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Summary of Steamboat Springs geothermal area,
with attached road-log commentary

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Steamboat Springs Geothermal Area

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This area is approximately 10 miles south of downtown Reno and largely just west of U.S. #395 (fig. 1). Thermal waters and gases

Figure 1 near here

have discharged from an area of approximately 5 km^2, with post-glacial (post-Lake Lahonton) hot spring discharge restricted to the Main Terrace just west of the highway and the Low Terrace to the southeast adjacent to Steamboat Creek. This hot spring system has the longest and most complex geologic history of any active geothermal area yet studied in detail in the world (White and others, 1964; Silberman and others, 1979; fig. 2).

Figure 2 near here

The area has attracted interest in its geothermal potential for many years. Hot spring water was used in the local spas for bathing and heating by the early 1900's, and efforts were made to pipe the water to Reno for heating purposes in 1916 (White, 1968, p. C6, C7, and C15-C16). The first geothermal well at Steamboat Springs was drilled about 1920 in efforts to obtain a dependable supply of hot water for the local resort (White, 1968, p. C45-C55), and the first well specifically searching for steam for generation of electricity was drilled in 1950 (Rodeo well). During the late '50's and early '60's, 8 to 10 additional geothermal exploration wells were drilled in the immediate area, ranging from 218 to 558 m deep; maximum measured temperature was 186°C (White, 1968), but these early geothermal efforts were not successful in identifying a reservoir of adequate temperature and permeability. Chemical geothermometers predicted reservoir temperature ranging from about 180°C to 230°C (Brook and others, 1979; Nancy Nehring, written communication, 1979[1/]). A 930 m-deep geothermal test well was then drilled in 1979 by Phillips Petroleum Company 2.5 km SW of the Main Terrace near the crest of Steamboat Hills. Its maximum temperature is near the geochemical maximum but detailed data have not been released.

The Steamboat area has been of long-standing interest to economic geologists for its bearing on hydrothermal ore deposits, and is now viewed as the present-day equivalent of geothermal systems of Tertiary age that formed epithermal gold-silver deposits throughout the Great Basin of the western United States and elsewhere (White and others, 1964; White, 1967, 1968, in press). At Steamboat, hot-spring sinter deposits, chemical sediments in spring vents, and veins intersected in drill holes all contain significant concentrations of gold, silver, mercury, antimony, arsenic, thallium, and boron (table 1). The oldest hot spring sinter was deposited about 3 million years ago, prior to the extrusion

Table 1 near here

of basaltic andesite from a vent near the crest of Steamboat Hills 2.5 km southwest of the Main Terrace. This andesite is 2.53±0.11 m.y. old (Silberman and others, 1979) and is a key unit in understanding the history of the spring system. The basaltic andesite under Sinter Hill in the western part of the thermal area (GS-6 drillhole) was locally replaced almost completely by adularia (Schoen and White, 1967) that

[1/] Nehring's data, included in her Master's thesis, San Jose State University, 1979, predicts $T_{SiO_2} = 183^\circ C$, $T_{Na/K} = 230^\circ C$, $T_{NaKCa} = 230^\circ C$, and $T_{^{18}O}$ of $SO_4-H_2O = 210^\circ C$.

White, 1967) that yielded a K/Ar age of 1.1±0.1 m.y.; this alteration probably occurred during deposition of the overlying chalcedonic sinter deposits. Thermal activity that formed the younger sinter deposits has probably been continuous but varying in magnitude for at least the past 0.1 m.y. and possibly longer. Other intervals of activity probably have occurred (fig. 2) but are not clearly decipherable from preserved evidence.

The thermal area lies approximately on a line that connects four rhyolite domes, the largest of which is 5 km southwest of the springs and is 1.14±0.04 m.y. old. Three domes from 1.5 to 5 km northeast of the springs yielded ages of 1.2 and 3.0 m.y. old. Vertical uplift under Sinter Hill is likely to have been caused by a shallow intrusion correlative with these younger domes (White and others, 1964; fig. 2).

