Bulk Mineable

PRECIOUS METAL DEPOSITS

GUIDEBOOK FOR FIELD TRIPS

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TRIP		PAGE
6	**PRECIOUS METAL DEPOSITS OF THE CARLIN TREND**	

FIELD TRIP 11

ROAD LOG/TRIP GUIDE: STEAMBOAT SPRINGS AND VIRGINIA CITY

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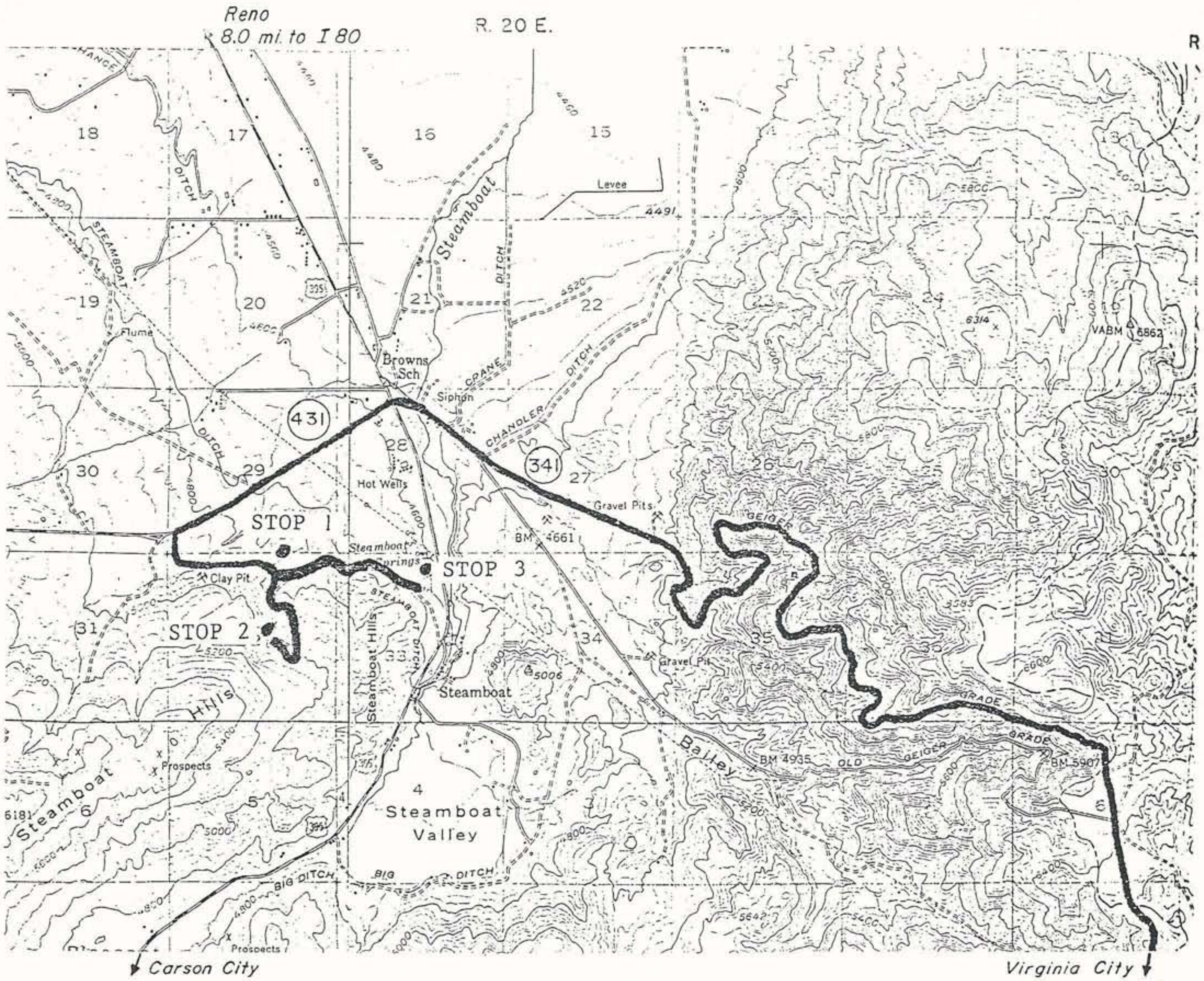
Modified from Hudson (1986), Bonham and Hudson (1981), Ashley(1980), and White (1985)

Mileage Cum.	Inc.	
0.0	0.0	Junction of U.S. 395 and Nevada Route 431 (10.3 mi. south of junction of I-80 and U.S. 395). Turn west onto Rte. 431, Mt. Rose Highway.
0.4	0.4	To the south is Geothermal Development Associates' 5 MW geothermal plant on the High Terrace.
0.9	0.5	To the south is a linear valley known as Mud Volcano Basin, formed by a hydrothermal explosion along a northerly striking fault in the basin and ejecting altered granodiorite to either side. The explosion probably occurred prior to Tahoe glaciation (Late Pleistocene) (White and others, 1964). SS-3 (Table 1) is altered ejecta from the east side of the basin.
1.4	0.5	TURN LEFT (south) on to graded dirt road at bend in highway.
1.55	0.15	Bear left.
1.7	0.15	Clay pit to the south. As described by Schoen and others (1974), the center of the pit consists of well-ordered kaolinite with alunite or completely opalized basaltic andesite. Near the edge of the altered area, moderately ordered kaolinite with alunite occurs. In the transition zone to nearly unaltered basaltic andesite is moderately ordered kaolinite, alunite and a trace of montmorillonite. Small amounts of kaolin were used in ceramics manufacture in Reno.
1.9	0.2	Grove of Jeffrey pine (<u>pinus jeffreyi</u>). These commonly grow in highly acidic soils produced by oxidation of pyrite and H_2S. Normal sagebrush and other vegetation cannot grow in the acidic soils so the pines have no competition for moisture.
2.0	0.1	Tailings from 1930s mercury recovery to south.
2.1	0.1	Road to Mud Volcano Basin to north. SS-9 (Table 1) of pyritic silicified alluvium from top of knoll to south.
2.2	0.1	STOP 1. Park near sharp right turn in road. Walk about 300 ft northwesterly up the slope of Sinter Hill to an area of chalcedonic-sinter rubble.

This was formerly an excellent outcrop of sinter interpreted by White and others (1964) as older than the 2.5 m.y.-old basaltic andesite. Chalcedonic sinter generally requires many thousands of years as well as temperatures of near 125°C for conversion from opaline sinter. Note that 125°C requires burial to a depth of about 50 ft to provide sufficient pressure for water to coexist with steam. Gravity-stratified microbanding in chalcedony-filled cavities now dips 30° SE while relict sinter banding dips 42° SE. This indicates an initial dip of 12° SE when the sinter was calcedonized and later was tilted 30° southeasterly possibly caused by the intrusion of a rhyolitic dome under Sinter Hill about 1.2 Ma (White and others, 1964). Note the black surfaces on many of the sinter fragments. When broken open cinnabar is revealed disseminated in the sinter. The black color develops on exposure to sunlight, for reasons not well understood. Sample SS-1 (Table 1) comes from this locality.



0	1	2	3 mi.	
0	1	2	3	4	5 km

Map 1.

Walk over crest of hill to the northwest to a "sauna" built over an old geothermal well. Steam often can be seen venting from this area. Note the potholed ground in the vicinity. Acid leaching beginning in 1982 has dissolved the underlying chalcedonic sinter creating small collapses and lowered the ground surface as much as a foot.

Return to the vehicles and continue south on graded road.

2.4 0.2 To the west are three geothermal wells. The only visible one is 1203 ft deep Nevada Thermal #3 which erupts intermittently. One of the older wells, no longer evident, was known as the mercury well because a film of metallic mercury condensed on metallic objects held in the escaping gases. Sample SS-4 (Table) is of leached, kaolinized granodiorite just west of Nevada Thermal #3. Note the 2.5 Ma basaltic andesite higher up on the slope to the west.

Proceed uphill on grade road.

2.85 0.45 Turn right up hill.

