NOTICE CONCERNING COPYRIGHT RESTRICTIONS

GEOCHEMICAL DATA AND CONCEPTUAL MODEL FOR THE STEAMBOAT HILLS GEOTHERMAL SYSTEM, WASHOE COUNTY, NEVADA

Robert H. Mariner and Cathy J. Janik

U.S. Geological Survey, Menlo Park, California

ABSTRACT

Geothermal fluids from the Steamboat Hills are silica-rich, Na-Cl waters. Maximum temperatures in the geothermal system are at least 230° to 235°C based on sulfate-water isotope and enthalpy-chloride relations and possibly as high as 243°C based on Na-K and gas geothermometry. The hottest geothermal well in the system (23-5) may have excess enthalpy. Chloride concentrations in the deep thermal fluid are ≥706 ppm. Geothermal fluids are currently produced from both a high-temperature and a moderate-temperature well field. The high-temperature fluids are related to one another and to the moderate-temperature fluids principally by boiling. As the high-temperature fluids boil and cool to moderate temperatures, silica precipitates from solution, calcium and magnesium concentrations increase, and K/Na values partially adjust to the lower temperatures. Full chemical equilibrium may occur only in the high-temperature waters. In the new part of the moderate-temperature field (wells PW2-1 to PW3-4), K/Na values were initially very similar, but utilization has caused some wells to change composition. However, the general trend over time is to lower silica and K/Na values in all moderate-temperature wells. This trend probably indicates that heat is being "mined" from the aquifer-rock. Mixing of cold, low-chloride ground water with thermal water is important only near the toe of the system in the sediments which fill the valley. Steam-heated ground waters occur in the sediments along the north side of the Steamboat Hills.

INTRODUCTION

The Steamboat Springs thermal area (fig. 1) is located south of Reno at the north end of the Steamboat Hills, one of several transverse ridges which divide a major north-south structural trough into separate basins. The Virginia Range east of the trough consists predominantly of Tertiary andesite with some basalt and rhyolite (Thompson and White, 1964). The Carson Range to the west of the trough is predominantly Cretaceous granodiorite with various amounts of metamorphosed Triassic and older marine and volcanic rocks. The granodiorite is related to the Sierra Nevada batholith. At least four rhyolite domes of Pleistocene age have been intruded into the basaltic andesite, granodiorite, and metamorphic rocks which make up the bulk of the Steamboat Hills and the Virginia Range. The southernmost of these intrusive domes may supply most of the heat discharged by the geothermal system (Silberman and others, 1979). Faults in the geothermal area trend either northeastward parallel to the trend of the transverse ridge, or northward, parallel to the structural trough (Thompson and White, 1964). A few northwest-trending lineaments have been noted on air photos.

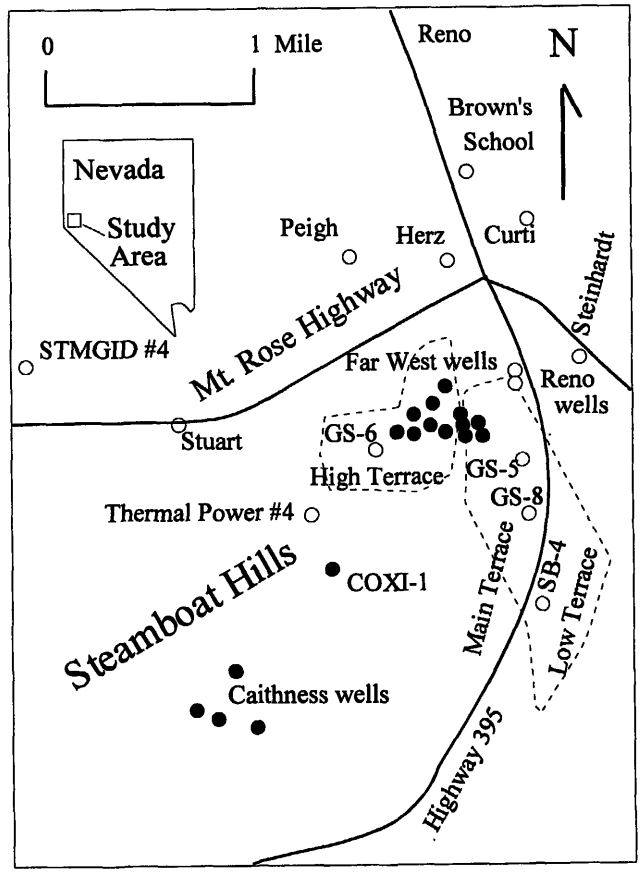

Fig. 1. Location of selected thermal and cold wells in and near the Steamboat Hills.

The geothermal system in the Steamboat Hills has been present for at least 3 m.y., although the activity seems to have been intermittent (Silberman and others, 1979). The thermal fluids and related deposits at Steamboat Springs have been of commercial and scientific interest since the 1860's (see White, 1968). The surface expression of the geothermal system consists of three prominent silica terraces (fig. 1). The High Terrace has not discharged thermal fluid in historical times; the Main Terrace and Low Terrace have both discharged thermal fluid in historic times (White, 1968) but were inactive when we began sampling in 1991. Sorey and Colvard (1992) discuss factors affecting this decline in spring flow. Some leakage from GS-5, a shallow research hole drilled on the Main

Terraces in the 1950's (White and others, 1964), was present through 1993 but had ceased to discharge fluid onto the terrace by the summer of 1994. These terraces consist of siliceous sinter deposited from the thermal spring waters and are as much as 80 feet thick (White and others, 1964). Natural discharge from the system was about 1130 gpm in the 1950's (White, 1968). Geochemical data for the terrace springs are given by White and others (1963), Cohen and Loeltz (1964), Bateman and Scheibach (1975), and Nehring (1980). Wells drilled by Nevada Thermal Power Co. in 1962 one mile west of the Main Terrace attained a maximum temperature of 186°C at 726 feet. Phillips Petroleum drilled a deep well (3050 feet) in 1979 near the crest of the Steamboat Hills, about 1½ miles south-southwest of the Thermal Power Co. well. This deep well encountered 228 °C fluids (Desormier, 1983). A geochemical study of the Steamboat geothermal system under way at that time indicated a maximum system temperature of about 230°C with reservoir chloride estimated to be near 700 mg/L (Nehring, 1980). Subsequent drilling has led to the development of two geothermal fields in the Steamboat Hills. A high-temperature geothermal field (Caithness Power) is located on the top and south side of the Steamboat Hills at elevations of 5300 to 5800 feet. The Caithness Power production wells are 2500 to 3000 feet deep and are drilled near a contact between Cretaceous granite and Triassic (?) metamorphic rock. Production is from hydrothermally altered granodiorite and metamorphic rock at depths of 2200 to 2700 feet. Fluids from the Caithness power plant are reinjected in the COXI-1 well (3471 feet deep). The COXI-1 well is located about 3/4 mi. NE of the power plant on a direct line to the moderate-temperature field. The moderate-temperature field (Far West) extends from the High Terrace to the north end of the Main Terrace at an elevation of about 4700 feet along the north side of the Steamboat Hills. Wells in this field are about 1500 feet deep and produce fluid from hydrothermally altered Pliocene to Pleistocene basaltic andesite. Fluids from the Far West power plants are reinjected at the north side of the old plant and east side of the new plant. Domestic wells in the valley north and east of the Steamboat Hills recover warm to hot water from Pleistocene valley fill.

The purpose of our study is to construct a geochemical model of the Steamboat Hills geothermal system and to evaluate changes in the chemical characteristics of the reservoir fluid over time as they relate to induced changes in the system.

