GL02082

GEOLOGY AND GEOCHEMISTRY OF THE STEAMBOAT SPRINGS AREA, NEVADA

KS, STRUCTURE, AND GEOLOGIC HISTORY OF STEAMBOAT SPRINGS THERMAL AREA, WASHOE COUNTY, NEVADA

By Donald E. White, G. A. Thompson, and C. H. Sandberg

ABSTRACT

amboat Springs has been the site of intense thermal activ- rough all or most of the Quaternary. The springs emerge the northeast end of Steamboat Hills, a northeast-trending transverse to the dominant regional trends; the hills are the axis of a chain of basins that lies between the north- ing Virginia and Carson Ranges.

nearly a hundred years the springs have been noted for port and deposition of mercury and antimony, as well as ore and gangue minerals. This report, one of a series, rus the general geology of a small area of current thermal ity that also contains evidence of very extensive activity in ast.

-Tertiary metamorphic and granitic rocks form the base- Middle and late Tertiary volcanic rocks are abundant in surrounding area but are notably scarce in the thermal where the most widespread Tertiary volcanic rock is a cteristic soda trachyte of the Alta Formation. Dikes and sive rocks of the younger Kate Peak Formation also occur, cularly at depth below younger rocks. A basaltic andesite of the Lousetown Formation and possibly a concealed shal- ntrusion of the Steamboat Hills Rhyolite are early Quater- in age and constitute the latest volcanic outbreaks that oached the surface.

perimental geochemistry on the granite system and propor- of feldspars to quartz in the norms of the analyzed rocks e Steamboat Hills Rhyolite indicate that the magma evolved g the late stages of the total volcanic activity in an environ- where the water-vapor pressure was probably between and 3,000 bars, the water content was 6 to 8 percent, and temperature immediately prior to eruption was close to C. A minimum depth of burial of 6 to 9 km for the magma ber is indicated from these data.

complex history of erosion alternating with alluviation ghout the Quaternary is revealed from the surface map- and subsurface drill-hole data. In general, the hot-spring sits were formed as local facies of the sedimentary forma- during periods of alluviation, each of which may correlate a Sierran glaciation. The oldest hot-spring deposits ante- the local lava flows of the Lousetown Formation, and ther- activity may have been continuous for most or all of the ternary. The record is reasonably good in indicating con- ous thermal activity since a glaciation correlated with the win, or third youngest stage of Pleistocene age. During ds of deep erosion and low water table, springs did not ys emerge at the surface, but for at least parts of these ds thermal waters continued to circulate below the surface, lving H_2S that oxidized to H_2SO_4 and attacked surficial s.

The hot-spring deposits consist almost entirely of siliceous sinter and very small amounts of calcium carbonate. The large accumulations around structurally favorable outlets are called hot-spring terraces. Sinter deposits found at Steamboat Springs are classified genetically into two major groups and nine main subdivisions. All primary or single-stage types consist of opal. After burial and prolonged contact with hot silica-bearing waters, most of the older spring deposits were reconstituted into chalcedonic sinter of relatively high density. Some chalcedonic sinter contains notable quantities of HgS.

A violent mud-volcano eruption occurred in the northwestern part of the thermal area, probably slightly earlier than the Tahoe Glaciation. This eruption may have been similar to the eruption of Lake City Hot Springs in northeastern California in 1951. The energy for eruption was stored in the upper part of the hydrothermal system, and no new magma was directly involved.

The report includes logs of wells and diamond drill holes that yielded cuttings or core that could be studied in detail. These data have contributed much to our understanding of relations at depth. Veins and hydrothermal mineral assemblages of each drill hole are described. Relict textures are commonly preserved in rocks completely replaced by new hydrothermal minerals; these textures have proved invaluable in recognizing the nature of the original rocks and in reconstructing the geologic history.

Ancestral Steamboat Hills was a topographic and probably also a structural high prior to Kate Peak volcanism. The major structural relief was largely attained prior to the local eruptions of the Lousetown Formation.

Three well-defined systems of faults have been recognized in the thermal area. An east-northeast system is parallel to the axis of Steamboat Hills and is largely but perhaps not entirely restricted to Lousetown lava flows and older rocks; most of this system is antithetic, with downdropped sides toward the structural axis of the hills. Post-Lousetown movement is as much as 100 feet, but pre-Lousetown movement may be considerably greater.

Northwest-striking faults control Pine Basin in the west-central part of the thermal area, and are approximately contemporaneous with the east-northeast system.

The most numerous faults of the thermal area strike nearly north, and many are antithetic. Some of these faults are relatively old but many displace pre-Lake Lahontan alluvium and sinter of middle Pleistocene age and are the youngest faults of the area. No fault displacement is clearly younger than the Lake Lahontan and Recent sediments.

A system of faults of the north-striking group called the Steamboat Springs fault system provides the structural control for the Low and Main Terraces. Although some evidence sug-

gests west-dipping reverse or thrust movement for the system, the favored interpretation is that of east-dipping normal faults. Total movement may exceed 1,000 feet, nearly all of which was earlier than pre-Lousetown pedimentation and later than the Alta and Kate Peak Formations. Fractures cut the opaline hot-spring deposits but movement on the fractures is negligible. Open fissures in the Main Terrace form from enlargement of fractures by acid leaching of opaline sinter, and not by physical separation of the walls as formerly supposed.

Throughout late Tertiary and Quaternary time, the thermal area has been rather delicately balanced between structural uplift and erosion on the one hand and inundation by volcanic products, hot-spring deposits, and alluvium on the other. At least two cycles of deep entrenchment, alluviation, and pedimentation have occurred. The balance between erosion and burial of the thermal area must have resulted at least in part from coincidence, because the local base level for erosion (Steamboat Creek) has been controlled at least since late Tertiary time by an interplay of influences, including subsidence of the basin of Truckee Meadows, uplift of the Virginia Range, and entrenchment of the Truckee River through this range.

The Steamboat thermal area and its deposits exist because of a combination of favorable circumstances. These include a long history of volcanism in the area; a large magma chamber of at least $50\ km^3$ that has evolved heat, water, and mineral matter for at least 100,000 years; favorable topographic and water-table relations; and a balance between structural uplift and erosion on the one hand and inundation by volcanic products and alluvium on the other, which has favored preservation of evidence of the complex history.

INTRODUCTION

LOCATION

The Steamboat Springs area is in southern Washoe County near the west border of Nevada (fig. 1). The most intense thermal activity at the present time and throughout most of the Quaternary is localized in an area of about 4 square miles (fig. 2) that straddles the common boundary of the Virginia City and Mount Rose quadrangles (Thompson and White, 1964). The largest part of this area is immediately west of Steamboat Creek, a tributary of the Truckee River that heads in Washoe Lake to the south.

The springs emerge near the northeast end of Steamboat Hills, a northeast-trending range transverse to the dominant regional trends; the hills lie near the axis of a chain of basins between the north-trending Virginia and Carson Ranges. These ranges are offshoots of the northwest-trending Sierra Nevada Range, whose main crest lies 20 miles west of the Carson Range at the latitude of the hot springs.

PURPOSE AND SCOPE

Steamboat Springs has provided an opportunity for fundamental research on processes related to ore transport, ore deposition (rev. by White, 1955a), and geothermal processes in general under natural conditions that cannot be duplicated in the laboratory. Spring systems of this type are a phase of volcanism in whic the cooling of a magma body of probable batholithi proportions (White, 1957a, p. 1642) is accompanie by separation of a vapor phase at high temperature an pressure. Most studies of ore deposits concern pr cesses that occurred millions of years ago; most studie of igneous rocks concern either volcanic rocks of ap preciable age or active volcanism at the earth's surfac Experimental geochemistry has greatly aided investi gation of these natural processes, but it is limited t simple chemical systems and rapidly occurrin reactions.

The regional geologic setting of Steamboat Springs i presented by Thompson and White (1964). The pre ent report concerns the rocks, structure, and geologi history of the thermal area. Discussion of the therm activity and geochemistry of the waters and altere rocks is reserved largely for later reports.

FIELDWORK AND ACKNOWLEDGMENTS

Fieldwork was carried on from 1945 to 1952. Th thermal area (pls. 1 and 2) was mapped on a scale o 1 inch =250 feet and detailed maps of the sprin terraces (reserved for later reports) were mapped on scale of 1 inch =50 feet. The topographic mappin was done by Robert G. Reeves and Hale C. Tognon The detailed geology was mapped by White, assiste at different times by Douglas Baker, William Eber Robert Horton, William Reinken, James Scott, R. Vassar, and Reeves and Tognoni. Contributions b P. F. Fix during early stages of the study are speciall acknowledged.

The geophysical survey conducted by C. H. San berg has added greatly to an understanding of t subsurface geology. Results of the gravity surveyin have been published separately (Thompson and San berg, 1958), and results of all geophysical work a incorporated in this report where particularly pertinen and are also summarized in a separate section.

Diamond drilling with scientific objectives was ca ried on from June 1950 to February 1951. Eig holes were drilled to depths ranging from 130 to 6 feet; total depth of the eight holes was 3,307 feet. T success that may be claimed for the whole study due in large measure to this drilling program, whic provided drill-core and physical data concerning t structure, rocks, temperatures, and geochemical rel tions at depth. Drilling was also done by private inte ests during the study, and much useful informatio has been acquired through cooperation with the i dividuals involved, including B. C. McCabe of Magm Power Co. Special mention should be made of t helpful cooperation given by Mrs. Edna J. Carve

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I–I′, pl. 2; table 3, GS–6 drill hole).
trachyte was cored when the Senges

well, an old churn drill hole between the Main and High Terraces (fig. 3), was deepened in 1950 to 195 feet. The core in this well is altered soda trachyte that presumably overlies granodiorite.

