanic rocks have been folded, regionally metamorphosed, and intruded by granitic rocks.

METAMORPHOSED SEDIMENTARY ROCKS

The metamorphosed sedimentary rocks are best exposed in several small areas along the west and south borders of the quadrangle and in a small patch half a mile southwest of Castle Peak. These rocks consist of argillite (indurated fine-grained sediments without fissility or cleavage), slate, conglomerate, sandstone, and limestone. Near granitic contacts, a more intense metamorphism has produced hornfels, contact schist spotted with andalusite and cordierite crystals, marble, and tactite. The conglomerate contains abundant pebbles of andesite, and much of the finer grained rock shows tuffaceous textures in places and has the chemical composition of an intermediate volcanic rock. Some of the fine-grained rocks in Steamboat Hills and elsewhere are not distinctly bedded, but the rounding of pebbles in the conglomerate, the presence of sandstone and limestone lenses, and the local occurrence of well-bedded rocks all indicate that the original sediments were largely water laid. Limestone lenses are found in Steamboat Hills, northwest of Jumbo, and southwest of American Flat; at the last place the limestone once supplied material for a small limekiln.

As no diagnostic fossils have been found, the age of the old sedimentary rocks is uncertain. Black, cherty-looking silicified wood, which was identified as a conifer, possibly *Araucarioxylon*, by Roland W. Brown, occurs in the area southwest of Castle Peak. Small pelecypods, which were first found by V. P. Gianella, occur in the same area; they were examined by S. W. Muller and found to be unidentifiable (oral communication, 1950). L. H. Daugherty (1941) reported *Araucarioxylon* in the Upper Triassic system of Arizona and also near Winnemucca, Nev. S. W. Muller (oral communication, 1951) has collected similar fossil wood in the Upper Triassic system in a number of widely scattered localities in Nevada.

Gianella (1936, p. 37–38) assigned the pre-Tertiary rocks in the southern part of the Comstock lode district to the Triassic(?) system on the basis of lithologic similarity to fossiliferous Triassic rocks in Eldorado Canyon, about 10 miles to the southeast in the Pine Nut Range, but he pointed out the possibility that some of the rocks might be as old as Paleozoic. Calkins, (1944, p. 9), on the basis of similar evidence, concluded that the pre-Tertiary rocks in the Comstock lode district are not younger than Jurassic.

METAVOLCANIC ROCKS

Metavolcanic rocks are exposed in the southwestern part of the quadrangle; the original rocks were largely basalt. Metavolcanic rocks also occur immediately north of the quadrangle in the Truckee River canyon; these rocks are predominantly andesites. All of these lavas and pyroclastic rocks have been strongly metamorphosed, generally to albite-epidote-amphibole rocks. Contact metamorphism near bodies of granitic rocks has locally formed andesine-hornblende-biotite rocks, some of which are schistose.

The original thickness of the old volcanic rocks probably differed greatly from place to place; the estimated maximum thickness is at least 1,000 feet (Gianella, 1936, p. 40). In the Comstock lode district, the bulk of the pre-Tertiary volcanic rock is metabasalt overlying the old sediments, but some altered andesite is interbedded with the sediments (Calkins, 1944, p. 9). The predominance of andesite north of the quadrangle, as has been mentioned, coupled with the abundance of andesitic debris in the old sedimentary rocks also indicate that the pre-Tertiary sedimentary and volcanic rocks partly interfinger; the sedimentary rocks were derived partly from the volcanic rocks. The relations are similar to those in the Yerington district, where Knopf (1918, p. 13) concluded that all the pregranitic rocks are of Triassic age. The metavolcanic rocks in the Virginia City quadrangle are considered as Triassic(?) in age.

GRANODIORITE AND RELATED ROCKS

Granodiorite and allied varieties of granitic rocks are exposed in small areas along the west base of the Virginia Range, along the east slope of the Flowery Range, and in the southern part of the Comstock lode district. From the southwest corner of the quadrangle they are exposed almost continuously southwestward across Lakeview summit into the Carson Range of the Sierra Nevada. Intrusive contacts with the pre-Tertiary sedimentary rocks are well shown east of Sutro Springs near the east border of the quadrangle, in Steamboat Hills, and northwest of Jumbo near the west border. Intrusive contacts with the metavolcanic rocks are exposed in American Ravine, which is in the southern part of the Comstock lode district, and southwest of Jumbo.

Although the granitic rocks range in composition and texture, by far the most abundant type is granodiorite containing about twice as much plagioclase as orthoclase. Gradational changes in total amount of hornblende and biotite and also in the relative proportions of these two minerals are the most obvious, but the quartz and feldspar also range considerably in amount. These changes are not always marked by sharp contacts, and so all of the granitic rocks are shown on the map under one symbol. Smaller bodies and in some places the border apophyses of large bodies tend to contain more orthoclase and quartz, less of the dark minerals, and less plagioclase; also the plagioclase is more sodic. The small intrusions in the Comstock lode district are quartz monzonite porphyry (Calkins, 1944, p. 10). Dikes of aplite and pegmatite and veins of quartz are abundant near the contacts of granitic bodies, and also cut the metamorphic rocks in many places where no granitic rocks are exposed. Large crystals of hornblende, orthoclase, and plagioclase, like those in the granodiorite, are common in the metamorphosed country rock and in xenoliths within a few inches to a few feet of the contacts. The rocks containing these metacrysts are somewhat similar to the granodiorite in appearance but are darker and have a porphyritic appearance, and the matrix of the metacrysts is finer grained than the granodiorite.

Most of the granodiorite is relatively structureless with strong lineation or foliation only in small areas. In the southwest corner of the quadrangle, the largest area of highly foliated granitic rock, is so distinctive that it has been shown separately on the map. Here massive rock grades eastward through a narrow zone into foliated rock in which the planar structure strikes about north and dips 35°–40° E. The foliation may be parallel to a contact with metamorphic rocks less than a mile to the east, but the actual contact is concealed beneath Tertiary volcanic rocks. In the field the foliation appears to represent a thorough shearing; inclusions of metamorphic rock are drawn out into biotite schist. Thin sections of the granitic rock show alined biotite flakes and an occasional bent plagioclase crystal. The larger crystals of feldspar, which are mostly of plagioclase but include a little orthoclase, lie in a matrix of smaller crystals of orthoclase and quartz, formed by crushing and recrystallization.

The granitic rocks of the Virginia City quadrangle extend southwestward in nearly continuous outcrops to the granitic rocks of the nearby Sierra Nevada; all were evidently emplaced about the same time. The age of intrusion of the main Sierra Nevada batholith has been considered by several authors to be Late Jurassic or Early Cretaceous (Hinds, 1934, p. 192; Knopf and Kirk, 1918, p. 62). More recently, Larsen and his coworkers (1954), using the lead-alpha activity ratios of the accessory minerals, found the age to be Cretaceous.

TERTIARY SYSTEM

The Tertiary rocks are volcanic agglomerates, tuffs, and lavas together with a small amount of sedimentary rocks derived from the volcanic rocks. In composition the volcanic rocks range from basalt to rhyolite, but they consist predominantly of different kinds of andesite.

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HARTFORD HILL RHYOLITE TUFF

The oldest of the Tertiary formations was called the Hartford Hill rhyolite by Gianella (1936, p. 45). It is here named the Hartford Hill rhyolite tuff. At the type locality, Hartford Hill, near Silver City, it is about 1,000 feet thick. At its base on the south slopes of Hartford Hill it includes a few feet of conglomerate, which contains pebbles of the underlying metavolcanic and granitic rocks. It is overlain by Alta formation. The Hartford Hill is extensively exposed in the Comstock lode district and south and southwest of the Virginia City quadrangle. Over most of the remainder of the quadrangle it either was never deposited or was removed by erosion before the deposition of the andesites. The most northerly exposures are in two small patches northeast of Sutro Springs and in a small area near Castle Peak; the main glory hole of the Castle Peak quicksilver mine also contains some altered rhyolite tuff seemingly interbedded with andesite.