White (1968) estimated that magma volume equivalent to 100 km^3 must have cooled and crystallized just to supply the convective heat losses assumed at present rates for 100,000 years. Three thousand km^3 would be required for 3 m.y. of continuous activity at present rates, but this seems improbable, judging from mass- and heat-flow constraints. However, intermittant activity during at least 10 percent of the total interval (=0.3 m.y.) is viewed as a reasonable estimate, especially in view of the complex history of activity.

The long time span from the earliest hydrothermal activity to the present and the puny volume of rhyolite domes extruded during this time interval may be best explained by a huge magma chamber underlying the area but at great depth. In view of the complex histories of most large silicic volcanic systems, two or more cycles of evolution of the magma system seem likely. None culminated in the ash-flow tuff eruptions and caldera collapse that many other such systems have undergone, perhaps due to the great depth of the Steamboat system (R. L. Smith, U.S. Geological Survey, oral communication, 1975).

Sinter at Steamboat Springs generally contains detectable quantities of Au and Ag, and dark siliceous muds deposited in the present springs contain as much as 15 ppm of Au, 150 ppm of Ag, 0.01 percent Hg, and 3.9 percent of Sb as stibnite and metastibnite (Brannock and others, 1948; White, 1967; table 1). Hg is notable in some chalcedonic sinter, and has been mined and recovered in small quantities from acid-leached opaline residues resulting from solfataric alteration of granodiorite and basaltic andesite in the Silica Pit (White and others, 1964; Schoen and others, 1974). Hg^{o} has been identified in vapor from several drillholes and hot spring vents, cinnabar is common in small amounts with native S where vapor escapes through porous acid-decomposed sinter, and clusters of small crystals of cinnabar have been deposited on test specimens of sulfide minerals, especially galena, immersed for several months in non-producing geothermal wells. Stibnite has been deposited as needlelike crystals on the walls of several hot-spring pools such as spring 8 (table 1 and fig. 1). Coatings of orange-red metastibnite (amorphous Sb_2S_3) also formed on the discharge apron of spring 8 at some unknown time after systematic spring measurements were terminated in 1952, and has also formed in the discharge blast of at least three erupting geothermal wells. Sample W-941c of table 1 has the highest contents of Au, Ag, and other metals in any surface-formed deposit yet analyzed.

All cinnabar identified in the Steamboat thermal area occurs within 15 m of the present topographic surface, and no Hg was found analytically in drillcore at depths below 26 m (table 1). Some cinnabar occurs in acid-leached rocks above the water table in environments indicating deposition from a vapor phase, as in the Silica Pit (fig. 3). These

Figure 3 near here

relations may provide the keys for understanding the "opalite-type" of Hg deposits that are rather common in western Nevada (Bailey and Phoenix, 1944).

Stibnite was recognized in veinlets and cavities in drill core to a maximum depth of 45 m below the surface. In six drillholes in the active Low and Main Terraces, the deepest observed stibnite occurred at temperatures that ranged from 100° to $146^{\circ}C$ but trace quantities of Sb occur at greater depths (table 1). In spite of the much higher concentrations of As in the waters relative to Sb (White, 1967, table 13.3), no arsenic sulfides were recognized in surface deposits and drill core.

Spectrographic analyses of eleven samples of core from GS-5 drillhole (table 1) consist mainly of chemically precipitated SiO_2 (sinters to -25.6 m and chalcedony-quartz-calcite veins at greater depths). These were analyzed spectrographically by Chris Heropoulos of the U.S. Geological Survey, utilizing standard and newly-developed short wave-length radiation (SWR) techniques to attain lower levels of detection for critical elements not sufficiently sensitive by routine emission spectrographic methods. Visible pyrargyrite (Ag_3SbS_3) had been identified previously in sample 273 and subsequently in core samples

238 and 353 (not analyzed), but silver minerals were not recognized in other core from this hole.