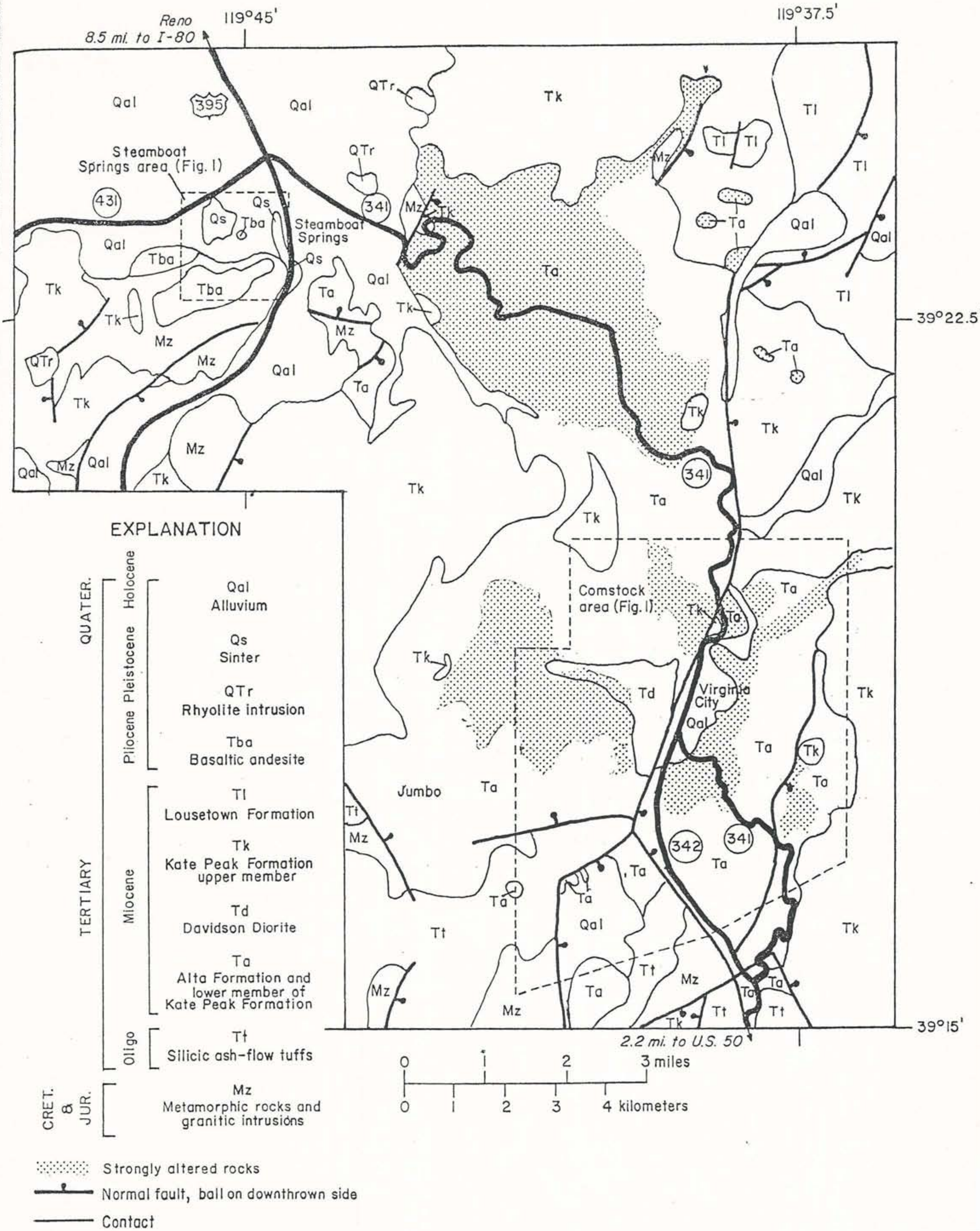


Figure 1. Simplified geologic map of the Steamboat Springs—Virginia City region, Nevada. Geology modified from Thompson (1956) and Thompson and White (1964).

3.0 0.15 STOP 2. Park on drill pad for Phillips geothermal well Cox 1-1 (about 3200 ft deep).

To the west is the old Silica Pit described by Schoen and others (1974) converted to a sump for the geothermal well. About 250 ft south of the wellhead on the bank is basaltic andesite completely replaced by cristobalite opal. Abundant sulfur is obvious in places and has been recently exploited for fine specimen crystals. Minor cinnabar occurs locally. Sample SS-7 (Table 1) comes from this vicinity. At the top of the bank to the south, the transition from leached to kaolinized to weakly montmorillonized basaltic andesite is exposed. About 200 ft west of the sulfur quarry, leached granodiorite consisting of acid pitted original quartz plus opaline and cristobalite residues that retain the original volume of feldspars, biotite and hornblende. Follow the road west about 350 ft to the sharp bend. Near the center of the depression about 100 ft east of the bend is USGS drill hole GS-7. About 130 ft south of the bend near the center of the pit are exposures of pyritic opal and cristobalite replaced granodiorite. A few hydrothermal breccias occur in this area. Sample SS-6 (Table 1) is from this locality. High on the pit walls to the south, abundant cinnabar can be found. About 150 ft to the east, several collapse breccias are visible in the pit wall. Extreme sulfuric acid leaching probably created large voids into which overlying material collapsed. Note some fragments are leached basaltic andesite from slightly above the rim of the pit and the extreme leaching of the granodiorite with highly pitted original quartz. Sample SS-5 (Table 1) is of this material.

Return to vehicles. Go out road you came in on.

3.15 0.15 Turn left on to graded road. Note tableland of basaltic andesite to east.

3.7 0.55 Turn right on to road. Tire nailed to tree at junction. CAUTION: This is a poor road, watch for rocks.

3.9 0.2 Bear left. Note chalcedonic sinter on slope to north. Note also stunted Jeffrey pines growing on the sinter. Compare these to Jeffrey pines growing on leached or kaolinized rocks in other areas.

3.95 0.05 Bear right (straight).

4.05 0.1 Turn right. Steamboat Ditch will be on your left (east).

4.15 0.1 Turn left. Ford over Steamboat Ditch. CAUTION: Use care approaching the ditch. Quite bumpy.

Turn right after ford. Exposure along road is pyritic partially cristobalite and opal replaced granodiorite (SS-8, Table 1).

4.2 0.05 Essentially unaltered basaltic andesite caps the granodiorite to the north. CAUTION: Many holes in the road ahead.

4.6 0.4 STOP 3. Main Terrace.

Park outside opening in fence. Cross zone of open and closed fissures about 400 ft to the northeast to corroded valve and 4 ft vertical pipe of GS-4 drillhole, a core hole drilled by USGS in 1949. Water level in fissures is usually about 10 ft deep; most flowing springs are at a lower elevation to the east and north, either seeping or discharging up to several gpm. Notice the porous vuggy nature of most of the 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 to the northeast (one has an aggregate quarry in it), ages 1.1 and 3.0 m.a. On the east, volcanic rocks of the Virginia Range, largely Early Miocene andesites and dacites. To the north, Reno and the Truckee Meadows. To the northwest, the low light-colored ridge is the High Terrace (power substation and GDA geothermal project on top) which is still thermally active but with the 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 is Sinter Hill, with a few stunted pine trees, underlain by chalcedonic sinter ranging from about 1.1 to 3 m.a. To the southwest, we look over 2.5 m.a. basaltic andesite lava that flowed over a pediment cut on Mesozoic granodiorite and metamorphic rocks. The eroded cinder cone forming the apparent crest (from this view) of the Steamboat Hills lacks a crater form and is 2.5 km from the Main Terrace. Up to 6000 ft geothermal wells have been drilled just this side (northeast) of the high point on the eroded cinder cone.

Walk about 100 ft northwest of GS-4 to the fissure. This is spring 39. Remanents of sulfide-rich mud (gray material) are visible downslope (east) of the fissure which was in continual eruption from late October 1985 to February 1986. S-39 (Table 1) is of this material. The sulfides were probably precipitated at depth and carried in suspension to the surface. About 50 ft northwest are two side-by-side holes (spring 41s). This spring erupted at the same time as spring 39 depositing sinter-derived sand with thin layers of sulfide-rich mud along the margins of the pits. S-41s (Table 1) is the -200 mesh fraction of that material.

Walk 400 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 of systematic observation (1945-1952; 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. Usually, a transition from pyrite to sulfur deposition can be seen about one foot down stream from from the vent.

Walk north about 200 feet to spring 10. This "geyser" erupts every 10 minutes to 4 hours with a water level change of up to 2 feet (Heinrick Koenig, oral comm., 1986). Note pyrite-rich opaline coatings on the walls of the vent and occasionally sulfur. Upslope about 100 ft to the west is drillhole GS-5, 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 (Sigvaldason and White, 1962; White, 1985, Table 1).

Walk about 40 ft northwest of spring 10 to spring 11. Usually, when discharging, the northern vent is lined with sulfur and the southern vent lined with pyritic opal. A good example of strong variation in chemistry over a very small distance. Continue north about 75 ft to spring 42. This spring usually deposits sinter as a gooey hydrous silica gel in abundance when flowing. Continue north about 100 ft to spring 12. About 25 ft to the northwest is spring 13w, which usually has sulfur-rich and pyritic vents side-by-side.

Walk to the northwest about 200 ft to the highest springs that commonly discharge from open fissures (10 ft lower than the crest of the Main Terrace farther to south). Springs 23 (in swale to north) and 24, at times of very high turbulent discharge, deposit black siliceous muds carried in suspension. The muds are very metalliferous (S-24, Table 1) and high in boron (White, 1985, Table 1). Minute (<0.1 mm) needles of stibnite and cubic to framboidal pyrite occur in the muds.

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 occurs locally and sporatically in "closed" parts of fissures; dig down a few inches in the loose sinter rubble where hot vapor is escaping. Part of the "closed" fissures probably are caused by human activity since bottles and other human debris have been found 6 ft deep in fissures filled by loose sinter rubble (Heinrick Koenig, oral comm., 1986). Also, note the gradual change horizontally into coherent horizontally bedded sinter. Condensing steam with Hg° 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 (approx. 300 ppm at 95°C).

About 250 ft southwest of spring 24 is the Rodeo well drilled in 1950. This was the first geothermal well specifically exploring for steam to generate electricity.

Walk south along the fissures. About 100 ft north of the powerline is a dug out hole. SS-10 (Table 1) is a sample of sinter from this location.

Return to vehicles. Return on road you came in on.

5.1 0.5 Ford over Steamboat Ditch. Turn right up road on west side of ditch.

5.2 0.1 Turn left.

5.55 0.35 Turn right on to graded road.

6.35 1.8 Turn right on to Nevada Rte. 431.

7.8 1.45 Junction with U.S. 395. Continue straight. Now on Nevada Rte. 341, Comstock Highway.

Hydrothermally altered rocks of the Geiger Grade area are 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 km^2. Alteration assemblages present include: alunite-quartz, pyrophyllite-quartz-diaspore, kaolinite-quartz, illite-quartz, smectite-quartz, metahalloysite-quartz, with disseminated pyrite abundances up to 20%. 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 flows and numerous intrusions 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 porphyry copper system with a possibility of high-level massive enargite-gold deposits as enargite occurs in a few of the prospects in the area.

8.3 0.5 Quarry for lightweight aggregate located in a dome of rhyolite of Pleistocene (1.2 Ma) age can be seen to the northeast about 1.5 mi. away.

9.5 1.2 Begin climb up Geiger Grade.

10.7 1.2 Clay pit on south side of the highway. Material from 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 biotite dacite dike of the lower member of the Kate Peak Formation. All rocks in the pit have undergone argillic alteration and all are oxidized, except for several pods of relict unoxidized pyritic rock with illite and montmorillonite 6 to 10 ft above the floor of the central part of the pit. Metahalloysite-rich rocks exposed in the eastermost part of the pit probably originally contained hypogene halloysite. Clay minerals in the rocks in the west part of the pit, which are transitional to rocks with propylitic assemblage, are more problematic and could be largely or entirely of supergene origin. Prominent resistant ledges across the draw approximately 1000 ft to the northeast have strong alunite-quartz-pyrite alteration.

10.8 0.1 On both sides of the road are excellent exposures of ferricrete, iron oxide-cemented alluvium.