METHODS AND PROCEDURES

The two-phase production fluids from the Caithness wells were sampled using a portable cyclone separator and methods described by Giggenbach and Goguel (1989) and by Fahlquist and Janik (1992). Waters produced from Far West wells were conductively cooled to <40°C through stainless steel coils immersed in an ice-water bath. Samples were filtered through a 0.1μm membrane filter under nitrogen pressure drive. Samples for cation analysis were acidified to pH 2 with Ultrex nitric acid. Alkalinity was determined on site by acid titration (0.05N H_2SO_4) to inflection point. Samples for sulfide determination were preserved with zinc acetate, stored in a refrigerator during the day, and titrated that evening. Samples for silica were filtered and then diluted 1:4 with distilled-deionized water. Sample pH was determined with a glass electrode and the meter was standardized against two buffers of known pH-temperature dependence. Results of chemical and stable-isotope analyses on all waters collected for this study are given in Table 1. To determine steam fractions for reconstituting the separator samples (Caithness wells 21-5, 83-A6, 23-5, and 13-5), we estimated the well enthalpy from dissolved silica in the separated liquid. We assumed that the dissolved silica in the thermal fluid was in chemical equilibrium with quartz in the aquifer and that the feed water contained no steam. The enthalpy of the feed water for each liquid-steam sample pair is then determined by an iterative process. In these calculations, an enthalpy for the feed water is assumed and the steam fraction at the separator condition is calculated. Dissolved silica in the feed water is calculated from the liquid fraction value and used to estimate the temperature at which the fluid would be in chemical equilibrium with quartz. Iteratively, the enthalpy value for the feed water is increased or decreased, as required, and the calculations redone until the temperature of the feed water equals the temperature obtained from the reconstituted silica concentration. Calculated steam fractions and total-fluid compositions for Caithness wells are listed in Table 1 following each analysis of separated liquid. Gas analyses are given in Table 2.

CHEMICAL DATA

Thermal waters encountered in the geothermal wells drilled in the Steamboat Hills are silica-rich, sodium-chloride waters (Table 1; fig. 2). The fluid from the high-temperature wells (Caithness Power) and moderate-temperature wells (Far West) are chemically very similar (fig. 2). Chemical differences across the high-temperature field are small and appear to be due to small differences in temperature. The hottest well, 23-5, produces fluid with slightly more silica, chloride, sodium, and potassium but slightly less sulfate than the other high-temperature wells. Calcium and magnesium concentrations for the high-temperature wells may not be representative of aquifer compositions because of precipitation of carbonate during flashing. However, it appears that calcium concentrations increase slightly and silica concentrations decrease slightly in the most recent samples from all three production wells. These changes probably indicate cooling of the reservoir. Fluid from the moderate-temperature wells contains less silica and potassium but more sodium, calcium, magnesium, bicarbonate, chloride, and sulfate than fluid from the high-temperature wells. Systematic differences are apparent in water composition across the moderate-temperature field. A slight decrease in chloride and silica concentration from west to east is coupled with slight increases in sodium, bicarbonate, and calcium. The decrease in chloride requires some dilution (maximum of about 3½ %), and some water-rock reaction is required to increase sodium, calcium, and bicarbonate concentrations. The decrease in silica could be due to a temperature decrease. Calcium concentrations do not change uniformly across the field; instead a high calcium region occurs in an area extending NE-SW across the middle of the new part of the field (fig. 3). This appears to be related to water-rock reaction rather than dilution; chloride concentrations do not decrease in the high calcium area. The size of this calcium "high" may have decreased slightly between Jan. 1993 and Aug. 1993. K/Na values were initially very similar (fig. 4) in the new part of the moderate-temperature field (wells PW2-1 to PW3-4). Development has caused the K/Na values of different well waters to change in different ways (fig. 4). However, the general trend of all the moderate-temperature wells has been to lower K/Na values than initially observed. Decreases in K/Na and silica indicate that the fluids of the moderate temperature field are becoming cooler. A possible explanation is that part of the heat which is being extracted from the field is being mined from the aquifer-rock.

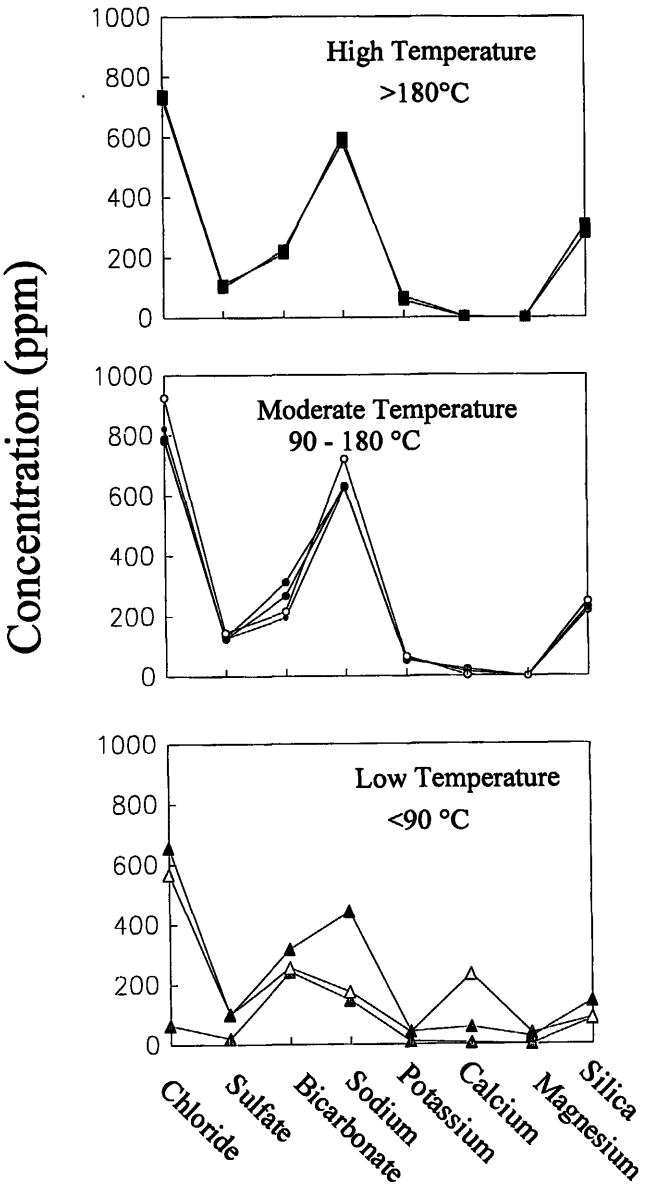

Fig. 2. Scholler diagrams for low-temperature, moderate-temperature, and high-temperature waters in and adjacent to the Steamboat Hills.

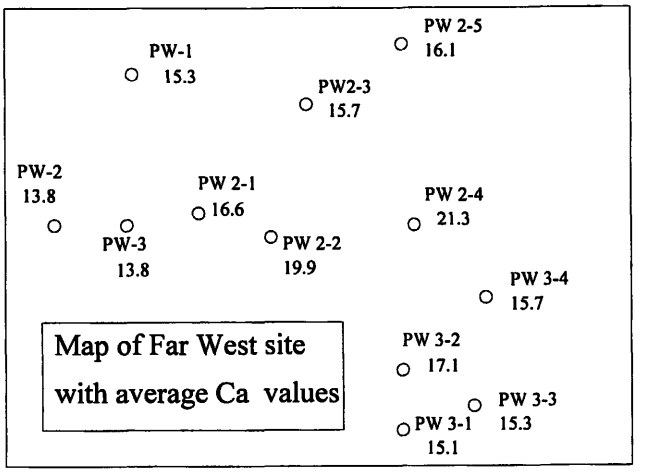

Fig. 3. Areal distribution of Ca over the moderate-temperature field. Note the high-calcium zone extending SW-NE across the field.

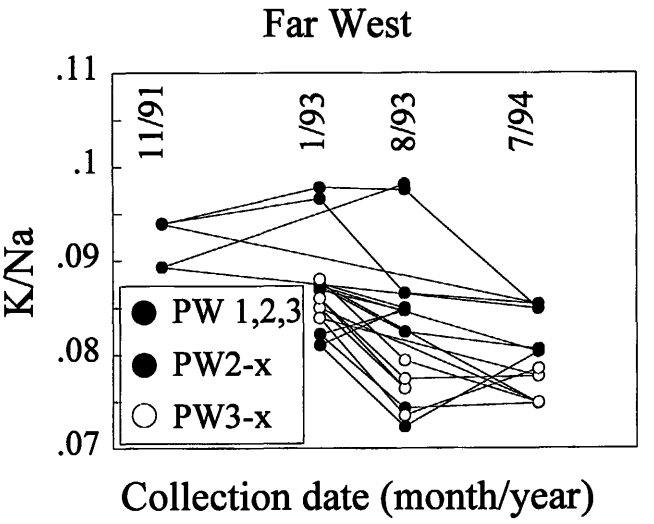

Fig. 4. K/Na values for the moderate-temperature field by date of sample collection. Note the decrease in K/Na and increased scatter with time.