In GS–5 drill hole, the drill core from 525 to 546 feet in depth immediately below a dike of the Kate Peak Formation (section *B–B′*, pl. 2; table 3, GS–5 drill hole) is different in appearance from the overlying dike. The rock is fine grained and contains only a few phenocrysts. A low-dipping planar structure is present and is cut by reddish veinlets; these characteristics are suggestive of soda trachyte.

Thin sections show this rock to be thoroughly argillized. The larger of the original plagioclase phenocrysts are as long as 1½ mm and are more abundant than is typical of fresh soda trachyte. Hornblende relicts as long as 3 mm are recognizable and are relatively abundant.

Alined relict plagioclase and hornblende crystal about 0.02 mm in diameter are fairly abundant in a fine grained argillized groundmass. Apatite crystals are a much as 0.08 mm in diameter. Plagioclase is largel argillized but hydrothermal potassium feldspar is present; hornblende is replaced by granular quartz an fine-grained argillic minerals, commonly with som pyrite.

The relative abundance of plagioclase and hornblend phenocrysts suggests that the rock is not typical of mos soda trachyte of the area, although it may be a les common phenocryst-rich type. Its association with dike suggests that it too is a dike and that it coul have been a feeder for some of the local soda trachy lava flows.

Fossil leaves found in the Sutro Member of the Al Formation in the Comstock district suggest an Olig cene age for that part of the Alta (Axelrod, 1949 Since the Sutro Member is near the lower part of t Alta, the stratigraphically higher soda trachyte of t thermal area may be considerably younger, but co clusive evidence is lacking. Thompson's (1956) a assignment of Oligocene(?) for the Alta Formati is herein retained.

KATE PEAK FORMATION

The regional distribution and characteristics of t Kate Peak Formation have been summarized by Thom son and White (1964). The formation assign to the Miocene or Pliocene on plate 1, probably has age span from Miocene to early Pliocene (Axelr 1958).

In Steamboat Hills and the Carson Range, volca rocks of the Kate Peak Formation are more abund

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most of the rocks elsewhere in the thermal area. The volcanic fragments commonly range from less than 1 inch in diameter to a maximum of about 4 inches; a single exception is a boulder 1½ feet in diameter at a depth of 196 feet. The large boulders typical of most Kate Peak tuff-breccias are almost entirely absent. Most fragments are angular but a few are rounded or subrounded to such a degree that stream abrasion is indicated at least locally. In this respect also, the rocks of the drill hole differ from typical tuff-breccia of the Kate Peak.

Study of thin sections of the tuff-breccias provides evidence of thorough hydrothermal alteration. The most abundant phenocrysts are andesine and labradorite; these have the size, zoning, and composition of phenocrysts in rocks belonging to the Kate Peak. They are partly to almost completely replaced by hydrothermal potassium feldspar in the upper part of the section and by clay minerals and decreasing amounts of potassium feldspar in the lower part (Sigvaldason and White, 1961). Phenocrysts of ferromagnesian minerals are completely altered, generally beyond recognition of original identity. Some rocks contain a few recognizable relict shapes of hornblende, augite, and hypersthene crystals, all of which are characteristic dark phenocrysts of Kate Peak volcanic rocks. No definite olivine relicts were identified. The groundmass of the volcanic rocks as well as the matrix of the fragments consists of a fine-grained mixture of hydrothermal chalcedony and potassium feldspar, some of which has the characteristic crystal habit of adularia.

The presence of metamorphic and granodioritic debris is confirmed near the basal contact of the tuff-breccias, and a little foreign material including clastic quartz occurs at depths from 200 to 230 feet. The striking predominance of volcanic fragments and the complete absence of detrital quartz except for the small amounts mentioned indicate an assemblage that is unlike any of the Quaternary sedimentary deposits known in the region. The absence of similar rocks in the nearby GS-6 drill hole and the Senges well is a puzzling fact that has compounded the problems of correlation.

The absence of coarse fragments and the presence of some stream-rounded pebbles suggest that these rocks may be a phase of the Truckee Formation, not identified with certainty elsewhere in the thermal area. On the other hand, the absence of bedding, abundance of rounded pebbles, and diatomite characteristic of most of the rocks of the Truckee Formation suggest that these rocks are a relatively fine grained phase of Kate Peak tuff-breccia, a small part of which has been transported and deposited by streams.

Hydrothermally altered rocks penetrated by GS-5 drill hole (table 3, p. B16; and section *B-B'*, pl. 2) at depths from 135 to 154 feet may be tuff-breccias of the Kate Peak Formation. Relict textures are very obscure in most of these rocks in contrast to most of the hydrothermally altered rocks of the area. A few textures interpreted to be relicts of plagioclase and hornblende and some recognizable heterogeneity of fragments constitute the evidence for assigning these rocks to the Kate Peak Formation. They are not identical to the altered rocks of GS-2 drill hole that have just been discussed but are grouped with them for convenience.

DIKES

Completely argillized dikes were penetrated by GS-5 drill hole on the Main Terrace at depths from 465 to 525 feet and in GS-7 drill hole in the silica pit area from 253 to 329 feet (table 3, p. B18; sections *B-B'* and *D-D'*, pl. 2).

The rock in GS-5 drill hole from 465 to 525 feet is light colored, moderately soft, and argillized, and it contains large conspicuous altered relicts of phenocrysts of plagioclase as much as 3 or 4 mm in diameter, sparse rounded grains of quartz, and abundant disseminated crystals of pyrite in light-gray to greenish-gray matrix. Rare relicts of biotite that help to distinguish between rocks of the Alta and Kate Peal Formations (Thompson and White, 1964) B18 can b recognized but obvious relicts of other original darl minerals are lacking. A few primary inclusions witl fine-grained texture also have been found in som fragments.

In thin sections plagioclase phenocrysts are almos entirely altered to clay minerals, dominantly illite montmorillonite. Relict phenocrysts of hornblend as much as two thirds mm in diameter are recognizabl and relicts of biotite and pyroxene are very rar Apatite crystals as much as 0.1 and rarely as much a 0.3 mm in diameter seem unaffected by alteration. Mos thin sections contain one or two rounded and partl resorbed quartz grains. The phenocrysts are in a fin grained groundmass consisting of argillic minerals an anhedral quartz grains that are probably secondar

A dike was also penetrated by GS-7 drill hole in tl silica pit area from 253 to 329 feet in depth. The roc is light gray to medium gray green. Relict phenocrys are generally not conspicuous although pseudomorpl of plagioclase, probable augite, and other ferroma nesian minerals can be identified from crystal form The rocks are soft and claylike in appearance but c not swell or disintegrate in water. Pyrite is less abu

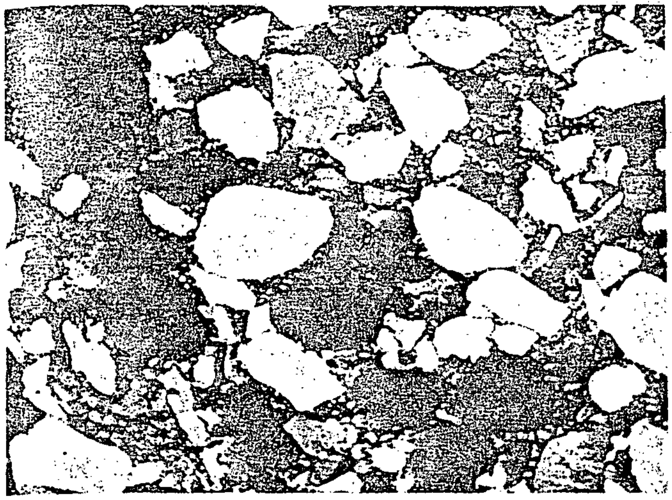


FIGURE 6.—Photomicrograph of quartzite of the pre-Lousetown alluvium. Sample from northwest side of Pine Basin, consists of windblown sand, dominantly quartz, cemented by chalcedony. Some grains as small as 0.1 mm diameter show rounding but many larger grains are angular. Crossed nicols, × 39.

very small open cavities remain that are lined with chalcedony or euhedral crystals of quartz.

The internal structure and contact relations of the quartzite are obscure because of the absence of outcrops that are clearly in place. The quartzite is considered to be a local deposit of windblown sand. The dominance of quartz grains and the abundance of rounded grains as small as 0.1 mm in diameter require the action of wind, probably blowing from the west or southwest over terrane that was almost entirely granitic in nature. The windblown sand presumably accumulated in a gulley on the lee side of, and entrenched into, granitic terrane to the west.

The deposit was cemented by quartz, chalcedony, and opal after the area was buried by younger stream deposits. Hot-spring activity was taking place concurrently, as indicated by sinter that probably underlies the quartzite and is described in a later section.

PEDIMENT GRAVELS

Pediment gravels older than the Lousetown Formation are widely distributed in the thermal area. They are nearly everywhere overlain by lava flows of the Lousetown. In the absence of strong cementation or hydrothermal alteration the gravels are less resistant to erosion and do not crop out; with rare exceptions, the best exposures of the gravels are highly altered (fig. 7).

The pediment gravels were deposited on a fairly evenly sloping, rock-cut surface formed by lateral planation of streams flowing across the eastern and northeastern part of Steamboat Hills after the deeply eroded valley of the area had been partly buried by the older pre-Lousetown alluvium. The higher slopes southwest of the thermal area are relatively steep, with gradients commonly on the order of 10° (see Thompson and White, 1964, pl. 1). These slopes are capped by basaltic andesite with little or no underlying alluvium. Below the 5,200-foot contour, however, the slopes change rather abruptly downward to the north and east to an average gradient of about 3°. These lower slopes are underlain by the pediment-cut surface mantled by gravels and then by the lava flows. In a few places where local topographic highs of granodiorite apparently were not planed off, the gravels are missing.

