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A Geochemical Study of the Southwest Part of the Black Rock Desert and Its Geothermal Areas; Washoe, Pershing, and Humboldt Counties, Nevada

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ABSTRACT

Several hydrothermal systems were explored in northwestern Nevada in parts of Washoe, Pershing, and Humboldt Counties. These hydrothermal systems included the Great Boiling springs and Mud springs at Gerlach, the Fly Ranch hot springs in Hualapai Flat, Double Hot and Black Rock springs at the southern end of the Black Rock Range, Trego hot spring, Soldier Meadows hot springs, and hot springs at Pinto Mt., at Pyramid Lake Needles region, and in the San Emidio and Smoke Creek Deserts.

Thermal and nonthermal groundwater was analyzed to determine the water quality of the various hot spring regions. Water discharged from the hot springs of Trego, Gerlach, San Emidio and Smoke Creek Deserts, and Pyramid Lake Needles area is classified as Na-Cl. This water is characterized by high values of Na^+, Cl^-, HCO_3^-, and SiO_2 and is neutral in pH. Water discharged from the hot springs of Soldier Meadows, Pinto Mt., Double Hot springs, and Fly Ranch hot springs is classified as $Na\text{-}HCO_3$. This water is similar to the nonthermal water of these areas, and probably represents circulation of meteoric water near a heat source, with very little addition of magma-derived fluids. The similarities of the trilinear plots of the chemical quality of nonthermal and thermal waters suggest the origin of the thermal waters is deep circulation of meteoric water with the addition of some connate water.

Based on the use of the silica, Na/K, and Na-K-Ca geothermometers, the Great Boiling springs at Gerlach appears to be the most promising geothermal prospect in the study area. The subsurface temperature calculated for this area was 175 to 200°C. The springs along the eastern edge of the San Emidio Desert have the greatest potential for yielding commercial geothermal fluids based on a geochemical temperature of 216°C. Hualapai Flat (Fly Ranch) contains a large number of hot springs, but temperatures of the reservoir based on geochemistry ranged from 125 to 155°C.

INTRODUCTION

The growing interest and need for geothermal power as an energy source has resulted in an increase in the study of known thermal systems. The Black Rock Desert region in northwestern Nevada has many hot springs, and thus is an ideal area for the study of, and exploration for, thermal resources. Therefore, geological and geochemical research was conducted in this thermal region (fig. 1).

The Black Rock Desert covers an area of about 4,190 km² in parts of Humboldt, Pershing, and Washoe Counties, Nevada. The town of Gerlach is in the southwest corner of the area, where the Black Rock, San Emidio, and Smoke Creek Deserts come together (fig. 1). A reconnaissance hydrogeochemical survey of approximately 3,200 km² was conducted covering parts of the Black Rock, Smoke Creek, and San Emidio Deserts. Both surface and groundwaters were analyzed to determine water quality and subsurface thermal reservoir temperatures to provide an evaluation of the area as a potential source of thermal energy. The field work was undertaken in December 1974, and January 1975, with detailed investigations during the summer of 1975.

Previous geologic work conducted in this region includes the description of the geology and mineral deposits of Washoe County by Bonham (1969), of Pershing County by Tatlock (1969), and of Humboldt County by Willden (1964).

GERLACH THERMAL AREA

The Gerlach hot spring system (Great Boiling springs) lies 1½ km northwest and west of the town of Gerlach, at the southeastern end of the Granite Range. All of the hot springs of this area