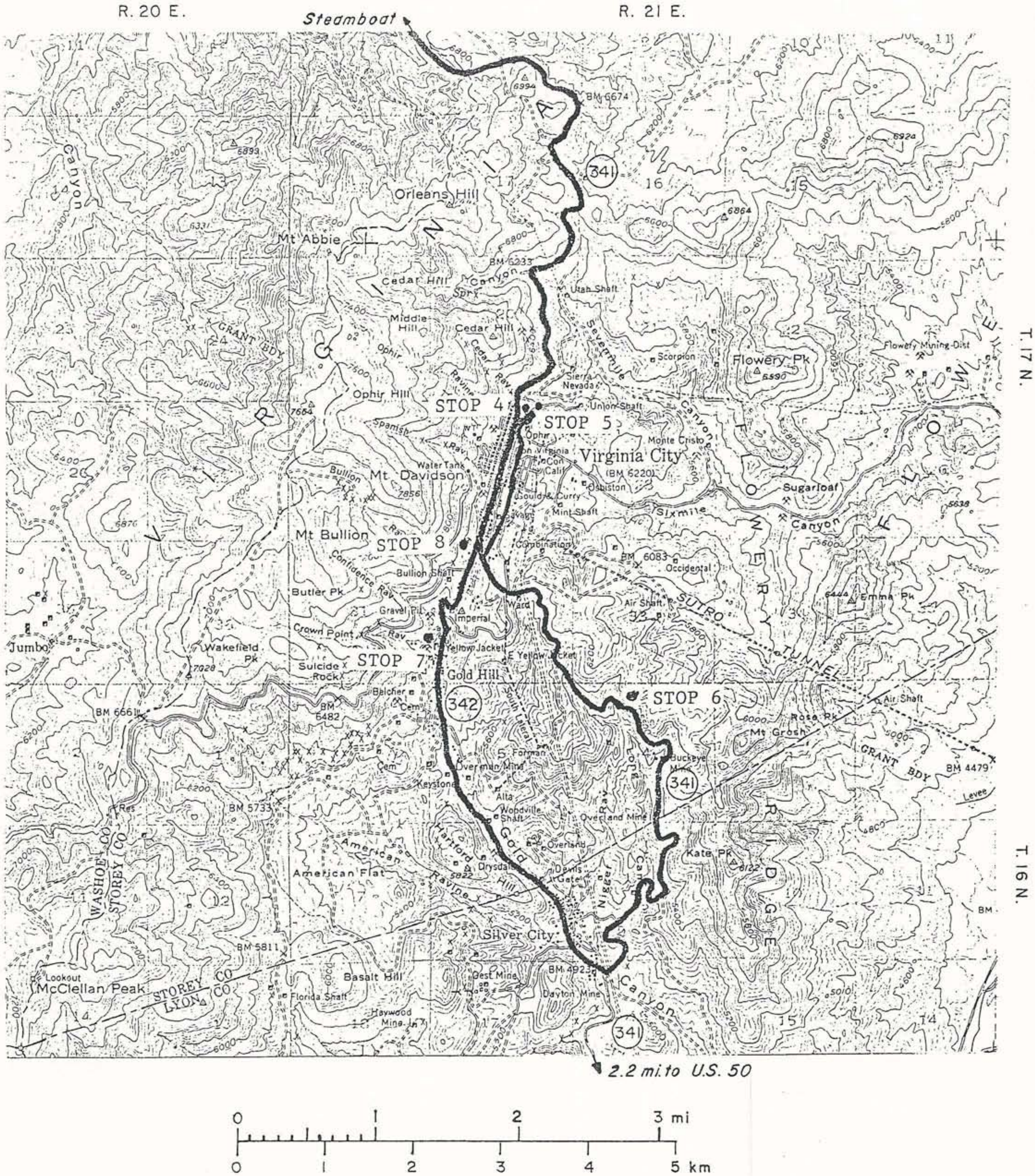
10.95 0.15 Curve in road. Note adit to east up canyon about 300 ft. Dump at the portal contains fragments of hydrothermal breccia with quartz-kaolinite-pyrite alteration and traces of enargite.

Proceeding up the Geiger Grade, note that in many places soils developed on altered areas support only Jeffrey pine whereas elsewhere the vegetation is mainly pinyon, juniper and shrubs.

11.3 0.35 Unaltered volcanic breccia of the Kate Peak Formation in roadcuts on curve. This rock is typical of the abundant breccias in the upper member of the Kate Peak Formation. Fragments and matrix are usually similar composition.

11.5 0.2 Return to mostly altered Alta Formation.

12.0 0.5 Pyroxene andesite of the Alta Formation forms the road to the north side of the road. Unaltered andesite, in part with a glassy matrix, is in contact with partly oxidized pyritic propylitized andesite and other patches of pyrite-poor to pyrite-free propylitized andesite. The least altered rock is one the few fresh



R. 20 E.
R. 21 E.
Steamboat
T.17 N.
T.16 N.
Orleans Hill
Mt Abbie
Cedar Hill
Middle Hill
Ophir Hill
STOP 4
STOP 5
Utah Shaft
Flowery Pk
Flowery Mining Dist
Scorpion
Sierra Nevada
Union Shaft
Monte Cristo
Virginia City
(BM 6220)
Mt Davidson
Water Tank
Sixmile Canyon
Sugarloaf
Mt Bullion
STOP 8
Bullion Shaft
Butler Pk
Confidence Rav
Combination
Occidental
SUTRO TUNNEL
Emma Pk
Air Shaft
Imperial
Gravel Pit
Crown Point Rav
Jumbo
Wakefield Pk
Yellow Jacket
STOP 7
Suicide Rock
Gold Hill
STOP 6
342
341
Rose Pk
Mt Grosh
GRANT BDY
BM 4479
Levee
Belcher
Cem
Forman
Overman Mine
Keystone
Alta
Woodville Shaft
Overland Mine
Buckeye Mine
Overland
Hartford
Drysdale
Devils Gate
Gold Hill
Kate Pk
American Ravine
American Flat
WASHOE CO
STOREY CO
Silver City
BM 5811
BM 5733
BM 6661
BM 4923
Basalt Hill
Lookout
McClellan Peak
STOREY CO
LYON CO
Florida Shaft
Haywood Mine
Dayton Mine
Canyon
2.2 mi. to U.S. 50
0
1
2
3 mi
0
1
2
3
4
5 km

Map 2.

exposures in the type area of the Alta Formation. Note the prominent patches of unaltered Alta on the south side of the highway. The lack of alteration in these patches is probably due to impermeability at the time of alteration.

12.4 0.4 Roadcut on west exposes rocks with variably argillic (montmorillonite, sepiolite, kaolinite) alteration with alunite-quartz ribs.

12.65 0.15 Geiger Lookout.

Roadcut to the east exposes matrix supported hydrothermal breccias that irregularly cross cut the Alta Formation. The alteration is mainly alunite-quartz, often in the breccias, and pyrophyllite-quartz mainly in the unbrecciated wall rocks. The alunite contains subequel amounts of alunite and natroalunite components.

To the west at the overlook on the bold outcrop is fragment supported hydrothermal breccia. The alteration is alunite-quartz. On the south end of the outcrop is a narrow fluidized breccia. White cement on the west side of the outcrop is supergene(?) alunite. A good overview of Steamboat Springs is from the overlook.

13.6 0.95 Note the prominent ledges on the hills on both sides of the road. These contain alunite-quartz alteration and are usually hydrothermal breccias. Note that other alteration assemblages are mostly covered with talus and colluvium since they are much less resistant.

14.0 0.4 Exposed on the first south bend in the road west of the horseshoe bend are mainly alunite-quartz pyrite altered rocks of the lower member of the Kate Peak Formation. On the western end of the bend are montmorillonite-quartz altered rocks. About on the nose of the bend are hydrothermal breccias with some of the clasts consisting of pre-Tertiary plutonic and metamorphic rocks. Pre-Tertiary basement crop outs at the bottom of the Geiger Grade, suggesting at least 1200 ft of vertical transport. Around the west end of the bend are exposed rocks with pyrophyllite-quartz alteration and alunite-quartz alteration with unoxidized pyrite.

15.45 1.45 Old Geiger Grade historical marker on south side of highway. Note Jeffrey pine growth on soil derived from altered rock on slope below. Road cut to north is described by Whitebread (1976, fig. 10) consisting of propylitized Alta Formation with zones of illite-quartz and montmorillonite-quartz.

17.4 1.95 Geiger Summit. This is the approximate southern limit of strongly altered rocks of the Geiger Grade area. Propylitization continues to the south into the Comstock district. Outcrops ahead in the distance are unaltered flows of the upper member of the Kate Peak Formation. Road cuts ahead are mostly weakly pyropylitized flows of the Alta Formation.

18.2 0.8 Hills in the distance to the east are underlain by lavas of the upper member of the Kate Peak Formation. White outcrops are lacustrine sediments that inter-finger with the uppermost part of the Kate Peak. The tableland to the north is underlain by the late Miocene Lousetown Basalt.

18.35 0.15 Curve in the road is on the northern part of the Comstock Fault. Kate Peak is to the east (hanging wall) and Alta to the west (footwall).

19.2 1.0 Again, this curve in the road is on the Comstock Fault. To the east (bulldozed area) is unaltered upper member Kate Peak and to the west (footwall) is calcite and minor epidote- bearing propylitized Alta Formation.

20.1 0.9 Road cut exposes propylitic alteration in the footwall of the Comstock. Rock of this type having the assemblage epidote-albite-chlorite-calcite exposed in the Virginia City area is the propylite of Richtofen (1866). Most of the road cut is lahars and flows of the lower member of the Alta Formation which here overlies Mesozoic gabbro about 200 ft below. A dike of dacite of the lower member of the Kate Peak cuts the Alta in the northwestern part of the road cut. Weak stockwork quartz veining occurs in the road cut. An exposure of strong stockwork veining occurs a few hundred feet to the east on the slope west of the road sign. Visible on the ridge to the east past the Utah Mine dump is some of the northernmost exposed acidic alteration in the hanging wall of the Comstock Fault. This is overlain by the unaltered upper member of the Kate Peak Formation.

20.7 0.6 Sierra Nevada Shaft dump to east of highway. In the road cut to the west is the contact of the upper member of the Kate Peak overlying altered Alta. The Comstock Fault is uphill to the west. Displacement of Kate Peak on the fault is about 1500 feet.

21.0 0.3 Entrance to the Cedar Hill Pit to the west. Pit has the only exposed calcite veining on the surface along the Comstock.

21.05 0.35 Enter Virginia City.

21.25 0.2 STOP 4. Turn left into rest area, north end of C Street (Rte. 341).

