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LARRY GARSIDE
NEVADA BUREAU OF MINES
UNIVERSITY OF NEVADA
RENO, NEVADA 89507

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

By Donald E. White

U. S. Geological Survey

345 Middlefield Road

Menlo Park, California 94025

Steamboat Springs Geothermal Area, Nevada

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This area is approximately 10 miles south of downtown Reno and largely just west of U.S. #395 (figs. 1 and 2). Thermal waters and gases have

Figures 1 and 2 near here

discharged from an area of approximately 5 km^2, although post-Pleistocene (post-Lake Lahonton) hot-spring discharge is 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. 3).

Figure 3 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 more dependable supply of hot water for the local resort (White, 1968, p. C45-C55), and the first well specifically searching for steam for generating electricity was drilled in 1950 (Rodeo well, fig. 2). During the late 1950's and early 1960's, 8 to 10 additional geothermal exploration wells were drilled in the immediate area, ranging from 218 to 558 m deep; maximum

4989c
1/19/83

measured temperature was 186°C (White, 1968), but these early geothermal efforts were not successful in identifying a reservoir of adequate temperature and permeability. However, 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

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

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geothermal test well was then drilled in 1979 by Phillips Petroleum Company 2.5 km southwest 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 the epithermal type of gold-silver deposits throughout the Great Basin of the western United States and elsewhere (White and others, 1964; White, 1967, 1968, 1974, 1981). 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

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Table 1 near here

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about 3 million years ago, prior to the extrusion of basaltic andesite from a vent near the crest of Steamboat Hills 2.5 km southwest of the Main Terrace (figs. 1 and 2). 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 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 variable in magnitude for at least the past 0.1 m.y. and possibly longer. Other intervals of activity probably have occurred (fig. 3) but are not clearly decipherable from preserved evidence.

The thermal area lies approximately on a line that connects four rhyolite domes (QTsh of fig. 1), 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 million years of continuous activity at present rates would require 3,000 km^3 of magma, but this seems improbable, judging from mass- and heat-flow constraints. However, intermittent activity during at least 10 percent of the total

4989c
1/19/83

interval (=0.3 m.y.) is viewed as a conservative 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 in 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 Au, 150 ppm Ag, 0.01 percent Hg, and 3.9 percent Sb as stibnite and metastibnite (Brannock and others, 1948; White, 1967; table 1). Mercury 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 (fig. 2; White and others, 1964; Schoen and others, 1974). Elemental mercury was identified in vapor from several drill holes and hot-spring vents, cinnabar is common in small amounts with native sulfur where vapor escapes through porous acid-decomposed sinter of the Main Terrace, 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

4989c
1/19/83

needlelike crystals on the walls of several hot-spring pools such as spring 8 (table 1 and fig. 2). 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 initial discharge blasts of at least three erupting geothermal wells. Sample W-941c of table 1 has the highest contents of Au, Ag, and other metals of 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 drill core 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. 4). These relations may provide the

Figure 4 near here

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 drill holes in the active Low and Main Terraces, the deepest observed stibnite occurred at temperatures that ranged from 100° to 146°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 drill hole (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-wavelength 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, where contents are commonly one to two orders of magnitude higher than in deeper deposits. Germanium 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 from 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). Silver 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. 2 west of Pine Basin), where the maximum temperature was approximately 185°C at the bottom of the well (221 m). Any base-metal elements in water erupted 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 of gelatinous silica and metals 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 shallower 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; White, 1974). 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, but with little or 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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4989c
1/19/83

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4989c
1/19/83

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4989c
1/19/83

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Road log, Steamboat Springs geothermal area

Miles

0.0 Intersection, U.S. #395, State 27, and State 17-27 (north end of fig. 2 and approximately 10 miles south of Reno). Drive south on U.S. #395 along east base of Main Terrace, Steamboat Springs (fig. 2).

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 on crest of Main Terrace.

1.9 Stop 1 (fig. 2). Park car. Cross zone of open and closed fissures about 300 feet to the east to corroded valve and 4 feet vertical pipe of GS-4 drill hole, a core hole drilled by U.S.G.S. in 1949. Water level in fissures approximately 10 feet 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 from old, probably Pleistocene springs. The different varieties of sinter and their significance are described by White and others (1964, p. B30-B33); 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 northeast, ages 1.1 and 3.0 m.y. (fig. 1; Silberman and others,

4989c
1/19/83

1979). On beyond and to the east, volcanic rocks of the Virginia Range are largely andesites and rhyodacites 10-15 m.y. old, with alteration and bleaching, probably related to the Comstock Lode district (Virginia City 7 mi to southeast, and below the skyline).

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 feet below surface and discharging subsurface. The flanks of this terrace consist of late Pleistocene sinter, disconformably overlying chalcedonic sinter. Probably no surface discharge has occurred here for more than 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. (Stop 2 will be in Pine Basin, due west, fig. 2). To the southwest, we look over basaltic andesite lava 2.5 m.y. old (Silberman and others, 1979) that flowed out over a pediment cut on Mesozoic granodiorite and metamorphic rocks. The eroded cinder cone forming the apparent crest (from this Main Terrace view) of Steamboat Hills lacks a crater form and is 2.5 km from the Main Terrace. The first deep geothermal well drilled in the area (Phillips' Steamboat ~~Spring~~ No. 1) 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. 2 and 4).

Continuing stop 1, walk 300 feet northeast from GS-4 drill hole to a small sinter cone--spring 8, on the east lip of the Main Terrace and just north of a power line. Over many years this spring has discharged approximately 1 liter per minute of water high in Sb (0.4 ppm) and As (3.5 ppm; White, 1967); this was one of only four springs of the monitored 27 that discharged continuously during 7 years of systematic observation (1945-1952; White, 1968, 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 feet to the northwest to GS-5 drill hole, which is 574 feet deep, with a maximum temperature of 172°C and studied in the most detail. Abundant quartz-calcite veins estimated to range up to ~ 7 feet thick and dipping 45° to 80° E. Some pyrargyrite is visible, with Ag generally greater than 20 ppm (see table 1).