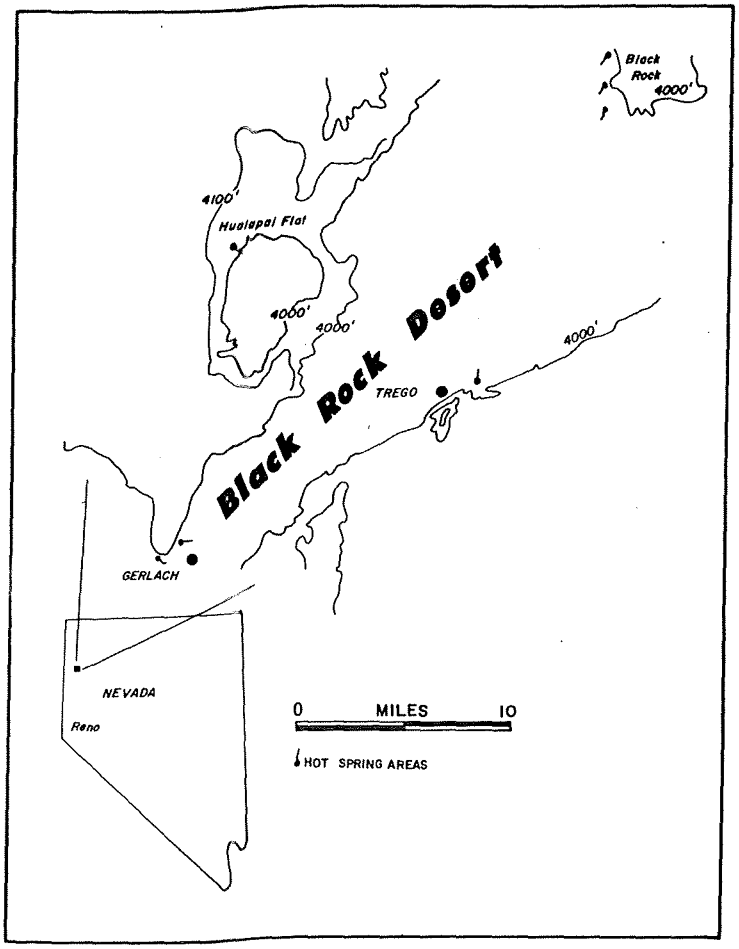

Figure 1.—Index map of study area.

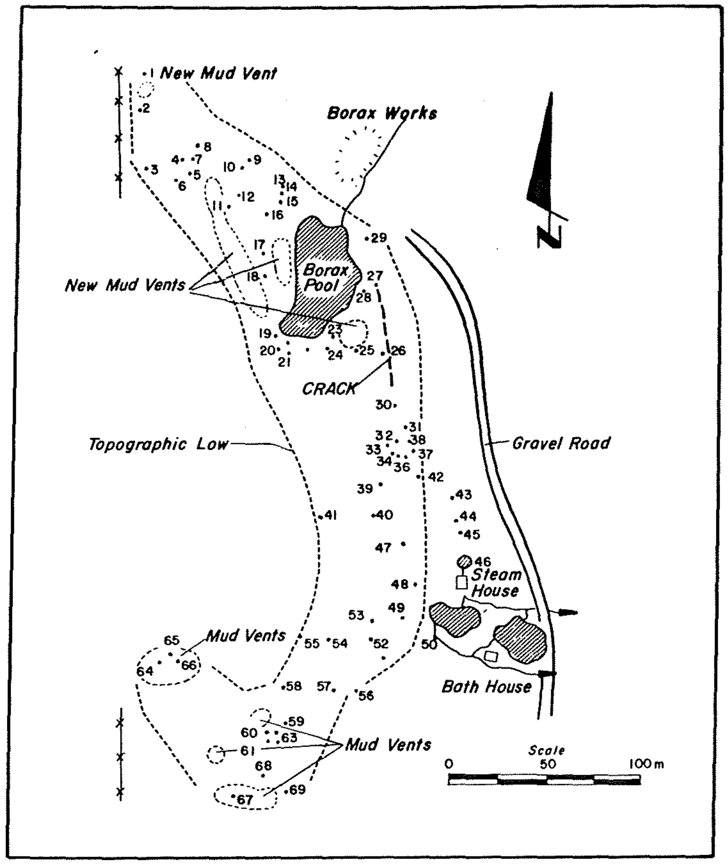

Figure 2.—Map of the Great Boiling springs showing spring and mud vent locations (see table 1). Based on work by Berry and Downs 1966 and Harrill 1973, *in* Olmstead and others 1975.

are within the Gerlach KGRA, which encompasses 8,972 acres and includes the town of Gerlach. The system comprises two spring clusters: the Great Boiling springs on the northeast in NW¼, sec. 15, T. 32 N., R. 23 E. (fig. 2) and the Mud springs on the southwest in SE¼, sec. 16, T. 32 N., R. 23 E. (fig. 3).