Some domestic well waters in the area are fresh waters with no thermal component, some are fresh waters with an added steam component, and others are a mixture of thermal and fresh water. Fresh waters without a thermal component are represented only by STMGID #4, a water company well, north of the Mt. Rose highway and west of the geothermal system (fig. 1). The Stuart and Peigh domestic wells, along and north of the Mt. Rose highway, appear to yield largely fresh waters to which a steam component has been added. The slightly elevated chloride in the Stuart well water suggests that it may have a small component of thermal water. Curti, Steinhardt, and Herz wells yield slightly to strongly diluted thermal waters which have undergone only a little water-rock reaction at low temperatures. Water from the well at Brown's School, in contrast, has a chloride concentration virtually identical to that of the water from the Curti well but proportions of Ca and Na which are very different. Ca-Na-Cl waters (such as from the Brown's School well) typically develop where albitization of plagioclase removes sodium from solution and replaces it with calcium. Cl/Br values for this water are identical to those of thermal waters in the Steamboat Springs thermal system; thus the water is probably associated with the Steamboat Springs thermal system. Solution-mineral equilibrium calculations show that the water is saturated with respect to albite and unsaturated with respect to plagioclase. Albitization of a fine-grained plagioclase-rich tuff is probably converting the typical Na-Cl thermal water observed in the area into this unusual Ca-Na-Cl type of water. The high strontium concentration (7½ ppm) of this water could be derived from dissolution of plagioclase.

GEOTHERMOMETRY

In the high-temperature field, estimated aquifer-temperatures (Table 3) range from 202°C to 226°C (t_{quartz}) ; 206 to 232°C ($t_{sulfate\text{-}water\ isotope}$). Well 23-5 is always the hottest. The higher values from the sulfate-water isotope geothermometer may represent temperatures in the main upflow zone. The sulfate-water isotope geothermometer resets more slowly than the silica geothermometers even at high temperatures. The Na-K-Ca, K-Mg, and Mg-Li geothermometers are questionable in the high temperature field because of potential calcium and magnesium loss in the well bore and/or separator. The most reliable geothermometry for the moderate-temperature waters indicates temperatures from about 180°C on the west to about 155°C on the east (Table 3; fig. 5). The chalcedony, K-Mg, and some Na-K geothermometers indicate similar aquifer temperatures in the moderate-temperature field. The K-Mg geothermometer (fig. 5) indicates the presence of a low-temperature trough extending NE-SW across the middle of the new part of the field; this correlates with the high-calcium region mentioned in the previous section. Neither the chalcedony nor Na-K-Ca geothermometers show the "low-temperature" feature as well as the K-Mg geothermometer or the dissolved calcium concentrations. Geothermometer temperatures in both the high-temperature and moderate-temperature fields appear to be decreasing slightly with time but the data interval, Nov. 1991 to July 1994, is too short and the apparent temperature changes too small for us to be certain that the declines are real.

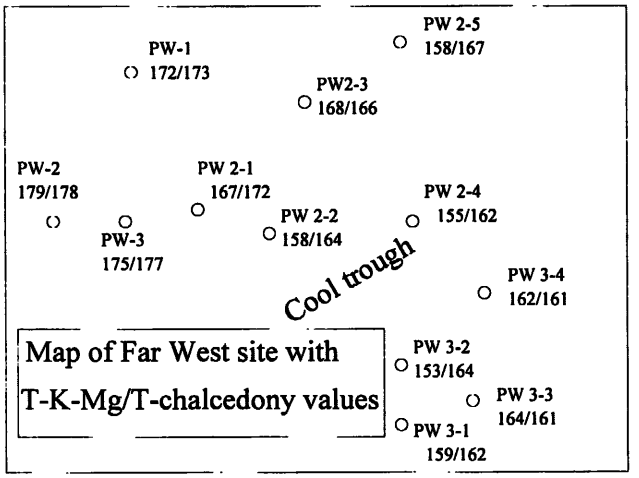

Fig. 5. Map of moderate-temperature site showing K-Mg and chalcedony geothermometer values. Note the "cool" trough trending NE across the field. This trough corresponds exactly with the "high" calcium zone shown on Fig. 3.

Relative sodium, potassium, and magnesium concentrations of selected samples (fig. 6) as well as Na-K and K-Mg geothermometer calculations (Table 3) show that the high-temperature fluids are near full equilibrium with the country rock at 210° to 240°C; the moderate-temperature fluids are partially equilibrated; and the low-temperature fluids are out of chemical equilibrium. Some uncertainty exists about which Na-K geothermometer should be used in constructing the fully-equilibrated line on these diagrams (Fournier, 1991). The Na-K geothermometer of Truesdell (1976) produces temperature estimates (Table 3) near the values calculated from the K-Mg and chalcedony geothermometer in the fluids from the moderate-temperature field. However, data from the moderate temperature part of the field plot as a straight line trending toward the Mg corner of the Na-K-Mg diagram, indicating that simple addition of magnesium by water-rock reaction is the dominant process, although we have shown above that a minor adjustment of the K/Na values does occur. Equilibrium between Na, K, and Mg would result in the data plotting along an arc rather than a straight line (fig. 6). Thermal spring data from Nehring (1980) show about the same range on the Na-K-Mg plot (fig. 6) as the moderate-temperature wells, although this may be related to loss of divalent cations associated with precipitation of carbonates during boiling near the spring rather than from water-rock equilibrium.

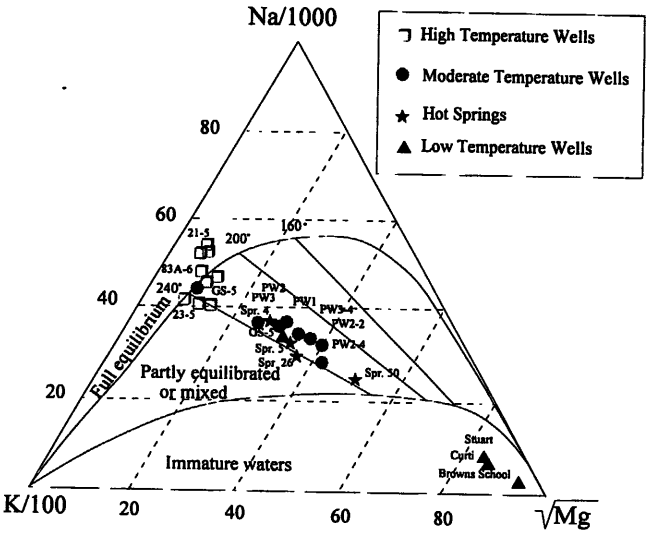

Fig. 6. Na-K-Mg diagram (Giggenbach, 1988) for selected thermal waters associated with the Steamboat Hills. Thermal spring data from Nehring (1980). Notice the increase in magnesium without adjustment of the K/Na values.