These data demonstrate that Au, As, Sb, Hg, Tl, and B all tend strongly to concentrate in the near-surface deposits of this active system, with contents commonly one to two orders of magnitude higher than in deeper deposits. Ge also shows some upward concentration, but Ag generally favors the middle and deep parts of the explored system. Sample W-310d of table 1 is representative of metal-enriched deposits of thermal water that has flowed slowly to the surface; contents of the "epithermal" elements (Au, As, Sb, Hg, Tl, and B) are relatively high in comparison with the "base-metal" elements (Cu, Zn, Pb). Ag favors the second group but also occurs with the first group. Sample 941c formed in the discharge blast of water erupted from a depth of 220 m in Nevada Thermal No. 4 well (west border of fig. 1 west of Pine Basin), where the temperature was approximately 185°C. Any base-metal elements in erupted water from this depth rapidly by-passed the natural environments of intermediate depths. Thus, both groups of metals were still available for rapid precipitation in these unusual surface deposits. A metal-bearing dark siliceous mud (W-50, spring 24, table 1) has high concentrations of the epithermal elements and also has modest concentrations of the base-metal group. These muds were flushed out of the system as black suspended matter conspicuous only during periods of near-maximum discharge (Brannock and others, 1948, p. 223); precipitation had already occurred, largely below the surface at unknown depths. However, Au, As, Sb, Hg, and Tl may have continued to precipitate as lower temperatures and depths were attained.

Stable isotopes of Steamboat's thermal waters indicate a great dominance of meteoric water in the system but as much as 10 percent of magmatic water could have been present but not identifiable isotopically (Craig, 1963; White and others, 1963). The isotope relations show an increase in $\delta^{18}O$ of 2 to 3 per mil in the hot water relative to the cold meteoric recharge, with no change in the hydrogen isotopes. This "oxygen-shift" is a phenomenon common in high-temperature geothermal waters, and results from interaction at high temperatures between meteoric water (low in ^{18}O) and rock silicates (high in ^{18}O) during hydrothermal alteration.

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Road log, Steamboat Springs geothermal area

Miles	
0.0	Intersection, U.S. #395, State 27, and State 17 (approximately 10 miles south of Reno). Drive south on U.S. #395 along east base of Main Terrace, Steamboat Springs (fig. 1)
1.4	Turn right (west) from #395 on rough road to Main Terrace (turn is obscure; watch for break in fence)
1.7	Take right fork to crest of Main Terrace
1.9	Stop 1 (fig. 1). Park car. Cross zone of open and closed fissures about 300 feet to NE 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 approximately 10' depth; all flowing springs are at lower altitudes to 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 NE, ages 1.1 and 3.0 m.y. On beyond and to E, volcanic rocks of the Virginia Range, largely andesites and rhyodacites 10-15 m.y. with alteration and bleaching related to the Comstock Lode district (Virginia City 7 mi. to SE).

To the N., Truckee Meadows and Reno. To NW, the low light-colored ridge is the High Terrace, still thermally active but with water level 40 ft below surface and discharging subsurface; probably no surface discharge in past approximately 30,000 yrs. Farther to W (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. (Stop 2 will be in Pine Basin, due west.) To the SW, 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 (NE) 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 NE 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.

Walk upslope ~250 ft to the NW to GS-5 drillhole, which is 574' 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 (see table 1).

Walk on to the NW 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, 150 ppm Ag, 3% Sb, and high contents of Hg, As, Tl, and B (see table 1).

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^{o} 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 ($\sim$300 ppm at 95°C).

2.1 Return south to cars, past the old Rodeo well. This was the first geothermal well (drilled in 1950) specifically exploring for steam to generate electricity. Drive S to same intersection as earlier 1.7 mi and turn right (west) to Pine Basin. The lava-capped ridge on the left (south) is underlain by hydrothermally altered granodiorite and thin pediment gravels. The hill on the right (N) at approximately 2.5 mi is Mill Hill where a former small mill attempted to separate HgS from altered rock from Silica Pit. Ford the irrigation ditch and enter "forest" of stunted Ponderosa pines, which are growing about 1500 ft lower in altitude than their lowest limit in the Carson Range to the west. Their growth here is due to acidity produced by H_2SO_4 from oxidation of both H_2S and pyrite. Normal sagebrush and other vegetation cannot grow in acid soil that pines can tolerate, so the pines have no competition for the limited moisture. (When driving in the Virginia Range to the east, note similar altered ground, here entirely due to oxidizing pyrite without H_2S, and sustaining growth of anomalous Ponderosa pines at soil pH's down to 3.5.)