GREAT BOILING SPRINGS

The Great Boiling springs area (fig. 2) contains over 70 springs ranging in temperature from a few degrees above ambient (15°C) to boiling (greater than 94°C). Individual spring temperatures (table 1), measured in July 1975, are recorded and compared with temperatures measured by Harrill in July 1973 (Harrill 1973 *in* Olmstead and others 1975). From these data it is obvious that the Great Boiling springs area is very dynamic with large increases in temperature (up to 60°C) having occurred in the northern section of the area. Smaller increases (up to 20°C) were also noted in the southwestern section of this spring group. All the increases in temperature were noted in areas of recent mud vent activity.

Chloride ion concentrations were used to outline areas of most extensive thermal activity as suggested by Mahon (1970). An iso-chloride map was constructed for the Great Boiling springs area. The areas of highest chloride concentration correspond to areas of increased temperature and mud vent activity in the northern section of the Great Boiling springs. In general, this map outlines the area of greatest surface activity as noted by high spring temperatures, greatest increases in spring temperatures (table 1), and area of most intensive mud vent activity.

Siliceous sinter (SiO_2) occurs in the northern section of the Great Boiling springs, but probably was deposited in past times since these springs are not depositing sinter now. Siderite ($FeCO_3$) at present is being deposited by the springs throughout the Gerlach hot spring area.

Gravity surveys (Crewdson 1978, this volume) indicate that the basement is faulted, forming a horst and graben sequence. Fault scarps and hot springs were noted in close proximity throughout the region; therefore, it is likely that most of the hot springs of this area are structurally controlled.

Mixing of shallow nonthermal groundwater and thermal water is evident in the Gerlach KGRA (known geothermal resource area) as indicated by the wide range of temperatures of the springs (28 to 96°C). Nonthermal groundwater flowing from the mountain slopes mixes with the thermal water migrating up the permeable fault zones that flank the mountains.

Table 1.—Gerlach thermal area.

Spring Number	Temp.-July 75 (°C)	Temp.-July 73 (°C)	Difference (°C)
1	64.5	60.6	+3.9
2	49.0	40.0	+9.0
2 mv	59.3	——	——
3	64.1	49.4	+14.7
4	32.3	42.2	−9.9
5	44.0	50.0	−6.0
6	29.0	33.3	−4.3
7	dry	36.7	——
8	dry	43.3	——
9	75.0	72.2	+2.8
10	69.8	50.5	+19.3
11	69.5	31.7	+37.8
12	——	33.9	——
13	61.0	70.0	−9.0
14	41.8	36.7	+5.1
15	30.0	35.6	−5.6
16	47.5	36.7	+10.8
17	dry	57.8	——
18	58.0	50.6	+7.4
19	90.0	96.1	−6.1
20	38.3	48.3	−10.0
21	44.5	59.4	−14.9
22	55.3	40.6	+14.7
23	35.1	48.3	−13.2
24	93.5	33.3	+60.2
25	56.6	48.3	+8.3
26	62.8	61.7	+1.1
27	63.0	33.3	+29.7
28	95.5	42.8	+52.7
29	44.0	47.8	−3.8
31	60.5	74.4	−13.9
35	32.0	27.2	+4.8
37	65.0	48.9	+16.1
39	48.5	52.2	−3.7
40	31.8	35.6	−3.8
41	72.8	58.9	+13.9
42	28.3	28.9	−0.6
43	45.8	43.3	−2.5
44	55.8	56.7	−0.9
45	60.3	59.4	−0.9
46	83.8	86.7	−2.9
48	51.5	——	——
49	42.0	——	——
50	84.0	92.2	−8.2