The gravels vary greatly in thickness, appearance and composition from place to place. As mentioned the unit is absent in places and has a maximum measured thickness of 27 feet in GS–6 drill hole (table 3 p. B17). In the main excavation of the silica pit (pl. and fig. 7), hydrothermally altered alluvium and Steamboat basaltic andesite flows dip about 15° N.; the thickness of the alluvium ranges from about 10 feet near th floor of the pit to about 6 feet near the original land surface entrenched by the pit. With exceptions tha have been noted, this is probably the usual order o thickness.

In appearance the unit ranges from a predominating dark color where fresh volcanic rocks are abundant t glaring white where all silicate minerals have been attacked by sulfuric acid and replaced by opal as in th

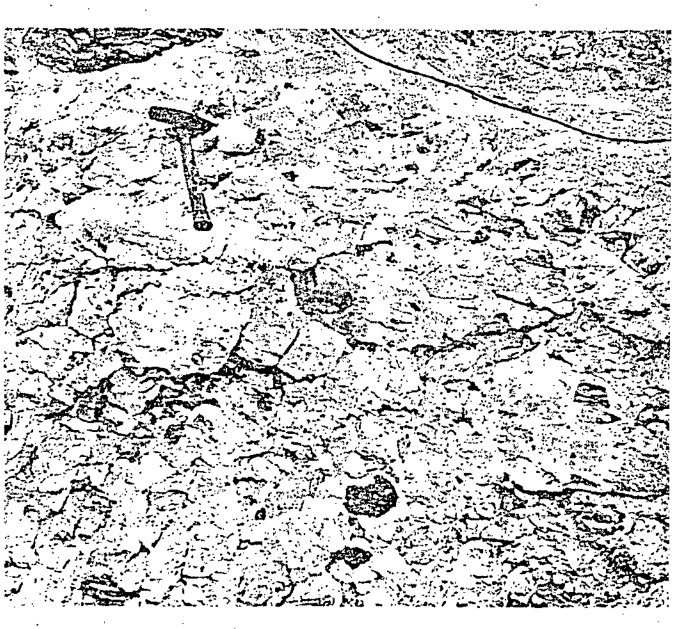


FIGURE 7.—Hydrothermally altered pediment gravels of the pre-Lous town alluvium overlain by bleached basaltic andesite of the Lousetow Formation. Basal contact of the flow is shown just above and to t right of the pick. Silica pit, about 450 feet from entrance.

The thickest carbonate layer that has been observed was less than one-half of an inch, and it was underlain by much thicker layers of sinter. Even these thin carbonate layers apparently have only a temporary existence at Steamboat Springs for similar bands have not been observed in drill core from the older sinters. Reasons for the scarcity or absence of carbonate are the slow rate of deposition of sinter, resulting in extended exposure of any carbonate layers to weathering; the dissolution of $CaCO_3$ by sulfuric acid which commonly formed at and near the surface from oxidation of H_2S; and the fact that the Steamboat waters are normally undersaturated in calcium carbonate through intermediate depth zones (unpublished geochemical data not discussed here). The geochemistry of silica in these hot-spring waters has been considered elsewhere (White and others, 1956).

The following types of sinter have been recognized at Steamboat Springs, and are likely to include most types found elsewhere:

A. *Single-stage or primary sinters*

1. Thin-bedded opaline sinter considered to be primary deposition of silica on broad discharge aprons. High contents of dissolved silica, high rates of evaporation, and rapid cooling of water discharged at temperatures near boiling are required. This type of sinter has rarely formed in recent years at Steamboat Springs but it has been common in the past (fig. 8).

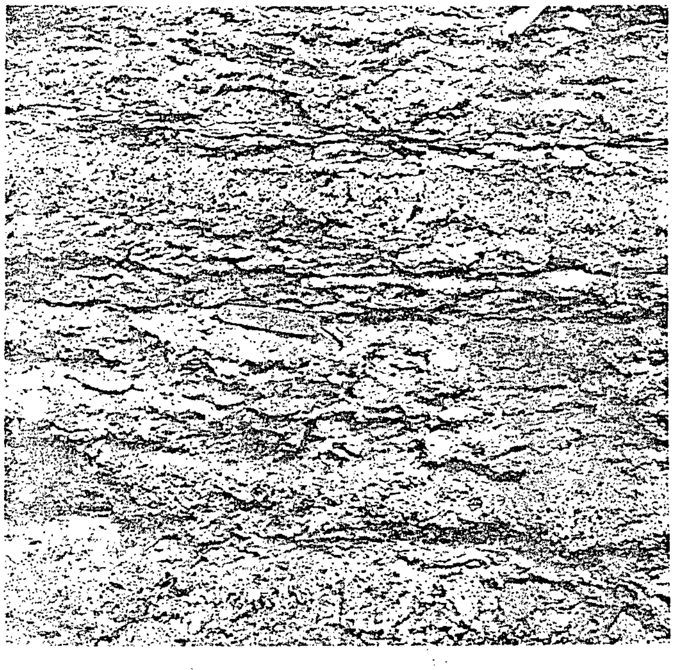


FIGURE 8.—Opaline hot-spring sinter in wall of trench near spring 5, Main Terrace, showing interbedding of single-stage thin-bedded sinter with multiple-stage fragmental sinter (see text).

2. Geyserite, or microbanded opaline sinter of colloform, botryoidal, or "knobby" habit. Hot-sprin sinters of many different types are commonly an improperly called geyserite. In sinter deposits o the world, even where geysers are most prominen true geyserite constitutes only a small part o the total deposits. Of all the types at Steamboat this is most likely to be interbedded with travertin layers. It is most abundant on sinter cones, and i deposited either by geysers or by vigorously spouting springs called perpetual spouters. Wate with a high silica content at or above the surfac boiling temperature is ejected and cools and evaporates rapidly, precipitating silica that was probably monomeric or "soluble" rather than colloida at the moment of precipitation (White and other 1956, p. 53). Geyserite should be distinguishe from other types of sinter because of its usefulne in recognizing proximity to former spring vent and fissures.
3. Bedded opaline sinter with abundant casts of plar roots and stems, commonly of salt grass (fig. 9 This type may not be forming at Steamboat at tl present time. It is, however, one of the most con mon types of opaline sinter, and is particularl abundant near the crest of Sinter Hill. Many c the plant casts lie parallel to the bedding, ind cating that the plants were already dead whe incorporated in the sinter. In many places, however, the casts or molds are perpendicular to tl

FIGURE 9.—Bedded sinter with abundant casts of roots and stems, pr ably of salt grass. Photograph taken normal to surface of a b Most casts are parallel to the bedding.

FIELD TRIP 11.
VIRGINIA CITY MINING DISTRICT.

GEOLOGY OF THE STEAMBOAT SPRINGS — VIRGINIA CITY REGION, NEVADA

Donald M. Hudson

INTRODUCTION

Steamboat Springs is an active geothermal area, depositing precious-metals. It is commonly considered analogous to many epithermal precious-metal deposits. The historic Virginia City region includes the Comstock district, a major precious-metal district in the U.S. that is famous for its high-grade bonanza ore bodies. The region encompassing Steamboat Springs and Virginia City lies immediately southeast of Reno, Nevada in the Steamboat Hills and the Virginia Range.

REGIONAL GEOLOGY

Stratigraphy

The oldest rocks exposed in the area are Mesozoic metasediments and metavolcanics. Triassic meta-andesites are exposed near Carson City and are overlain by Upper Triassic silicic volcanics and limestones and Lower Jurassic siltstones, limestones, conglomerates, and andesitic volcanics (Bingler, 1977). In apparent regional thrust contact are upwards of 7000 m of intermediate to felsic flows and ash-flow tuffs of the upper(?) Mesozoic Double Spring Formation of Noble (1962) (Hudson, 1983). In the vicinity of Reno this upper sequence is referred to as the Peavine Sequence (Bonham, 1969). The Mesozoic rocks are regionally metamorphosed to the greenschist facies, although near plutonic contacts, amphibolite facies hornfels, schists, marble, and skarns occur.

Scattered exposures of Cretaceous granodiorite and quartz monzonite porphyry occur in the Steamboat Hills, the west flank of the Virginia Range, and south of Virginia City (Thompson, 1956; Thompson and White, 1964).

The oldest Tertiary rocks are felsic ash-flow tuffs exposed south of Virginia City. Originally mapped as Hartford Hill Rhyolite by Gianella (1936), Bingler (1977, 1978) delineated eight ash-flow units of late Oligocene to early Miocene age, some of which are correlative to units in the Singatse Range (Proffett and Proffett, 1976) and the Gabbs Valley Range (Ekren and others, 1978) to the southeast of Virginia City. The tuff exposed on Hartford Hill is the Oligocene Mickey Pass Tuff.

The Miocene Alta Formation unconformably overlies the ash-flow tuffs. In the Virginia City area the lower ~400 m consist of pyroxene andesite agglomerate with a few interbedded flows. Locally within the upper 30–70 m of the agglomerate are up to 60 m of lacustrine shales, siltstones, tuffaceous sandstones, and conglomerates of the Sutro Member. The upper 700 + m of the Alta Formation consist of pyroxene and hornblende pyroxene andesites with minor interbedded agglomerate.

The Alta Formation has yielded K-Ar ages of 14.4 m.y. (Whitebread, 1976) and 16.5 m.y. (Silberman and McKee, 1972). The Alta Formation is hydrothermally altered throughout its area of exposure in the Virginia Range, and K-Ar ages are suspect. The Davidson Granodiorite, which intrudes the Alta at Virginia City, has yielded a K-Ar and fission-track age of about 17 m.y. (Silberman and Ashley, unpub. data, 1976). Axelrod (1966, p. 504) believes the flora collected from the Sutro Member of the Alta Formation (Calkins, 1944) to be early Miocene. The contact between the Alta and the Santiago Canyon Tuff appears to be an erosional unconformity (Bonham, 1969, p. 27). Thus, the age of the Alta Formation appears to be between 20 and 17 m.y., which agrees with Axelrod's (1966) paleobotanical age.