From here much of the north and middle parts of the district are visible. The discovery of silver made by O'Riley and McLaughlin in 1859 was just downhill from the Ophir Pit about 1000 ft to the southwest. About 1500 ft to the north is the Cedar Hill Pit with serictic alteration and stockwork veining exposed above the pit. About 5500 ft to the SSW is the Loring Cut. This line of pits defines the surface trace of the Comstock Lode. Note also the escarpment formed by recent movement of the Comstock Fault. Surface exposure of the Lode is very poor, mostly covered by dumps and alluvium. The lode dips about 35° E. Numerous dumps are visible from the various shafts that explored the lode at depth. To the NW about 3000 ft is the Sierra Nevada New Shaft, the northernmost productive mine. To the SE about 1000 feet (near the swimming pool) is the Ophir Shaft. About 2000 ft to the south are dumps from the famous Con. Virginia.

Continue south of Rte. 341.

21.35 0.1 Turn left onto Carson Street (follow arrow to cemetery).

21.4 0.05 Bear left to cemetery (follow sign).

21.6 0.2 STOP 5. Cemetery parking lot.

Boulders around the parking lot include good examples of stockwork veining from the Ophir pit. Note numerous generations of veining, a few of which have adularia (whiter that quartz on margins of veins). Also blocks of the upper member of the Kate Peak Formation quarried for use as foundations for buildings and headframes.

Walk through the main gate of the Masonic Cemetery to the top of the hill behind the grave of Col. Storey (namesake of county) about 1200 ft east of parking lot. Good examples of highly silicified, weakly alunitized hydrothermal breccias in the Alta Formation. These are surrounded by pyrophyllite-quartz and kaolinite-quartz alteration (poorly exposed). About 1600 ft below is anhydrite-quartz-illite-pyrite alteration exposed in a crosscut. The alteration exposed on the surface grades into the anhydrite-bearing assemblage a few hundred feet beneath the surface. This outcrop probably originally lay about 300 to 500 ft below the paleosurface at the time of hydrothermal activity.

Walk northwest through the hole in the fence and down the steep slope to the road. The prospect pit along the way exposes kaolinite-quartz alteration. East along the road is the Union Shaft dump. Much quartz vein material near the shaft contains galena, sphalerite, pyrite and chalcopyrite. Bordering Sevenmile Canyon, about 2000 ft NE, are bold exposures of alunite-quartz alteration. Farther along that trend of bold outcrop (near the Scorpion dump visible near the top of the ridge) is a porous silicified zone with minor disordered kaolinite which may be weathered exposures of the anhydrite-bearing assemblage. Follow the road west to a large Jeffrey pine south of the road.

Just east of the Jeffrey pine is a hard ledge 3 to 4 ft wide of alunite-quartz alteration bordered by a 1 to 2 ft zone of pyrophyllite-quartz alteration. This is bordered by kaolinite-quartz alteration to west of the tree and east to the gully in the slope. Zoned farther out is illite-quartz with minor montmorillonite. The host rock is the Alta Formation. The zoning of alteration exposed here is rather typical of the high-level alteration in the district. This again passes downward to anhydrite-quartz-illite-pyrite within a few hundred feet.

Return to the parking lot. Good example of propylitic alteration with epidote and trace calcite exposed along the road.

Follow road north out of parking lot.

21.8 0.2 Turn right onto Carson Street.

21.82 0.02 Turn left onto D Street.

21.9 0.08 Cross Sixmile Canyon Road then bear left onto E Street (dirt road).

22.0 0.1 V&T depot to right. Dump of Con. Virginia Shaft to east and C & C Shaft farther to east. Con. Virginia Bonanza orebody lies between the shafts. Orebody about 1100 ft north to south, tops out about 1000 ft below the surface. Between 1872 and 1881 yielded 27,800,000 oz. Ag and 1,400,000 oz. Au from 800,000 tons of ore. The orebody lies in the hanging wall of the Comstock Fault and displaced downward some 1500 ft to the east relative to the orebodies along the main lode by postmineral movement.

22.2 0.2 Turn left onto Taylor Street, turn right behind St. Mary's in the Mountains Church onto F Street.

22.3 0.1 Washington Street. Go straight.

22.55 0.15 Cross V&T tracks. Savage Mine dump to east.

22.6 0.05 New Savage Mine portal to east behind metal building.

22.65 0.05 Hale and Norcross dump to east. Combination Shaft farther to east. Deepest shaft in district at over 3200 ft.

22.75 0.1 Chollar Mine to east. Original adit open to tourists.

22.9 0.15 Turn left onto Rte. 341, Occidental Grade.

23.25 0.35 Cross bridge over V&T tracks. About 200 ft north of highway on road east of tracks is an excellent example of fragment-supported hydrothermal breccia with alunite-quartz alteration. Note extensive area of alteration to east and south. Most bold outcrops are alunite-quartz and some have hydrothermal breccias.

23.5 0.25 Note road cuts in propylitized Alta. Assemblage contains epidote west of the highway and abundant calcite with little of no epidote east of the highway.

24.1 0.6 South of curve along road to Forman Shaft are southernmost exposures of alunite-quartz alteration in hanging wall of Comstock Lode.

Ridges to north and south capped by Knickerbocker Andesite.

24.9 0.8 STOP 6. Occidental Lode.

Walk up hill to northwest. Note quartz after calcite infloat near base of hill. Continue uphill along lode. Note massive calcite, often cementing propylitized Alta, crosscutting quartz and calcite veins, and banded calcite. Slickensided sufaces result from postmineral movement of fault. Footwall (west) has good exposures of epidote-bearing propylitic alteration with little or no calcite replacement. Note lack of pyrite in veins. About 300 to 400 ft down dip, calcite passes into quartz-adularia veining with several percent pyrite. Continue up past open stopes. Note there is no apparent indication of ore versus waste. At about 6000 ft elevation, the lode passes rapidly vertically to a reddish silicified porous limonitic rock with stockwork quartz veins. This is probably supegene leached anhydrite-quartz-illite alteration. A few ocurrences of calcite are exposed up the hill, but this marks change in lode mineralogy. If one were to continue over the top of the hill back to about 6000 ft elevation, the lode changes back to mostly calcite. The silicified, stockworked rock contains anomalous Au and Ag values.

Walk east from the lode over the hill. You are now on the hanging wall of the Occidental Lode and on one of the few exposures of flows of the lower member of the Kate Peak Formation. Rock is propylitized with variably epidote and calcite. Reddish upper member of the Kate Peak on the ridges to the east. From the top of the hill about 2000 ft to the southeast is a light-colored, tree-covered knoll just below the contact of the upper Kate Peak. On this knoll is cristobalite-opal kaolinite alteration very similar to that in the Silica pit at Steamboat Springs. This alteration probably formed above the paleowatertable at the time of hydrothermal activity in the district.

Continue downhill across the road to about 1000 ft east of the lode.

Small bold outcrop is excellent exposure of quartz-diaspore alteration. Several faults lie between this exposure and the Occidental Lode, so that this was formed about 500 ft higher than where you left the lode. Walk south across road to outcrop.

Near the road is illite-quartz alteration. Top of outcrop is kaolinite-quartz alteration. Southside of outcrop is quartz-diaspore. Note the similar lateral zoning to that at the Masonic Cemetery. Alunite-quartz ledges are exposed to the east and north.

Walk back to vehicles. Abundant float of Knickerbocker Andesite along the way. Red jasper common in Knickerbocker and underlying propylitized andesites.

Continue south on Rte. 341.

25.8 0.9 Occidental Lode exposed on ridge to west. Mainly calcite as at stop 6. Weakly propylitized Alta in road cut.

26.0 0.2 Lyon County line.

26.25 0.25 Reddish outcrop on curve is lahar of upper member of Kate Peak Formation.

26.8 0.75 Begin exposures of mudflows and breccias of the lower member of the Alta Formation. Epidote-bearing propylitic alteration.

27.4 0.6 Santiago Canyon Tuff exposed in road cuts ahead. Underlies the Alta.

27.7 0.3 Return to Alta Formation is road cuts.

28.0 0.3 Turn right onto Rte. 342. Gold Canyon. Gold discovered in 1850 by travelers to California at mouth of Gold Canyon at the Carson River. West of junction is (was) Nevex Gold Co.'s proposed open pit on the Silver City Lode.

28.15 0.15 Enter Silver City.

28.3 0.15 American Ravine to west. Grosh Brothers prospected this area for silver in mid-1850s but died before finding mineable ore. Most of Gold Canyon placered but total production and payings small.

28.6 0.3 Central Silver City.

28.85 0.15 Devils Gate. Good exposures of lower member of Alta Formation. Silver City Fault zone to west. Enter Storey County.

29.3 0.45 Lucerne Cut to west. Massive calcite exposed between Mesozoic andesite (footwall) and Santiago Canyon Tuff (hanging wall). East fault of Silver City Fault zone just west of highway juxtaposing tuff and Alta to east.

29.6 0.3 Road to left at base of Justice dump leads to the Drysdale pit about 0.6 mi south. Exposed in pit is massive calcite and stockwork veining is a footwall splay of the Silver City Fault. Good examples of blocky, often highly zoned calcite, lamellar calcite, and calcite partially or totally replaced by quartz.

29.8 0.2 Headframe to east is Lady Washington Shaft.

29.9 0.1 Overman 2 pit to west on Silver City Lode. Footwall (west) is lower member and hanging wall is upper member of Alta Formation.

30.0 0.1 New York Shaft headframe to east.

30.5 0.5 Mine car found in Hale and Norcross dump displayed on dirt road to west. Twin Peaks (east) and Crown Point Ravine (out of sight to west) are the type localities of "propylite" of Richtofen (1866). The assemblage on Twin Peaks consists of albite, chlorite, and minor epidote and calcite. The assemblage in Crown Point Ravine is albite, chlorite, epidote, and trace montmorillonite with widely scattered quartz veining.

30.8 0.3 Crown Point Mine to west. The other major deep bonanza orebody lies about 1000 ft beneath the highway. Discovered a year before the Con. Virginia, production from the orebody was slightly larger with an average grade a bit lower than the Con. Virginia.

31.1 0.3 Turn left onto dirt road.

31.15 0.05 To the north is the Gold Hill depot of the V&T Railroad. Farther north is the Con. Imperial pit. Original gold discovery in quartz made where pit is now by James Finney (Old Virginny) in Jan. 1859 and was known as Gold Hill.