The formation is composed of light-pink to dull-purple vitric-crystal tuff, tuff-breccia, and welded tuff. The bulk of the rock is made up of fragments of glass and pumice, which in most places are completely devitrified. Crystals of quartz, orthoclase, plagioclase, and biotite are abundant in places but almost completely absent in other places. Fragments of granitic and metamorphic rocks are common, and in a few places they constitute as much as 10 percent of the rock.

The Hartford Hill rhyolitic rocks were formerly considered to be largely rhyolite flows (Gianella, 1936, p. 45–47; Calkins, 1944, p. 11), but the preponderance of broken crystals, fragments of pre-Tertiary rocks, flattened pumice lapilli, and relict tuff textures in the devitrified matrix indicate a pyroclastic origin for most, if not all, of the formation. This conclusion is borne out by the presence of remnants of undevitrified welded tuff on the west and south slopes of McClellan Peak. Similar rocks near the Carson airport, south of the quadrangle, were mapped by Reid (1911) as pitchstone dikes, but they are in fact extrusive pyroclastic rocks. A small mass of irregularly dipping tuff-breccia on the slopes west of American Flat probably fills one of the source vents of the rhyolite tuff.

There is evidence of some interbedding of the Hartford Hill rhyolite tuff with overlying Alta formation; this can be seen near Jumbo and at the Castle Peak mine. Calkins (1944, p. 11) found similar evidence south of the quadrangle at the Daney mine. It is probable, therefore, that if the Alta formation is Oligocene the Hartford Hill rhyolite tuff is partly Oligocene, but it may be partly or mainly Eocene in age.

ALTA FORMATION

The older of the two extensive andesite formations was described by Gianella (1936, p. 53) as the Alta andesite, after the Alta shaft on the Comstock lode. The formation consists mainly of tuff-breccia, flow breccia, and lava flows, but it contains the sedimentary Sutro member, which ranges in texture from shale to conglomerate. The andesites are extensively exposed in the southern two-thirds of the Virginia City quadrangle; the Sutro member is present only in the Comstock lode district. In the northern part of the quadrangle the Alta is missing, but similar andesites reappear northwest of Reno on the slopes of Peavine Peak.

Calkins (1944, p. 12) divided the Alta andesite of the Comstock lode district into four members with an aggregate thickness of about 2,700 feet, but this subdivision and thickness have only local significance, for elsewhere the section is less complete, and the members are less easily recognized. The lower member is most distinctive; it is commonly a tuff-breccia altered to shades of red and green. This tuff-breccia is composed of andesite fragments containing sparse phenocrysts of hornblende and abundant phenocrysts of plagioclase about 1 millimeter in diameter. The sedimentary Sutro member is generally above the lower member, but it forms discontinuous lenses at different stratigraphic horizons. Where it is coarsest it consists of andesite and rhyolitic debris; its most characteristic rock, however, is a fine-grained evenly bedded grayish-green shale.

Above the Sutro is a pyroxene andesite, which where fresh is almost as dark as basalt and has many transparent phenocrysts of plagioclase about 2 millimeters in diameter, inconspicuous phenocrysts of pyroxene, and scattered phenocrysts of hornblende. Where the rock is weathered it is greenish gray, and the feldspar phenocrysts are white, and the pyroxenes are represented by conspicuous dark pseudomorphs. This pyroxene andesite, together with the tuff-breccia of the lower member, constitutes the most widespread rock types in the Alta formation. The uppermost member described by Calkins is hornblende-pyroxene andesite with larger phenocrysts than the other members; it may be an intrusive rock with associated intrusion breccias.

In Steamboat Valley and near Jumbo the Alta includes a soda trachyte. The soda trachyte is generally a light to medium purple, but it has been derived from a black semivitreous rock; this unaltered rock is exposed in a small area in Steamboat Hills west of the quadrangle. The trachyte consists of small tabular phenocrysts of sodic plagioclase, with or without hornblende, in a very fine grained groundmass of plagioclase, potash feldspar, and red iron oxide. In many places the phenocrysts and elongated crystals of the groundmass show a striking alinement, which has given the rock a platy parting.

The Alta formation is more altered on the average than the younger rocks; the groundmass is everywhere devitrified, and the hypersthene is almost all replaced by secondary minerals.

One of the extrusive centers of the Alta formation was almost certainly in the Comstock lode district, for its thickness and its diversity of composition decrease rapidly away in all directions from this area. Possibly the main vents were in the area now occupied by the Davidson granodiorite. The Alta formation probably interfingers with the overlying Kate Peak formation in some places—near Bailey Canyon and Sixmile Canyon—but the rock types are not sufficiently distinctive to be absolutely sure of this relation; the division between the two formations is necessarily arbitrary in many areas. Unconformable relations are demonstrated locally by fresh andesite of the Kate Peak lying on Alta formation that has been hydrothermally altered and weathered.

The best indication of the age of the Alta is given by fossil leaves found in the Sutro member in a road cut in Long Canyon. They suggest an Oligocene age (Axelrod, 1949, p. 1935).

AMERICAN RAVINE ANDESITE PORPHYRY

The American Ravine andesite porphyry, which was named by Gianella (1936, p. 44), has been mapped only in the Comstock lode district, where it occurs in American Ravine and in Gold Canyon. The greater part of it is a fine-grained andesite with slender hornblende phenocrysts set in a groundmass composed largely of subparallel laths of labradorite; the interior of the mass in American Ravine consists of a coarser porphyry (Calkins, 1944, p. 17). The American Ravine andesite porphyry is clearly intrusive into the Hartford Hill rhyolite tuff and probably into the Alta andesite (Calkins, 1944, p. 16). Of the extrusive rocks with which the porphyry might be correlated, some phases of the Alta formation and of the Kate Peak formation are similar, but the most striking resemblance in composition and texture is with the Lousetown formation; in fact, the only marked difference is in the greater alteration of the porphyry. The age of the porphyry is therefore uncertain; Calkins regards it as probably intermediate in age between the Alta formation and the Kate Peak formation, and that position is tentatively assigned to it here.

DAVIDSON GRANODIORITE

The summit of Mount Davidson is part of a stock of what Gianella (1936, p. 64–68) named Davidson diorite, here called Davidson granodiorite. This stock is the only deep-seated intrusion of Tertiary age in the Virginia City quadrangle. Smaller intrusive bodies are exposed to the north and west of the stock; in these the rock is porphyritic.

But in the stock the granodiorite is hypidiomorphic and medium grained, and presumably it crystallized under many hundreds of feet of cover. The chief constituent is zoned plagioclase, the average composition of which is andesine. Quartz and orthoclase occur in smaller grains between the other minerals. Augite and hypersthene were originally present, but the hypersthene has been almost completely replaced and the augite has largely been altered to fibrous amphibole and other minerals. The rock also contains biotite, commonly altered to chlorite, and perhaps a little original hornblende.

Becker (1882) and later workers called it a diorite; Gianella (1936, p. 66), although retaining the name diorite, noted that the rock is close to granodiorite in composition. Chemical analyses were made of two specimens in connection with the present study, one from the main body in Bullion Ravine and the other from the smaller intrusion a mile west of Mount Davidson. These two analyses, which are almost identical, indicate a composition between average quartz diorite and average granodiorite (Daly, 1933, p. 447 and 457). The silica content is 63.5 percent, much more than Daly's average for diorite (57.6 percent) and more than his average for quartz diorite (62.4 percent) but less than his average for granodiorite (65.7 percent). All of the other constituents are closer to granodiorite than to quartz diorite. This bears out petrographic observations of considerable amounts of quartz and orthoclase, which are not conspicuous because of their fine grain. The change in name, to Davidson granodiorite, is thus required.