A small stock of pyroxene hornblende granodiorite with related peripheral porphyry dikes is intruded into the Alta Formation in the Virginia City area. The Davidson Granodiorite is similar in major-element chemistry to the Kate Peak Formation (Thompson and White, 1964) but is older since dikes of the Kate Peak Formation intrude the Davidson Granodiorite.

The American Ravine Andesite Porphyry is a localized hornblende andesite porphyry south of Virginia City. The age is uncertain but may be between the Alta and Kate Peak Formations (Thompson, 1956).

Overlying the Alta Formation is the Miocene Kate Peak Formation, consisting of andesitic to dacitic and rarely rhyolitic flows, intrusions, and lesser breccias. The Kate Peak Formation is characterized by 3–8 mm plagioclase and various combinations of biotite, hornblende, and pyroxene phenocrysts.

The Kate Peak Formation is divisible into a lower hydrothermally altered sequence and an upper unaltered sequence. The lower sequence is altered to varying degrees throughout its area of exposure in the Virginia and Carson Ranges (H.F. Bonham, personal comm.; Hudson, 1977; and unpub. data). This altered lower sequence includes both extrusive and intrusive rocks. The overlying unaltered Kate Peak Formation in the Carson and Virginia Ranges often lies with slight angular unconformity with the underlying altered Kate Peak as well as an erosional surface between the two sequences. There are also unaltered intrusive equivalents of the upper Kate Peak. The unaltered Kate Peak Formation has yielded biotite and hornblende K-Ar ages of 14.9–12.3 m.y. (Whitebread, 1976).

The extensive alteration and mineralization in the Virginia Range, as well as in the Carson Range and the Peavine district, are related to the emplacement of the lower sequence of the Kate Peak Formation (H.F.

Bonham, personal comm.; Hudson, 1977). Adularia from the Comstock Lode and the Occidental Lode has yielded K-Ar age of 13.7 ± 0.4 and 12.8 ± 0.4 m.y., respectively. These are similar to K-Ar ages from sericite at 14.6 ± 0.4 m.y. and from alunite at 11.8 ± 1.2 m.y. from the Peavine District (M.L. Silberman, written comm., 1979). These K-Ar ages overlap the K-Ar ages of the unaltered Kate Peak; however, the unaltered Kate Peak overlies altered rocks in the Comstock Lode and Peavine districts. Thus the lower Kate Peak Formation as well as the associated mineralization is older than dated.

The Kate Peak Formation is overlain by fluvial and lacustrine sediments of the Truckee Formation (or sandstone of Hunter Creek). The sediments consist of volcanic conglomerate and sandstone, shale, and diatomite. Tuffs and tuff breccias are interbedded with the sediments and may indicate interfingering of the upper Kate Peak Formation with the Truckee Formation (Thompson, 1956). The age ranges from late Miocene to Pliocene.

The Washington Hill Rhyolite forms a dome in the northwestern part of the Virginia Range. Pumice from an early explosive phase is incorporated into the upper beds of the Truckee Formation (Thompson, 1956).

Stratigraphically above the Truckee Formation are the Lousetown Formation, Mustang Andesite, and Knickerbocker Andesite. The Lousetown Formation (olivine basalt and pyroxene andesite flows and intrusion) occurs in the northern part of the Virginia Range, and the Knickerbocker Andesite (olivine pyroxene hornblende basaltic andesite flows and intrusions) occurs in the vicinity of Virginia City. Flows of both formations were erupted onto a very low relief erosional surface. The Mustang Andesite overlies the Lousetown Formation in the northern Virginia Range. The lower part of the Lousetown Formation yielded a K-Ar age of 6.9 ± 0.2 m.y. (Dalrymple and others, 1967). The K-Ar age of the Mustang Andesite is about 9 m.y. (Morton and others, 1977). The Knickerbocker Andesite is probably about the same age as the Lousetown Formation.

Basaltic andesite erupted from a vent near the crest of the Steamboat Hills has yielded a K-Ar age of 2.53 ± 0.11 m.y. (Silberman and others, 1979). The McClellan Peak olivine basalt occurs as local flows filling paleochannels south and southeast of McClellan Peak south of Virginia City and near Clark Mountain in the northern Virginia Range (Thompson, 1956; Rose, 1969). The McClellan Peak Basalt near Silver City has yielded a K-Ar age of 1.14 ± 0.04 m.y. (Doell and others, 1966). A group of Pleistocene rhyolite domes occur from the Steamboat Hills to the Virginia Range along a northeasterly zone. These domes have yielded K-Ar ages of 1.2–1.5 m.y. (M.L. Silberman, unpub. data, 1976).

Quaternary sedimentary deposits include pediment gravels, terrace gravels, alluvial fans, and stream sediments. Pleistocene Lake Lahontan sand and silt cover much of the Carson and Truckee River Valley floors.

Structure

Late Tertiary faulting is mostly northerly trending with steeply to moderately, primarily easterly dipping dip-slip faults with western rotation of fault blocks. The most prominent fault in the region is the Comstock Fault system, including the Comstock, Silver City, and Occidental Faults. These faults dip about 45° east. Precious-metal mineralization occurs within these faults and several smaller structures in the Virginia City area. The bulk of the deformation in the region appears to postdate the Lousetown Formation and the Knickerbocker Andesite. Faulting has been active into the Quaternary with displaced alluvial fans north and west of the Steamboat Hills (Thompson and White, 1964) and many sag basins and displaced alluvium within the Virginia Range (Thompson, 1956). Quaternary faults in the Steamboat Springs area localize the spring vents.

MINERALIZATION

General

Pre-Tertiary mineralization in the Virginia Range includes veins and skarns near the contacts of Mesozoic plutons that have yielded minor amounts of precious metals, lead, zinc, copper, tungsten, and iron (Bonham, 1969; Moore, 1969). The major period of mineralization in the Virginia Range is related to lower Kate Peak Formation magmatism. The major centers are the Comstock district, the Geiger Grade area, and the Washington Hill area, as well as the Jumbo district and the Flowery district. Pliocene and/or Quaternary mineralization, mainly mercury, occurs at Steamboat Springs and Castle Peak.

Comstock District

Abundant literature exists on the history of the Comstock district, and only a brief summary from Becker (1882), Smith (1943), and Bonham (1969) is included here. The Comstock Lode was discovered in 1853 by placer miners working their way up Gold Canyon near Silver City and Six Mile Canyon near the present site of Virginia City. Lode mining began with the near-surface ore bodies on the Comstock Fault. Mining continued downward along the lode with the discovery of the Crown Point Bonanza on the 1000 level and the Big Bonanza in a hanging wall structure on the 1400 level of the Consolidated Virginia mine during the 1870's. Exploration continued as deep as 3200 feet, but by the 1880's all mining, except for a few high-grade pockets on the East Vein zone in the hanging wall of the Comstock Fault, was largely confined to old stope fill and low grade ore in the upper levels. From 1920 to 1950 mining was largely in open pits and block caving in shallow levels. Houston International Minerals Corp. renewed mining in the Consolidated Imperial pit in the late 1970's. United Mining Corp. is currently mining underground in the New Savage Mine and reworking dumps. Total production from the district is over 190 million oz. Ag and 8 million oz. Au with minor production of Cu and Pb (Bonham, 1969).

Structure

Two distinct periods of faulting occur in the district. Pre-mineral (and probably syn-mineral) faulting occurs on the Comstock Fault, the Silver City Fault, and the Occidental Fault as well as a few vertical, often N. 45° E. striking structures in the hanging wall of the Comstock Fault (Con. Virginia Bonanza, East Vein zone, Garfield Structure). The Comstock Fault (fig. 1) has an average dip of 45° E. (Becker, 1882). The fault branches in the upper 100–150 m with dips on the eastern branches near vertical to steeply east dipping. The fault steepens in dip about 600 m below the surface. The bulk of the lode is sandwiched between the East Clay and the West Clay. These are gouge zones some 3–12 m wide created by post-mineral movement on the Comstock Fault. The gouge contains fragments of quartz veined material and is sometimes ore grade. The Black Dike (basalt) intrudes the West Clay in many areas of the Comstock (Becker, 1882) and shows some later offset.

Coats (1940) estimates about 800 m of pre-mineral movement and about 530 m of post-mineral movement of the Comstock Fault. Recent work indicates pre-mineral offset of probably less than 200 m. Faulting was renewed following the deposition of the Knickerbocker Andesite. Offset on the West Clay is about 250 m and about 350 m on the East Clay. Numerous northerly trending higher angle post-mineral faults occur in the hanging wall of the Comstock Fault with displacements of 10-150 m. Post-mineral faults, including the Comstock Fault, commonly display a right-lateral component of the dip-slip motion except on the Occidental Fault near the Occidental Shaft where a left-lateral component occurs.

The post-mineral offset of the Comstock Fault apparently displaced the hanging wall ore bodies as well as slivers of ore bodies formed on the Comstock Fault relatively downward. The vertical extent of ore bodies along the Comstock rarely exceed 150 m (Smith, 1943, p. 276). Most of the ore bodies within the Comstock Fault occur near the surface, and many cropped out. The ore bodies situated at deeper levels appear to be located east of the East Clay and were transported downward by post-mineral offset of the Comstock Fault. Thus, probably all of the ore bodies were originally formed at about the same elevation.

The relative position of the ore bodies is also controlled to some extent by cross faults that cut the Comstock Fault. The cross faults generally have a N. 70° W. trend (Reid, 1905; R.G. Carrington, personal comm.) which are post-mineral, but some may have pre- or syn-mineral movement which helped to localize ore bodies (R.G. Carrington, personal comm.).