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). At times of very high turbulent discharge, springs 23 and 24 deposited black siliceous muds largely in suspension and with as much as 15 ppm Au, 150 ppm Ag, 3 percent Sb, and high contents of Hg, As, Tl, and B (see table 1 and plate 3 of White, 1968).

4989c
1/19/83

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 horizontally bedded sinter along fractures (White and others, 1964, p. B53-B54). Active disintegration is now occurring most actively in the "closed" parts of the 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° 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 becomes rapidly saturated with soluble opaline SiO_2 ($\sim$ 300 ppm at 95°C).

Return south to cars, past the old Rodeo well. This was the first geothermal well drilled specifically in 1950 for steam to generate electricity, but was not successful. This was contemporaneous with New Zealand's pioneering efforts that soon proved hot-water systems as potential sources of steam.

2.1 Drive south 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 (north) at approximately 2.5 mi is Mill Hill, where a former small mill attempted to separate HgS from altered rock from the Silica

4989c
1/19/83

Pit. Ford the irrigation ditch and enter "forest" of stunted Ponderosa pines, which are growing about 1500 feet lower in altitude than their lowest limit in the Carson Range to the west. Their growth here is due to acidity produced from oxidation of both H_2S and pyrite to H_2SO_4. Normal sagebrush and other vegetation cannot grow in soil as acid as pines can tolerate, so the pines have no competition for the limited moisture. (When driving on State 17 to Virginia City in the Virginia Range to the east, note similar altered ground, here entirely due to oxidizing pyrite without H_2S, but also sustaining growth of anomalous Ponderosa pines at soil pH's down to $\sim$3.5.)

2.9 Stop 2, road junction in Pine Basin. Leave cars and walk 300 feet to the north-northeast 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 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°C for conversion from opaline sinter. Note that 125°C requires burial to a depth of approximately 50 feet 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° southeast, as compared to the relict bedding, which dips 42° southeast. These data indicate an initial dip of ~ 12° southeast when the sinter was chalcedonized. At some later time the chalcedonic sinter was rotated 30° to the southeast, perhaps due to the rise of rhyolite magma under Sinter Hill about 1.2 m.y. ago (see fig. 3 from Silberman and others, 1979, as well as 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 due to 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 southwest to site of three former geothermal wells. The only visible one, Nevada Thermal No. 3, is 1,263 feet deep; it sometimes erupts intermittently as a man-made geyser. One of the older wells, no longer identifiable, was known as the Mercury Well because a metallic film of Hg° 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 overlies pediment gravels, entirely bleached and difficult to recognize except for relict outlines and the slight color differences of clasts. The gravels, in turn, overlie 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). The Silica Pit was converted in 1981 into a storage pond for effluent for a new geothermal well, Cox No. 1, drilled by Phillips Petroleum Company about 300 feet southeast of the old GS-7 drill hole of fig. 2. Many detailed relations are now obscured.

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 a branch road to the north to the transformer station, an abandoned mill, and a private home on the High Terrace.

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 and includes a few blocks of this sinter, some of which contains dispersed cinnabar. GS-2 drill hole fig. 2; (now destroyed) penetrated 75 feet of chalcedonic sinter lying on sediments and volcanic rocks. These in turn are unconformable on granodiorite at -351 feet.

Chalcedony-quartz-calcite veins much like those of GS-5 and also dipping to the east are prominent from -90 feet to 333 feet, and several contain visible ruby silver (pyrargyrite).