The intrusive relation of the Davidson granodiorite to the Alta formation is shown by intricate intrusive contacts, by inclusions of andesite in granodiorite, and by metamorphism of the andesite (Calkins, 1944, p. 18). Partly on the basis of a chemical analysis published in 1878 (King, 1878, p. 676) the Davidson granodiorite has been correlated with the Alta andesite (Hague and Iddings, 1885, p. 21–22, 40; Calkins, 1944, p. 18). The old analysis was of a specimen taken from the "Eldorado outcrop" ("Gould and Curry croppings" on Becker's (1882) map), and although this entire area is shown as "diorite" on Becker's map, it actually contains several different rocks, including Alta andesite, as mapped by Calkins and Thayer (1945). The old analysis is very similar to recent analyses of the Alta and quite different from those of Davidson granodiorite. The recent analyses of Davidson granodiorite show that it is almost identical in composition with some of the andesite porphyry of the Kate Peak formation. It may therefore be younger than it has generally been considered in the past and may be contemporaneous with part of the Kate Peak formation. It cannot be younger than all of the Kate Peak formation because it is cut by a few dikes of andesite porphyry of the Kate Peak formation.

KATE PEAK FORMATION

The Kate Peak formation, named for Kate Peak in the Flowery Range, east of Silver City (Gianella, 1936, p. 69), occupies the most extensive area of any formation in the Virginia City quadrangle. Coarse agglomerate that contains blocks of andesite of contrasting color and texture is perhaps the most abundant rock in the Kate Peak formation, but lava flows and flow breccias also occur in a great adundance and variety. Though most of the Kate Peak rocks are andesites, their composition and texture are remarkably varied. Many have a groundmass of silicic glass, which makes their chemical composition more comparable to dacite than to andesite. Large, nearly equidimensional plagioclase phenocrysts occur in nearly all the Kate Peak rocks; hornblende is the most common dark mineral, but biotite is abundant in some places and orthorhombic and monoclinic pyroxenes are not rare; some specimens contain all these minerals. On the whole the Kate Peak formation is more silicic than the Alta formation, but it is also more varied, and there is considerable overlap in the range of composition of the two formations.

A vitrophyre member of the Kate Peak occurs in the northeastern part of the quadrangle. This member is composed of devitrified perlitic glass, containing phenocrysts of plagioclase, biotite, and hornblende; a chemical analysis indicates that it is a rhyolite, locally it is spherulitic. It is generally characterized by highly contorted flow banding.

The maximum thickness of the Kate Peak formation is more than 2,000 feet. The vitrophyre member is at least 1,000 and probably nearly 2,000 feet thick in its thickest part.

Most of the intrusions shown on the map as Kate Peak formation are composed of biotite-hornblende andesite porphyry so nearly identical in appearance, composition, and texture with the most distinctive of the Kate Peak lavas that they are believed to be products of the same period of vulcanism. Coats (1936) has studied the structure and petrography of five of these intrusions. The andesite porphyry intrusions in the Comstock lode district were formerly considered to be older than the Kate Peak formation (Gianella, 1936, p. 68). But the continuity of the swarm of dikes north of Virginia City from areas where they cut the Kate Peak formation into areas where they cut only the Alta formation, and the lack of any difference other than degree of alteration, constitutes good evidence that the dikes are related to the younger formation.

The distribution of the Kate Peak indicates that it was erupted from many vents in the Virginia Range, the Flowery Range, the Steamboat Hills, and the Huffaker Hills, and in many places outside the quadrangle. Pipelike intrusions such as Sugar Loaf, and some of the dikes, probably served as feeders. A few of the dikes north of Virginia City are composed partly of andesite breccia resembling the extrusive agglomerates of the formation.

The top of the Kate Peak formation intertongues with the overlying Truckee formation, which contains fossil leaves and diatoms indicating an age near the Miocene-Pliocene boundary (Calkins, 1944, p. 23). This suggests that the Kate Peak formation is Miocene or early Pliocene in age.

TRUCKEE FORMATION

King (1878, p. 412–423) used the name Truckee Group for sedimentary rocks in western Nevada that he considered to be Miocene in age. According to King (1878, p. 415), the most important and characteristic exposures of these rocks are about 40 miles east of Reno in what are now called the Hot Springs Mountains. A thick section of sedimentary rocks exposed in the Truckee Canyon above Reno was also called Truckee by King. The name Truckee formation is here used for similar sedimentary rocks beneath the Lousetown formation in the northern part of the Virginia City quadrangle. In this quadrangle the formation is composed of stream and lake deposits, which occur in many disconnected areas. The Truckee formation is light-colored, commonly glaring white, as in the Chalk Hills north of Virginia City, and texturally the rocks range from shale to conglomerate and tuff-breccia. Beds of diatomite are common, and diatomite was formerly quarried as an abrasive in the Chalk Hills; tuffs are widespread; the dominant constituent, however, is andesitic detritus. The thickness in the Chalk Hills is uncertain because of many small faults but may be 3,000 feet or more; elsewhere in the Virginia City quadrangle it is much less.

As already noted, the base of the Truckee formation intertongues with the upper part of the Kate Peak formation; it may be in part contemporaneous with the vitrophyre member of the Kate Peak formation. Basaltic andesite of the Lousetown overlies the Truckee formation with an angular unconformity as much as 20° west of Chalk Hills, and with a smaller angular discordance, or none, at other places.

The age of the Truckee formation at the type locality, where King thought it was Miocene, is now thought to be early Pliocene (Yen, 1950; MacDonald, 1950). The extensive exposures of the Truckee formation in the Truckee Canyon above Reno are also Pliocene, as shown by fossil leaves found near Verdi (D. I. Axelrod, oral communication, 1951). In the Virginia City quadrangle, the best indication of the age of the Truckee formation is given by fossil leaves and diatoms found at and near the abandoned diatomite quarry in the Chalk Hills. K. E. Lohman, who examined the diatoms, and R. W. Brown and R. W. Chaney, who studied the leaves, agree in placing the age near the Miocene-Pliocene boundary (Calkins, 1944, p. 23). Later, D. I. Axelrod (oral communication, 1951) studied larger collections of the leaves and concluded that they are early Pliocene.

WASHINGTON HILL RHYOLITE

The name Washington Hill rhyolite is here given to the extrusive dome of devitrified rhyolitic glass and perlite in and immediately southwest of Washington Hill. Another large rhyolite dome 4 miles farther north, on the north side of the Truckee River and outside the quadrangle, is about contemporaneous with the one in Washington Hill, for pumiceous tuffs erupted from both domes are included in the Truckee formation. It is possible that the rhyolite vitrophyre member of the Kate Peak formation is also correlative with the Washington Hill rhyolite, but probably the vitrophyre is somewhat older.

The rock is light gray and highly flow-banded. Sparse phenocrysts of sodic plagioclase and biotite are set in a groundmass of rhyolitic glass that is entirely devitrified in the main mass at Washington Hill, possibly as a result of slow cooling in so large a body after its initial solidification. The devitrified groundmass contains radiating feathery aggregates of crystals that transgress the flow-banding, which indicates that they formed after the rock had ceased to move. The smaller mass to the southwest of Washington Hill is also largely devitrified but contains small areas of fresh perlite along the southeast side and near the center.

Although the Truckee formation in nearby areas contains blocks of devitrified rhyolitic glass identical with that in Washington Hill, the dome cuts through the adjacent pumice-bearing Truckee. This suggests that the dome is an end phase of eruptive activity that earlier supplied pumice to the Truckee formation. In the early stages of eruptive activity a large crater was blown out through the Kate Peak formation. The explosions spread pumiceous tuff and fragments of Kate Peak rocks over a wide area, where they now form part of the Truckee formation. In the final stages of eruptive activity the viscous lava of the dome pushed up into the crater, cutting through Kate Peak rocks and earlier beds of the Truckee and possibly flowing out over them locally. Still later beds of the Truckee contain blocks of the devitrified rhyolitic glass from the dome. The Washington Hill rhyolite is therefore regarded as contemporaneous with the upper part of the Truckee formation, considered to be of Pliocene age.