Mineralization

Descriptions of the nature of the Comstock Lode from the available literature are generally poor. Based on observations in the New Savage Mine, the Comstock Lode appears to be a stockwork zone. The zone is 20-40 m wide and widens to over 100 m near the surface. Ore-bearing zones are commonly 2-5 m wide, generally in zones of intense stockwork (R.G. Carrington, personal comm.). Veins make up 10-100% of the rock with individual veins usually 2 mm-3 cm wide, rarely exceeding 10 cm. There have been no detailed studies made of the veins but numerous crosscutting types are present. These include quartz, quartz with minor adularia, quartz-adularia-pyrite, adularia with lesser quartz, adularia-quartz-pyrite, pyrite, pyrite-quartz, quartz with minor pyrite, as well as other types. Quartz veins and quartz veins with minor adularia appear to be the dominant vein types. In quartz veins with minor adularia, the fine-grained adularia intergrown with fine-grained quartz occurs along the margins of veins with coarser quartz occupying the interior portion of the veins. Few veins contain more than 4 bands of mineral deposition and 1 or 2 is common. Amethyst occurs locally and is usually an indicator of ore (R.G. Carrington, personal comm.). Carbonate minerals rarely occur in the New Savage Mine but are reported from other mines on the Comstock (Bastin, 1922; Gianella, 1936).

Ore bodies tend to be located in kinks or in convex eastward portions of the Comstock Fault. The major hanging wall ore bodies occur opposite concave eastward portions of the Comstock Fault (L.J. Buchanan, personal comm.).

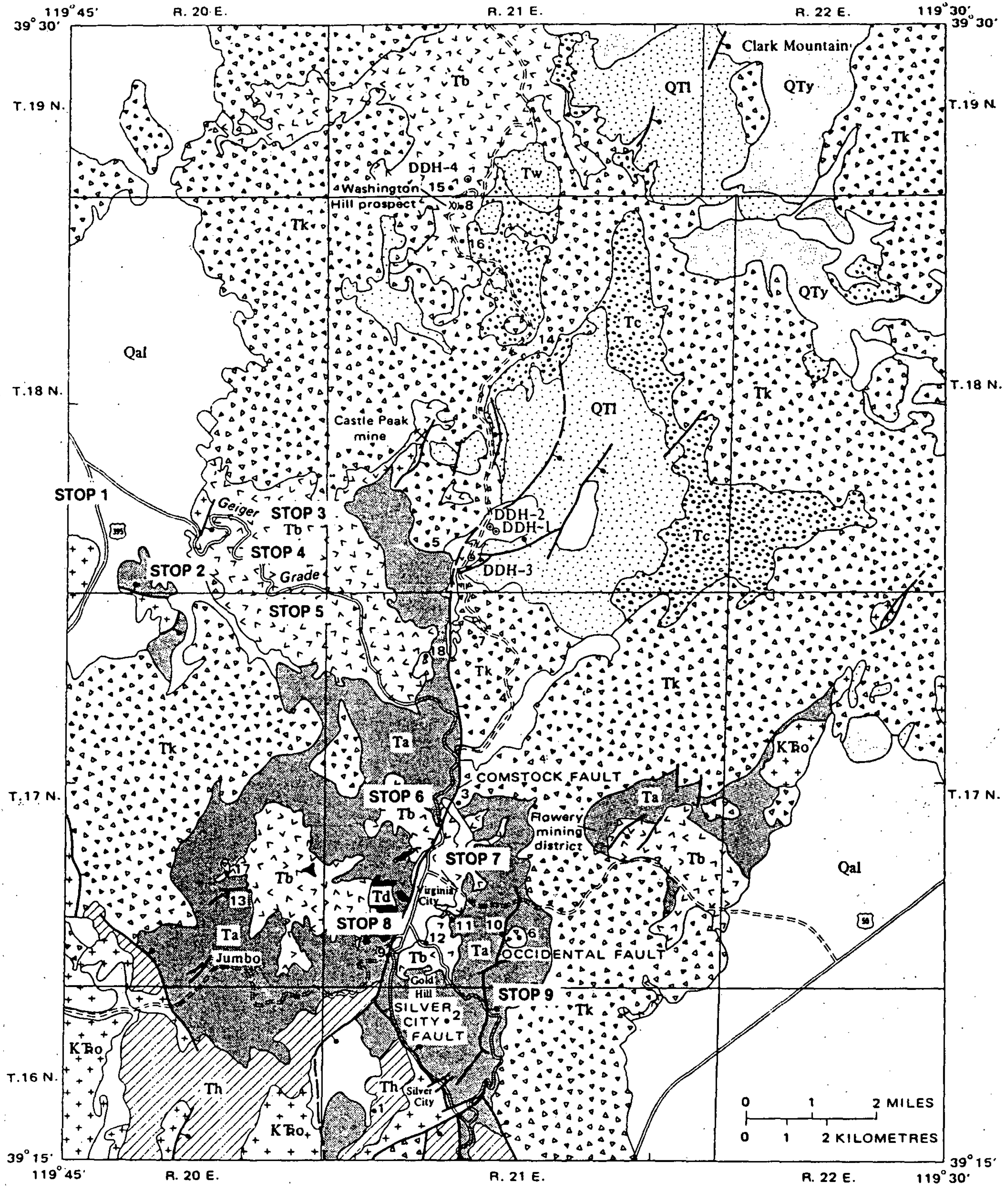
The mineralogy of the veins in the district is not well documented. Quartz with lesser adularia and rarely calcite are the dominant vein minerals in the Comstock Lode. The Silver City segment as well as the Occidental Lode are dominated by calcite with lesser quartz and adularia. The Silver City segment contains 1-2% sulfides in the vein material (Gianella, 1936) although the Comstock Lode appears to contain less than 1%. The dominant sulfides are pyrite and lesser sphalerite. Other minerals reported from the district are galena, chalcopyrite, Mn-oxides, argentite, stephanite, pyrargyrite, polybasite, electrum, silver, gold, and tetrahedrite (Terrill, 1914; Bastin, 1922).

Limited fluid-inclusion data indicates temperatures of 250°-300°C with evidence for boiling (Buchanan, 1981). O'Neil and Silberman (1974) show a water to rock ratio of nearly 1:1 based on ^{18}O shifts. A single sample from the Con. Virginia Bonanza possibly indicates a significant magmatic water input at some stage of mineralization (O'Neil and Silberman, 1974).

Alteration

The Comstock is the type locality of the propylite of von Richtofen (1866). The propylitic assemblage consists of albite-epidote-chlorite-calcite with pyrite and/or montmorillonite locally abundant, as well as zeolites (Coats, 1940). In the hanging wall of the Comstock Fault alteration assemblages include kaolinite-quartz, illite-quartz, sericite-quartz, illite-montmorillonite (some mixed layered)-quartz, alunite-quartz, pyrophyllite-quartz, pyrophyllite-quartz-diaspore, quartz-diaspore, alunite-kaolinite-quartz, silicification, and propylitization. There are numerous alunite-quartz zones in the hanging wall exposed at the surface, often as resistant ledges with roughly northerly trend. These zone outward to various combinations of kaolinite, pyrophyllite, and/or diaspore with quartz, which in turn zone outward to sericite-quartz, illite-quartz, and/or montmorillonite-quartz assemblages, then propylitization.

Adjacent to intense stock work veining (usually stoped out) in the New Savage Mine is sericite-quartz alteration. This assemblage extends 1-5 m beyond stoped material both in the hanging and foot walls. This grades rapidly (usually less than 1 m) outward to a chlorite-illite-albite assemblage in the less intense stock work zones. Occasionally adularia occurs with or in place of albite. Locally the chlorite-illite-albite assemblage is accompanied by strong silicification. All of the types of veins mentioned above occur in both of the alteration assemblages, although adularia appears to be more abundant associated with higher grade material (R.G. Carrington, personal comm.). Similar types of alteration occur in the various open cuts on the surface although kaolinite is locally abundant.



Geology modified after Thompson(1956, pl. 3)

Figure 1. Geologic map of part of the Virginia Range, Nevada, showing the location of field trip stops. Modified from Whitebread (1976, p. 4).

EXPLANATION

Qal	Alluvium	Holocene and Pleistocene	QUATERNARY
QTy	Younger rocks *Includes Steamboat Hills Rhyolite (Pliocene? and Pleistocene), Mustang Andesite (Pleistocene?), and McClellan Peak Olivine Basalt (Pleistocene)*	Pleistocene and Pliocene(?)	QUATERNARY AND TERTIARY(?)
QTl	Lousetown Formation *Flows and intrusions of basaltic andesite and basalt*	Pleistocene and Pliocene	QUATERNARY AND TERTIARY
Tw	Washington Hill Rhyolite	Pliocene	TERTIARY
Tc	Coal Valley Formation	Pliocene and Miocene	
Tk	Kate Peak Formation *Rhyodacite to andesite flows, breccias, and intrusive rocks*	Miocene	
Td	Davidson Granodiorite		
Ta	Alta Formation *Chiefly andesitic flows and flow breccias*		
Th	Hartford Hill Rhyolite Tuff		
KRo	Older rocks *Metavolcanic and metasedimentary rocks*		CRETACEOUS AND TRIASSIC(?)
Tb	Bleached rocks of the Kate Peak and Alta Formations		

Contact

Normal fault
Dashed where approximately located. Bar and ball on downthrown side

⊙ DDH-4
Diamond drill hole site

• 6
Sample locality

Figure 1. Continued.

ROAD LOG.
STEAMBOAT SPRINGS TO VIRGINIA CITY.

Mileage:
Cum. Inc.

0.0 0.0 Intersection of U.S. Route 395 and Nev. Route 341. Drive South on U.S. Route 395 along east base of Main Terrace, Steamboat Springs.

1.8 1.8 Turn Right (west) from U.S. 395 onto rough road to Main Terrace (turn is obscure; watch for break in fence.