Continue northward along the High Terrace to the junction with

4.1 Highway 27. Turn right.

4.5 Junction of State Highways 17 and 27 with U.S. 395.

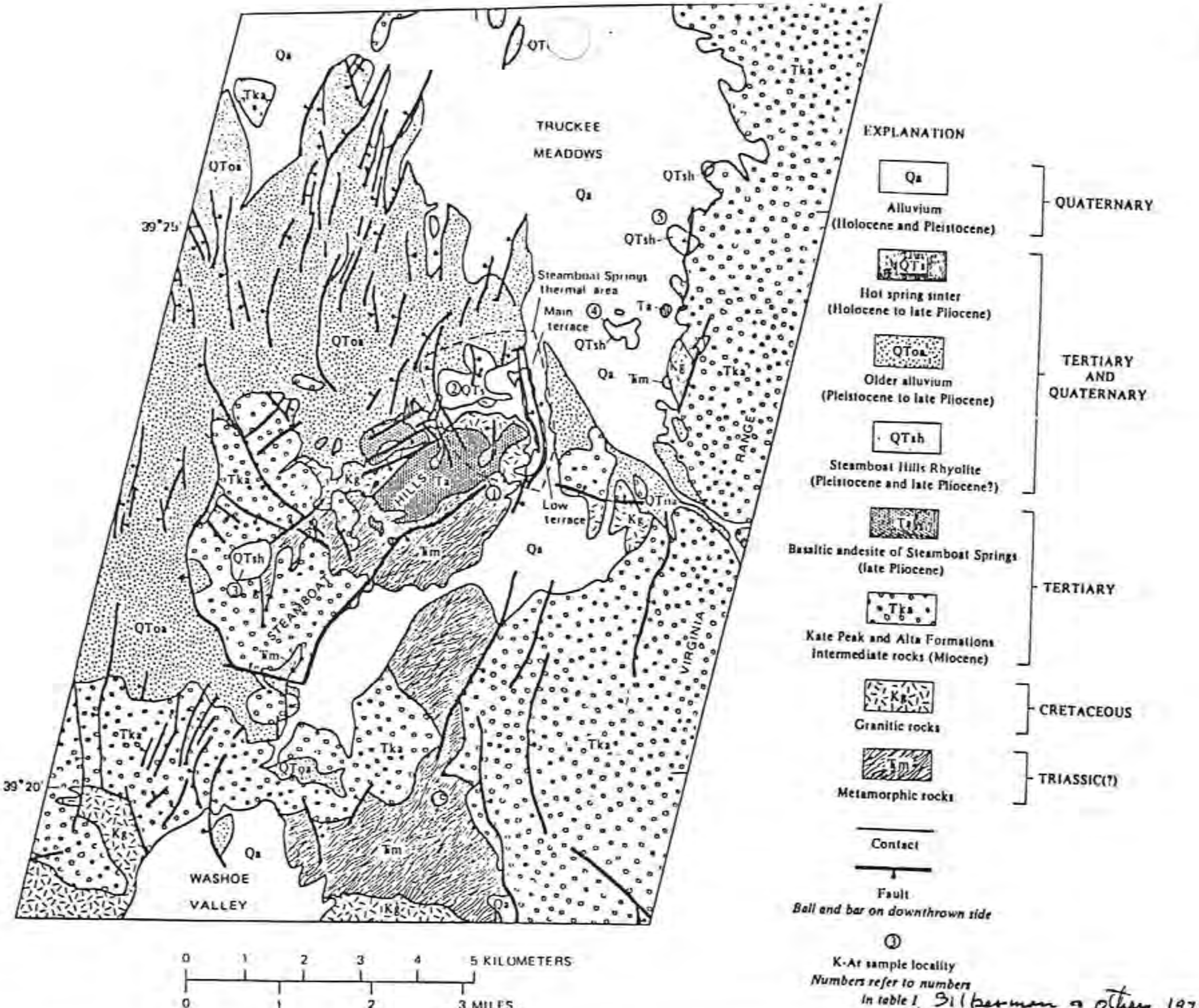
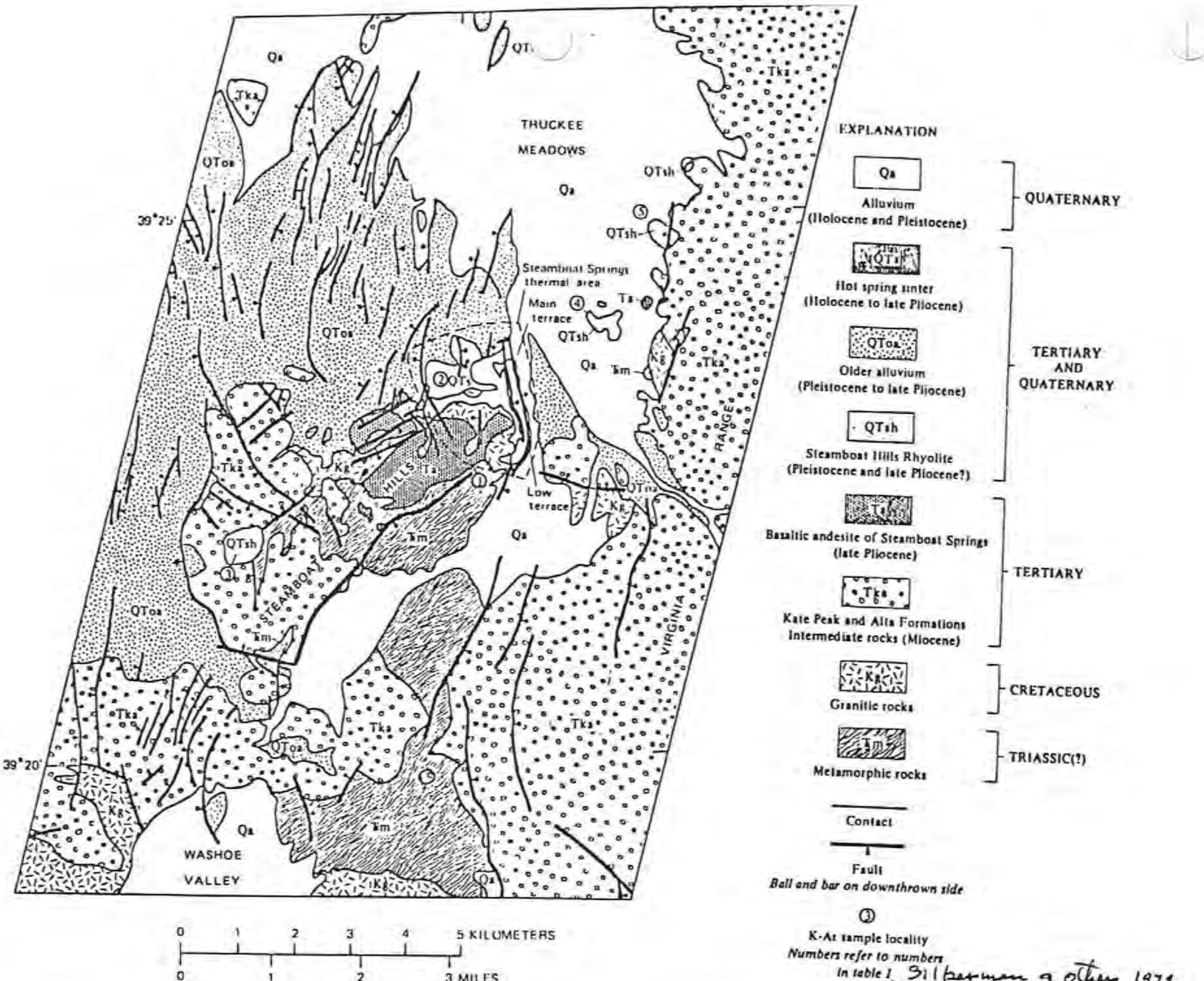


FIGURE 2.—Generalized geologic map of the region near Steamboat Springs, Nevada. ~~Geology modified from Thompson and White (1964).~~

(from Silberman and others, 1979.