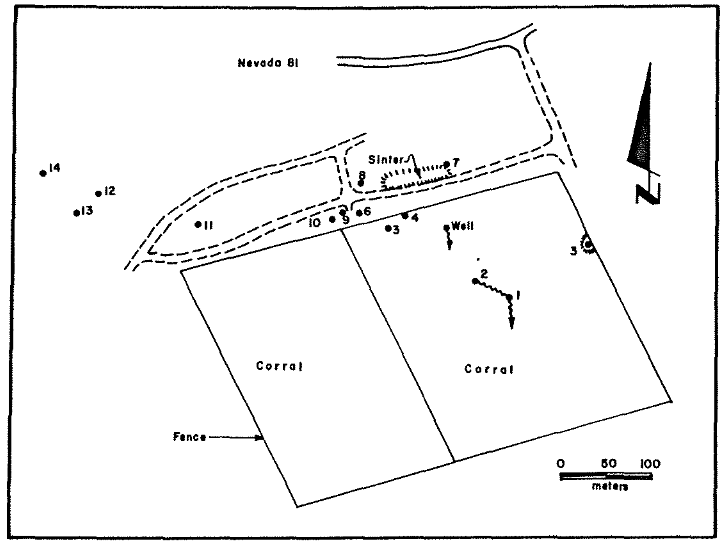

Figure 3.—Map of the Mud springs showing spring locations (see table 2). Based on work by Harrill 1973, *in* Olmstead and others 1975.

Table 2.—Temperatures of Mud springs thermal area and differences compared to Harrill's observations of 1973 (Olmstead and others 1975); blank space for new vent (hole dug in area)

Spring Number	Temp.-July 75 (°C)	Temp.-July 73 (°C)	Difference (°C)
1 pool	74.0	73.3	+0.7
vent	62.3	86.7	−24.4
2	60.5	60.6	0
3	65.5	65.6	0
4	85.0	85.0	0
5	72.5	72.8	0
6	38.8	37.8	+1.0
7	50.0	50.0	0
8	52.0	51.1	+0.9
9	84.3	84.4	0
10	43.6	44.4	−0.8
11	40.6	——	——
12	44.0	44.4	0
13	42.0	38.6	+3.4
14	56.3	59.4	−3.1

MUD SPRINGS

The Mud springs, 2½ km west of Gerlach, consist of 14 springs along an east-west lineation (fig. 3). A comparison of individual spring temperatures (table 2) measured by Harrill in July 1973 (Harrill 1973 *in* Olmstead and others 1975) indicates that the Mud springs have stayed fairly constant in temperature.

These springs occur at the intersection of an east-west lineation and the north-northeast trending fault along the east side of the Granite Range. This is consistent with the observation that the intersection of fault zones represents a more favorable site for rising thermal fluids than a single fault plane.

The thermal waters from these springs are identical in chemical quality to the thermal water from the Great Boiling springs, and so probably originate from the same reservoir (table 3).

FLY RANCH THERMAL AREA

The Fly Ranch hot spring cluster lies along the western margin of Hualapai Flat 30 km north of Gerlach. The springs issue from an equant mound nearly 2,000 feet (600 m) in diameter and bounded on the east side by a prominent east-facing fault scarp. The mound appears to be built up largely of hot spring deposits over the alluvium-and-soil-veneered floor of Hualapai Flat. The spring cluster is on a north-northeast trending intrabasin horst of Holocene age.

Table 3.—Comparison of the chemical quality of Mud springs and Great Boiling springs

	Mud Spring-2		Great Boiling Spring-19	
HCO	70 mg/l	1.15 epm	90 mg/l	1.48 epm
Co	0 mg/l	0.0 epm	0 mg/l	0.0 epm
Cl	2130 mg/l	60.0 epm	2100 mg/l	59.15 epm
SO	375 mg/l	7.8 epm	370 mg/l	7.7 epm
Total	2575 mg/l	68.95 epm	2560 mg/l	68.33 epm
Na	1470 mg/l	63.91 epm	1420 mg/l	61.74 epm
K	143 mg/l	3.67 epm	140 mg/l	3.59 epm
Ca	73 mg/l	3.65 epm	70 mg/l	3.50 epm
Mg	2.4 mg/l	0.2 epm	1 mg/l	0.08 epm
Total	1688 mg/l	71.43 epm	1631 mg/l	68.91 epm
SiO	165 mg/l		174 mg/l	
F	3.8 mg/l		4.5 mg/l	
B	1.1 mg/l		1.8 mg/l	
pH	7.0		7.4	
SEC*	8000		7600	
Temp	84.3°		98.0°	

*Electrical conductivity, microhos/meter.
Note: epm = equivalent per million.