2.1 0.3 **STOP 1. Main Terrace.** Park outside of fence near narrow opening in fence. Cross zone of open and closed fissures about 300 feet to the northeast to corroded valve and 4′ vertical pipe of GS-4 drillhole, a core hole drilled by U.S.G.S. in 1949. Water level in fissures is at approximately 10′ depth; all flowing springs are at lower altitudes to the east and north, either seeping or discharging up to several gpm. Notice the porous vuggy nature of most of the hot spring sinter, formed from direct precipitation of SiO_2 as X-ray amorphous common opal. The different varieties of sinter and their significance are described by White and others (1964, p. B30-B33) and details of the terraces and fissure systems are shown by White (1968, plates 1 and 3).

General: Three pumiceous rhyolite domes at 1:30 o'clock to the northeast, ages 1.1 and 3.0 m.y. On beyond and to the east, volcanic rocks of the Virginia Range largely andesites and rhyodacties 10-15 m.y. To the north, Truckee Meadows and Reno. To the northwest, the low light-colored ridge is the High Terrace, still thermally active but with water level 40 ft below the surface and discharging subsurface; probably no surface discharge in the past approximately 30,000 years. Farther to the west (10 o'clock) is Sinter Hill, with a few stunted pine trees, underlain by chalcedonic sinter ranging from about 1.1 to 3 m.y. old. To the southwest, we look over basaltic andesite lava 2.5 m.y. old that flowed out over a pediment cut on Mesozoic granodiorite and metamorphic rocks. The eroded cinder cone forming the apparent crest (from this view) of Steamboat Hills lacks a crater form and is 2.5 km from the Main Terrace. The most recent geothermal well drilled in the area is just this side (northeast) of the high point on the eroded cinder cone. The white dumps below the relict cone are acid-bleached andesite and granodiorite from the Silica pit (figs. 1 and 3).

Walk 300 ft northeast to a small sinter cone —spring 8, at the east lip of the terrace and just north of the power line. Over many years this spring discharged approximately 1 liter per min. of water high in Sb (0.4 ppm) and As (3.5 ppm); it was one of only three springs of the monitored 27 that discharged continuously during seven years (1945–1952) of systematic observation (White and others, 1964, pl. 4). Stibnite needles have formed at times on the walls and bottom of the pool. The red-orange layer of sinter around the vent is colored by metastibnite (amorphous Sb_2S_3) deposited at some unrecorded time after the detailed studies ceased.

Walk upslope 250 ft to the northwest to GS-5 drillhole, which is 574 ft deep, with a maximum temperature of 172°C, and studied in the most detail. Abundant quartz-calcite veins ranged up to 7 ft thick and dipped 45° to 80°E. Some pyrargyrite is visible, with Ag generally greater than 20 ppm.

TABLE I

GEOCHEMICAL SAMPLES FROM STEAMBOAT SPRINGS, NEVADA

Sept., 1982

values in ppm

Sample	Au	Ag	As	Sb	Hg	Tl	W	Cu	Pb	Zn	Mo
31	0.15	0.4	5	2	140	-.5					
32	-.05	-.1	73	60	19	0.5					
33	-.05	-.1	-5	2	13	0.5					
34	-.05	-.1	-5	-1	230	-.5					
35	0.05	-.1	280	200	11	2.5					
36	2.40	10.3	310	9800	150	190	4	30	105	40	-1
37	0.20	0.7	40	470	8.3	8.0	2	10	55	5	-1

31 Sinter from Sinter Hill
32 Material from hydrothermal explosion breccia apron
33 Siliceous residue, east end of Silica Pit
34 Hydrothermal breccia, south center of Silica Pit
35 Vertical channel sample, old sinter mound next to power pole, east of the top of the Main Terrace
36 -200 mesh fraction from mud in fissure at north end of Main Terrace (pyrite rich)
37 +200 mesh fraction of sample 36 (silica rich)

Walk on to the northwest to the highest springs that commonly discharged from open fissures (10 ft lower than the crest of the Main Terrace farther south). Springs 23 and 24, at times of very high turbulent discharge, deposited black siliceous muds in suspension, with as much as 15 ppm Au, 15 ppm Ag, 3% Sb, and high contents of Hg, As, T1, and B.

Near spring 24 and to the south, note that individual fissures "open" and "close." The open parts were formerly interpreted as "pull-aparts," but in places non-matching walls and abrupt closures demonstrate that the open parts resulted from dissolution and disintegration of sinter along fractures (White and others, 1964, p. B53-B54). Active disintegration is now occurring in "closed" parts of fissures; dig down a few inches in the loose sinter rubble where hot vapor is escaping. Also, note the gradual change horizontally into coherent horizontally bedded sinter. Condensing steam with Hg^0 and oxidizing H_2S produces native S, pink dispersed HgS, and strongly acid condensates (pH down to 1 or less). The acid condensate initially has no SiO_2 but is rapidly saturated with soluble opaline SiO_2 (300 ppm at 95°C).

Return south to bus, past the old Rodeo well. This was the first geothermal well (drilled in 1950) specifically exploring for steam to generate electricity.

Return to U.S. Route 395 on same road.

2.4 0.3 Turn left (north) on U.S. Route 395.

4.2 1.8 Intersection of U.S. Route 395 and Nev. Route 341. Proceed east on Route 341. Hydrothermally altered rocks of the Geiger Grade altered area are visible as white to pale brown patches on the slopes ahead. Because the pastel colors contrast with the relatively dark colors of the original andesites that have been altered, Thompson (1956) termed these rocks bleached. The exposed area of strongly altered rocks in the Geiger Grade area is about 14 km². Alteration assemblages present include: alunite-quartz, phyrophyllite-quartz-diaspore, kaolinite-quartz, illite-quartz, sericite-quartz, smectite-quartz, metahalloysite-quartz. The alteration distribution is controlled by numerous fracture zones with roughly N-S and E-W orientations. These are commonly manifested by bold exposures of alunite-quartz alteration. Hydrothermal breccias often occur along the fracture zones. Host rocks for the alteration and pyritization are the Miocene Alta Formation and flow and dikes of the Miocene Kate Peak Formation. The alteration is probably about the same age as the Comstock. The Geiger Grade alteration probably overlies a buried prophyry copper system.

4.7 0.5 Quarry for lightweight aggregate located in a dome of rhyolite of Pleistocene (1.2 m.y.) age can be seen on the left (northeast) side of the highway at a distance of about 2 km.

5.9 1.2 Begin climb up Geiger Grade.

7.1 1.2 **STOP 2. Clay pit on right (south) side of highway.** Material from the pit was used to make bricks during the first half of the century. Most of the pit is in andesite of the Alta Formation, but in the center of the pit is a porphyritic plagioclase-biotite dacite that may be a feeder dike(?) for a flow of the Kate Peak Foramtion. All rocks exposed in the pit have under gone argillic alteration and all are oxidized except for several pods of relict unoxidized pyritic rock with illite and montmorillonite 2 to 3 m above the floor of the central part of the pit. Metahalloysite-rich rocks exposed in the easternmost part of the pit probably originally contained hypogene halloysite. Clay minerals in rocks in the west part of the pit, which are transitional to rocks with propylitic assemblages, are more problematic, and could be largely or entirely of supergene origin. Prominent resistant ledges across the draw approximately 300 m to the northeast have strong quartz-alunite-pyrite alteration. On both sides of the road about 100 m to the northeast are excellent exposures of ferricrete.

7.4 0.3 Curve in road. Note adit on right side of road approximately 100 m to southwest. Dump at the mouth of adit contains fragments of hydrothermal breccia with quartz-kaolinite-pyrite alteration and traces of enargite.

Proceeding up the Geiger Grade, note that in many places soil developed on altered areas support only Jeffrey pine (*Pinus jeffreyi*) whereas elsewhere the vegetation is mainly pinyon, juniper, and sage.

7.6 0.2 Unaltered volcanic breccia of the Kate Peak Formation. This rock is typical of the abundant breccias in the Kate Peak. The most common rock type is porphyritic dacite. Fragments and matrix are usually similar in composition. The breccias of the Kate Peak probably include tuff breccias, flow breccias, and lahars.

8.1 0.5 Return to mostly altered Alta Formation. Unaltered basaltic andesite of the Lousetown Formation caps the hill at 11 o'clock.

8.3 0.2 **STOP 3. The top of the hill ahead is a quartz-alunite ledge.**

Pyroxene andesite of the Alta Formation forms the road cut on the left (east) side of the