2.9 Stop 2, road junction in Pine Basin. Leave cars and walk 300 ft to the north up the slope of Sinter Hill to an area of chalcedonic sinter rubble. This was formerly an excellent outcrop of chalcedonic sinter (White and others, 1964, figs. 13 and 14) interpreted as being older than the 2.5 m.y. basaltic andesite. Chalcedonic sinter generally requires many thousands of years of time as well as temperatures preferably >125^{o}C for conversion from opaline sinter. Note that 125^{o}C requires burial to a depth of approximately 50' to provide sufficient water pressure for water to coexist with steam at this temperature. Detailed relations in chalcedony-filled cavities of this sinter provide significant insights into the local geologic history. Gravity-stratified microbanding now dips 30° SE, as compared to the relict bedding, which dips 42° SE. These data indicate an initial dip of $\sim 12^{\circ}$ SE when the sinter was chalcedonized. At some later time the chalcedonic sinter was tilted 30° to the SE, perhaps due to the rise of rhyolite magma under Sinter Hill about 1.2 m.y. ago (see fig. 2 and discussion in White and others, 1964, p. B34-35). Note the black surfaces of many exposed sinter fragments, then break open the darkest ones. The red and pink color is from cinnabar dispersed in chalcedony. The black color develops in response to exposure to sunlight, for reasons still not well understood.

Return to cars but walk on south (if time permits) to site of 3 former geothermal wells. The only visible one, Nevada Thermal No. 3 is 1263 ft deep and generally erupts intermittently as a man-made geyser. One of the older wells was known as the mercury well because of a metallic film of Hg° that would condense on metal objects held in the escaping steam and gases. Continue generally southward over the old rough curving road up to the top of the bleached dumps of the Silica Pit, previously noted. The basaltic andesite is progressively altered from a fresh black rock to a vuggy tan opaline residue high in TiO_2; the changes were studied chemically and mineralogically by Schoen and others (1974). The basaltic andesite is underlain by pediment gravels, entirely bleached and difficult to recognize except for relict outlines and slight color differences of clasts. The gravels are, in turn, underlain by white leached granodiorite consisting of original quartz plus opaline residues from feldspars, biotite, and hornblende. Note the relict joint pattern of the original granodiorite, indicating no volume change (except near the original surface).

Return to cars in Pine Basin and proceed east on the entry road just past the ford over Steamboat ditch.

3.3 Turn left on the road to the north to the transformer station and an abandoned mill.

3.7 High Terrace. Note the fissure system, older and less well preserved than that of the Main Terrace. At a few places along the crest of the terrace, opaline sinter disconformably overlies chalcedonic sinter, some of which contains dispersed cinnabar. GS-2 drill hole (now destroyed) penetrated 75 ft of chalcedonic sinter lying on sediments and volcanic rocks. These in turn are unconformable on granodiorite at -351'. Chalcedony-quartz-calcite veins much like those of GS-5 are prominent from -90 ft to 333 ft, and several contain visible ruby silver (pyrargyrite).

Continue northward along the High Terrace to the

4.1 junction with Highway 27. Turn right.

4.5 Junction of #17, #27, and #395. Continue east on #17 to Geiger Grade, Virginia City and the Comstock Lode.

Table 1.--Spectrographic analyses of chemical precipitates, Steamboat Springs thermal area, Nevada; in ppm except where noted[1/].

	T, °C	Au	Ag	As	Sb	Hg	Tl	B	Cu	Zn	Pb
W-50, siliceous mud, Spring 24	95.5	15	150	700	1.5%	100	700	500	20	50	7
W-310d, sinter & stibnite, Spring 8	95	1.5	1	50	1.0%	30	70	1,000	1	0.2	---
W-941c, metastibnite & opal, erupting Nevada Thermal #4 well	96	60	400	600	>0.2%	<80	2,000	>2,000	>2,000	>2,000	400
GS-5 drillcore, depth in ft (m)											
11 (3.4) opaline sinter	42	0.3	2	150	700	2	10	1,000	15	15	n.d.
19 (5.8) " "	52	n.d.	0.3	30	500	500	5	500	3	5	n.d.
42 (12.8) " "	80	0.2	0.5	300	3,000	500	70	200	10	10	n.d.
84 (25.6) chalcedonic sinter	122	n.d.	<0.2	70	100	3	1.5	20	1.5	7	n.d.
113 (34.5) vein chalcedony	137	1.5	30	30	50	n.d.	1.5	15	5	15	n.d.
174 (53.1) " " -calcite	153	0.7	20	50	50	n.d.	1.5	15	10	10	n.d.
231 (70.1) " " "	163	0.3	70	70	30	n.d.	n.d.	15	3	30	n.d.
273 (83.2) " " "	168	n.d.	100	50	30	n.d.	n.d.	20	10	7	n.d.
346 (105.4) " " -quartz	171	n.d.	15	5	20	n.d.	n.d.	10	1	7	n.d.
363 (110.6) " " -calcite	172	n.d.	100	30	30	n.d.	<1	20	5	30	n.d.
446 (135.8) " " -quartz-calcite	171	n.d.	0.7	1.5	20	n.d.	n.d.	15	2	10	n.d.