UPPER TERTIARY AND QUATERNARY SYSTEM

KNICKERBOCKER ANDESITE

The Knickerbocker andesite was named by Gianella (1936, pp. 73–74) for the Knickerbocker shaft, just north of American Flat. Calkins (oral communication, 1948) later decided that the lava at the Knickerbocker shaft is Alta and that what Gianella described as Knickerbocker is best represented by the outcrops on Basalt Hill, south of American Flat. This report follows Calkin's mapping in regard to the distribution and relations of the Knickerbocker in the Comstock lode district. Knickerbocker andesite also occurs in small areas about a mile southeast of Basalt Hill, where much of it is intrusive. It also occurs along the west side of American Flat, where its petrographic character distinguishes it from the nearby Alta andesite, and in the canyon about a mile south of Sugar Loaf, where part of it is intrusive.

The Knickerbocker andesite, as represented by the exposures on Basalt Hill, has a general resemblance to the pyroxene andesite member of the Alta formation, but on fresh surfaces it is darker. On weathered surfaces, moreover, the Knickerbocker andesite is covered by a characteristic buff-colored rind. The Knickerbocker contains phenocrysts of plagioclase, augite, and hypersthene, in a partly glassy groundmass. In addition, it commonly contains scattered grains of olivine or green alteration products of olivine. The hypersthene is fresh, whereas in the Alta the hypersthene is almost all replaced.

The Knickerbocker clearly overlies the Alta formation, and dikes of it cut the Kate Peak formation. It is tentatively considered to be older than the Lousetown formation, but this is uncertain.

LOUSETOWN FORMATION

The type locality of the Lousetown formation is east of Lousetown Creek and 6 miles north of Virginia City (Thayer, 1937, p. 1648). The Lousetown is composed almost entirely of lava flows, and these came from at least four vents within the quadrangle: one on Clark Mountain, a second represented by the intrusive plug in the type area east of Lousetown Creek (Thayer, 1937, p. 1649), a third about 2 miles north-northwest of Castle Peak, and a fourth in Steamboat Hills. The flows immediately south of the quadrangle evidently came from a dissected cinder cone on the south slopes of McClellan Peak.

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The flows are gray olivine basalt in places, although olivine is not always discernible without microscopic examination; pyroxene andesite with a basaltic habit predominates in some areas. Near the type locality the formation can be divided into two series of flows, the lower of which contains less olivine and has slightly larger feldspar phenocrysts. The upper division, and most of that farther south, has a satiny luster, owing to the subparallel orientation of the lath-shaped feldspar crystals.

The basaltic andesite flows on the southwest side of Clark Mountain are correlated with the Lousetown on the basis of composition and stratigraphic position. The basaltic andesite of Steamboat Hills is regarded as probably Lousetown on the basis of similar composition and degree of erosion. Tentatively, it is considered to represent some of the latest of the Lousetown flows and to be later than the Steamboat Hills rhyolite, which is described below. This correlation, however, is rather uncertain; it is possible that this rock is as young as the McClellan Peak olivine basalt.

The Lousetown formation is post-Truckee. In a few places the Truckee formation grades upward into bedded basaltic pyroclastics beneath flows of basaltic andesite. This relation is well shown below the capping of Lousetown on the northernmost hill in sec. 32, east of the Chalk Hills, and also above the Tuffstone quarry, half a mile north of the quadrangle on Long Valley Creek. The degree to which the Lousetown has been deformed and eroded suggests that it is of late Pliocene or early Pleistocene age.

STEAMBOAT HILLS RHYOLITE

The Steamboat Hills rhyolite is here named for an occurrence of pumiceous rhyolite in the Steamboat Hills, 2½ miles west of the Virginia City quadrangle. The rhyolite also occurs in two widely separated areas within the quadrangle; one along the west base of the Virginia Range, northeast of Steamboat Hills, and the other at Sutro Springs, on the east side of the Flowery Range. All these occurrences are extrusive domes of fresh pumiceous rhyolite, containing very sparse phenocrysts of sanidine, quartz, plagioclase, and biotite. Some of the rhyolite is perlite, and a very little is obsidian. The extrusion of the dome in Steamboat Hills was preceded and followed by explosive eruptions, but there seems to have been little such activity at the other domes, which do not have craters. The Steamboat Hills rhyolite is probably contemporaneous with or slightly older than the basaltic andesite in Steamboat Hills, tentatively correlated with the Lousetown, but younger than most of the Lousetown in the Virginia City quadrangle. The evidence on which this interpretation is based is as follows: (1) Pumice fragments thought to be from the earliest explosive eruptions of Steamboat Hills rhyolite are locally abundant in the gravels beneath the basaltic andesite in Steamboat Hills; (2) pumice lapilli, perhaps from the last explosive eruptions, are scattered very sparsely on the surface of the same flows; and (3) most of the Lousetown in the Virginia City quadrangle appears to be more eroded than the domes of Steamboat Hills rhyolite and therefore to be older. On the basis of this evidence, the Steamboat Hills rhyolite is regarded to be of Pliocene or Pleistocene age.

MUSTANG ANDESITE

The Mustang andesite, which is here named for Mustang, 9 miles east of Reno on the Truckee River, and north of the quadrangle, is well exposed on the slopes of Clark Mountain. It is the youngest andesite and is present only in the northeastern part of the quadrangle. It is a fine-grained gray rock with abundant large hornblende phenocrysts, which are commonly partly replaced by magnetite. It resembles some of the hornblende andesites of the Kate Peak formation, except that it lacks large feldspar phenocrysts. Flows that are generally from 100 to 200 feet thick, but of relatively small extent, issued from a vent at the summit, about a quarter of a mile north of the quadrangle; the original form of some of the flows is still well preserved. The flows lie in part on the Kate Peak formation, in part on the Truckee formation, and in part on the Lousetown formation. They are not directly overlain by younger rocks, except alluvium, but debris eroded from them lies beneath the McClellan Peak olivine basalt. The Mustang andesite is considerably less eroded and less deformed than the Lousetown formation, and is therefore very probably of Pleistocene age.

M'CLELLAN PEAK OLIVINE BASALT

The name McClellan Peak olivine basalt is here given to what Gianella (1936, p. 76–77) called American Flat basalt; the change in name is required because American Flat has been applied to a formation in Colorado. Remnants of a flow of McClellan Peak olivine basalt are found on the east slope of McClellan Peak, nearby on American Flat, and in American Ravine, where a few feet of gravel occurs at its base. At these localities the flow is not over 50 feet thick; it lies unconformably on Alta formation, Hartford Hill rhyolite tuff, and pre-Tertiary rocks. It is not directly overlain by younger rocks. Essentially identical olivine basalt covers a much larger area in the northeastern part of the quadrangle, where a flow spread over the flats south of Clark Mountain, ran down Long Valley Creek, and continued eastward down the canyon of the Truckee River. The rock is gray on fresh fractures and contains abundant large phenocrysts of clear yellowish-green olivine. The weathered rock is coated with a thin black rind, and in some places the former Indian inhabitants of the area have chipped through the rind to make pictographs.

The flow in American Flat and American Ravine issued from the east slope of McClellan Peak, where the basalt is scoriaceous. The basalt in the northeastern part of the quadrangle originated at the base of the two cinder cones at the eastern edge of the quadrangle, in secs. 10 and 15. On the plain south of Clark Mountain the basalt flow must have surged to different heights as it forms irregular terraces along the northern edge of the plain. In sec. 17 in the southern part of this area, a tumulus, fed by a lava tube from higher ground, rises to a height of about 75 feet above the surrounding lava flow. The flow must have been fairly fluid, for in some places near Long Valley Creek it is less than 10 feet thick. Where it debouched into the canyon of the Truckee River it probably dammed the river as is indicated by a small patch of lake beds high on the north side of the river above the main highway. The basalt is younger than the Mustang andesite, for pebbles of the andesite occur beneath the basalt flow in the canyon of the Truckee River.