31.25 0.1 STOP 7. Park near outcrops south of wooden ore chute on north side of now filled-in Crown Point Ravine.

These exposures are about 350 ft above the top of the west Yellow Jacket orebody. Note the stockwork quartz veining, a few of which have adularia. The host rock is the lower member of the Alta Formation. Also note patches of sericitic alteration as irregular pods distributed through the outcrop. The greenish altered rocks have the assemblage chlorite and illite with either albite or adularia. Some zones are adularia rich and others albite rich, but cannot be distinguished in outcrop. This alteration assemblage resembles propylitic alteration but rarely contains either epidote or calcite and is typical of alteration along the lode, together with sericitic alteration. The distribution of alteration exposed here is typical of the lode and neither type of alteration can be correlated with ore. Some of the rock in this outcrop could be considered low grade ore.

CAUTION: Do not enter the Con. Imperial Pit. Much has been backfilled and the walls are very unstable. The poor exposure in the pit is not worth the risks. About 0.3 mi south, just west of the haulage road, is dump material from the Con. Imperial Pit. Excellent examples of stockwork veining in unoxidized rock with abundant adularia are present on the dump.

Return to highway.

31.4 0.15 Turn left onto Rte. 342.

31.95 0.55 Turn left opposite Comstock Motel onto Ophir Grade.

32.0 0.05 Turn right ("WATCH FOR HEAVY EQUIPMENT" sign). STOP 8.

Park south of cable across haulage road. Loring Obester pit. Walk down haulage road. West fault of Comstock Fault zone visible as scar above water tanks. East fault lies between pit and Rte. 342. Upper member of Alta and Davidson Diorite exposed in pit along with numerous small faults. Good examples of quartz after lamellar and blocky calcite exposed on the west end of upper bench. Third bench down has exposed back filled squaresets from the 1860s. Grade of ore adjacent to backfill is about 0.1 oz/ton Au and about 3 oz/ton Ag. To the west about 100 ft, the rock is barely anomalous in Au and Ag. Note the rock looks very much the same. Locally some of the highly gougy material makes higher grade ore.

Return to Rte. 342.

32.1 0.1 Turn left (north) onto Rte. 342.

32.35 0.25 Junction with Rte. 341.

END OF ROAD LOG

Continue north on Rte. 341.

Junction with U.S. 395, 14.5 mi.

Junction with I-80, 24.7 mi.

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STEAMBOAT SPRINGS GEOTHERMAL AREA
WASHOE COUNTY, NEVADA

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INTRODUCTION

Steamboat Springs geothermal area lies approximately 16 km south of downtown Reno, Nevada. Discharge of thermal waters and gases from an area of of about 5 km^2 over the past 3 m.y. are now mostly restricted to the Main Terrace just west of U.S. Highway 395 (Fig. 1) and the Low Terrace to the southest. Of the active geothermal systems studied in the world, Steamboat Springs has the longest and one of the most complex geologic histories (Fig. 2; White and others, 1964; Silberman and others, 1979).

The hot spring waters have been used in local spas and heating since the early 1900s. Several attempts were made in the 1950s and 60s to explore for geothermal steam for electrical power generation. Beginning in 1975, Phillips Petroleum Co. drilled numerous temperature gradient holes as well as production wells ranging from 100 to nearly 2000 m deep indicating a reservoir temperature of 228° C (Phillips Petroleum Co., unpub. data, 1981), with the highest temperatures encountered about 2.5 km southeast of the Main Terrace and little surface evidence of hydrothermal activity directly above. Currently, Geothermal Development Associates is developing a 5 mw geothermal electric plant about 1 km northwest of the Main Terrace.

Intermittent small-scale mining has occurred in the area. Probably less than 100 flasks of mercury have been produced from the district from several small mines in leached granodiirite and basaltic andesite, and sinter (Bonham, 1969). Some silica, shipped as glass sand, was produced from the Silica Pit (Fig. 1), and a small amount of kaolin was mined for brick manufacture in Reno from the Clay (Faith) pit (Papke, 1969).

STRATIGRAPHY

The Steamboat Springs area is underlain by pendants of early Mesozoic metavolcanic and metasedimentary rocks in late Mesozoic granodiorite. Erosional remnants of the early Miocene Alta Formation locally lie unconformably over the Mesozoic rocks. A few dikes of early middle Miocene Kate Peak Formation occur in the area. In the vicinity

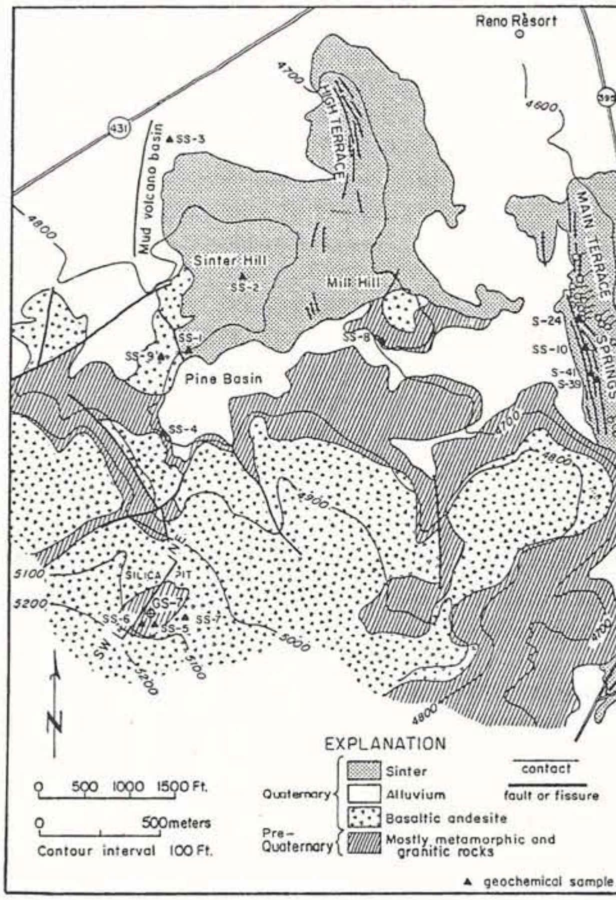

Figure 1. Generalized geologic map of the Steamboat Springs geothermal area, Nevada (redrawn from Schoen and others, 1974) showing geochemical sample locations for table 1.

of Sinter Hill (Fig. 1), the basement rocks are unconformably overlain by approximately 3 m.y.-old sinter which is overlain by basaltic andesite erupted from a vent near the crest of the Steamboat Hills which has yielded a K-Ar age of 2.53 ± 0.11 Ma (Silberman and others, 1979). The thermal area occurs approximately on a northwesterly striking line of four known rhyolite domes. About 5 km southwest of the Main Terrace is the largest of the domes which yielded a K-Ar age of 1.14 ± 0.04 Ma. One and one-half to 5 km to the northeast of the Main Terrace are three domes yielding ages of 1.2 to 3.0 Ma (Silberman and others, 1979). In the vicinity of Sinter Hill, uplift and tilting of the older sinter may be attributable to another buried rhyolite dome (White and others, 1964). Pleistocene sediments and interbedded sinter overlie the basaltic andesite in low-lying areas (Fig. 2). An outflow apron from a hydrothermal explosion breccia occurs around Mud Volcano Basin (Fig. 1) and is believed by White and others (1964) to be late Pleistocene (pre-Tahoe glaciation). Holocene sinter occurs mainly on the Main and Lower Terraces just east and west of U.S. Route 395.

STRUCTURE

The following structural description of the Steamboat Springs area is summarized from White and others (1964).

The Steamboat Hills has been a topographic and structural high during the late Cenozoic. Major structural relief was formed prior to the eruption of the basaltic andesite.

Three systems of normal faults are recognized in the thermal area. An east-northeast system lies parallel to the axis of the Steamboat Hills, restricted primarily to the basaltic andesite and older rocks. Down-thrown sides tend to be towards the axis of the hills. Maximum post-basaltic andesite displacements are about 30 m, but earlier movements could be much greater. Northwesterly striking faults in pine Basin are probably contemporaneous with the east-northeast system. The nearly north striking system of faults are the most numerous and many are antithetic. Youngest movement is clearly pre-late Pleistocene (pre-Lake Lahontan), but most of the displacements were earlier than the basaltic andesite. Total displacement on the Steamboat Springs fault system that provides the structural control for the Main and Low Terraces may exceed 300 m to the east.

SINTER

Silica deposited from flowing springs occurs as a hydrous silica gel that is commonly finely interlayered with algae. Gases trapped under the silica gel lend a bubbly appearance to the gelatinous sinter with the porous texture presevved in the younger partially dehydrated opaline sinter. Recently deposited sinter consists of opal which inverts to beta-cristobalite with increasing depth and age of the sinter and becomes dominately chalcedony (without opal) in the oldest sinter (White and others, 1964). Springs may deposit sinter for a time and at other times the hot waters may rapidly dissolve the sinter, particularly in erupting springs. Open fissures on the Main Terrace are probably created by dissolution of sinter along fractures during low water conditions by sulfuric acid condensed on the walls of the fissures (White and others, 1964). Collapse of sinter on Sinter Hill beginning 1982 also may have been caused by leaching by sulfuric acid above a steaming water table.

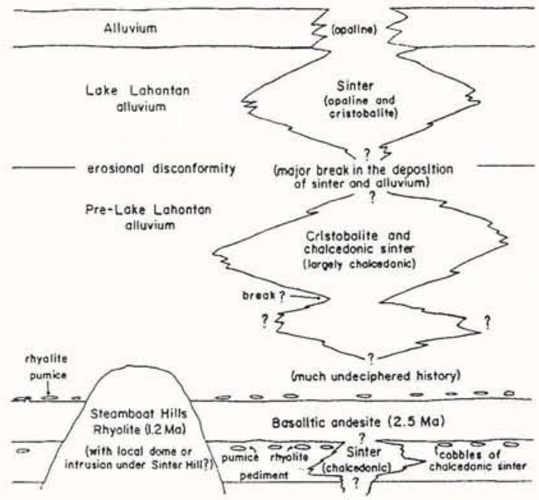

Figure 2. Composite stratigraphic relations for Steamboat Springs (redrawn from Silberman and others, 1979, fig. 3).