[1/]Semi-quantitative 6-step spectrographic analyses by Chris Heropolous, U.S. Geological Survey, including short wavelength radiation data; Bi, Se, and Te below detection; data on Be, Ge, and Sr not included.

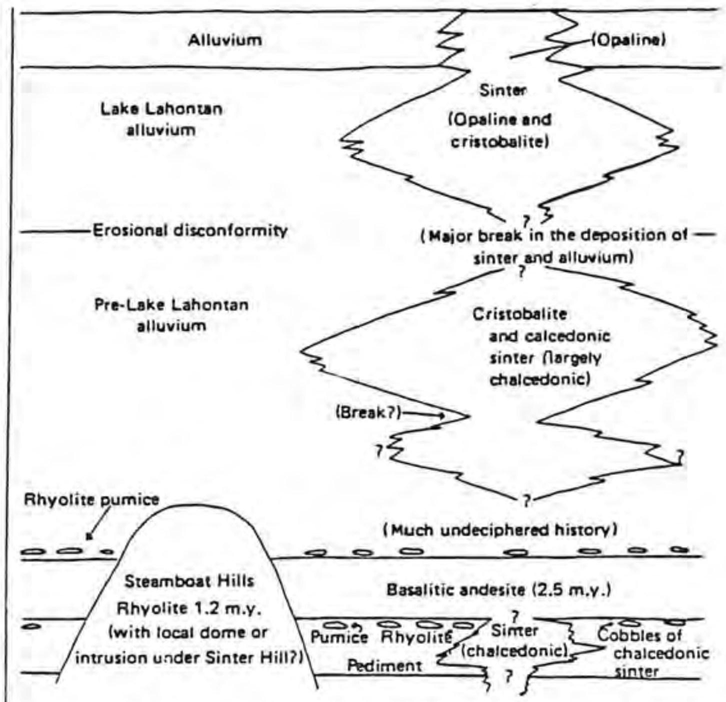

FIGURE 2—Composite stratigraphic relations at Steamboat Springs, (from Silberman & others, 1979).

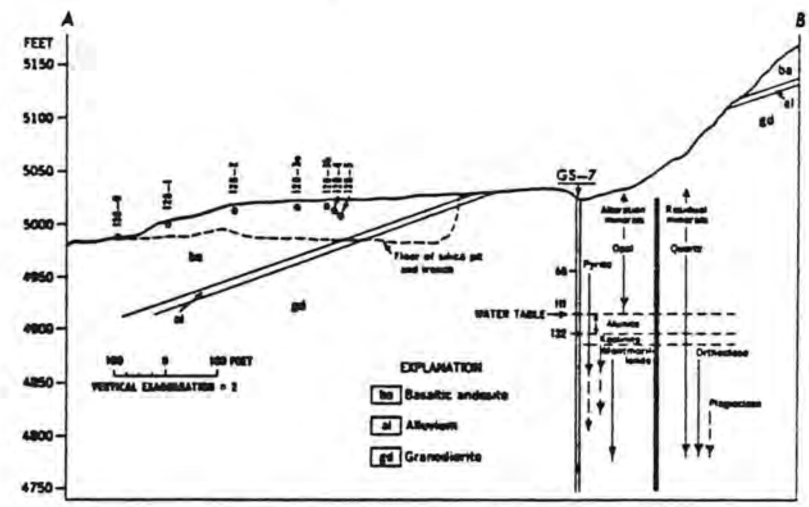

Fig. 3. Geologic cross-section of silica pit showing locations of samples and mineralogy of core from drill-hole GS-7.