HOT-SPRING DEPOSITS

Hot-spring deposits consisting mainly of siliceous sinter are abundant near Steamboat, and a small terrace and some fissure-filling of travertine occur near the north edge of the quadrangle, 2⅓ miles north of Washington Hill. East of the quadrangle, about 4½ miles east of Tibbie Peak, is a much larger area of travertine. The spring deposits at Steamboat Springs consist of siliceous sinter, ranging in texture from porous opal to dense chalcedony and quartz. Steamboat Springs is the only one of these localities where hot springs are still active, and there the stratigraphic relations indicate a considerable range in the age of the deposits; the oldest deposits antedate the basaltic andesite in Steamboat Hills, and the youngest are still being deposited.

PRE-LAKE LAHONTAN GRAVELS

The pre-Lake Lahontan gravels include a diverse group of alluvial fan and pediment gravel deposits. The recognition of these older gravels is based primarily on soil formation, using the criteria described by Hunt and Sokoloff (1950) and by Roger Morrison (oral communication, 1950). The stratigraphic relations, texture, degree of structural deformation, and degree of erosion are also helpful criteria. In the mountain ranges these gravels cap remnants of dissected surfaces; in the basins they are found in irregular patches where they have not been stripped away by erosion or concealed beneath younger deposits. In Sixmile Canyon and many other places, remnants of the pre-Lake Lahontan gravels are present but are too small to show on the map.

The deposits are composed of material ranging in size from sand to boulders several feet across. They generally contain an abundance of large boulders, which are scarce in the younger gravel deposits. The gravels are chiefly derived from granitic, metamorphic, and andesitic rocks, the proportions differing greatly from place to place. The soil formed on the gravels is characteristically much deeper than on younger gravels in the same area, being comparable to the soil on glacial moraines older than those of the Tahoe stage (Blackwelder, 1931) in the Sierra Nevada a few miles away. The leached zone, where fully preserved, is brown and clayey and is 2 to 4 feet thick. Buried granitic boulders in this zone are thoroughly rotted, andesitic boulders less so, although boulders of the same age lying on the surface remain relatively fresh and sound. The underlying zone of lime or silica enrichment is from 4 to at least 10 feet thick.

In many places the gravels are known to be later than the Lousetown lavas because they contain Lousetown debris. The gravels capping the ridge a mile north of Lousetown, however, contain little or no debris of this kind and may be older than these lavas. They are composed largely of metamorphic rocks that were probably derived from the vicinity of Castle Peak, and the same is true of the gravels capping the hill just south of the junction of Lousetown and Long Valley Creeks; but gravel capping the hill a mile and a half southeast of the junction contains pebbles of basaltic andesite of the Lousetown. Some of the pre-Lake Lahontan gravel is overlain by McClellan Peak olivine basalt, and some is deposited on terraces eroded in the basalt. The age therefore ranges through a large part of Pleistocene epoch prior to the Lahontan Lake stage.

LAKE LAHONTAN, POST-LAKE LAHONTAN, AND STREAM DEPOSITS

The Lake Lahontan and post-Lake Lahontan deposits comprise sediments of Lake Lahontan proper in the southeastern part of the quadrangle (Russell, 1885), the deposits in the swampy flood plain north of Huffaker Hills, which are slightly higher than Lake Lahontan, and the deposits of still higher ephermal lakes in closed basins such as the one 2 miles southeast of Lousetown. The stream deposits of Lake Lahontan and post-Lake Lahontan age include the alluvium deposited by the streams that flowed to these lakes and alluvium deposited by the present streams. On the geologic map the color symbol used for this alluvium is also used for some landslide material, talus, and for mine dumps in the Comstock lode district.

The lake deposits consist of sand and silt. Those in the southeast corner of the quadrangle contain a large proportion of quartz, feldspar, and biotite derived from granitic rocks in the Carson River drainage basin; and those in most other places consist preponderantly of volcanic debris.

The lake deposits along the Carson River are continuous with the main areas of Lake Lahontan deposits to the east. Soils on these lake deposits in the Virginia City quadrangle have a leached zone as much as a foot thick, which suggests that the deposits belong at least partly to the early high stage of Lake Lahontan (Roger Morrison, oral communication, 1951). The lake deposits in the Truckee Meadows are higher than the Lake Lahontan deposits in the canyon of the Truckee to the northeast, and not quite continuous with them. When the Truckee River is in flood, a temporary lake still spreads over the meadows almost as far south as the Huffaker Hills, because of the very low gradient. During the high stages of Lake Lahontan, similar flooding was undoubtedly more frequent and was perhaps continuous.

The stream deposits consist of sand, gravel, and cobbles of rather local derivation. In a few places they are strongly cemented with silica and iron oxides derived from nearby areas of bleached rocks; this may be seen in the lower reaches of Long Valley Creek. Both lake and stream deposits have been redistributed in places by the wind. In much of the southeastern part of the quadrangle the lake deposits are thinly veneered with wind-shifted sand. Eolian sands are also fairly abundant on the east side of Steamboat Valley and in the mountain valleys south of it. Some patches of wind-blown sand are weakly cemented and covered with shallow soil; other sand deposits are still moving, as demonstrated most convincingly by the wind-blown mill tailings in the lower part of Gold Canyon.

The deepest soils on the Lake Lahontan, and post-Lake Lahontan deposits are comparable to those on the Tahoe and Tioga moraines in the nearby Sierra Nevada; they are nowhere as deep as those on the older moraines.

BLEACHED ROCKS

Near-surface alteration by acids has caused local bleaching in most of the rocks of the quadrangle. Most of the bleaching, except at Steamboat Springs, seems to have resulted from weathering of altered rocks containing pyrite. The end products are chiefly secondary quartz, opal, and clay in different proportions, together with residual minerals from the original rocks, whose identity is revealed in some places by relict textures. Irregularly distributed limonite in cracks and diffusion bands commonly gives the rock a highly colorful appearance. The largest areas of bleached rocks are near Virginia City, along the Geiger Grade, near Washington Hill, and in Sixmile Canyon.

The unweathered rocks below bleached areas are best observed in mine workings or drill holes. In the Comstock lode district, bleached rock at the surface grades downward into greenish-gray altered andesite containing albite, clinozoisite, chlorite, epidote, calcite, and sometimes zeolites, all of which are peppered with pyrite. The bleaching, however, is dependent only on pyrite, and altered rocks that do not contain pyrite crop out more extensively than the bleached rocks (Coats, 1940). The bleached rocks near Washington Hill contain abundant opal in some places, in contrast to those in the Comstock lode district, where the silica is present as fine-grained quartz. Moreover, the unweathered rock in the Washington Hill area appears to have been affected by argillic and pyritic alteration without the chlorlite and epidote that are so characteristic of most of the altered but unbleached andesite in the Comstock lode district. At Steamboat Springs, the bleaching has been done by acid resulting from direct oxidation of rising hydrogen sulfide gas.

At that locality the bleaching affects Quaternary as well as Tertiary and pre-Tertiary rocks. Elsewhere in the quadrangle, rocks of the Kate Peak formation are the youngest that have been altered, with the exception of very local bleaching of the Truckee formation in the vicinity of Washington Hill. The widespread introduction of pyrite, whose oxidation caused bleaching, evidently preceded the deposition of the Truckee formation. The albite-chlorite-epidote alteration in the Comstock lode district affects not only the Alta formation and older rocks but also some of the biotite-bearing dikes of the Kate Peak formation.

STRUCTURE

The pre-Tertiary sedimentary and volcanic rocks strike, on the average, a little east of north and dip steeply east or west. The folding expressed by these steep dips did not affect the Tertiary rocks and is evidently part of the Mesozoic deformation of the Sierra Nevada region. The pre-Tertiary granitic rocks were seemingly emplaced during the end stages of this deformation or later, for they are sheared only locally.

The Cenozoic deposits were laid down on a surface of low to moderate relief cut on the metamorphic and granitic rocks. Repeated tilting and warping, accompanied by block faulting, took place along axes that trend from northeast to northwest and average north. In much of the area the strata have been tilted westward and also step faulted relatively downward to the east; a rather sharp anticline west of Virginia City is exceptional (see section *C–C′*). The older Cenozoic deposits are progressively more deformed than the younger.