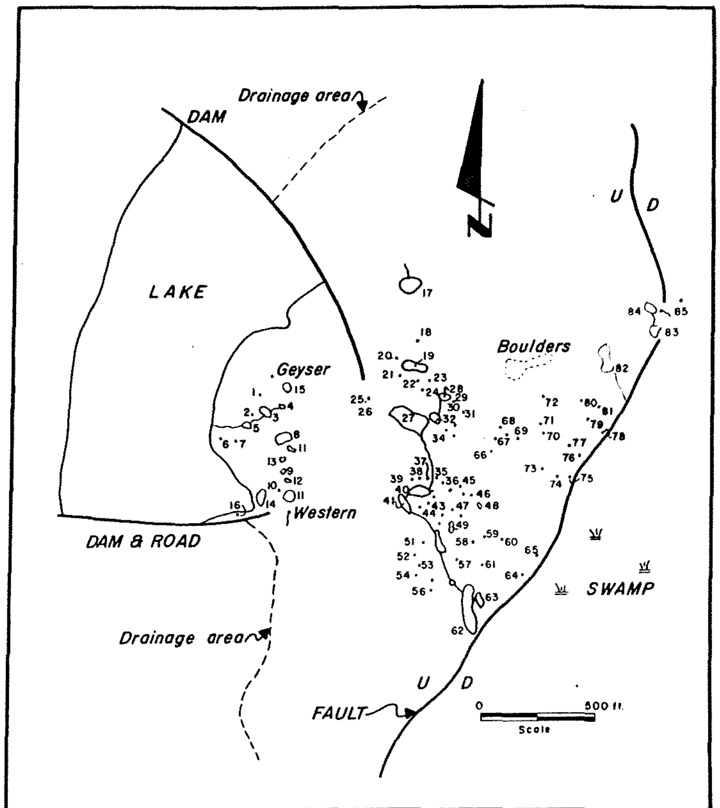

Figure 4.—Map of the Fly Ranch hot springs in secs. 1 and 2, T. 34 N., R. 23 E. showing the location of springs and wells. Based on U.S. Geol. Survey air photo GS-SWIR 1-9 and work by Berry and Downs 1966.

The Fly Ranch hot spring cluster includes about 120 springs and 4 wells that range in temperature from near ambient (15°C) to boiling (94°C; fig. 4 and table 4). Most of the springs contain water that is of mixed origin as indicated by the generally low temperatures (table 4). At the Geyser well, approximately 200 m north of the Western well, water temperature dropped sharply after a week of rain, then slowly increased over a 2-week period until it returned to its normal temperature of 86°C. Nonthermal surface runoff from the mountain slopes to the west probably migrates basinward, and mixes with thermal waters migrating up the permeable fault zone. The hottest springs occur on or very near the fault bounding the area to the east, giving some evidence for the migration of thermal waters up the fault zone.

Water flow from the four wells drilled in this area range in temperature from 86 to 96°C. The Western Geothermal, Inc. well (SW ¼, sec. 2, T. 34 N., R. 23 E.), drilled in 1964 to a depth of 1,008 feet (302.4m), still flows flashing 96°C water (Garside 1974). Approximately 8 km south of the hot springs, Western Geothermal, Inc. drilled an 800 foot (240 m) deep well at the Granite Creek Ranch (sec. 35, T. 34 N., R. 23 E.). This well was abandoned when shallow high temperatures and pressures caused the well to blow out (Garside 1974). All four wells and spring H-63 are depositing CaCO, either as travertine towers or as terraces of aragonite.

GEOCHEMICAL DATA

SAMPLING PROCEDURES

Analysis procedures established by the U.S. Geological Survey for sampling and analyzing groundwater were used (Brown and others 1970). Certain determinations were made in the field to minimize error, including the measurement of water temperature, conductivity, pH, and the concentrations of silica, sulfate, bicarbonate, and carbonate.

Chemical constituents determined included pH, electrical conductivity, alkalinity (HCO_3; CO_3), chloride $(Cl)^-$, sulfate $(SO_4)^=$ sodium (Na^+), potassium (K^+), calcium (Ca^{++}), magnesium (Mg^{++}), and silica (SiO_4). Total dissolved solids (TDS) were calculated by summation. Abnormally high concentrations of boron (B^{+++}) and fluoride (F^-) occur in the geothermal waters, and so, most of the samples were analyzed for these trace constituents.