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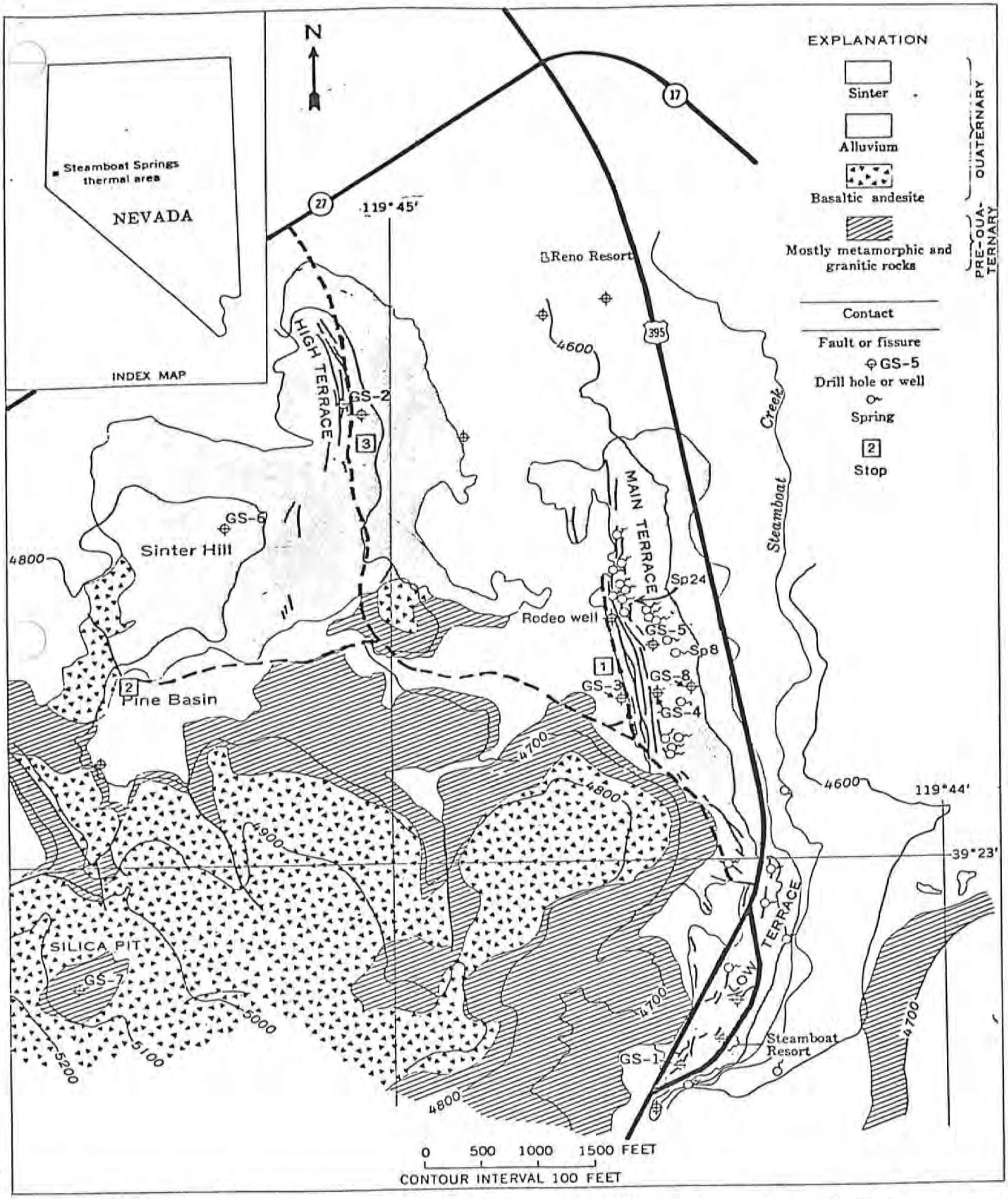

FIGURE 2.—Generalized geologic map of Steamboat Springs thermal area, Washoe County, Nev. (Modified from detailed map, White and others, 1964.)

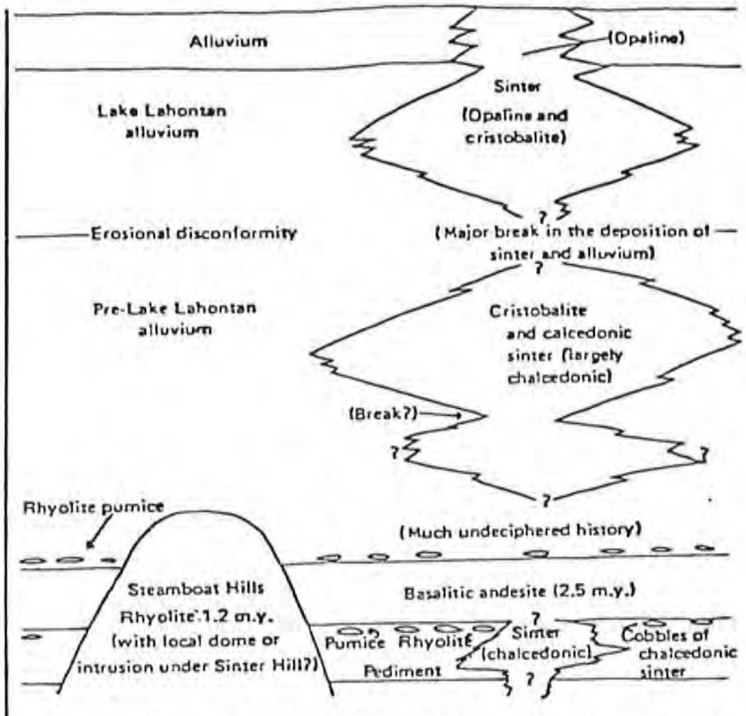

FIGURE 3 —Composite stratigraphic relations at Steamboat Springs. (from Silberman & others, 1979).