The general rough parallelism of Cenozoic structures with pre-Tertiary structures suggest that the structural trend was established primarily by the pre-Tertiary compressional folding and that subsequent deformation, though distinctly different in character, tended to follow the same trend. A general parallelism of Cenozoic faults with large-scale pre-Tertiary structures has also been noted in the Hawthorne and Tonopah quadrangles, Nevada (Ferguson and Muller, 1949, p. 14).

DEFORMATION OF THE CENOZOIC ROCKS

The Cenozoic structural relief resulted from combined normal faulting, tilting, and warping (Thompson, 1952). The mountain mass constituting the Virginia and Flowery Ranges is bounded on its east side mainly by normal faults (section *C–C′*). But on its west side (sections *A–A′* and *B–B′*) it is bounded largely by westward-dipping strata that form one limb of a broad syncline the axis of which is in the Truckee Meadows, and the other limb of which is along the east front of the Carson Range in the adjacent Mount Rose quadrangle. The rocks on the west side of the Virginia Range are also cut by normal faults formed contemporaneously with the syncline. But on most of these the east (or mountain) side is downthrown, and the basin side is upthrown. (See sections *B–B′* and *C–C′*.) The vertical components of movements on the normal faults are thus generally opposed to those on the fold, and the structural relief is therefore much less than would be produced by folding alone.

Folding and tilting imply crustal shortening in a horizontal direction, as opposed to normal faulting, which implies crustal extension. Combined folding and normal faulting thus require less horizontal movement than would be required by either alone. The net horizontal movement may in fact be zero in any large area deformed by contemporaneous folding and normal faulting. The simplest explanation of the Cenozoic deformation in the Virginia City quadrangle appears to be differential vertical uplift (or depression); this results in both folding and normal faulting because either one alone would have to be accompanied by large horizontal movements.

The sequence of structural events in the later part of the Cenozoic is better known than in the earlier part. The oldest Cenozoic rocks, the Hartford Hill rhyolite tuff and the Alta formation, dip only a little more steeply than the Kate Peak and Truckee formations. During and after the deposition of the Kate Peak and the Truckee, these rocks were faulted, tilted, and warped. Following this, a period of structural quiescence is indicated during the latter part of the Pliocene by the fact that upland erosion surfaces of low relief were most extensive at that time and have since been partly dissected, and by the lack of basin sediments of that age, which suggests that structural blocking of drainage had diminished or ceased. Renewed deformation in the Pleistocene was similar to the earlier deformation. The Lousetown flows in the central part of the quadrangle were tilted westward and cut by normal faults that block the drainage. The pre-Lake Lahontan gravels were also offset by many normal faults. The Lake Lahontan and post-Lake Lahontan deposits, in contrast, are little deformed, but whether this is due to structural quiescense or to the short time involved is an open question.

RELIABILITY OF STRIKES AND DIPS

In a volcanic terrane reliable measurement of deformation is often complicated by the lack of extensive stratigraphic markers and by initial dips that may have been very steep. Particularly in intermediate and silicic volcanic rocks, such as the predominant types in the Virginia City quadrangle, the flows and pyroclastics are not laid down nearly flat like marine sediments but may have initial dips as high as 30°. In this area, moreover, the eruptions from an individual vent may have spread over an area with a radius of only 5 or 10 miles, in some cases much less. The resulting volcanic pile, erupted from numerous vents and structurally deformed, is complex.

An accurate measure of structural deformation is given, however, by strikes and dips taken in the finely laminated sediments of the Truckee formation and the Sutro member of the Alta formation. Next in degree of reliability are strikes and dips of flows or fragmental volcanics, but in these rocks the amount of initial dip is usually very uncertain, so that the measured dip does not indicate the amount of structural deformation. Where possible, however, dips were taken in lenses of water-laid volcanic rocks, which occur sporadically in the Alta and Kate Peak formations. Contacts between formations involve a similar uncertainty about the initial slopes of erosion surfaces. Least reliable as indicators of tectonic deformation are the strikes and dips of platy parting in flows and altered agglomerate.

HARTFORD HILL RHYOLITE TUFF AND ALTA FORMATION

The Hartford Hill rhyolite tuff and the Alta formation are generally conformable, and both formations are generally tilted westward about 35°. That this is actual structural tilt and not merely initial dip is shown by the close correspondence between dips in the Sutro member of the Alta and in the volcanic rocks. The uniformity of the westward tilt is broken by an anticline near the crest of the Virginia Range west of Virginia City (section *C–C′*). This anticline, which may be related in origin to the intrusion of the Davidson granodiorite, is expressed by dips in the Sutro member as high as 60° westward and 30°

eastward. Other folds are suggested by eastward and westward dips in the rhyolite in the southwestern part of the quadrangle.

The structural relief resulting from the westward tilt is in considerable part nullified by many normal faults, on nearly all of which the strata are displaced downward to the east. The Comstock fault, which passes under Virginia City, and the intersecting Silver City fault, in Gold Canyon, dip eastward about 45°. Many other faults explored in mine workings east of Virginia City have similar eastward dips of 30°–50°. These dips, which are unusually low for normal faults, are explained by tilting of the fault planes along with the enclosing strata. This is indicated by a rather constant angle of about 70° between the fault planes and stratification planes.

The total vertical throw on the Comstock fault was estimated by Gianella (1936, p. 85), on the basis of displacement of the Sutro member near Crown Point Ravine, to be 3,450 feet, but if the eastward dips in the footwall strata are considered, the revised estimate is about 2,500 feet. The escarpment west of the Comstock fault has a maximum height of roughly 1,500 feet, 1,000 feet less than the throw of the fault. Since faulting began, erosion of the footwall block has exceeded that of the hanging-wall block by at least 1,000 feet.

KATE PEAK FORMATION AND TRUCKEE FORMATION

The Kate Peak formation and the Truckee formation, like the older Tertiary rocks, are generally tilted westward (section *A–A′*). Their average dip is about 30° on the west side of the Virginia Range but is a little less in the Flowery Range. They are thus tilted almost as much as the Hartford Hill rhyolite tuff and Alta formation. Nowhere are these formations deformed as much as the Alta is in the anticline west of Virginia City, but such deformation is local and unusual even for the Alta formation.

In some places the initial dips of the volcanic rocks were probably high, and where they were westward they would account for part of the apparent tilting. But the general correspondence of dips measured in lacustrine sediments of the Truckee in the Chalk Hills with those measured in the Kate Peak volcanic rocks nearby supports the view that most of the measured dips represent actual structural deformation. The dips in the vitrophyre member, however, have no significance as a measure of structural deformation, for the flow banding is highly contorted, and the initial dips are as high as 90°. Another example of what are probably steep initial dips can be seen 3 miles northeast of Huffaker Hills, where well-bedded pyroclastics of pyroxene andesite slope away from a local source.

In Flowery Ridge dips in the Kate Peak formation are low and erratic and this led Calkins (1944, p. 32) to the conclusion that these rocks may not be appreciably tilted. West to northwest dips averaging about 30° are the rule on the east side of Flowery Ridge and in the Flowery Range to the northeast. A possible explanation of this discrepancy is that the rocks in the upper part of the Kate Peak formation have been less deformed than those in the lower part. North of the Chalk Hills and east of Tibbie Peak, the dips measured on the flows and agglomerates in the lower part of the Kate Peak formation correspond closely with the dips in the underlying Hartford Hill rhyolite tuff. The conclusion seems warranted that the major part of the general westward tilting in the Virginia City quadrangle took place during and after the period of Kate Peak volcanism and Truckee sedimentation.

The eastward dip of the Truckee formation north of Castle Peak suggests the presence of a broad northward-trending anticline between that area and the west slope of the Virginia Range, where the andesites dip westward. A parallel syncline with its axis east of Washington Hill is indicated in the same way. The westward tilt of the Truckee formation in the Chalk Hills is remarkably uniform on the whole, but locally it is disturbed by strong folding. The best example of the local deformation is at the main diatomite quarry, in sec. 36, where the beds are nearly vertical. Some of the smaller wrinkles at other places in the Chalk Hills are similar to those formed in the soft sediments of modern lakes by the pressure of moving ice.