NONTHERMAL WATER

The predominant dissolved ionic species in nonthermal waters are the anions Cl, and SO_4 and the cations Na, Ca, K and Mg. Silica (SiO_2) is also common. In table 5 we list the average chemical quality of nonthermal groundwater in the Black Rock Desert and surrounding regions. The anion HCO_3, a ubiquitous component of all naturally occurring surface and groundwaters, is common. There is no known significant source of Cl in the geologic sequence to account for the high level of concentration observed. Chloride within the system is thought to be derived principally from deep sources in the geothermal areas. Concentrations of Na and SiO_2 are great enough to suggest additional input from geothermal areas.

Table 4
Fly Ranch thermal area

Spring Location	Temp. (°C)	pH	Remarks
H-1	32.4	8.4	
H-2	33.0	8.36	
H-3	35.0	8.4	
H-4	27.0	8.4	
H-5	31.0	8.2	
Geyser well	86.0	8.4	Temp. after rain 56°C, 14 days later 86°C
H-8	43.0	7.5	
H-9	32.4	8.4	
H-10	35.0	8.4	
H-11	37.0	8.5	
H-12	39.0	8.28	
Western	96.0	7.2	Western geothermal well
H-14	34.0	8.6	
H-16	94.0	7.2	Well with travertine cone
H-17	32.0	8.15	
H-18	91.0	7.15	Well with travertine cone
H-19	34.6	——	
H-23	38.5	——	
H-24	29.0	——	
H-26	56.5	7.18	
H-27	31.5	7.9	
H-29	35.0	——	
H-30	30.5	7.8	
H-31	35.0	——	
H-33	44.0	——	
H-34	33.0	——	
H-38	47.6	——	
H-41	33.5	——	

Table 5.—Average chemical quality of nonthermal groundwater

Parameter	Average Value	Range	Average Ionic Ratio (%)
Temp (°C)	15.9	13-28.9	
pH	7.8	6.8-9.7	
SEC*	1085	288-8700	
TDS**(mg/l)	970	205-6553	
HCO_3 (mg/l)	275	74-1450	33.8
Cl (mg/l)	260	12-3250	54.8
SO_4 (mg/l)	73	6-300	11.4
Na (mg/l)	238	18-2050	75.6
K (mg/l)	15	.4-112	2.8
Ca (mg/l)	48	.2-650	17.5
Mg (mg/l)	7	.1-21	4.1
SiO_2 (mg/l)	54	18-100	

*Specific electrical conductance.
**TDS = total dissolved solids.

Figure 5 is a trilinear plot of the percentage of equivalent per million (epm) for the major anions and cations of the nonthermal waters. Averages of all values presented in table 5, column 3, are also plotted. The pattern indicates two distinctly different influences: (1) mixing with water high in Cl and Na, and (2) mixing with water high in dissolved SO_4 and Na. In the first case, mixing with water from geothermal areas is indicated (table 6). Waters high in SO_4 are most prevalent near those margins of the basins where volcanic rocks are present. As groundwater moves toward the center of the basin, the proportion of SO_4 gradually decreases.

Some of the increase in Na is most likely due to ion exchange. As waters move through the system, Na ions on minerals in the flow path are preferentially exchanged for Ca and Mg ions in the water, causing an increased percentage of Na in the water.

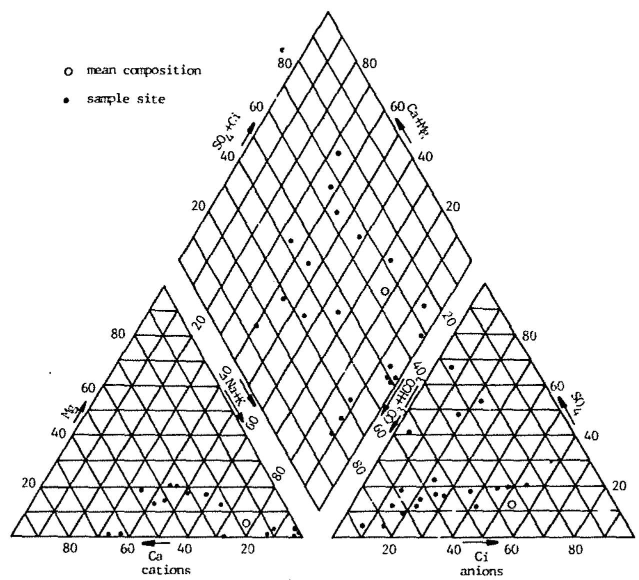

Figure 5.—Percentage chemical composition of nonthermal (less than 20°C) groundwaters in the Black Rock Desert region.