RELATION OF GEOTHERMAL FLUIDS

A major question about the geothermal fluids in different parts of the Steamboat Hills area is their relation to one another. Conservative constituent ratios and enthalpy-chloride diagrams may help resolve this question. Chloride and bromide are nonreactive constituents at these temperatures; that is, their concentration in the water can be changed only by boiling or dilution. Because neither constituent occurs in any appreciable concentration in the dilute ground water nor do they partition into the steam phase during boiling at these temperatures, the ratio of Cl/Br will be constant in all waters derived from a single high-temperature parent water. All thermal waters sampled in this area have the same Cl/Br value (about 600 on a weight/weight basis). All waters in this area that have a thermal component could be derived from the fluids encountered in the Caithness high-temperature wells. An enthalpy-chloride diagram (fig. 7) shows how these fluids can be related. The high-temperature fluids (83-A6, 21-5, and 13-5) can boil with steam loss to produce the moderate-temperature fluids (Far West) and low-temperature fluids of the Main Terrace (represented by GS-5). Gas

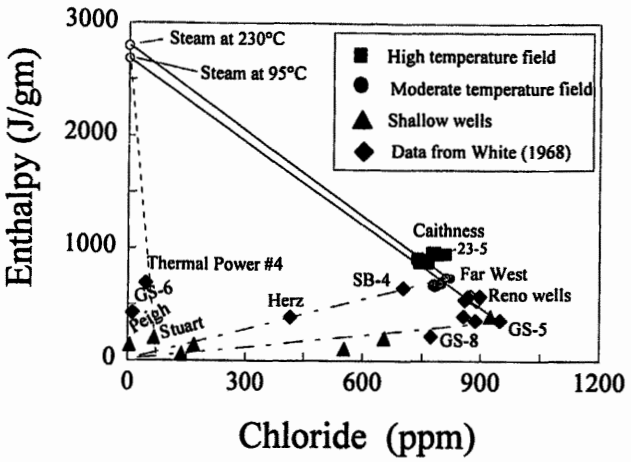

Fig. 7. Enthalpy-chloride diagram for thermal waters associated with the Steamboat Hills. Data for SB-4, SB-8, Reno wells, Thermal Power 4, and GS-8 are from White (1968).

data (Table 2) show that Far West fluids are strongly degassed relative to the probable recharge water which should contain 600 to 700 micromoles of N_2 and 2½ to 3 micromoles of Ar per kilogram of water. The thermal fluid has clearly boiled before it gets to the Far West site. Dilution occurs in some of the moderate temperature (Far West) wells as shown by the trend extending toward the low-chloride, low-enthalpy corner of the diagram. Dilution of GS-5 or Far West fluid followed by conductive cooling could produce the waters encountered in most of the domestic wells. Water from the Stuart domestic well (64 to 86 ppm-Cl at 46° to 48°C) must consist of highly diluted thermal water (GS-5, Far West, or Caithness type) to which some steam has been added. Data for Thermal Power 4 (White, 1968) shows that it is similar to the Stuart well, but contains even more heat derived from steam. Peigh appears to also have some geothermal heat, but it is so low in chloride that it may not contain any high-chloride thermal water. White (1968) reported a similar fluid in GS-6. The δD-$\delta^{18}O$ plot (fig. 8) is consistent with boiling Caithness fluid (average -117‰ δD and -12.8‰ $\delta^{18}O$) from 230° to 180°C to produce Far West fluids (average -116‰ δD and -12.6‰ $\delta^{18}O$) and further boiling of these fluids to 95°C to produce GS-5 and the hot spring waters. Some domestic wells could have a steam component and others are simply diluted thermal water. Caithness well 23-5 is clearly unique on the enthalpy-chloride plot and its relation to the other thermal wells is less certain.

Caithness well 23-5 discharges a fluid which contains more heat than expected from its dissolved chloride concentration (fig. 7). This could indicate an excess-enthalpy fluid or a fluid which has recently boiled and the silica has not re-equilibrated with quartz at the new fluid temperature. Total gas concentrations are highest in Caithness fluids (Table 2) and well 23-5 has the highest He relative to N_2 and Ar (Fig. 9) so it should be most like the parent high-temperature fluid. However, gas geothermometer values for samples from 23-5 have some unusual characteristics. Temperature estimates are 175° to 185°C for two of the three gas geothermometers (Table 2) even though the chemical geothermometers for the same well (23-5) indicate appreciably hotter temperatures (>220°C). A possible explanation could be an influx of 180°C steam (and gas) which is somehow drawn in when near-well pressure decreases as the well flows. If the fluid feeding 23-5 has boiled prior to addition of the 180°C steam (and gas) then most of the gas we collected from 23-5 would be from the 180°C steam component. A second possibility is that fluid from 23-5 represents the purest example of the deep reservoir water, although even it would have boiled prior to reaching the bore. The other high-temperature waters could be slightly diluted 23-5 water or conductively cooled common parent water which also produced 23-5 water by boiling. Diluting a higher-temperature water to produce other high-temperature waters does not appear likely because we have little evidence for dilution in the Caithness waters. Conductive cooling of a higher-temperature water to produce other Caithness water is also unlikely. The narrow range of maximum temperatures from the gas geothermometers is 239° to 243°C and is consistent for

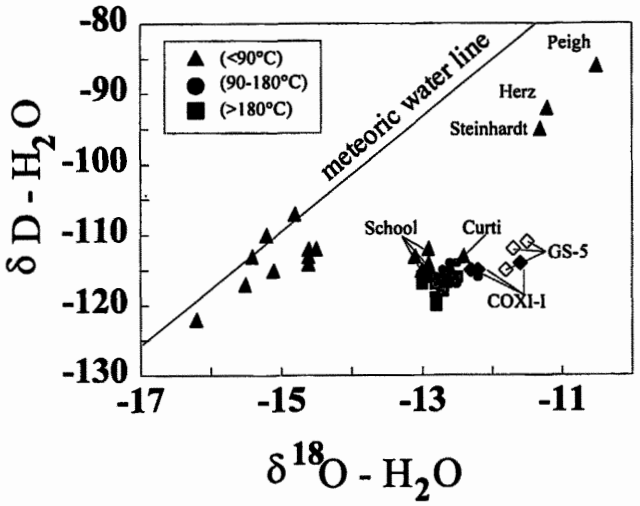

Fig. 8. δD-$\delta^{18}O$ diagram for selected thermal waters associated with the Steamboat Hills.

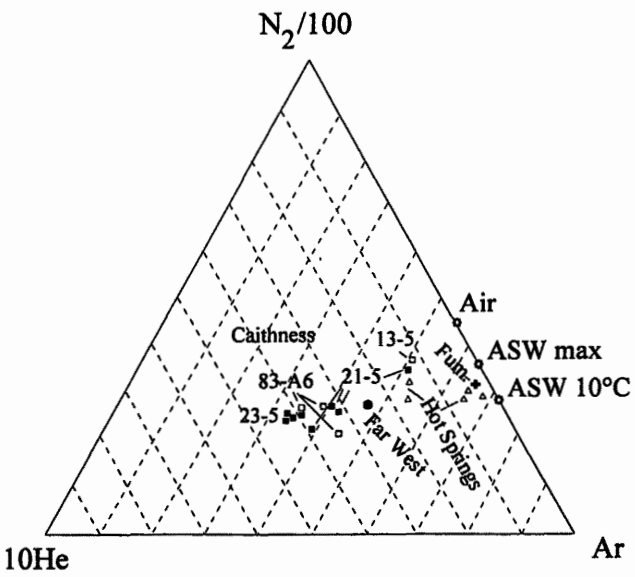

Fig. 9. N_2-He-Ar plot for samples from the Steamboat Hills. ASW - air saturated water.

all gases collected in this study and even for the gas data from hot springs reported by Nehring (1980). Values for t_{Na-K} are also as high as 243°C for 23-5 fluids; this could therefore represent the maximum temperature for the deep part of this system.

The amount of "apparent" excess enthalpy in well 23-5 appears to be increasing slightly with time although the feed temperature, based on the quartz geothermometer, seems to have decreased by about 6°C over a three year period. Extrapolating the enthalpy-chloride trend for the most reliable data from well 23-5 (1/27/93-7/25/94) to intercept the enthalpy-chloride trend for the other high and moderate temperature wells, indicates a possible common origin at 706 ppm-Cl and temperature of 233°C. Support for this temperature comes from the sulfate-water isotope geothermometer which indicates aquifer-temperatures as high as 232°C.