The faulting in the Kate Peak formation and the Truckee formation is similar to that in the older Tertiary rocks. The faults are normal; they generally trend between northeast and northwest, and most of them dip eastward. The northern extension of the Comstock fault cuts the Kate Peak formation as well as the Alta formation. The faulting on the east side of the Flowery Range is probably much more extensive than is shown on the map; some of the most important faults are believed to be concealed by alluvium near the base of the range.

LOUSETOWN FORMATION

The Lousetown formation is much less deformed than the older rocks. The flows generally lie on an erosion surface cut across the Truckee formation and all older rocks; this is particularly well shown on the west side of the Chalk Hills, where flows of the Lousetown lie on the beveled edges of tilted beds of the Truckee (section *A–A′*). After the Lousetown flows were poured out of the vent in the central part of this area, they were themselves faulted and tilted westward roughly 5°. Although no strong folding of the Lousetown has been detected, some gentle warping is suggested by differences in the general westward slope of the surface west of the Chalk Hills.

The Lousetown, like the older formations, is cut by normal faults, most of which trend between northeast and northwest and dip eastward. Two miles west of the Chalk Hills there is a depression with a closure of 100 feet, which contains an ephemeral lake. The basin is bounded on the west by a fault that has thrown down the Lousetown flows on the east by more than 300 feet. This displacement, however, probably measures only the latest movement on a fault older than the Lousetown; for the Truckee formation 2 miles east of the fault is many hundreds of feet thick and dips westward, whereas it is entirely absent a mile west of the fault. A long series of movements in the same direction appears to have occurred; it began with the formation of the Pliocene lake basin in which Truckee sediments were deposited, continued with the westward tilting of the Truckee sediments, and ended with the displacement and westward tilting of the Lousetown flows. The fault is in line with the Comstock fault, which it resembles in strike and direction of displacement, and its aggregate throw may be as great as that on the Comstock fault. Together the two faults mark a major fault zone over 10 miles long. The later movements of the Comstock fault may well have been contemporaneous with the movements on this fault.

There are at least five other closed basins in the Virginia City quadrangle; the failure of erosion and deposition to keep pace with their formation indicates that the faults along them are as young as those cutting the Lousetown flows.

QUATERNARY DEPOSITS

Warping and tilting of post-Lousetown deposits is generally on too small a scale to be readily detectable, but is evident in a few places. The gravels near the foot of Geiger Grade, at an altitude of 4,880 feet, dip westward as much at 20°; and even allowing for probable initial dip they must have been tilted westward at least 5° or 10°. Faulting is well shown in many places. The pre-Lake Lahontan gravels in the Truckee Meadows are cut by many faults, some of which have displacements of several tens of feet. The uplifted gravels near the lower end of Sixmile Canyon are also faulted. The gravel-covered surfaces in the Chalk Hills appear to have been tilted northeastward, and if they ever formed a single continuous surface, they have been stepped down toward the southwest along faults that have not been located.

GEOMORPHOLOGY

Early geomorphic history.—Throughout the early part of the Tertiary, the drainage was well integrated, and the region was undergoing erosion even when volcanism was very active. Volcanism was not a major factor in blocking the drainage. This is indicated by the deep erosion of pre-Tertiary rocks and the lack of notable lower

Tertiary sedimentary deposits, with the sole exception of the Sutro member of the Alta formation, which is local and small in volume. The Hartford Hill rhyolite tuff and Alta formation formed volcanic piles thousands of feet thick locally, and this probably resulted in considerable topographic relief with the mountains roughly along the same axes as the present ranges. Perhaps by late Miocene and certainly by Pliocene time the drainage was broken by block faulting and warping, and the lake deposits of the Truckee formation were accumulating in local basins. Erosion in the highlands and deposition in basins, along with structural deformation and volcanism, have continued intermittently to the present.

Erosion surfaces.—Upland surfaces of relatively low relief, in striking contrast to the rugged mountain slopes, are cut across the Tertiary strata in many places. These surfaces probably began at least as early as the time of the Truckee lakes, which constituted local base levels of erosion. One such surface is represented by the summit area of the Virginia Range from McClellan Peak northward to Orleans Hill. Deep erosion of this area, prior to the formation of this surface, is indicated by the removal of rock which once covered the Davidson pluton; Gianella (1936, p. 99) suggested that at least 2,500 feet of rock has been removed. To the north and northeast this summit surface slopes downward to a lower extensive surface on which lie the Lousetown flows west of the Chalk Hills. Here the lower surface truncates the upturned edges of the Truckee strata, which are so soft that they must have been eroded rapidly; this surface is clearly post-Truckee and pre-Lousetown. The northward extension of the Lousetown flows into the valley of Lousetown Creek shows that this pre-Lousetown surface was already undergoing dissection along the main drainage lines before the Lousetown flows covered it. Extensive upland surfaces of low relief in the surrounding region, as well as in the Virginia City quadrangle, are cut on the Kate Peak formation and are covered by the Lousetown flows. These upland surfaces of relatively low relief were most extensive in the middle or late Pliocene; they had been much dissected by the time the Lousetown flows were erupted.

Many pediments have been cut at successively lower altitudes, and their dissected remnants slope away from the margins of the ranges. The broadest of these surfaces are on soft rocks such as lake beds or bleached volcanic rocks. Some were cut after the extrusion of the Lousetown flows and are covered with gravel containing Lousetown debris. The lowest erosional benches are close to the Truckee and Carson Rivers.

The swamps along Steamboat Creek in the northwest corner of the quadrangle and the very low gradient of the Truckee River across the

Truckee Meadows farther north can only be explained by Pleistocene uplift of the Virginia Range relative to the Meadows. Reestablishment of a normal gradient by downcutting was perhaps delayed by Lake Lahontan, an arm of which occupied the Truckee Canyon through the Virginia Range. After Lake Lahontan receded the river cut through the soft lake desposits but has not significantly entrenched the bedrock in the canyon, which still controls the gradient in Truckee Meadows.

The Carson River meanders sluggishly through dissected Lake Lahontan sediments in the southeast corner of the quadrangle, because it is graded to volcanic bedrock in a canyon farther downstream, 4 miles east of the quadrangle.

Summary of formation of present topography.—The present topography, then, is the result of constructional volcanism, structural deformation, and erosion. Some of the steep mountain slopes are fault escarpments modified by erosion (east side of the Flowery Range), others are dip slopes modified by erosion (portions of the west side of the Virginia Range), and still others are a direct product of differential erosion of hard and soft rocks. The latter are well shown where the mountains rise steeply from the upper edges of many of the pediments. North of the lower reaches of Sixmile Canyon, for example, a broad pediment, now dissected, is cut on the altered Alta formation, and above this the steep slopes cut on the more resistant Kate Peak formation rise precipitously.

MINERAL DEPOSITS

Deposits of silver, gold, and quicksilver have been exploited in the Virginia City quadrangle, the silver-gold deposits of the celebrated Comstock lode district having been by far the most important. Nonmetallic deposits that have been worked include sand and gravel, pumice, clay and silica, and diatomite. Thermal waters at Steamboat Springs have been utilized for heating purposes and for mineral baths.

METALLIC DEPOSITS

Metallic deposits of at least three ages have been mined or prospected. The oldest, which are pre-Tertiary in age, are in granitic and metamorphic rocks, generally close to the contacts of granitic bodies. Small amounts of gold, silver, and tungsten have been mined from these old deposits in scattered localities, but no important production has resulted. The Tertiary deposits include the famous silver-gold deposits of the Comstock lode district, a number of widely scattered prospects that contain a little gold and silver, the quicksilver deposit at the Castle Peak mine, and quicksilver prospects near Washington

Hill. The youngest metallic deposits, which are of Quaternary age, include small amounts of gold, antimony, and quicksilver associated with Steamboat Springs; several attempts to work these deposits have failed because of their low grade and because of the difficulties of coping with the hot water.