ALTERATION

Where the water table lies well below the surface, such as in the Silica Pit (Fig. 3), H_2S oxidizes to sulfuric acid by reaction with atmos-

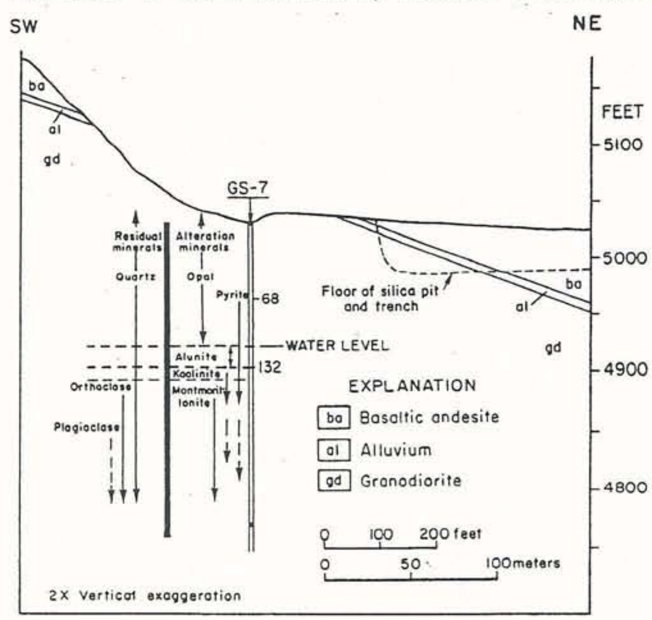

Figure 3. Geologic cross section of the Silica Pit showing wall-rock alteration in core from drill hole GS-7 (redrawn from Schoen and others, 1974, fig. 3).

TABLE 1. Geochemical analyses from Steamboat Springs, Nevada (ppm)[1]

	Ag	As	Au	Cu	Hg	Mo	Pb	Sb	Sn	Tl	Zn	Cd	Ga	Pd	Se	Te
SS-1, older sinter from Sinter Hill	.51	<1.0	.22	5.2	662.0	.8	5.0	12.9	.6	<.5	5.4	<.5	<.5	<.25	<2.0	<.5
SS-2, younger sinter from Sinter Hill	.18	<1.0	<.05	3.8	53.4	<.5	1.0	34.6	.6	<.5	6.1	<.5	<.5	<.25	<2.0	<.5
SS-3, ejecta from hydrothermal explosion breccia apron	.16	99.1	<.05	4.1	13.4	<.5	4.5	50.8	3.2	<.5	5.7	<.5	.6	<.25	<2.0	<.5
SS-4, leached granodiorite near Nevada Thermal #3	.05	37.0	<.05	20.4	5.9	.9	11.3	17.3	2.5	<.5	10.1	<.5	2.4	<.25	<2.0	<.5
SS-5, collapse breccia in leached granodiorite in Silica Pit	.06	1.5	<.05	20.6	11.7	<.5	2.4	1.4	2.8	<.5	6.3	<.5	<.5	<.25	<2.0	<.5
SS-6, pyritic leached granodiorite in Silica Pit	.08	<1.0	<.05	33.9	412.0	<.5	8.7	.6	1.6	<.5	4.9	<.5	5.4	<.25	<2.0	<.5
SS-7, leached basaltic andesite east of Silica Pit	.06	<1.0	<.05	1.6	14.8	<.5	2.7	.4	1.3	<.5	5.1	<.5	<.5	<.25	<2.0	<.5
SS-8, pyritic leached granodiorite near ford over Steamboat Ditch	.06	197.0	<.05	10.2	11.6	<.5	6.4	2.0	1.7	3.6	7.9	<.5	5.8	<.25	<2.0	<.5
SS-9, pyritic silicified alluvium SW of Sinter Hill	.39	847.0	<.05	10.2	11.6	<.5	3.7	41.0	1.7	1.6	21.2	<.5	.6	<.25	<2.0	<.5
SS-10, sinter near spring 39 on Main Terrace	1.01	9.7	.18	3.2	4.5	<.5	1.2	33.7	1.0	.6	6.0	.5	<.5	<.25	<2.0	<.5
S-24, black mud from spring 24 on Main Terrace[2]	39.0	1384.0	10.3	572.0	458.0	<.5	69.4	12000.0	209.0	1107.0	79.0	<.5	6.5	.33	31.8	<.5
S-39, black mud from spring 39 on Main Terrace[2]	44.6	196.0	5.11	61.7	29.2	<.5	10.9	459.0	2.3	155.0	53.3	<.5	2.1	<.25	<2.0	<.5
S-41s, black mud from spring 41s on Main Terrace[2]	27.3	81.1	2.46	36.5	38.3	<.5	10.9	129.0	2.0	40.0	60.9	<.5	1.0	<.25	<2.0	<.5

[1] Samples collected by D. M. Hudson, May, 1986 except for S-39 and S-41s collected from erupting springs December, 1985
Analyzed by ICP by Geochemical Services, Inc., Torrance, California
[2] Sulfide-rich -200 mesh fraction

Bi and Pt < .5 ppm for all samples

pheric oxygen, possibly facilitated by bacteria (Ehrlich and Schoen, 1967). The descending acidic water leaches the rock leaving opal, anatase and residual original quartz. In the first few meters below the water table, dilution of the acid results in alunite and cristobalite replacement of the rock. Further dilution results in kaolinite and quartz or cristobalite replacement for the next few meters below the water table (Schoen and others, 1974).

Hydrothermal alteration below the water table consists of replacement of wall rock by quartz and K-feldspar above about 100 m depth, passing into illite and mixed-layered illite-montmorillonite, particularly as selvages around quartz, calcite and/or pyrite veins, at greater depths. Albite and calcite replacement of plagioclase, and chlorite and calcite replacement of mafic minerals, occurs below 100 m and becomes the dominant alteration assemblage with increasing depth (Sigvaldason and White, 1961, 1962; Schoen and White, 1965, 1967).

GEOCHEMISTRY AND MINERALIZATION

The Steamboat Springs geothermal system is noted for anomalous values of Ag, As, Au, Hg, Sb, Tl, and B (Table 1; and White, 1981). Based on limited sampling the system tends to be low in Cu, Pb, Mo, Zn, Cd, Se and Te (Table 1), but in a few instances high Cu, Pb and Zn occur in sulfide-rich material (Table 1; White, 1981, Table 2). Siliceous sulfide-rich muds deposited on the Main Terrace with highly anomalous metal values (SS-24, SS-39 and SS-41s, Table 1) precipitated minerals at an unknown depth and were carried to the surface in suspension during a period of high turbulence. White (1985) notes a strong tendency for Au, As, Sb, Hg, Tl and B to concentrate in the near-surface environment of the active system and Ag concentrating in the middle and deeper parts of the explored system. Cinnabar is visible locally in all ages of sinter and in acid-leached rocks. Cinnabar has not been observed below 15 m depth from drillholes (White, 1985). Stibnite and metastibnite occur as needle-like crystals in several hot-spring pools and was recognized in drill core up to 46 m below the surface up to a temperature of 146° C (White, 1967). Pyrargyrite was identified at 72.5, 83.2, and 107.6 m deep in drillhole GS-5 on the Main Terrace but not recognized in any other drilling (White, 1985). Pyrite is typically cubic in most observed localities but tends to be framboidal in erupted siliceous muds on the Main Terrace. In acid-leached rocks formed above the water table, Hg and to a lesser extent As and Sb are anomalous indicating vapor transportability. Native sulfur is also common in the acid-leached rocks resulting from oxidation of H_2S.

THERMAL WATERS

Hydrogen and oxygen isotopic data indicate the Steamboat Springs geothermal system is a meteroic water system, although a small amount of magmatic water content could be present. Nehring (1980) determined the source of the water to be from the Carson Range to the west with light delta-D values and virtually no interaction with groundwater sources in the immediate vicinity of Steamboat Springs. Hot water ascends along deep faults and vents to the surface or migrates laterally in uncemented alluvium. Exchange with wall rocks yields up to a 3 per mil ^{18}O shift. Tritium values in thermal discharge waters suggest a residence time of much greater than 50 years (Nehring, 1980).

Boiling occurs in upper parts of the geothermal system. Sigvaldason and White (1961, 1962) note water temperatures at the boiling point for two drillholes initiating about 70 m deep while waters in other drillholes were somewhat below the boiling curve. Calculations based on delta-D and chloride data suggest initial boiling temperatures for various drillholes range from 210 to 170° C (Nehring, 1980) or up to 200 m for pure water. Nearly all springs are saturated or supersaturated with calcite (Nehring, 1980) and although no calcite precipitation is known from the surface deposits, several drillholes have calcite veins (White and others, 1964), probably precipitated from boiling hydrothermal fluids.

Seasonal fluctuations and seismic activity creates wide variations in discharge rates (White and others, 1964). Individual springs have been active for decades while others start and stop over periods of weeks or months. Recent prolonged venting of a deep geothermal well about 2.5 km southwest of the Main Terrace apparently lowered water levels on the Main Terrace up to one meter within a few weeks of the start of venting and a recovery of water levels within three weeks of the end of venting, indicating a relatively rapid change in discharge conditions within the system (D.M. Hudson, personal data, 1986).

Given the approximately 3 m.y. history of thermal activity, White (1968) estimates 3000 km^2 of magma would be required if geothermal activity has continued at present rates of heat flow by conductive loss of heat. White (1985) considers intermittent activity during at least 10 percent of the total time (0.3 m.y.) to be a reasonable estimate of geothermal activity. Also, the puny volume of rhyolite evident in the vicinity would not sustain continuous geothermal activity for 3 m.y. unless a huge magma chamber at great depth were to supply intermittent pulses of magma to the near-surface environment.

CONCLUSION

The Steamboat Springs geothermal area serves as a modern analog for many hydrothermal ore deposits. The shallow boiling system has many of the features of epithermal and hot springs deposits found through out the world. Study and understanding of this modern metal-depositing system can lead to a better understanding of and exploration for fossil hydrothermal systems.