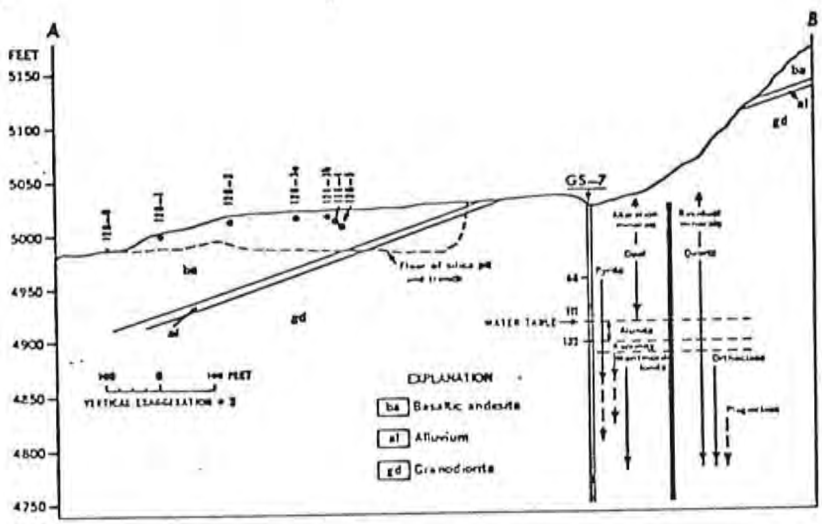

Fig. 4. Geologic cross-section of silica pit showing locations of samples and mineralogy of core from drill-hole GS-7.
(from Schoen & others, 1974)

TABLE 4. Spectrographic Analyses of Chemical Precipitates in Active Geothermal Areas
(In ppm except where noted; n.d., not detected)

Geothermal area	T, °C	Au	Ag	As	Sb	Hg	Tl	B	Cu	Zn	Pb	Others		
Steamboat Springs, Nevada[1]														
W-50, siliceous mud, spring 24	95½	15	150	700	1.5%	100	700	500	20	50	7			
W-310d, sinter and stibnite, spring 8	95	1.5	1	50	1.0%	30	70	1,000	1	0.2				
W-941c, metastibnite and opal, erupting well[2]	96	60	400	600	0.2%	80	2,000	2,000	2,000	2,000	400			
GS-5 drill core depth in ft (m)														
11 (3.4) opaline sinter	42	0.3	2	150	700	2	10	1,000	15	15	n.d.	Be 3	Ge 7	Sr 300
19 (5.8) opaline sinter	52	n.d.	0.3	30	500	500	5	500	3	5	n.d.	0.7	30	20
42 (12.8) opaline sinter	80	0.2	0.5	300	3,000	500	70	200	10	10	n.d.	5	5	200
84 (25.6) chalcedony-cristobalite sinter	122	n.d.	0.2	70	100	3	1.5	20	1.5	7	n.d.	1	1	100
113 (34.5) vein chalcedony	137	1.5	30	30	50	n.d.	1.5	15	5	15	n.d.	5	n.d.	300
174 (53.1) vein chalcedony-calcite	153	0.7	20	50	50	n.d.	1.5	15	10	10	n.d.	5	n.d.	500
231 (70.1) vein chalcedony-calcite	163	0.3	70	70	30	n.d.	n.d.	15	3	30	n.d.	3	n.d.	300
273 (83.2) vein chalcedony-calcite	168	n.d.	100	50	30	n.d.	n.d.	20	10	7	n.d.	3	n.d.	150
346 (105.4) vein chalcedony-quartz	171	n.d.	15	5	20	n.d.	n.d.	10	1	7	n.d.	1.5	n.d.	1,000
363 (110.6) vein chalcedony-calcite	172	n.d.	100	30	30	n.d.	1	20	5	30	n.d.	1	1	700
446 (135.8) vein chalcedony-quartz-calcite	171	n.d.	0.7	1.5	20	n.d.	n.d.	15	2	10	n.d.	1	1	300
Broadlands, New Zealand[2]														
Ohaki pool	100	85	500	400	10%	2,000	630			70	25			
Hole 2, inside silencer, erupting center	100	50	2,000	50	1,000	600?	150		2.5%	50	400	Fe 1,000	Mn 200	
Carlin Au deposit, Nevada, for comparison[3]		7	0.43	600	130	25	30	70	40	150	30	Ba 500		

[1] Semiquantitative 6-step spectrographic analyses by Chris Heropoulos, U.S.G.S., including short wavelength radiation data, Bi, Se, and Te below detection
[2] Weissberg et al., 1979, table 15-1
[3] Radtke et al., 1972

STEAMBOAT SPRINGS GEOTHERMAL PROJECT

by
William L. Desormier
Phillips Petroleum Company,
P.O. Box 6256, Reno, Nevada 89513

The Steamboat Springs area is at the western boundary of the Basin and Range province just east of the Sierra Nevada. The Steamboat Springs are located in Washoe County, Nevada approximately ten miles south of downtown Reno (Figure 1). Detailed descriptions of the thermal system can be found in White, 1968, and Silberman and others, 1979. The main area of exploration is in the Steamboat Hills which are at the extreme southern end of the Truckee Meadows, a north-south trending graben, situated between the Carson Range on the west and the Virginia Range on the East.

The Carson Range consists mainly of Cretaceous granodiorite of the Sierra Nevada batholith. The Virginia Range consists mainly of Tertiary volcanic rocks that vary from rhyolite to basalt but are mostly andesite (Thompson and White, 1964). In the Steamboat area four Quaternary rhyolite domes occur (Figure 1). The surface thermal features lie approximately on the line connecting these rhyolite domes. Bedrock in the Steamboat Hills consists of Triassic (?) metamorphic rocks, Cretaceous granodiorite, Tertiary and Quaternary volcanic rocks and Pleistocene-to-Recent siliceous sinter.