PRE-TERTIARY

The pre-Tertiary deposits, which have been extensively prospected but have yielded no ore in commercial quantities, are mostly quartz veins in granitic and metamorphic rocks but they include material disseminated in contact-metamorphic rocks. The principal areas that have been prospected are (1) southwest of Jumbo, (2) 3 miles northwest of Jumbo, (3) in Steamboat Valley, (4) south of Sutro Springs, and (5) 2 miles east of Sutro Springs. These prospects commonly show pyrite, copper stain, and occasionally a little galena which is said to be argentiferous. Similar deposits 3 miles south of Steamboat Valley and a mile west of the quadrangle have produced a small amount of gold and silver. Scheelite has been found in contact rocks 2 miles northwest of Jumbo, where the granitic rocks abut against limestone; scheelite also occurs in contact zones in granitic rock west of Jumbo, and in quartz veins in granitic rocks in Steamboat Valley.

TERTIARY

The silver-gold deposits of the Comstock Lode district have been described by Becker (1882), Bastin (1923), Gianella (1936), and others. The total production is estimated to have been about $400 million, and slightly more than half of this value was in silver (Smith, 1943, p. 295). The ratio of silver to gold has been estimated as 40:1 by weight (Nolan, 1933, p. 633). The Comstock lode was discovered in the 1850's and reached a peak of productivity in the 1870's. Since then, production has declined, and all mining had ceased by 1950. The deposits are associated with the Comstock fault, which dips eastward about 45° beneath Virginia City, and with the Silver City fault, a branch that extends down Gold Canyon and also dips eastward about 45°. Great bonanzas of crushed quartz, in part exceedingly rich in silver sulfides and native gold, were found at intervals along the Comstock fault and in steeper fractures in the hanging wall. Nearly all of the production has come from depths no greater than 2,000 feet below the outcrop of the fault at Virginia City, in spite of extensive exploration to the depth of about 3,000 feet. Some of the production in the southern part of the Comstock lode district has come from many cross faults and branches of the Silver City fault. The Occidental vein, which lies parallel to the Comstock fault a mile and a half farther east, has yielded a relatively small amount of gold and silver. Two veins roughly parallel with the Comstock fault have been mined by open pits on the north side of Sixmile canyon 3 miles east of Virginia City. Several veins in the Jumbo district have been extensively prospected but have not proved profitable.

The Comstock ore deposits were formerly thought to be older than the Kate Peak formation, which was regarded as overlying them unconformably (Gianella, 1936, p. 103). The present study, however, indicates that they are as young as the Kate Peak but probably older than the Truckee formation and are therefore probably Miocene in age. Quartz veins of the Comstock lode cut dikes and other intrusions of biotite andesite porphyry that is regarded by the present writer as part of the Kate Peak formation. The Kate Peak volcanics have been intensively altered over large areas, but the Truckee formation and younger rocks have been altered hardly at all, except locally at Steamboat Springs, where the process of alteration is still going on. It seems possible that the mineralization may have started as early as Oligocene and extended through the Miocene. Hot water, hydrogen sulfide, and carbon dioxide that were present in the Comstock mines (Becker, 1882, p. 386) might be regarded as an indication that processes associated with deposition of the Comstock ore did not stop in middle Tertiary time. The most productive deposits may have been formed in the older Tertiary rocks for reasons of depth, temperature, and pressure; or possibly because of the greater length of time these older rocks were subjected to the process of mineralization.

Cinnabar was discovered in 1927 near Castle Peak, 6 miles north of Virginia City, and over 2,500 76-pound flasks of quicksilver was produced from the deposit (Bailey and Phoenix, 1944, p. 184). The ore was localized along a fault trending northward and dipping 55° to the east, and in jointed ground in the footwall. The ore was mainly in the Alta formation, although alteration extends into the overlying Kate Peak formation; the Lousetown formation is unaltered. Scattered occurrences of cinnabar have been prospected in the vicinity of Washington Hill, but no workable ore has been discovered there. In that area the volcanic rocks have been altered to opal, quartz, clay, and alunite. In the Washington Hill area there is much bright-red iron oxide that looks so much like cinnabar that it has undoubtedly deceived some prospectors.

No Tertiary placer gold deposits are known, although stream deposits of the Truckee formation contain much detritus derived from bleached and altered rocks.

QUATERNARY

Deposits of placer gold, derived from the Comstock lode, have been worked in Gold Canyon. The most extensive of these gravel deposits lies south of the Virginia City quadrangle. There have been attempts, on a much smaller scale, to work Quaternary gravels near the lower end of Sixmile Canyon.

Small amounts of stibnite, gold, and cinnabar are found in Quaternary siliceous sinter and other rocks at Steamboat Springs. Stibnite has been observed to precipitate in the pools of some of the hot springs, and native mercury has been detected in the vapor of a hot well (Brannock, Fix, Gianella, and White, 1948, p. 220–225); the mud in some of the hot pools also contains appreciable quantities of silver and gold. None of the minerals have been found in sufficient quantity to constitute ore, in spite of considerable prospecting.

NONMETALLIC DEPOSITS

Several nonmetallic materials useful in construction are available in the Virginia City quadrangle, and have been exploited to satisfy local needs in Reno and the surrounding region. Alluvial sand and gravel are abundant and have been dug in many places for road material and concrete aggregate. Coarse sand at the foot of slopes of disintegrated granitic rocks is commonly used for road material. The pre-Lake Lahontan gravels have been quarried in places, but it is advisable to avoid them where aggregate of high quality is required, for the pebbles have been weathered and softened to depths of many feet. Windblown sand, very uniformly sized, is abundant in the hollows between granodiorite hills in the eastern part of Steamboat Valley and in a number of small valleys on the west side of the Virginia Range farther south.

Pumice is plentiful in the Truckee formation and in the Steamboat Hills rhyolite; perlite occurs locally in the Steamboat Hills rhyolite, in the vitrophyre member of the Kate Peak formation, and in the Washington Hill rhyolite. Some pumice and perlite have been quarried in the Steamboat Hills rhyolite near Sutro Springs, but the most extensive quarrying of these materials has been done on Long Valley Creek half a mile north of the quadrangle, where pumiceous tuff of the Truckee formation is crushed and made into lightweight concrete building blocks. Similar but more coherent pumiceous tuff has been quarried on the north side of the Truckee River in the same area and has been used without crushing as lightweight building stone.

Intermixed silica and clay are available in enormous quantities in the areas of bleached rocks. Some of this material has been dug along the Geiger Grade for use in brick manufacturing in Reno.

Diatomite is widespread in the Truckee formation, though commonly it is thin bedded and impure. Massive pure diatomite was formerly quarried in the Chalk Hills and shipped out for use as a silver polish, but it has been supplanted by diatomite that is more easily accessible in other areas.

THERMAL WATERS

The thermal waters of Steamboat Springs near the west border of the quadrangle have been used locally in mineral baths and for heating purposes. An effort was once made to pipe hot water into Reno for heating purposes; a later plan was to use hot water and steam taken from deep bore holes to generate electric power. Thus far, none of these extensive plans has been successful, partly because the highly mineralized waters tend to corrode pipes or to fill them with mineral precipitates; if these difficulties can be overcome the area has excellent possibilities for the establishment of greenhouses, and perhaps for other uses.

Because thermal waters in the Steamboat area contain much sodium chloride and boron, they are not suitable for irrigation. For this reason Steamboat Creek is not used for irrigation below the springs. Much ground water north and northeast of the springs also has been contaminated by subsurface discharge from the system, but warm water of good quality locally overlies contaminated water. Much if not most of the ground water on the east side of Truckee Meadows is warm and is high in mineral content. The major exception is east and northeast of Steamboat, where wells in the alluvial fans generally yield cold to slightly warm water of good quality.

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