SYSTEM MODEL

The chemical and temperature relations are compatible with a simple model for the geothermal system (fig. 10) with upwelling of 230°-235°C fluid near Caithness well 23-5. This fluid (elevation about 3000 feet) moves laterally and loses heat principally by boiling to temperatures of 210° to 200°C to feed the other high-temperature wells. Between the Caithness production wells and the Caithness injection well (COXI-1), most of the fluid rises to a shallower aquifer (about 4500 feet elevation) and boils further to a temperature near 180°C . Steam lost during boiling shows up in altered ground slightly southwest of COXI-1 and in altered ground and fumaroles ½ mile north of COXI-1. Some minor dilution (≤3½%) and water-rock reaction occurs as the moderate-temperature fluids traverse the Far West site. The fluid from GS-5 and the springs which existed on the Main and Low Terraces could be produced directly by boiling of the high-temperature fluid or by additional boiling of the moderate-temperature fluid. Steam lost from high-temperature fluids as they boil appears in the highly diluted thermal waters and steam-heated groundwaters encountered at several sites on the north side of the Steamboat Hills and in the adjacent valley. In a second but less likely model, parent fluid with maximum temperatures of 240° to 243°C boils to produce the fluid encountered in 23-5. Other high temperature fluids are then produced by diluting 23-5 fluid or by conductive cooling of the parent fluid.

SUMMARY

Thermal waters in the Steamboat Hills and the adjacent valley are all related to a single high-temperature fluid rising beneath the Steamboat Hills. The main process which produces the different thermal fluids is boiling. Dilution is important only for low-temperature (<100°C) waters in the Pleistocene and Recent fill. Water-rock reaction modifies cation concentrations at intermediate and low temperatures, but only the high-temperature waters approach full chemical equilibrium. A few steam-heated ground waters occur along the north side of the Steamboat Hills. The maximum system temperature is at least 230° to 235°C (sulfate-water isotope geothermometer and enthalpy-chloride) and the silica (quartz) geothermometer resets to give temperatures at the base of the high-temperature well bores. Gas geothermometers indicate possible maximum system temperatures of 240° to 243°C. Fluids from well 23-5 probably contain excess enthalpy. Chloride concentrations in the deep thermal fluid which feeds the system are at least 706 ppm-Cl.

Production-induced chemical changes of the fluids from the high-temperature and moderate-temperature fields have been minor within the 1991 to 1994 time interval. Silica concentrations in both the high-temperature and moderate-temperature fluids have decreased slightly. Calcium concentrations have increased slightly in the high-temperature field but do not show a consistent change with time in the moderate-temperature field. Increases in calcium and decreases in silica are consistent with lower reservoir temperatures and may indicate system cooling. However, much of the change in calcium and silica is based on the 1994 sample set, and one set of samples does not establish a trend Slight decreases in K/Na values in the moderate-temperature fluids relative to the high-temperature fluids show that some re-equilibration to lower temperatures is occurring.

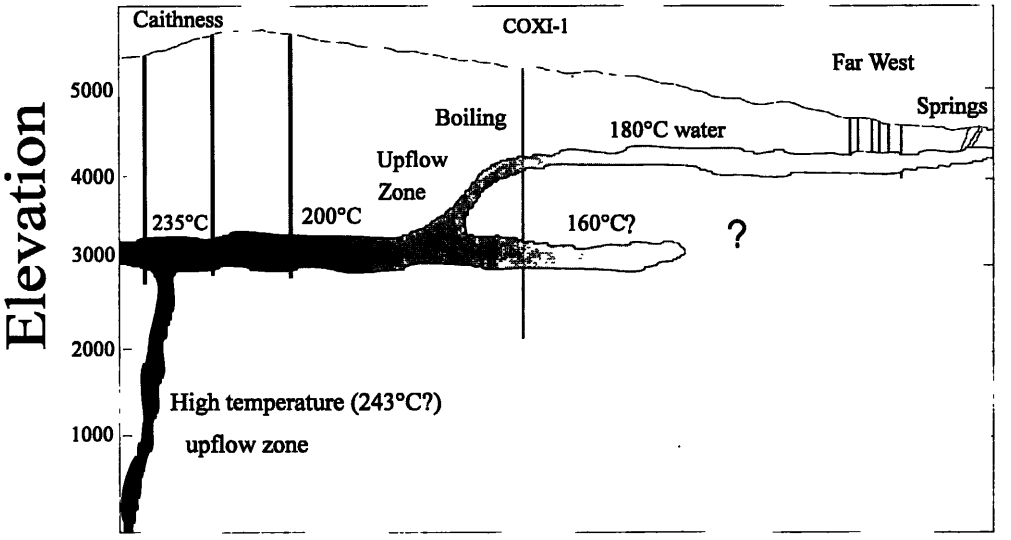

Fig.10. Conceptual model for the Steamboat Hills geothermal system.

ACKNOWLEDGMENTS

This work was supported by the U.S. Department of Energy under contract number DE-AI01-91CE31020. Such support does not constitute an endorsement by DOE of the views expressed in this publication. The authors appreciate the cooperation and assistance of Caithness Power Company and SBGEO (Far West) in sampling the geothermal wells. We particularly appreciate the assistance of Chuck Stuart and Ted DeRocher in sampling the high-temperature wells. Chuck Stuart also helped us with locating and sampling the domestic wells. Lynne Fahlquist, Linda Johnson, Anne Gartner, and Bill Evans of the U.S. Geological Survey participated in sample collection and analyzed gas and sulfate-isotope samples. Chemical analyses of water samples were carried out by Dale Counce at Los Alamos National Laboratory. Mike Sorey and Martha Scholl provided helpful reviews. We also had useful discussions with Bob Fournier. Collin Goranson and Peter van de Kamp freely shared their knowledge of the geothermal system(s) in the Steamboat Hills.

REFERENCES

Arnorsson, S., and Gunnlaugsson, E., 1985, New gas geothermometers for geothermal exploration - Calibration and application: Geochimica et Cosmochimica Acta, v. 49, p. 1307-1325.

Bateman, R.L., and Scheibach, R.B., 1975, Evaluation of geothermal activity in the Truckee Meadows, Washoe County, Nevada: Nevada Bureau of Mines and Geology Report 25, 38 p.

Cohen, P., and Loeltz, O.J., 1964, Evaluation of hydrogeology and hydrogeochemistry of Truckee Meadows area, Washoe County, Nevada: U.S. Geological Survey Water Supply Paper 1779-S, 63 p.

D'Amore, F., and Panichi, C., 1980, Evaluation of deep temperatures in hydrothermal systems by a new gas geothermometer: Geochimica et Cosmochimica Acta, v. 44, p. 549-556.

Desormier, W.L., 1983, Steamboat Springs geothermal project: Geothermal Resources Council Field Trip Guidebook for the Role of Heat in the Development of Energy and Mineral Resources in the Northern Basin and Range Province, p. 27-30.

Fahlquist, L., and Janik, C., 1992, Procedures for collecting and analyzing gas samples from geothermal systems: U. S. Geological Survey Open-File Report 92-211, 19 p.

Fournier, R.O., 1979, A revised equation for the Na/K geothermometer: Geothermal Resources Council Transactions, v. 3, p. 221-224.

Fournier, R.O., 1991, Water geothermometers applied to geothermal energy. *in* F. D'Amore (co-ord.) Application of Geochemistry in Geothermal Reservoir Development, UNITAR/UNDP Centre on Small Energy Resources, Rome, Italy, p. 37-70.

Fournier, R.O., and Rowe, J.J., 1966, Estimation of underground temperatures from the silica content of water from hot springs and wet-steam wells: American Journal of Science, v. 264, p. 685-697.

Fournier, R.O., and Truesdell, A.H., 1973, An empirical Na-K-Ca geothermometer for natural waters: Geochimica et Cosmochimica Acta, v. 37, p. 1255-1275.

Giggenbach, W.F., 1988, Geothermal solute equilibria: Derivation of Na-K-Ca-Mg geoindicators: Geochimica et Cosmochimica Acta, v. 52, p. 2749-2765.

Giggenbach, W.F., and Goguel, R.L, 1989, Collection and analysis of geothermal and volcanic water and gas discharges 4th ed., New Zealand DSIR Rept. No. CD 2401, 81 p.

Goranson, C., van de Kamp, P., and DeLong, T., 1990, Geothermal injection and monitoring program history at the Caithness Power, Inc., flash steam power plant Steamboat Springs, Nevada: Proceedings of the Symposium on Subsurface Injection of Geothermal Fluids, October 29-30, 1990, Santa Rosa, California, Sponsored by the Underground Injection Practices Council Research Foundation, p. 101-121.