Phillips Petroleum Company has one well in the area, Steamboat #1, that is capable of producing geothermal fluid of commercial quantity and quality (Figure 2). Steamboat #1 is located outside the area of surface thermal features and collared some 1000 feet above the hot springs. This site was chosen because a temperature hole at this location was the only one at the time with a high-conductive gradient at intermediate depths. The Steamboat #1 well produces from a zone of fractured and hydrothermally altered granodiorite and metamorphic rocks in the 2200-2700 foot interval. From top to bottom the Steamboat # 1 well intersects approximately 270 feet of basaltic andesite flows and scoria from the Pliocene Lousetown Formation; 690 feet of Triassic (?) metamorphosed sedimentary and volcanic rocks; 840 feet of Cretaceous granodiorite, and then 1260 feet of alternating granodiorite and metamorphic rocks.

Steamboat #1 produces from a 442°F reservoir which is one of the hottest in Nevada. The estimated flow rate is 600,000 lbs/hour through a 9 5/8 inch flow line and the produced fluid is about 15% steam and 85% hot water. The produced fluid is chemically similar to the hot springs being of the sodium-chloride type with a total dissolved solids content of approximately 2200 ppm.

Recent geothermal exploration at Steamboat Springs began in 1975 when Phillips and Gulf Mineral Resources Company became partners in a

50/50 joint venture with Phillips as the operator. The near surface thermal anomaly was delineated by drilling 25 shallow temperature-gradient holes (Desormier, 1977). Following this, five intermediate-depth (844-1966 feet) temperature-gradient holes were drilled. Based on the results of these holes the Steamboat #1 well was located and, in 1979, drilled to a depth of 3050 feet. After the completion of Steamboat #1 nine additional intermediate-depth (950-1990 feet) temperature-holes were drilled by Phillips and Gulf.

The second deep test, Cox I-1, was completed in May 1981 to a total depth of 3471 feet (Figure 2). The hottest part of the well (350°F) at a depth of 950 feet was cemented off because it was a major lost circulation zone during drilling. The Cox I-1 drill site was chosen based on the results of intermediate-depth stratigraphic test #9. It is now known that strat. test #9 (T.D. 950 feet) was completed at the temperature reversal zone. The Cox I-1 well is a non-commercial producer and is located near the boundary of the high temperature geothermal reservoir. After evaluating the Cox I-1 well a structural model was developed (Figure 3) depicting the fault zone from which the Steamboat #1 well produces. The temperature data from strat. test #13 agree with the structural model. Strat. test #13 has a bottom-hole temperature higher than 350°F and a bottom-hole temperature gradient greater than 17°F/100 feet and is nearly identical to strat. test #3. The Steamboat # 1 well was drilled adjacent to Strat. test #3 and the location was chosen based on the results of Strat. test #3.

The static water level in the Steamboat #1 well is approximately 1000 feet below ground level. This elevation difference results in reduced flowing wellhead temperatures and pressures. If the well were collared at a lower elevation, then flowing temperature and pressure would be higher. To offset this problem, future wells will be drilled at lower elevations. Phillips' next well will be adjacent to strat. test #13 (Figures 2 and 3) approximately 340 feet below the Steamboat #1 well.

Initial studies indicate the reservoir size is from 13 to 26 billion barrels (Baza, 1980). Estimates of minimum electrical generating capacity are in the 120 to 240 mw range. Current estimates indicate that Steamboat #1 and a comparable well are sufficient to support a 10 mw power plant. An injection well and a spare well also will be necessary.

Current plans are to drill a reservoir confirmation well during 1983. Next, the Cox I-1 well will be injection tested and an additional well will be drilled as a spare. Then, a 10 mw binary cycle pilot plant, which is tentatively planned for operation in 1987, can be built.

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STEAMBOAT SPRINGS - PHILLIPS PETROLEUM COMPANY

Work on prospect began:	1975
Shallow drill holes:	Approximately 25.
Intermediate depth drill holes: (844 - 1990 feet)	Fourteen.
Wells drilled:	Two - Steamboat #1 and Cox I-1.
Productive wells:	One - Steamboat #1.
Wells in reservoir:	One.
Reservoir temperature:	442°F (228°C).
Reservoir fluid:	Sodium-Chloride water: 2200 ppm T.D.S.
Reservoir rocks:	Fractured granodiorite and metamorphosed sedimentary and volcanic rocks of Mesozoic age.
Flow rate of productive well:	Approximately 600,000 lbs/hour (1250 GPM) total flow when flowing to the atmosphere through a 9 5/8 inch flow line.
Remarks:	Hydrological study of the area is being conducted because of the need to understand the relationship between the geothermal reservoir and the numerous domestic water wells in the surrounding area. Existing power substation in the area.