THERMAL WATER

The major ionic species in thermal waters are essentially the same as those in nonthermal waters, except that CO_3 is present in a few of the samples due to the somewhat higher pH levels encountered. Significant differences exist in the level of concentration and proportions of the various ions. Comparison of tables 5 and 6 shows these differences clearly.

Table 6
Average chemical quality of thermal water

Great Boiling Spring-19		
HCO_3	90 mg/l	1.48 epm
CO_3	0 mg/l	0.0 epm
Cl	2100 mg/l	59.15 epm
SO_4	370 mg/l	7.7 epm
Total	2560 mg/l	68.33 epm
Na	1420 mg/l	61.74 epm
K	140 mg/l	3.59 epm
Ca	70 mg/l	3.50 epm
Mg	1 mg/l	0.08 epm
Total	1631 mg/l	68.91 epm
SiO_2	174 mg/l	
F	4.5 mg/l	
B	1.8 mg/l	
pH	7.4	
SEC*	7600	
Temp	98.0°C	

*Specific electrical conductance.

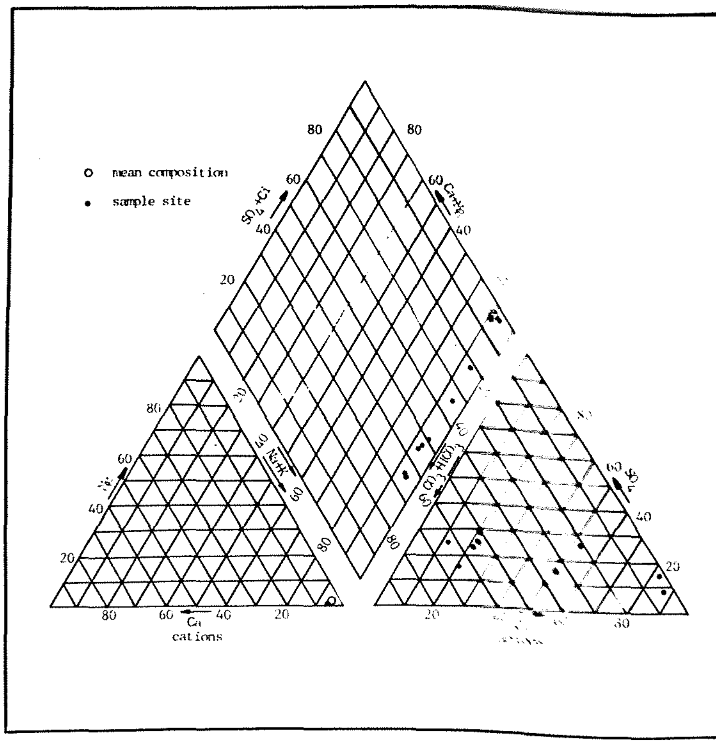

Figure 6.—Percentage chemical composition of thermal (30°C or greater) groundwaters in the Black Rock Desert region.

Table 6 shows a wide variation in concentrations of the major ions. Waters from each of the individual geothermal systems are consistent in composition. Figure 6 is a trilinear plot of thermal groundwater analyses from the Black Rock, San Emidio, and Smoke Creek Deserts, Hualapai Flat, and Pyramid Lake. Waters subjected to heating and slight mixing are seen to correspond closely to the composition of nonthermal waters (fig. 5). The effect of increased mixing is shown by the range of chemical compositions about the mean composition of the geothermal waters.

White (1957) has divided thermal waters of volcanic origin into several different types based on chemical composition. Water discharged from the geothermal systems of Trego, Gerlach, San Emidio Desert, Smoke Creek Desert, and Pyramid Lake is classified as Na-Cl. Thermal waters of this type are dominated by Na, Cl, and HCO_3, and are neutral in pH. Other characteristics include very high SiO content and significant F and Li concentrations.