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SUMMARY OF THE GEOLOGY OF THE COMSTOCK DISTRICT, NEVADA

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INTRODUCTION

The Comstock district lies in the Virginia City ea, about 30 km southeast of Reno. The discov- of low-grade placer gold in 1850 was followed discovery of lode silver and gold in 1859 ith, 1943). The main period of production, om 1863 to 1880, combined with intermittent oduction by underground and open pit methods to present has yielded over 260 million grams of d and 6 billion grams of silver (Bonham, 1969). history of the Comstock district is long, plex and interesting. For a complete early story, the reader is referred to the excellent mary by Smith (1943). The important previous logic studies were by Becker (1882), Gianella 36) and Calkins (1944). The following is a mary of unpublished geologic investigations by self from 1983 to the present, except where dicated.

STRATIGRAPHIC AND STRUCTURAL SETTING

The base of the stratigraphic section consists early Jurassic argillite and limestone of the dnerville Formation overthrusted by Mesozoic ta-andesite, metadiorite, and metagabbro of the avine Sequence. The age of thrusting is prob- ly middle Jurassic. These rocks are intruded by te Mesozoic granodiorite and granite. The Meso- ic rocks are unconformably overlain by silicic h-flow tuffs including (from oldest to youngest) Mickey Pass Tuff, the Lenihan Canyon Tuff, the ne Hill Tuff, the Santiago Canyon Tuff, and an named tuff, which range in age from 28 to 20 Ma ingler, 1978). Unconformably overlying the ffs and Mesozoic rocks are over 1000 m of andes- ic flows, flow breccias, mudflow breccias, and custrine sediments of the early Miocene Alta rmation, the main host rock for orebodies in the strict. The above sequence is intruded by horn- ende andesite prophyry dikes and stocks and ocks and dikes of the Davidson Diorite (ranges om diorite to quartz diorite to granodiorite to desite porphyry). The Davidson Diorite has elded K-Ar and fisson-track ages of about 17 Ma L. Silberman and R. P. Ashley, unpub. data, 76). Overlying the Alta Formation are andesitic to dacitic flows with accompanying dikes and stocks of the lower member of the Kate Peak Formation. During the latter stages of emplacement of the lower member, normal faulting, mineralization, and alteration occurred. Adularia from the Comstock and Occidental Lodes have yielded K-Ar ages of 12.6 to 13.7 Ma (Bonham, 1969; Whitebread, 1976). The upper member of the Kate Peak Formation, which displays the same textures and composition as the lower member, was emplaced on an erosional surface developed on the altered rocks. The upper member has yielded K-Ar ages from hornblende and biotite ranging from 12.3 to 14.9 Ma (Whitebread, 1976). Following a period of erosional and structural quiescence, the late Miocene or Pliocene Knickerbocker Andesite covered much of the district up to 20 m thick. Renewed normal faulting commenced about 2.5 to 3 Ma (Birkeland, 1963). An olivine basalt, which has yielded a whole rock K-Ar age of 1.14 Ma (Doell and others, 1966), erupted from the east side of McClellan Peak and flowed down American Ravine, part of the topography developed as a result of the recent tectonism and uplift in the area.

The major structures that predate, or are synchronous with, mineralization are the Comstock, Silver City and Occidental faults (Fig. 1). Numerous fractures or small faults are occupied by silicified ribs, alunite-quartz ledges, hydrothermal breccias, or veins. These relations, combined with the presence of gouge cemented by vein material and gouge displaying numerous episodes of brecciation and recementation, suggest that mineralization was contemporaneous with movements of the faults. Dip-slip displacement on the Comstock and Silver City faults that predated, or was synchronous with mineralization, can be estimated to be about 400 m from offsets of the ash-flow tuffs and lacustrine sediments in the Alta Formation. Early movement on the Occidental fault similarly can be estimated at about 100 m by offset of lacustrine sediments in the Alta Formation. Post-Miocene dip-slip displacements are estimated from offset of the Knickerbocker Andesite and the upper member of the Kate Peak Formation to be 400 to 500 m on the Comstock fault zone, about 250 m on the

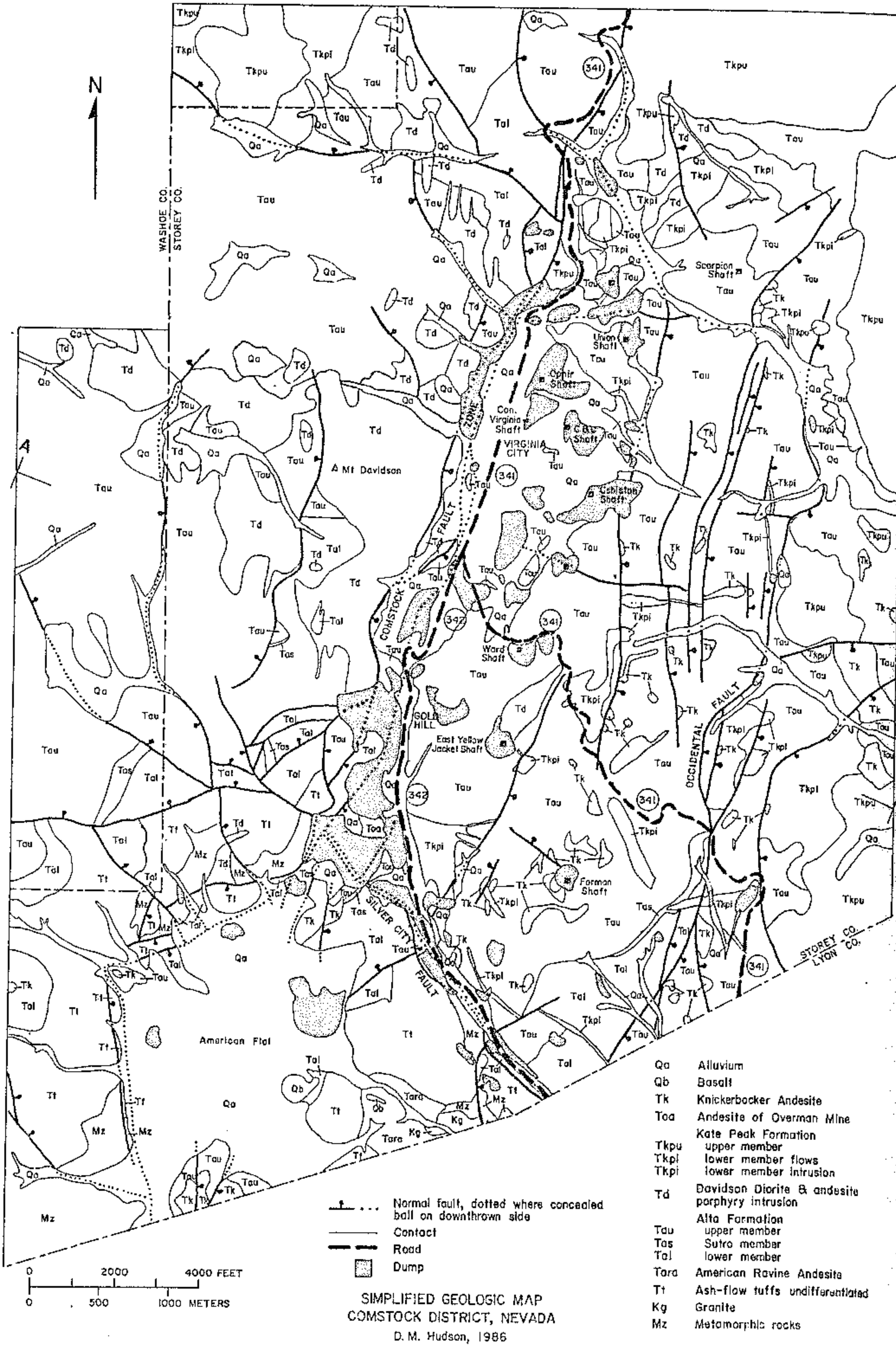


Figure 1. Simplified geologic map of the Comstock district, Storey County, Nevada. Based on unpublished mapping by D. M. Hudson, 1983-1985.

Silver City fault zone, and up to 200 m on the Occidental fault. This recent movement on the Comstock and Silver City fault zones occurred along pairs of parallel major faults that, with few exceptions, bound the earlier mineralized faults on either side with lesser displacement faults occurring between the major bounding faults. The major bounding faults of the Comstock fault zone are about 50 m apart at depth and splay apart to nearly 200 m at the surface. The Comstock, Silver City, and Occidental faults dip 40 to 35 degrees to the east and flatten slightly with depth, but near the surface the Comstock fault bends to nearly vertical (Fig. 2). These faults have been rotated to lower than original dips by post-Miocene westward tilting as shown by westward dips of the Knickerbocker Andesite of 10 to 15 degrees. A number of other post-Miocene normal faults, generally of small displacement, parallel the Comstock fault zone or have roughly east-west strikes (Fig. 1).

STRUCTURAL SETTING AND MORPHOLOGY OF OREBODIES

Most of the known orebodies occur within the Comstock or Silver City fault zones. A few orebodies occur in hanging wall fractures of the Comstock fault zone, such as the famous Con. Virginia bonanza, and a few small orebodies occur in the footwall of the Comstock and Silver City faultzones as well as in the Occidental fault. The vertical extent of orebodies rarely exceeds 150 m and strike lengths rarely exceed 300 m with mining widths up to 45 m (Becker, 1882). Anomalous Ag and Au, occasionally of mineable grade, occur above and below the main ore horizons as well as along strike.

Movement on the Comstock fault that postdated mineralization displaced the hanging wall orebodies, as well as portions of orebodies that formed in the Comstock fault, relatively downward. Thus, most of the orebodies within the Comstock fault zone occur near the surface and several crop out, whereas orebodies within the hanging wall are situated at deep levels. It is likely that all orebodies on the Comstock Lode formed at about the same paleoelevation. However, orebodies on the Occidental and Silver City Lodes may have formed at higher paleoelevations.