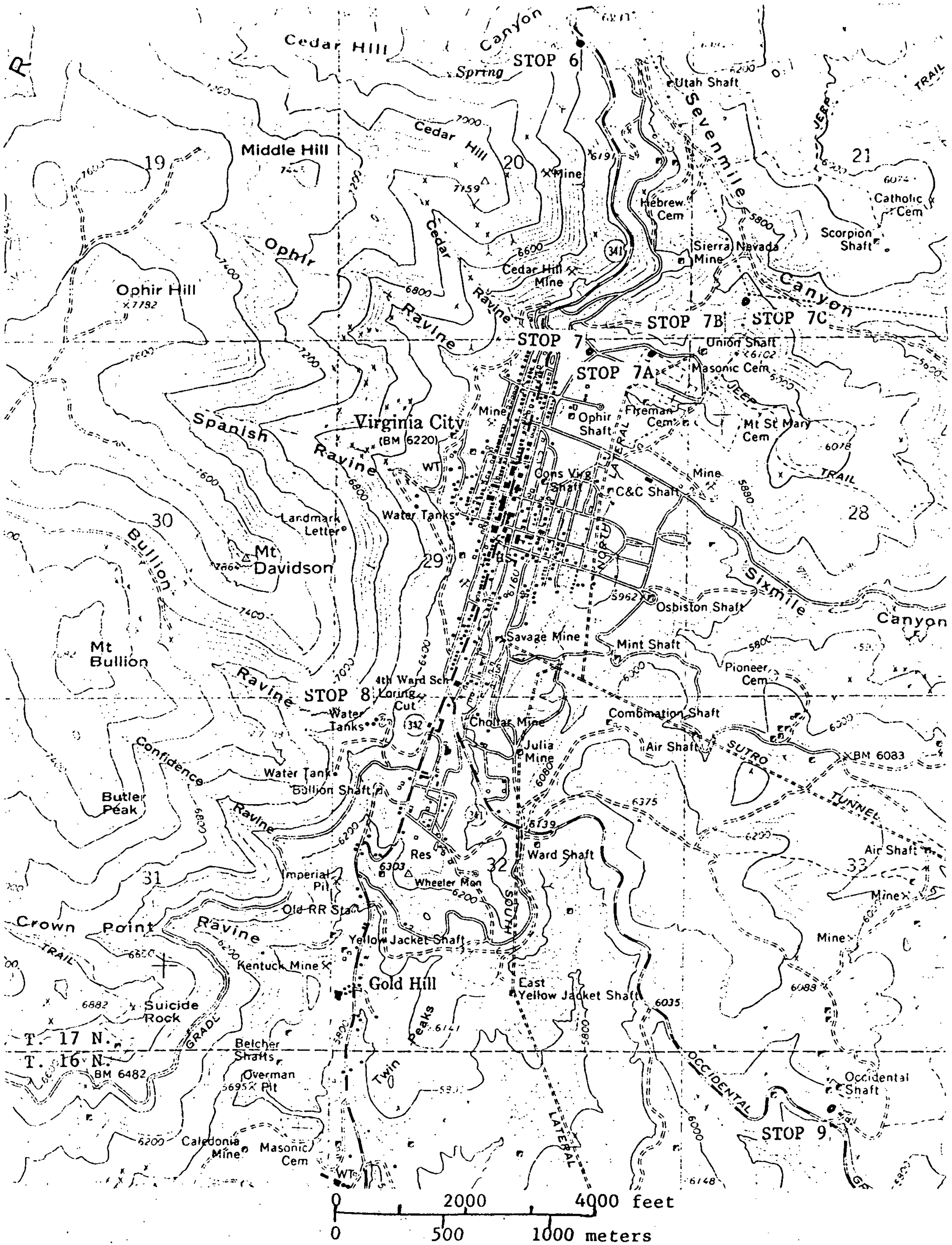


Figure 2. Location map of field trip stops in the Comstock District. Topographic base from U.S. Geological Survey Virginia City 7½′ quadrangle, 1982.

road. Unaltered andesite, in part with a glassy matrix, is in contact with oxidized propylitized andesite which contains some patches of partly oxidized pyritic propylitized rock and other patches of pyrite-poor to pyrite-free propylitized rock. The least altered rock is as fresh as can be found in the type area of the Alta. Note the prominent patches of unaltered Alta on the right (west) side of the highway. The lack of alteration in these patches of Alta is probably due to impermeability at the time of alteration.

8.6 0.3 Roadcut on left (west) exposes rocks with variable argillic (montmorillonite, sepiolite, kaolinite) alteration with quartz-alunite ribs.

8.8 0.2 **STOP 4. Geiger Lookout.** Roadcut on left (east) exposes hydrothermal breccias. The breccias are matrix supported and irregularly cross cut the Alta andesites. The alteration is alunite-quartz mainly in the breccias and pyrophyllite-quartz with minor diaspore mainly in the unbrecciated wall rocks. The alunite contains subequal amounts of alunite and natroalunite components.

Walk down (west) to overlook. The outcrop at the overlook is a fragment supported hydrothermal breccia. The alteration is alunite-quartz. On the south end of the outcrop is a narrow breccia. White cement on the west side of the outcrop is supergene(?) alunite.

9.8 1.0 Note the prominent ledges on the hills on both sides of the road with quartz-alunite alteration.

10.2 0.4 **STOP 5.** Most of this road cut consists of quartz-alunite-pyrite altered rocks of the Kate Peak Formation. On the west end of the bend is montmorillonite-quartz altered rock. The east end of the bend exposes rocks containing pyrophyllite-quartz alteration and quartz-alunite alteration with unoxidized pyrite. On the bend are hydrothermal breccias. Some contain fragments of pre-Tertiary plutonic and metamorphic rocks. Pre-Tertiary basement crops out at the bottom of the Geiger Grade, suggesting at least 400 m of vertical transport.

11.7 1.5 Old Geiger Grade historical marker on right (south) side of highway. Note Jeffrey pine growth on soil derived from altered rock on the slope below the marker. The road cut on the left (north) side of the road is described by Whitebread (1976, fig. 10).

13.0 1.3 Road cut on left exposes unaltered upper Kate Peak Formation filling in a paleochannel in propylitized and argillized lower Kate Peak Formation.

13.6 0.6 Geiger Summit. Outcrops ahead in the distance are unaltered flows of the Kate Peak Formation. Road cuts ahead are mostly unaltered flows of the Alta Formation.

14.4 0.8 Hills in the distance on the left side of the road (east) are underlain by lavas of the Kate Peak Formation. White outcrops are beds of diatomite. To north is the western end of the Geiger Grade altered area.

15.5 1.1 Surface of east-dipping Comstock Fault is visible ahead to the south.

15.6 0.1 Beginning at this point, flows of the Alta Formation exposed in road cuts are commonly propylitized.

16.1 0.5 **STOP 6.** Road cut exposing propylitically altered andesite of the Alta Formation. Rock of this type having the assemblage epidote-albite-chlorite-calcite exposed in the Virginia City area are the type propylite of von Richtofen. The dike of dacite of the Kate Peak Formation cuts the Alta in the northwestern part of the road cut. The dike is somewhat altered and quartz veins can be seen cutting across the contact. Very similar, although more intense, quartz veining can be seen underground in the Comstock district.

16.9 0.8 Sierra Nevada Shaft to left (east) of highway. In road cut to right is the contact of the upper Kate Peak overlying altered Alta. The block of Kate Peak is down dropped about 400 m on the Comstock Fault to the west.

17.3 0.4 Enter Virginia City.

17.5 0.2 Nevada Centennial Marker describing the Comstock Lode district is on the left (east) side of the road. The viewpoint provides an overview of the Virginia City area and the north end of the Lode. Mt. Davidson is on the uphill (west) side of town, to the south. The apex of the Comstock Lode (and the trace of the Comstock Fault) is along the west side of town, at the foot of Mt. Davidson, marked approximately by a line of shafts and cuts that exploit the Lode from the surface to depths of about 700 ft (215 m). The major shafts of the "Bonanza Group" including the Ophir and Consolidated Virginia, and the "Central Group" including various shafts on the Gould and Curry, Savage, Hale and Norcross, and Chollar claims, are mostly not visible from this viewpoint, but the large dumps of these mines are visible below the main street of Virginia City. Dumps of the C. & C. and combinations shafts are visible to the southeast and south-southeast. Production from these two shafts at depths greater than 2500 ft (780 m) is relatively minor.

17.6 0.1 Turn left (east) onto Carson Street and then bear left to Masonic Cemetery.

17.8 0.2 **STOP 7. Masonic Cemetery parking lot.** Walking tour of alteration in the hanging wall of the Comstock Lode.

Many of the boulders bordering the parking lot are stockwork from the Comstock. Note the numerous generations of veins. A few have visible adularia (whiter than quartz on margins of vein). Also blocks of unaltered Kate Peak Formation.

Proceed along northern road to the east about 800 ft (260 m) to road cut below Masonic Cemetery.

STOP 7A. Just below the Masonic Cemetery are several ledges of alunite-quartz alteration (hard material) with selvages of pyrophyllite-kaolinite-quartz-diaspore alteration 30 to 500 cm wide. Zoned outward (east) is montmorillonite-quartz alteration with narrow zones of sericite-quartz alteration.

Continue along road about 900 ft (300 m) to Union Shaft.

STOP 7B. The dump of the Union Shaft contains all of the major rock types exposed at depth. Included are the Davidson Granodiorite (phaneritic), Triassic(?) meta-andesite (weakly schistose), Alta Formation (fine-grained porphyritic andesite) and intrusives of the Kate Peak Formation (large phenocrysts). Many of the rocks contain quartz veins, some of which are as stock works. Some veins contain visible sphalerite and pyrite with minor galena and chalcopyrite.

Continue northeast to ridge about 1100 ft (260 m).

STOP 7c. Most of the ridge is quartz-alunite alteration forming the bold outcrops. Isolated blocks contain unoxidized pyrite. Softer material is pyrophyllite-kaolinite-quartz-diaspore and sericite-quartz alteration. The prominent outcrops across the canyon to the northeast have similar types of alteration.

Return to Masonic Cemetery parking lot. Along the way from the Union Shaft are exposures of altered rocks containing variously pyrophyllite, sericite, illite, kaolinite and quartz.

18.0 0.2 Intersection of Carson Street and C Street (Route 341). Turn left (south) on to C Street.

18.9 0.9 Intersection of Routes 341 (straight) and 340 (left) and B Street (right). Turn right on to B Street. Loring Cut across street.

STOP 8. Loring Cut. Quartz vein is boldly exposed on the floor of the cut to the west as well as on the benches on the south (far) end of the cut. Locally good stock work veining is exposed. The quartz contains very low gold values. The gouge near an exposed underground working on the road in the southeast central part of the cut contains higher gold values. Alteration in the cut is kaolinite-quartz and sericitic-quartz around the quartz veins and propylitic alteration distal to the veins.

19.4 0.5 Cross bridge over Virginia and Truckee Railroad. Ridge ahead contains north-south and N45E trending quartz-alunite ledges. Also present are quartz-pyrophyllite-diaspore, kaolinite-quartz, illite-montmorillonite (mixed-layered)-quartz, and propylitic with epidote alteration assemblages.

20.2 0.8 Outcrop to right (south) is quartz-alunite ledge. To left in roadcut is propylitic and illite-montmorillonite alteration.

20.3 0.1 Cross northerly striking, east dipping post-mineral fault. Knickerbocker andesite caps ridges on either side of road.

20.5 0.2 Propylitized Alta Formation in roadcuts for next 0.3 miles. Assemblage contains chlorite, calcite, albite, rarely montmorillonite.