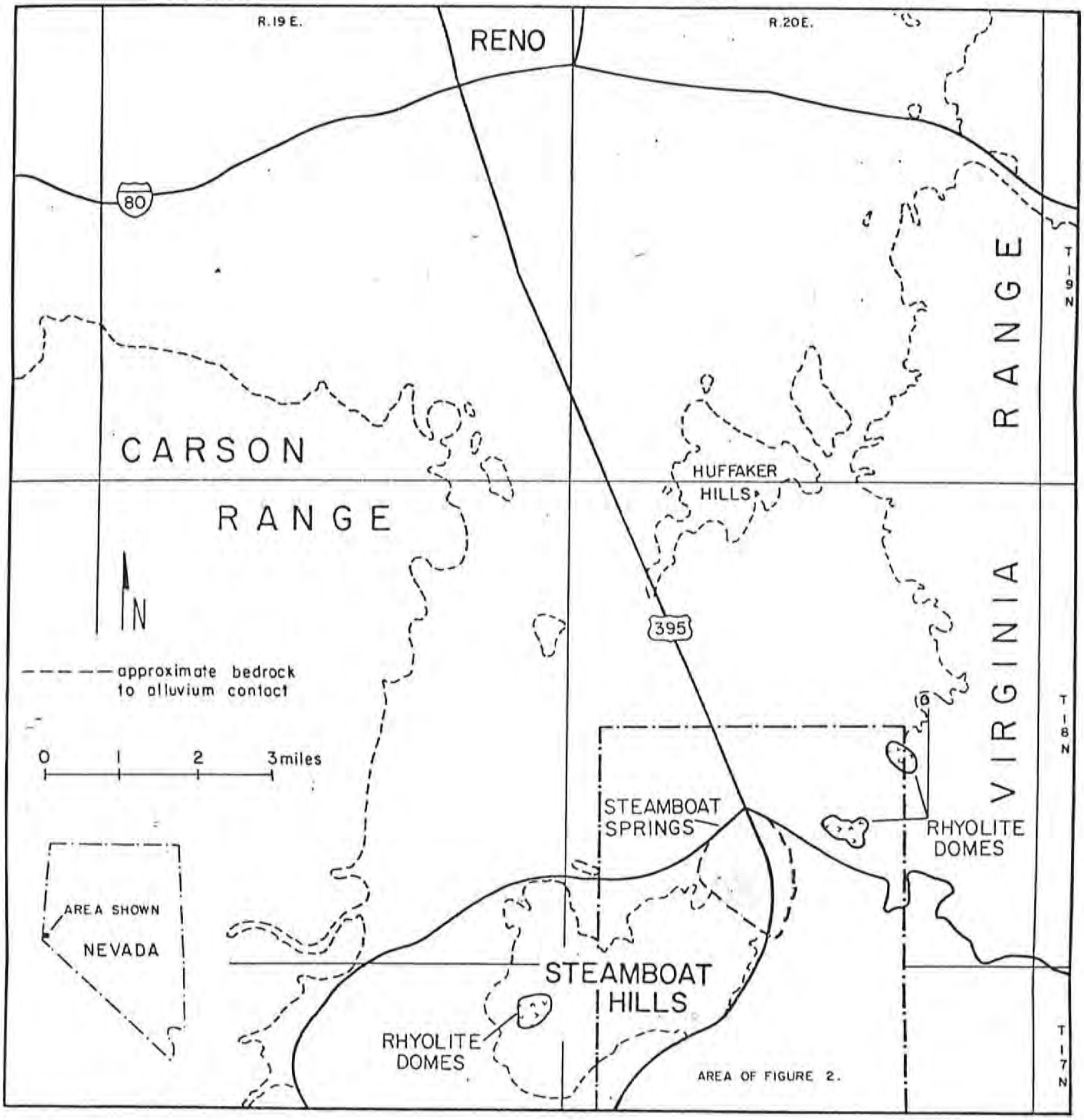

FIGURE 1.

(Modified from Bateman and Scheibach, 1975)

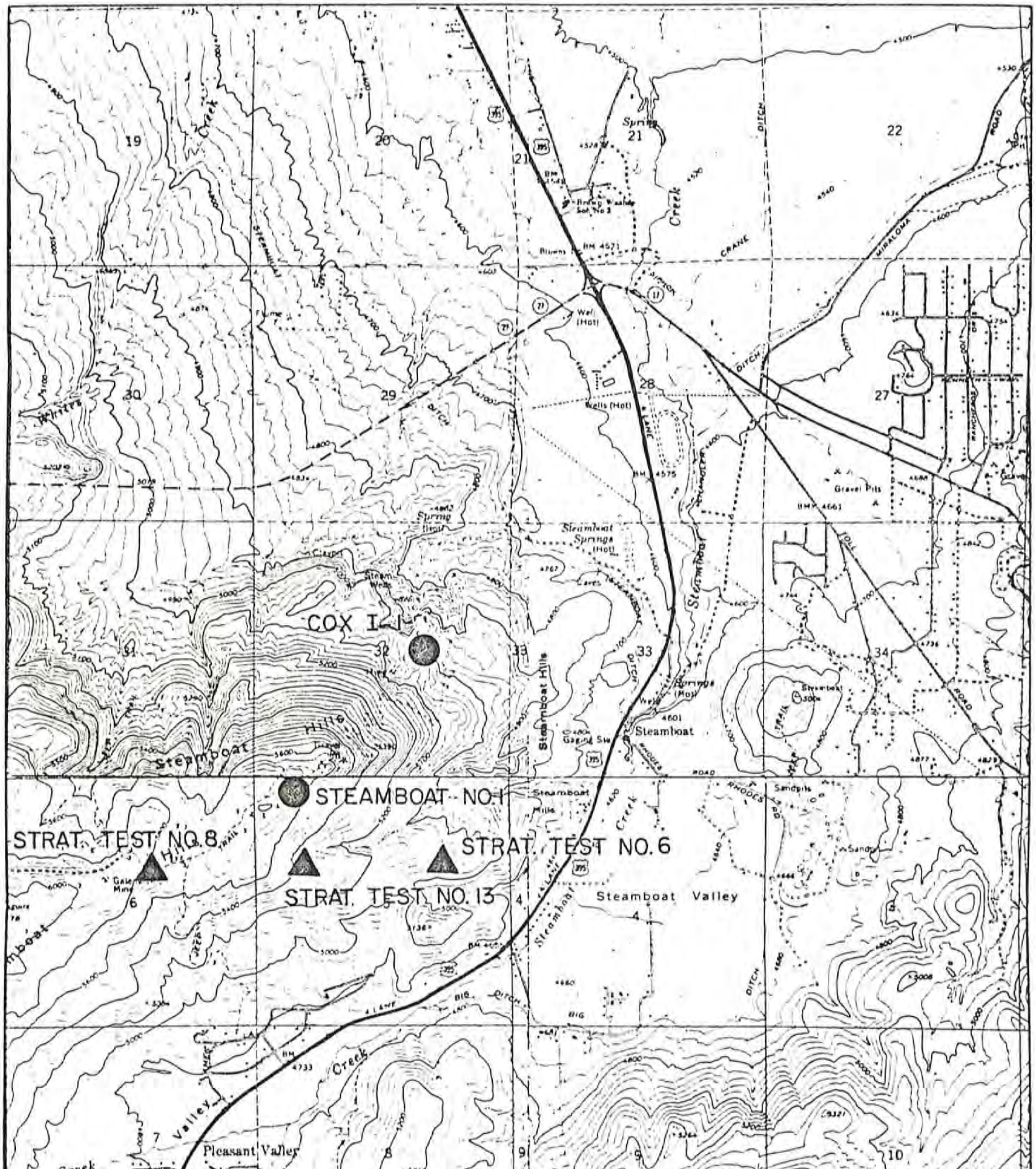
COX I-1
STEAMBOAT NO.1
STRAT. TEST NO.8
STRAT. TEST NO.6
STRAT. TEST NO.13
Steamboat Hills
Steamboat Springs (Hot)
Steamboat
Steamboat Valley
Pleasant Valley
Steamboat Creek
Gravel Pits
Rocky Hill Mine
Union Mine
Wells (Hot)
DITCH
MIRALOMA
RHODES ROAD
19
20
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FIGURE 2.