VEIN MINERALOGY AND PARAGENESIS

For the most part, The Comstock Lode is a stockwork zone. Vein densities vary from a few percent to nearly 100 percent of the rock volume, although vein density appears to have little relation to localization of ore. Individual veins commonly are 2 to 30 mm wide and rarely exceed 30 cm. The mineralogy of the stockwork zone is vertically zoned from a deep quartz zone to an intermediate quartz ± adularia zone to a shallower calcite + quartz ± minor adularia zone (Fig. 3). In the transition from the intermediate to shallower zones, veins contain calcite replaced by quartz. The higher-level calcite + quartz ± adularia veins are rarely preserved on the Comstock but crop out extensively on the Occidental and Silver City Lodes. The quartz + adularia zones contains many vein types. The volumetrically most abundant consist of coarse-grained quartz with occasional amethyst. Less common are quartz with minor adularia, with adularia occurring in fine-grained (5 to 500μ) intergrowths with quartz on vein margins, and coarse-grained quartz filling in the center of the veins. Far less abundant vein types include quartz + adularia + pyrite, adularia with lesser quartz, quartz + pyrite, and other types, all of which are usually fine grained. Veins are often banded but rarely contain more than four stages of gangue mineral deposition. As many as 30 generations of crosscutting veins occur but have not been studied in detail. The ore horizon is located in the upper portion of the quartz + adularia zone and extends

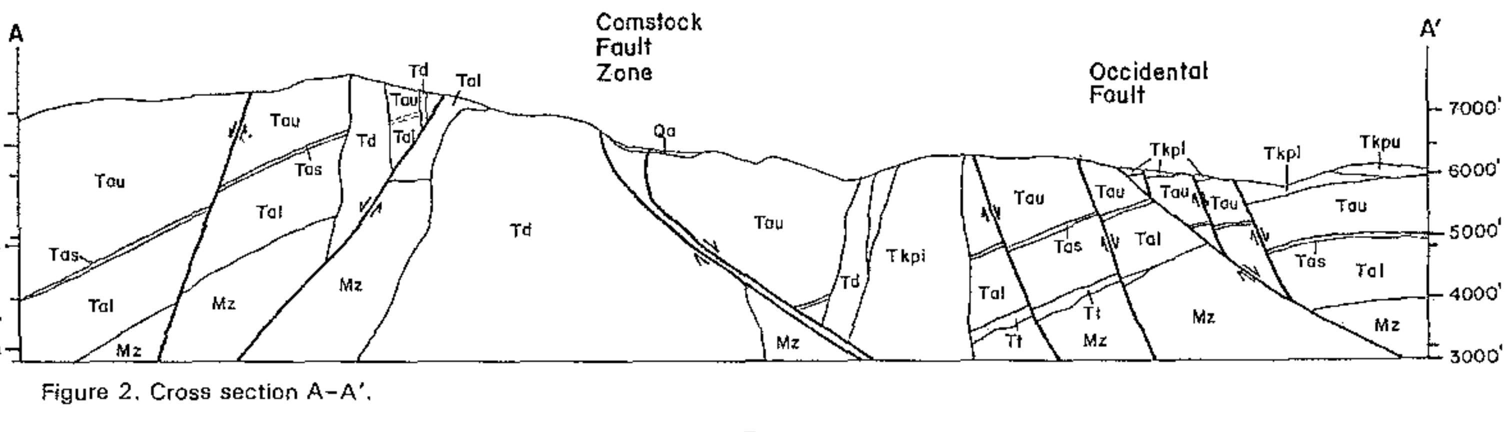


Figure 2. Cross section A–A'.

into the calcite + quartz ± adularia zone.

Based on a limited number of ore specimens obtained from the Mackay School of Mines Museum and from mine dumps, a paragenesis based on replacement textures indicated for the ore stage(s) is argentite ± electrum ⟶ galena ⟶ chalcopyrite ± electrum ⟶ sphalerite, with minor pyrite deposited throughout. This sequence occurs within a single band of ore deposition and in some instances is repeated several times within a single vein. It is unknown during which period or periods of veining ore deposition occurred. Associated gangue minerals are quartz, often adularia, and a few specimens contain calcite. Mn-oxides locally are abundant and often contain silver. The Mn-oxides are at least in part hypogene, based on intergrowths with unoxidized pyrite, but in the oxidized zone they could be in part supergene. Other ore minerals reported from the Comstock include stephanite, pyrargyrite, polybasite, native silver, tetrahedrite, uytenbogaardite and molybdenite (Becker, 1882; Terrill. 1914; Bastin, 1922; Gianella, 1936; Barton, 1978).

WALL-ROCK ALTERATION

Alteration of wall rocks displays considerable variation dependent on depth below the paleosurface and distance from major fractures (Fig. 3). In the inferred deeper portions of the hydrothermal system associated with the stockwork ore horizon (as exposed in the footwall of the Comstock Lode at the surface and as irregular pods in the vicinity of orebodies) is a sericite + quartz + pyrite assemblage commonly grading laterally and along strike into an assemblage of chlorite + illite + pyrite + albite and/or adularia. Both assemblages are associated with orebodies and neither is neccessarily indicative of ore. Isolated bodies of strong secondary biotite occur in the deeper levels but their relationship with the hydrothermal system is uncertain. Intermediate levels, above ore, are characterized by the assemblage quartz + anhydrite + pyrite + illite or sericite ± kaolinite. This intermediate level assemblage appears to underlie upward-expanding zones of intense hydrolytic alteration characterized by the presence of alunite and pyrophyllite. The core of these near-surface altered zones formed along faults or large fractures consists of quartz + alunite + pyrite ledges in some cases zoned outward to pyrophyllite + quartz ± diaspore + pyrite. These core assemblages grade laterally to a kaolinite + quartz + pyrite assemblage which in turn grades into an illite + quartz + pyrite ±

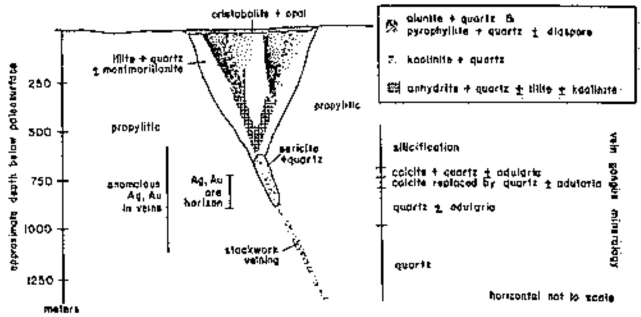


Figure 3. Restored diagrammatic west-east cross section of the Comstock Lode or one of its branches showing the approximate distribution of alteration and mineralization.

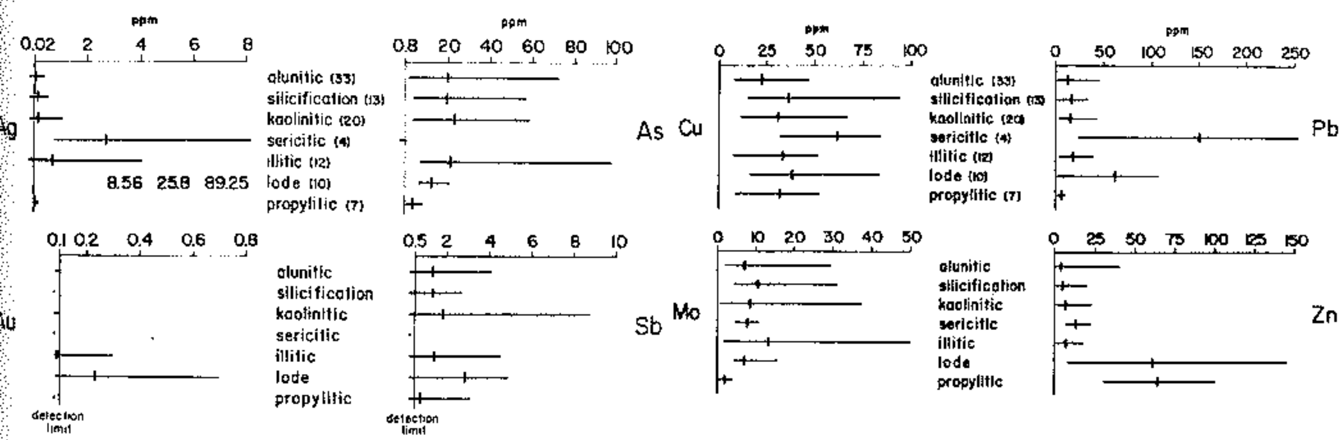
mixed-layered illite-montmorillonite assemblage in contact with propylitic rocks. The uppermost level alteration assemblage, locally preserved under the overlying upper member of the Kate Peak Formation, occurs as a roughly flat-lying assemblage of cristobalite + opal ± pyrite ± kaolinite ± alunite which probably formed above the paleowater table, similar in occurrence to Steamboat Springs described by Schoen and others, (1974). Therefore, estimated depths shown on Figure 3 for alteration zonation and ore horizon location can be approximated by reconstruction from an inferred shallow paleowater table below the paleosurface.

The Comstock district is often referred to as the "type locality" of propylite of Richtofen (1866). Propylitized rocks contain two distinguishable assemblages: albite + chlorite + epidote + quartz ± white mica ± pyrite, and albite + chlorite + calcite ± white mica ± pyrite. Zeolites occur locally (Coats, 1940). The calcite-bearing assemblage overlaps with the epidote-bearing assemblage but calcite is present in very small quantites when epidote is present in the rock. There appears to be a tendency for the calcite-bearing propylitic assemblage to lie higher in the system and distal from more intense hydrolytic alteration assemblages.

GEOCHEMISTRY

To date, very little geochemical characterization of the Comstock district has been reported. Corwall and others (1967) did limited sampling for Hg and Ag. Whitebread (1976) analyzed 20 samples for Ag, Au, As, Bi, Cu, Hg, Pb, and Zn. Figure 4 presents surface geochemical data for 100 samples, the bulk of which are from the Comstock Lode and its hanging wall.

Virtually nothing is known about vertical or lateral zoning of elements within orebodies or geochemical haloes around ore. Most of the assay



igure 4. Graphs showing range of geochemical values (length of bar) and average values (crossbar) for various alteration ssemblages from the Comstock district. Number in parentheses next to alteration assemblage is number of samples. Lode efers to lode material.

ecords for orebodies were reported in dollars and hose that reported silver and gold separately are f limited spatial extent so even gold-silver oning is virtually impossible to reconstruct. pparently other elements were rarely analyzed or. Therefore, useful geochemical zoning data ill probably remain unknown.

CONCLUSION

The Comstock district presents a well-preserved ecious metal hydrothermal system because of ostmineral faulting and limited erosion. The ockwork mineralization forms in wide, structur-lly controlled ore bodies with high average Au-Ag ades. Geochemical signatures, though based on mited sampling, suggest limited exploration efulness high in the system but a strong base tal association with ore. Alteration zoning, th lateral and vertical, and vertical vein min-alogy zoning can be useful in broadly defining ploration targets in this and similar systems.

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