Kharaka, Y.K., and Mariner, R.H., 1989, Chemical geothermometers and their application to formation waters from sedimentary basins. *in* Naeser, N.D. and McCollin, T.H. (eds.) Thermal History of Sedimentary Basins, Springer-Verlag, New York, p. 99-117.

McKenzie, W.F., and Truesdell, A.H., 1977, Geothermal reservoir temperatures estimated from the oxygen isotope composition of dissolved sulfate and water from hot springs and shallow drillholes: Geothermics, v. 5, p. 51-62.

Nehring, N.L., 1980, Geochemistry of Steamboat Springs, Nevada: Masters Thesis at San Jose State University, May 1980, 61 p.

Silberman, M.L., White, D.E., Keith, T.E.C., and Dockter, R.D., 1979, Duration of hydrothermal activity at Steamboat Springs, Nevada, from spatially associated volcanic rocks: U.S. Geological Survey Professional Paper 458-D, 64 p.

Sorey, M.L. , and Colvard, E.M., 1992, Factors affecting the decline in hot-spring activity in the Steamboat Springs area of critical environmental concern, Washoe County, Nevada: U.S. Geological Survey Administrative Report for the Bureau of Land Management, 109 p.

Thompson, G.A., and White, D.E., 1964, Regional geology of the Steamboat Springs area, Washoe County, Nevada: U.S. Geological Survey Professional Paper 458-A, 52 p.

Truesdell, A.H., 1976, Summary of section III geochemical techniques in exploration *in* Proceedings, Second United Nations Symposium on the Development and Use of Geothermal Resources, v. 1, p. liii-lxxxix.

White, D.E., Hem, J.D., and Waring, G.A., 1963, Data of geochemistry, Sixth Ed.: U.S. Geological Survey Professional Paper 440-F, 67 p.

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

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

Table 1. --Chemical data for Steamboat Hills area

[Concentrations are in ppm]

Site	$T_{°C}$	pH/$T_{°C}$	SiO_2	Ca	Mg	Na	K	Li	HCO_3[1]	F	Cl	Br	SO_4	B	H_2S	δD	$\delta^{18}O$	Coll. date *Steam frac.*
23-5	170	5.44/32	97	.4	<.02	168	22	2.0	86	.5	222	.5	25	12	9.2	-121	-14.3	11/5/91
Recalc.			*346*[2]	*1.4*	*<.07*	*600*	*78*	*7.1*	*307*	*1.8*	*792*	*1.8*	*89*	*43*	*33*	-	-	*0.7197*
	168	7.42/60	426	2.6	.08	692	86	7.4	330	2.6	887	1.6	102	46	7.8	-119	-12.4	1/27/93
Recalc.			*372*	*2.3*	*.07*	*604*	*75*	*6.5*	*288*	*2.3*	*774*	*1.4*	*89*	*40*	*6.8*	*-120*	*-12.8*	*0.1274*
	173	8.25/36	421	3.4	.05	673	90	8.1	296	3.0	887	1.5	92	47	7.9	-116	-12.5	8/2/93
Recalc.			*372*	*3.0*	*.04*	*594*	*79*	*7.2*	*262*	*2.6*	*783*	*1.3*	*81*	*41*	*7.0*	*-117*	*-12.8*	*0.1172*
	169	7.75/31	400	2.7	.2	691	87	7.1	323	2.4	917	1.6	100	45	5.9	-119	-12.5	7/25/94
Recalc.			*353*	*2.3*	*.18*	*610*	*77*	*6.2*	*285*	*2.1*	*810*	*1.4*	*88*	*40*	*5.2*	*-119*	*-12.8*	*0.1167*
	171	7.82/29	389	9.2	.02	665	87	7.0	312L	3.2	889	1.5	103	46	-	-117	-12.4	9/13/94
Recalc.			*347*	*8.2*	*.01*	*593*	*78*	*6.2*	*278L*	*2.8*	*793*	*1.3*	*92*	*41*	-	*-118*	*-12.7*	*0.1077*
83A-6	156	8.27/30	356	3.6	<.02	670	80	7.0	280	2.6	840	1.4	118	41	6.3	-117	-11.8	11/6/91
Recalc.			*313*	*3.2*	*<.02*	*590*	*70*	*6.2*	*246*	*2.3*	*739*	*1.2*	*104*	*36*	*5.5*			*0.1200*
	156	8.18/45	364	3.7	.02	639	74	6.4	262	3.2	840	1.4	111	51	6.4	-115	-12.6	8/2/93
Recalc.			*319*	*3.3*	*.02*	*560*	*65*	*5.6*	*230*	*2.8*	*737*	*1.2*	*97*	*45*	*5.6*	*-116*	*-13.0*	*0.1231*
	151	8.28/38	353	5.5	.04	626	79	6.9	279	3.2	868	1.5	116	44	5.8	-114	-12.5	7/25/94
Recalc.			*308*	*4.8*	*.03*	*547*	*69*	*6.0*	*244*	*2.8*	*758*	*1.3*	*101*	*39*	*5.1*	*-116*	*-12.9*	*0.1268*
21-5	155	8.49/29	318	2.1	<.02	688	64	6.1	272	2.8	850	1.4	129	42	4.6	-115	-12.2	11/5/91
Recalc.			*284*	*1.9*	*<.02*	*615*	*57*	*5.4*	*243*	*2.5*	*760*	*1.3*	*115*	*37*	*4.1*	*-116*	*-12.5*	*0.1058*
	154	8.12/22	321	2.8	.01	639	62	6.6	263	2.6	833	1.4	126	43	6.0	-117	-12.4	1/27/93
Recalc.			*286*	*2.5*	*.01*	*569*	*56*	*5.9*	*234*	*2.3*	*742*	*1.3*	*112*	*39*	*5.3*	*-118*	*-12.7*	*0.1088*
	154	7.14/33	320	5.6	.02	657	62	6.1	266	3.3	847	1.4	114	46	6.0	-116	-12.6	8/3/93
Recalc.			*288*	*5.0*	*.02*	*586*	*56*	*5.4*	*237*	*2.9*	*755*	*1.2*	*102*	*41*	*5.3*	*-117*	*-13.0*	*0.1084*
	152	8.47/31	304	5.4	.02	686	61	6.1	263	3.2	856	1.5	128	44	5.1	-116	-12.5	7/25/94
Recalc.			*272*	*4.8*	*.02*	*614*	*55*	*5.4*	*235*	*2.8*	*766*	*1.3*	*115*	*40*	*4.6*	*-117*	*-12.8*	*0.1050*
13-5	130	8.68/33	339	1.7	.05	690	58	6.1	289	3.0	904	1.5	130	46	4.5	-115	-12.2	8/7/93
Recalc.			*287*	*1.4*	*.04*	*584*	*49*	*5.2*	*245*	*2.5*	*765*	*1.3*	*110*	*39*	*3.8*	*-117*	*-12.8*	*0.1533*
COX I-1	137	8.48/32	380	4.8	<.02	840	88	7.9	522	2.6	873	1.5	113	44	-	-114	-11.6	11/6/91
	129	8.52/42	375	8.9	.03	709	77	7.6	367L	3.1	890	1.5	119	52	-	-115	-12.2	8/3/93
	140	7.29/35	379	10.0	.04	694	79	7.1	380	2.9	902	1.5	117	49	8.0	-115	-12.3	7/27/94
GS-5	95	8.66/30	246	2.5	<.02	720	64	7.7	230	2.4	925	1.6	146	47	2.2	-112	-11.7	11/4/91
	86	8.56/86	255	3.5	.3	678	66	7.0	179L	2.2	887	1.4	153	48	-	-115	-11.8	1/29/93
	96	8.38/82	208	2.6	.02	715	68	8.5	221L	2.8	949	1.4	168	56	-	-111	-11.5	8/3/93
PW-1	129	6.12/22	232	15.5	.3	596	56	6.0	298	2.0	781	1.4	127	45	6.9	-116	-12.2	11/7/91
	169	5.78[3]/14	238	16.3	.3	611	59	6.5	288	2.2	811	1.4	121	43	6.1	-117	-12.6	1/29/93
	167	6.27/31	245	14.4	.2	613	53	6.5	291	2.9	808	1.4	122	38	5.6	-117	-12.5	8/5/93
	166	6.37/36	235	14.9	.3	644	55	6.4	279	2.5	802	1.3	125	42	5.2	-115	-12.6	7/27/94
PW-2	120	6.21/18	248	8.3	.2	628	59	6.4	256L	2.2	800	1.4	127	43	6.8	-115	-12.2	11/7/91
	169	5.74[3]/13	248	13.8	.3	624	61	6.2	258	2.3	823	1.5	126	41	6.0	-117	-12.5	1/29/93
	164	6.21/30	257	13.9	.2	615	60	7.0	266	3.0	795	1.4	122	43	7.0	-114	-12.5	8/5/93
	168	6.39/38	233	13.7	.2	636	54	6.3	268	2.7	811	1.4	124	41	5.9	-115	-12.7	7/24/94
PW-3	172	6.16/21	239	14.5	.2	627	56	5.9	267	2.2	809	1.4	125	42	6.7	-116	-12.2	11/7/91
	168	6.28/37	261	13.2	.3	611	60	6.7	262	2.8	814	1.2	-	47	6.4	-116	-12.5	8/5/93
PW2-1	163	5.88[3]/28	238	18.3	.4	610	53	6.5	320	2.6	772	1.4	124	40	6.8	-116	-12.6	1/28/93
	163	6.56/35	231	14.8	.3	626	53	6.1	293	2.8	801	1.3	-	45	6.2	-117	-12.7	8/4/93
PW2-2	156	5.97[3]/17	227	19.9	.4	608	50	6.2	322	2.4	770	1.3	129	42	5.8	-116	-12.7	1/28/93
	149	6.24/33	217	19.3	.5	646	48	6.3	319	2.7	799	1.3	125	44	5.9	-116	-12.8	8/4/93
	156	6.36/30	195	20.6	.5	655	49	6.0	332	2.3	797	1.4	125	40	5.1	-116	-12.7	7/26/94
PW2-3	162	5.89[3]/28	214	16.0	.3	605	53	6.3	310	2.6	801	1.4	126	37	6.2	-116	-12.6	1/29/93
	160	6.34/35	223	15.4	.3	612	52	6.6	298	2.8	797	1.3	121	41	6.1	-116	-12.6	8/4/93
PW2-4	148	5.91[3]/31	216	21.6	.5	630	51	6.5	337	2.4	782	1.3	123	41	6.8	-116	-12.6	1/28/93
	145	6.10/37	216	20.0	.5	636	46	5.9	343	2.7	787	1.3	120	43	5.8	-115	-12.7	8/5/93
	151	6.25/40	193	22.2	.6	623	50	6.0	338	2.5	783	1.3	124	41	5.2	-115	-12.7	7/26/94