21.1 0.6 **STOP 9. Occidental Lode.** The Occidental Lode exposed up the hill is primarily banded calcite with lesser quartz and adularia. This sharply contrasts with the Comstock Lode which is quartz with minor adularia and very rarely calcite. The footwall is propylitized Alta with epidote occurring up to 100 m into the footwall. The hanging wall is lower Kate Peak towards the top of the hill and Alta near the bottom of the hill. The propylitic assemblage in the hanging wall rarely contains epidote. The hanging wall also contains small local patches of alunite-quartz, pyrophyllite-diaspore-quartz, kaolinite-quartz, and illite-montmorillonite-quartz like the hanging wall of the Comstock Lode but nowhere nearly as extensive. Post-mineral faulting on the Occidental Fault as well as other subparallel hanging wall faults has downdropped the slightly west dipping Knickerbocker Andesite (exposed on the ridge to the east) some 100 m.

Across the highway (south) near the bottom of the canyon are excellent exposures of the Sutro Member of the Alta Formation.

22.1 1.0 Lyon County Line. To the right (west) is the southern continuation of the Occidental Lode. Knickerbocker Andesite caps many of the ridges. To the left (east) for the next 0.5 miles are coarse flow breccias of the upper Kate Peak overlain locally by the Knickerbocker Andesite.

22.9 0.8 Agglomerates and flows of the lower Alta exposed in roadcuts.

23.6 0.7 Oligocene Mickey Pass Tuff exposed in roadcuts for next 0.5 miles.

24.1 0.5 Turn right (north) onto Nev. Route 342.

24.3 0.2 Enter Silver City.

24.9 0.6 Devil's Gate. Silicified Alta Andesite.

25.4 0.5 Lucerne Pit on left (west). Open pit on Silver City Fault. Footwall (west) is Mesozoic meta-andesite overlain by Mickey Pass Tuff on Hartford Hill. Hanging wall is upper part of Alta Formation.

25.7 0.3 Knickerbocker Andesite exposed in bottom of canyon to right (east). Post-mineral offset of the Knickerbocker on the Silver City Fault is about 170 m. Pre-Knickerbocker offset was about 400 m. Cut on the hill straight ahead in the distance is the Overman Pit on the Comstock Fault.

26.0 0.3 Overman #2 Pit to left on Silver City Fault. New York Shaft to right.

26.5 0.5 Gold Hill to right (east) and Crown Point Ravine (out of sight to left) are the type localities of "propylite" of von Richtofen (1866). The assemblage on Gold Hill consists of albite, chlorite, and minor calcite. In Crown Point Ravine. The assemblage is albite, chlorite, epidote, calcite, and minor montmorillonite.

26.7 0.2 The bleached exposures just north of the Pink House is the southern-most extent of argillized (kaolinite, montmorillonite, illite, alunite, pyrophyllite) rocks in the hanging wall of the Comstock Fault. This is also the southern end of the most productive mines on the Comstock Lode (Crown Point Mine).

27.2 0.5 Consolidated Imperial Pit to left.

27.9 0.7 Junction of Nev. Routes 342 and 341. Loring Cut.

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REFERENCES

Ashley, R.P., 1980, Road log — Steamboat Springs to U.S. Highway 50: unpublished S.E.G. Field Trip Guide.

Axelrod, D.L., 1966, Potassium-argon ages of some western Tertiary floras: Amer. Jour. Sci., v. 264, p. 497-506.

Bastin, E.S., 1922, Bonanza ores of the Comstock Lode, Virginia City, Nevada: U.S. Geological Survey Bull. 735-C, p. 41-63.

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

Bingler, E.C., 1977, Geology of the New Empire 7½' quadrangle: Nevada Bureau of Mines and Geology Map 59.

———————— 1978, Abandonment of the name Hartford Hill Rhyolite Tuff and adoption of new formation names for middle Tertiary ash-flow tuffs in the Carson City-Silver City area, Nevada: U.S. Geological Survey Bulletin 1457-D, p. D1-D19.

Bonham, H.F., 1969, Geology and mineral deposits of Washoe and Storey Counties, Nevada with a section on industrial rock and mineral deposits by Keith G. Papke: Nevada Bureau of Mines and Bulletin 70, 140 p.

Bonham, H.F. and Hudson, D.M., 1981, Road log — Steamboat Springs to Virginia City: in unpublished Research Symposium, Zoning in Volcanic and Subvolcanic Mineral Deposits; Implications for Exploration, October 5-7, 1981.

Buchanan, L.J., 1981, Precious metal deposits associated with volcanic environments in the southwest: Arizona Geol. Soc. Digest, v. 14, p. 237-262.

Calkins, F.C., 1944, Outline of the geology of the Comstock Lode district, Nevada: U.S. Geological Survey Open-file report.

Coats, R.R., 1940, Propylitization and related types of alteration on the Comstock Lode: Econ. Geol., v. 35, p. 1-16.

Dalrymple, G.B., Cox, Allan, Doell, R.R., and Gromme, G.S., 1967, Pliocene geomagnetic polarity epochs: Earth and Planetary Science Letters, v. 2, no. 3, p. 163-173.

Doell, R.R., Dalrymple, G.B., and Cox, Allan, 1966, Geomagnetic polarity epochs—Sierra Nevada data, part 3: Journal of Geophysical Research, v. 71, no. 2, p. 531-541.

Ekren, E.B., Byers, F.M., Hardyman, R.F., Marvin, R.F., and Silberman, M.L., 1980, Stratigraphy, geochronology, and preliminary petrology of Tertiary volcanic rocks in the Gabbs Valley and Gillis Ranges, Mineral County, Nevada: U.S. Geological Survey Bulletin 1464.

Gianella, V.P., 1936, Geology of the Silver City district and the southern portion of the Comstock Lode, Nevada: Nevada Univ. Bull., v. 30, no. 9.

Hudson, D.M., 1977, Geology and alteration of the Wedekind and part of the Peavine districts, Washoe County, Nevada: Univ. Nevada-Reno, unpub. M.S. thesis.

———————— **1983,** Alteration and geochemical characteristics of the upper parts of selected porphyry systems, Western Nevada: Univ. Nevada-Reno, unpub. Ph.D. dissertation.

Moore, J.G., 1969, Geology and mineral deposits of Lyon, Douglas, and Ormsby Counties, Nevada: Nevada Bureau of Mines and Geology Bulletin 75.

Morton, J.L., Silberman, M.L., Bonham, H.F., Jr., Garside, L.J., and Noble, D.C., 1977, K-Ar ages of volcanic rocks, plutonic rocks, and ore deposits in Nevada and eastern California—determination run under the USGS-NBMG cooperative program: Isochron/West, no. 20, p.19-29.

Noble, D.C., 1962, Mesozoic geology of the Southern Pine Nut Range, Douglas County, Nevada: Stanford Univ., unpub. Ph.D. dissertation.

O'Neil, J.R., and Silberman, M.L., 1974, Stable isotope relations in epithermal Au-Ag deposits: Econ. Geol., v. 69, p. 902-909.

Proffett, J.M., and Proffett, B.N., 1976, Stratigraphy of the Tertiary ash-flow tuffs in the Yerington district, Nevada: Nevada Bureau of Mines and Geology Report 27, 28 p.

Reid, J.A., 1905, The structure and genesis of the Comstock Lode: Calif. Univ. Pub., v. 4, p. 177-199.

Richtofen, F., Baron von, 1866, The Comstock Lode — its character and probable mode of continuance at depth: San Francisco, Sutro Tunnel Co., Towne & Bacon.

Rose, R.L., 1969, Geology of parts of the Wadsworth and Churchill Butte quadrangles, Nevada: Nevada Bureau of Mines Bulletin 71, 27 p.

Silberman, M.L., and McKee, E.H., 1972, A summary of radiometric age determinations on Tertiary volcanic rocks from Nevada and eastern California — part II, western Nevada: Isochron/West, no. 4, p. 7-28.

Silberman, M.L., Stewart, J.H., and McKee, E.H., 1976, Igneous activity, tectonics, and hydrothermal precious-metal mineralization in the Great Basin during Cenozoic time: Transactions of the Society of Mining Engineers, v. 260, p. 253-263.

Silberman, M.L., White, D.E., Keith, T.E.C., Dockter, R.D., 1979, Duration of hydrothermal activity at Steamboat Springs, Nevada, from ages of spatially associated volcanic rocks: U.S. Geological Survey Professional Paper 458-D.

Smith, G.H., 1943, The history of the Comstock Lode, 1850-1920: University of Nevada Bulletin, v. 37, no. 3, Geology and Mining Series No. 37, 307 p.

Terrill, A.C., 1914, Ores of the Comstock Lode: Columbia Univ., unpub. M.A. thesis.

Thompson, G.A., 1956, Geology of the Virginia City quadrangle, Nevada: U.S. Geological Survey Bulletin 1042-C, p. 45-77.

Thompson, G.A., and White, D.E., 1964, Regional geology of the Steamboat Springs area, Washoe County, Nevada: U.S. Geological Survey Professional Paper 458-A, p. A1-A52.

White, D.E., Thompson, G.A., and Sandberg, C.A., 1964, Rocks, structure, and geologic history of Steamboat Springs thermal area, Washoe County, Nevada: U.S. Geological Survey Professional Paper 458-B, 63 p.

White, D.E., 1968, Hydrology, activity, and heat flow of the Steamboat Springs thermal system, Washoe County, Nevada: U.S. Geological Survey Professional Paper 458-C, 109 p.

White, D.E., 1980, Road log — Steamboat Springs geothermal area: unpublished S.E.G. Field Trip Guide.

Whitebread, D.H., 1976, Alteration and geochemistry of Tertiary volcanic rocks in parts of the Virginia City quadrangle, Nevada: U.S. Geological Survey Professional Paper 936, 43 p.