(from Schoen & others, 1974)

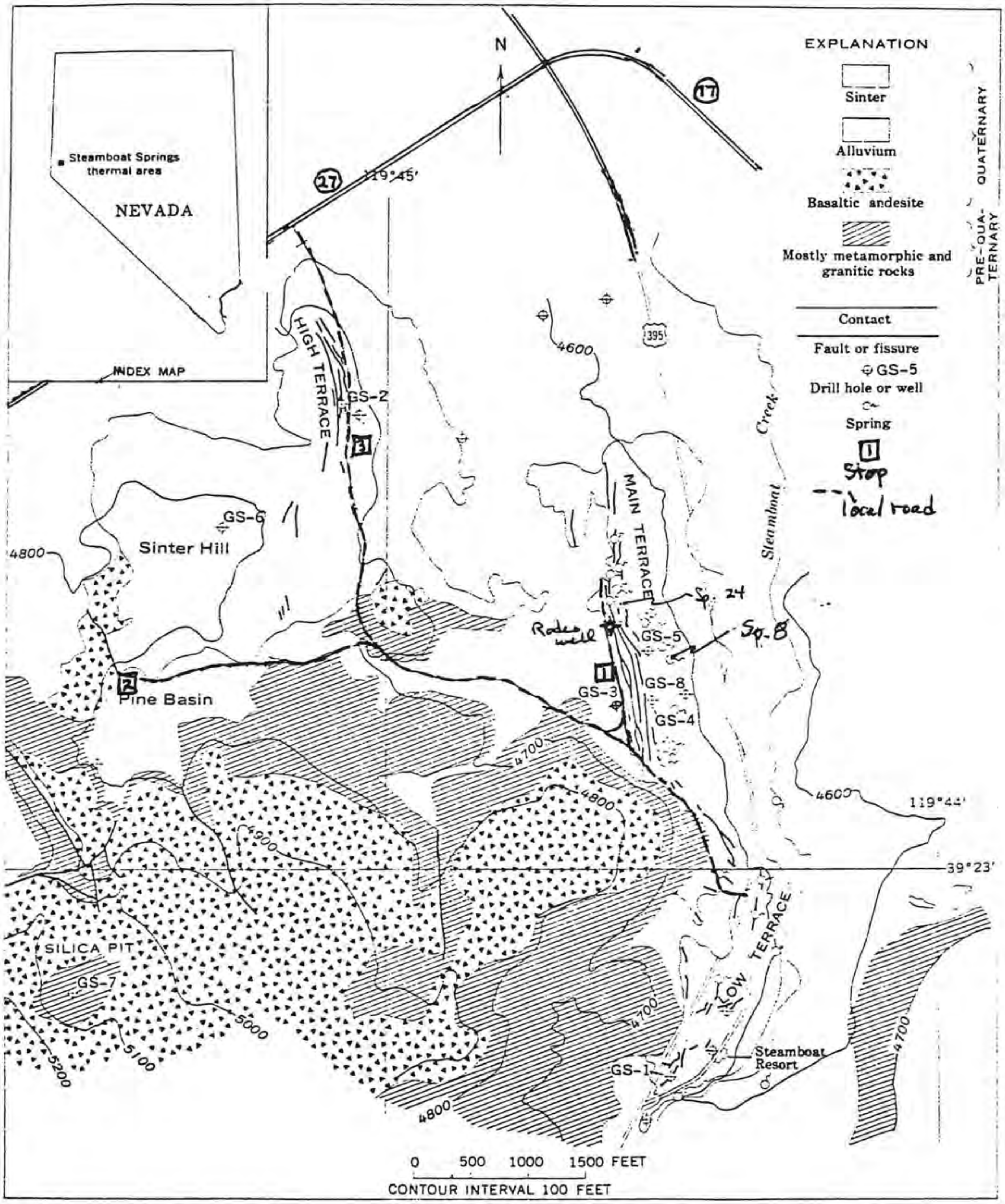

FIGURE 1.—Generalized geologic map of Steamboat Springs thermal area, Washoe County, Nev. (Modified from detailed map, White and others, 1964.)