Table 1.--Chemical data for Steamboat Hills area -- continued

[Concentrations are in ppm]

Site	$T_{°C}$	$pH/T_{°C}$	SiO_2	Ca	Mg	Na	K	Li	HCO_3[1]	F	Cl	Br	SO_4	B	H_2S	δD	$\delta^{18}O$	Coll. date
PW2-5	164	5.88[3]/29	223	17.5	1.2	607	53	6.5	312	2.1	795	1.4	124	41	6.0	-114	-12.6	1/29/93
	164	6.15/32	231	14.5	.4	643	53	6.9	306	2.8	796	1.3	125	48	5.6	-117	-12.6	8/4/93
	163	6.37/37	214	16.3	.3	633	51	6.4	301	2.4	805	1.4	126	42	4.9	-116	-12.6	7/26/94
PW3-1	152	5.96[3]/23	227	15.5	.5	625	55	6.3	329	2.4	789	1.3	127	41	6.1	-118	-12.7	1/28/93
	160	6.23/37	213	14.6	.4	630	50	6.9	329	2.6	788	1.2	-	40	4.5	-116	-12.8	8/4/93
	163	6.34/28	187	15.2	.5	654	49	6.0	327	2.2	783	1.4	126	40	2.9	-116	-12.7	7/26/94
PW3-2	161	5.90[3]/30	213	18.5	1.0	635	54	6.4	321	2.4	775	1.3	129	41	6.8	-118	-12.7	1/28/93
	167	6.15/32	217	15.7	.4	641	49	6.5	323	2.7	799	1.2	-	43	6.2	-116	-12.7	8/4/93
PW3-3	168	5.87[3]/33	218	15.8	.4	628	54	6.4	331	2.4	801	1.4	125	42	5.8	-117	-12.7	1/28/93
	162	6.05/33	218	14.8	.3	646	50	6.6	336	2.6	779	1.3	126	39	5.7	-116	-12.8	8/5/93
	163	6.20/39	182	15.3	.4	631	49	6.1	329	2.3	797	1.4	126	42	5.0	-115	-12.7	7/26/94
PW3-4	163	5.88[3]/32	218	15.9	.4	620	52	6.2	330	2.4	779	1.3	124	42	6.6	-116	-12.7	1/28/93
	173	6.08/42	218	15.0	.4	653	48	6.4	336	2.7	795	1.3	-	52	5.8	-117	-12.8	8/4/93
	161	6.18/35	180	16.3	.4	637	50	6.0	328	2.4	783	1.3	126	39	4.9	-116	-12.7	7/26/94
IW-3	88	6.17/28	244	14.2	.2	638	56	5.6	281	2.1	809	1.3	-	40	-	-116	-12.5	11/7/91
	99	5.95/32	265	14.7	.2	641	59	7.2	272	2.7	813	1.4	112	39	7.7	-116	-12.6	8/5/93
IW-5	97	6.15/38	219	16.6	.4	620	51	6.7	327	2.5	794	1.2	123	43	4.1	-116	-12.7	8/5/93
Stuart	48	7.67/40	86	4.7	1.5	126	9.0	.7	272	.8	68	.12	20	3.9	-	-112	-14.5	11/8/91
	46	7.07[3]/46	83	4.8	1.5	147	9.2	.9	286	.8	64	.11	20	6.6	-	-113	-14.6	1/26/93
	46	7.38/46	93	5.4	1.8	152	9.5	1.1	287	.7	82	.16	21	4.7	-	-112	-14.6	8/6/93
	47	7.88/35	87	5.9	2.1	168	9.5	1.2	288	1.1	86	.13	23	5.7	.1	-112	-14.6	7/27/94
Brown's	26	7.01/24	86	224	41	150	34	.9	300	.04	554	.94	97	20	-	-113	-13.1	11/8/91
School	-	6.44[3]/25	88	233	38	175	41	1.2	316	.1	568	1.0	101	29	-	-115	-13.0	1/23/93
	27	7.08/28	89	251	48	186	44	1.5	353	<.04	639	1.0	108	31	-	-112	-12.9	8/6/93
	29	7.06/27	92	255.	46	205	46	1.8	384	.1	636	1.0	103	38	-	-114	-12.9	7/28/94
Curti	48	6.88/39	143	57	26	443	42	4.4	334	.6	656	1.1	104	36	-	-113	-12.4	11/8/91
Steinhardt	34	7.31/34	91	5.1	.8	231	17	2.1	306	.4	171	.3	42	8.6	-	-95	-11.3	11/8/91
Peigh	34	7.03/30	61	37	8.5	8.3	4.2	<.01	158	.03	5.6	<.02	6	<.05	-	-86	-10.5	11/8/91
Herz	14	7.41/14	55	86	13	35	13	.3	217	.07	138	.2	19	.3	-	-92	-11.2	11/8/91
Stmgid 4	20	7.84/20	38	30	1.9	12	3.2	<.01	132	.03	1.0	<.02	7.4	<.05	-	-117	-15.5	11/8/91
Galena Ck. Pk.	20	8.78/32	48	15	5.3	5.5	4.0	.02	100L	<.02	.5	.03	.5	.05	-	-113	-15.4	8/7/93
Thomas Ck.S.	15	8.0L	65	17.7	14.5	13	5.7	.03	164L	.03	1	<.02	.7	<.03	-	-122	-16.2	8/7/93
Tick Spr.	12	7.9L	19	100	21	20	.4	.02	210L	.03	48	.03	143	.03	-	-115	-15.1	8/7/93
Jumbo Gr. S.	15	8.0L	25	95	18	36	1.2	.03	375L	.1	7	.06	68	.11	-	-114	-14.6	8/7/93
Tahoe Mdw.	8	5.83/8	18	14.5	4.0	11.5	1.6	.02	8	<.02	52	<.02	.4	<.01	-	-107	-14.8	8/8/93
Third Ck. Spr.	6	7.29/6	33	5.0	1.6	2.1	2.2	.01	34	<.02	.2	<.02	.2	<.01	-	-110	-15.2	8/8/93

[1] Total alkalinity as bicarbonate

[2] Sample contains steam. The correction factor (1/% water) was determined by extrapolating the measured chloride and sodium values to the least squares line established for the four other collection dates. This indicates that the water line contained 28% liquid and 72% steam.