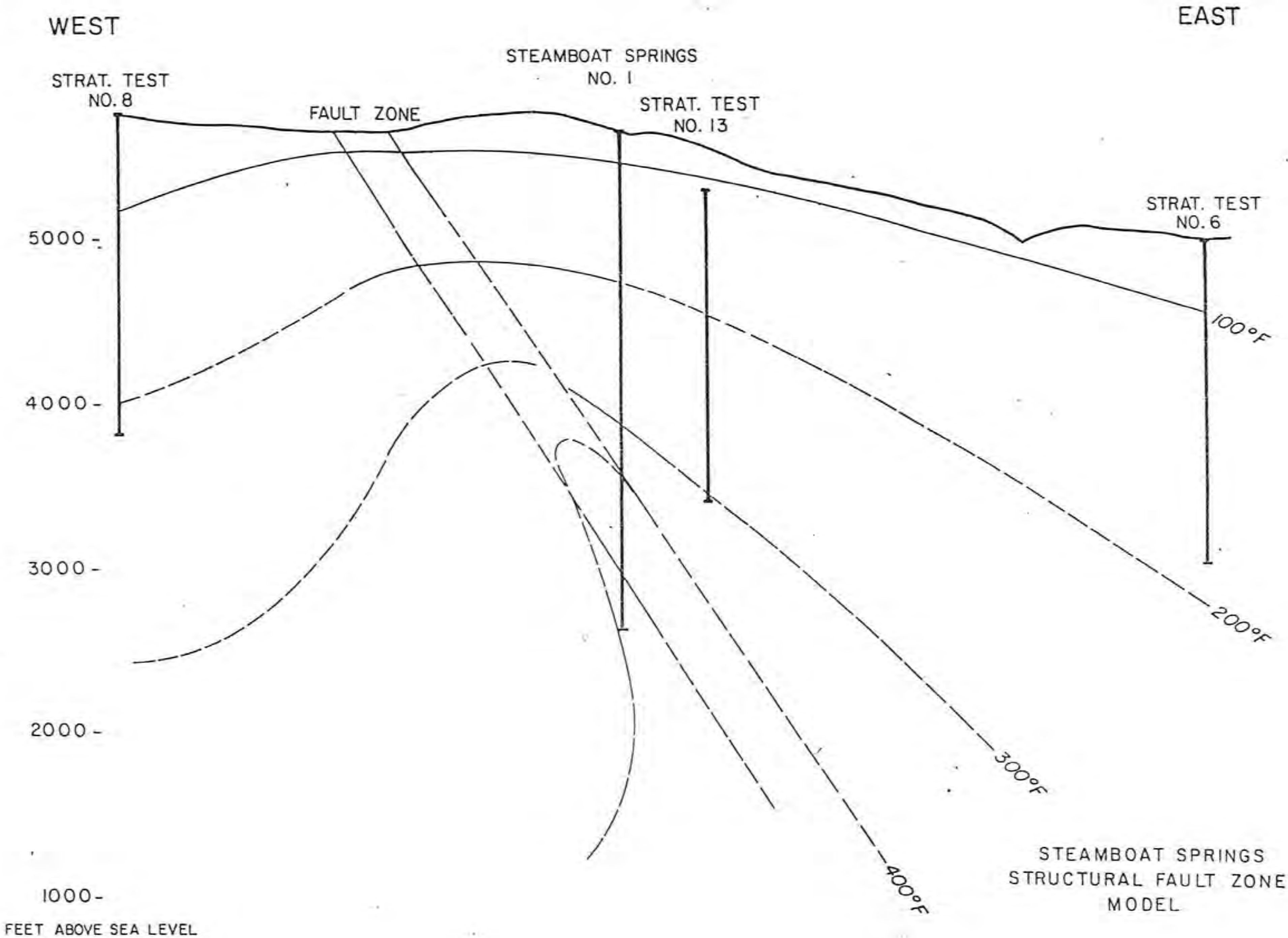
WEST
EAST
STEAMBOAT SPRINGS
NO. 1
STRAT. TEST
NO. 8
STRAT. TEST
NO. 13
FAULT ZONE
STRAT. TEST
NO. 6
5000
4000
3000
2000
1000
FEET ABOVE SEA LEVEL
100°F
200°F
300°F
400°F
STEAMBOAT SPRINGS
STRUCTURAL FAULT ZONE
MODEL

FIGURE 3.