[3] pH value may be in error

L Indicates a laboratory value (no field value available)

Table 2.-- Gas analyses and gas geothermometers for samples from the Steamboat Hills area

Site	Date	Coll. T °C	Steam Fraction	G/S mol/mol	CO_2	H_2S	H_2	CH_4	NH_3	N_2	O_2	Ar	He	N_2/Ar	T-DP[1] °C	T-HA[2] °C	T-CO_2[3] °C
					[Gas concentrations are in mole percent]												
23-5	11/5/91	167	0.7197	0.01107	97.7	1.04	0.021	0.0051	0.0054	1.21	-	0.018	0.0022	67.2	174	180	243
	1/27/93	168.5	.1274	.01152	97.7	1.02	.024	.0081	.0058	1.22	.0025	.018	.0021	67.8	173	173	243
	8/2/93	172	.1167	.01199	97.8	1.00	.023	.0052	.007	1.15	-	.017	.0019	67.6	175	184	243
	7/25/94	170	.1077	.01169	97.7	1.01	.024	.0064	.0051	1.23	-	.017	.0021	72.4	175	185	243
83A-6	11/6/91	156	.1200	.00372	97.1	1.35	.041	.0100	.015	1.44	.0008	.023	.0031	62.6	187	193	242
	8/2/93	156.5	.1231	.00711	97.4	1.16	.032	.0050	.008	1.33	.0005	.021	.0019	63.3	184	188	242
	7/25/94	151	.1268	.00282	94.8	2.36	.056	.0107	.013	2.79	-	.043	.0040	64.9	200	183	241
21-5	11/5/91	154	.1058	.00454	97.7	1.03	.052	.0089	.0083	1.24	-	.022	.0022	56.4	190	201	243
	1/27/93	153.5	.1088	.00372	97.3	1.21	.051	.0078	.02	1.38	.0087	.024	.0018	57.5	192	198	242
	8/3/93	155	.1084	.00482	95.2	1.11	.030	.0050	.017	3.58	.0072	.054	.0015	66.3	183	157	241
	7/25/94	152	.1050	.00133	92.8	3.32	.092	.0070	.036	3.67	-	.060	.0049	61.2	221	188	239
13-5	8/7/93	130.5	.1533	.00297	93.4	1.27	.029	.0038	.016	5.18	-	.072	.0016	71.9	186	147	240
PW1	11/7/91	128.6	.0875	.00309	96.9	1.95	.050	.0046	.012	1.06	.0054	.021	.0012	50.5	201	201	242
Fumarole at PW3-4	7/28/94	98	-	.00134	91.7	4.55	.144	.0048	.078	3.44	-	.078	.0006	44.1	241	194	239
					[Dissolved gas concentrations in millimoles of gas/ kilogram-fluid]												
PW2		30	-	-	7487	-	-	.2	-	52.4	<.05	.9	-	58.2	-	-	-
PW2-1		30	-	-	8682	-	-	.21	-	57.5	<.05	1.1	-	52.3	-	-	-
PW3-1		30	-	-	9621	-	-	.24	-	64.2	<.05	1.2	-	53.5	-	-	-

[1] - D'Amore and Panichi (1980); [2] - Giggenbach and Goguel (1989); [3] - Arnorsson and Gunnlaugsson (1985)

Table 3. -- Chemical geothermometry for the Steamboat Hills area

Site	t_{qtz}	$t_{chalc.}$	t_{NaKCa}	$t_{NaK(F)}$	$t_{NaK(T)}$	t_{MgLi}	t_{KMg}	$t_{sulfate-water}$	Date
	[Temperatures are °C]								
23-5	226	211	242	237	212	237	218	232	1/27/93
	226	210	244	243	221	244	229	230	8/2/93
	222	202	242	237	214	232	189	219	7/25/94
	221	202	231	242	219	298	245		9/13/94
83-A6	213	197	235	233	207	-	-	223	11/6/91
	214	199	232	230	204	294	237	212	8/2/93
	212	196	233	238	214	287	231	214	7/25/94
21-5	205	188	225	211	180	-	-	213	11/5/91
	206	189	223	215	186	319	254	207	1/27/93
	206	189	214	212	183	292	236	206	8/3/93
	202	184	213	208	176	293	230	209	7/25/94
13-5	207	189	219	201	170	269	208	210	8/7/93
PW-1	190	171	205	215	181	231	176	222	11/7/91
	192	173	198	206	184	223	166	212	1/29/93
	194	175	199	205	173	234	177	199	8/5/93
	191	172	199	204	171	227	170	193	7/27/94
PW-2	195	176	211	212	181	241	184	216	11/7/91
	195	176	208	215	185	225	174	200	1/29/93
	208	191	207	214	185	238	182	213	8/5/93
	191	171	200	203	170	236	177	177	7/24/94
PW-3	192	173	202	207	176	230	177	224	11/7/91
	199	181	208	216	186	228	174	-	8/5/93
PW2-1	192	173	198	206	173	223	166	204	1/28/93
	190	170	199	203	171	225	169	-	8/4/93
PW2-2	188	169	193	200	168	220	162	207	1/28/93
	186	165	189	192	158	215	156	207	8/4/93
	178	157	189	193	159	211	156	193	7/26/94
PW2-3	184	164	199	205	174	226	169	216	1/29/93
	187	167	198	204	171	227	168	215	8/4/93

Table 3. -- Chemical geothermometry for the Steamboat Hills area -- cont.

Site	t_{qtz}	t_{chalc}	t_{NaKCa}	$t_{NaK(F)}$	$t_{Na-K(T)}$	t_{MgLi}	t_{KMg}	$t_{sulfate-water}$	Date
	[Temperatures are °C]								
PW2-4	185	165	193	200	166	214	157	213	1/28/93
	185	165	186	190	155	213	154	206	8/5/93
	178	156	191	199	165	192	154	200	7/26/94
PW2-5	187	168	198	205	174	195	143	208	1/29/93
	190	170	198	201	168	226	163	209	8/4/93
	185	164	195	199	166	227	167	194	7/26/94
PW3-1	188	169	200	206	174	213	159	207	1/28/93
	184	164	195	198	164	225	161	-	8/4/93
	175	153	192	193	159	211	156	198	7/26/94
PW3-2	184	164	197	203	171	198	146	202	1/28/93
	186	165	192	194	161	220	160	-	8/4/93
PW3-3	185	165	199	204	172	218	163	202	1/28/93
	186	166	194	196	162	226	167	196	8/5/93
	174	152	193	196	162	217	161	190	7/26/94
PW3-4	185	165	198	203	170	222	165	196	1/28/93
	186	166	192	193	157	219	160	-	8/4/93
	173	151	194	197	163	216	161	201	7/26/94
GS-5	182[a]	179	224	215	175	235	180	213	11/4/91
	182[a]	179	224	215	185	234	177	208	1/29/93
	170[a]	162	226	212	182	323	240	216	8/3/93

$t_{qtz.}$ and $t_{chalc.}$ - Fournier and Rowe (1966); Fournier (1991);
[a] - adiabatic boiling assumed; $t_{Na-K-Ca}$ - Fournier and Truesdell (1973);
$t_{NaK(F)}$ - Fournier (1979); $t_{NaK(T)}$ - Truesdell (1976);
t_{MgLi} - Kharaka and Mariner (1989); t_{KMg} - Giggenbach (1988);
$t_{sulfate-water}$ - McKenzie and Truesdell (1977)