Water discharged from the thermal areas of Soldier Meadows, Pinto Mt., Double Hot springs, and Hualapai Flat is classified as Na-HCO_3, and as such does not fit within the classification scheme proposed by White (1957). This composition is indicative of deep circulation of meteoric water near a heat source, with very little addition of magma-derived fluids. This hypothesis is based on: (1) lack of excessive Na and Cl and much lower concentration of B, and (2) close chemical correspondence between this water and nonthermal waters found near the margins of these basin areas.

GEOCHEMICAL THERMOMETERS

The distribution of single elements between different phases (rock/water) depends on temperature. Geochemical thermometers have been developed based on the measurement of the distribution coefficient of each element in different phases. There are several basic assumptions that have to be considered when using geochemical indicators to predict subsurface reservoir temperatures associated with thermal waters (Fournier and others 1974):

(1) Temperature-dependent reactions occur at depth.
(2) All constituents involved in a temperature-dependent reaction are sufficiently abundant.
(3) Water-rock equilibration occurs at the reservoir temperature.
(4) Little or no re-equilibration or change in composition occurs at lower temperatures as the water flows to the surface.
(5) The hot water coming from deep in the system does not mix with cooler, shallow groundwater.

Reservoir temperatures were estimated from silica content (Fournier and Truesdell 1974), the sodium-potassium ratio (White 1965 and 1968; Ellis 1969), and the sodium-potassium calcium contents (Fournier and Truesdell 1973). Table 7 lists the results of using the various geochemical thermometers on the thermal springs of the Black Rock, San Emidio, and Smoke Creek Deserts, Hualapai Flat, and Pyramid Lake. The silica (SiO_2) method is generally considered the most reliable for estimating subsurface temperatures. Therefore, the other methods should be interpreted only after studying the temperatures estimated by the silica method.

The two most promising geothermal prospects based on the use of geochemical thermometers are the Great Boiling springs area at Gerlach, and the hot springs along the eastern margin of the San Emidio Desert. The Great Boiling springs have an estimated

Table 7.—Estimations of subsurface temperatures.

Spring	Location	Surface (°C)	Silica (°C)	Na/K (°C)	Na-K-Ca (°C)	Silica Correction (°C/% mixing)
Gerlach	32/23-15	28-96	175-200	175	191-223	243/8-67%
Hualapai	34/23-2	25-96	125	115	155	145/50%
San Emidio	29/23-9	79-95	180-192	175	216	238/15-63%
Sold. Mea.	40/24-23	44-63	155	34	65	137/68%
'Well'	37/25-10	36	125	230*	223*	extensive mix
Pinto Mt.	40/28-30	93	165	155	165	————
Double Hot	36/26-4	77.6	140	65	130	175/61%
Black Rock	36/26-34	94.5	150	30	120	176/50%
Trego	33/25	86	128	50	120	163/65%
McCl.	33/25	36	135	100	151	extensive mix
Pyramid	26/21-12	60-82	140	175	210	195/65-81%
'New'	34/22-18	29	129	420*	86	extensive mix

*High values caused by extensive mixing.

subsurface temperature between 175 to 200°C, while the San Emidio springs have an estimated temperature between 180 to 216°C. There is indication of only slight mixing in the hotter springs of these areas, and the various geothermometers show excellent correlation.

Geochemical thermometers were used on the hot wells of the Fly Ranch KGRA (Hualapai Flat) rather than on spring discharge due to the extensive mixing of cold groundwater with the warm natural springs. The results indicate a low subsurface temperature range from 115 to 155°C, which is not a commercial temperature range by today's standards. A temperature range of 125 to 145°C is probably more realistic because some doubt still remains about using the Na/K and Na-K-Ca methods with the presence of travertine, and the uncertainity of the amount of cold water mixing.

Other hot spring areas that were not studied in detail, but show good agreement among the various geothermometers used to estimate reservoir temperatures, are: Pinto Mt. (155 to 165°C), Trego (120 to 128°C), and the Double Hot-Black Rock hot spring area (120 to 150°C).

CONCLUSIONS

All of the hot spring areas studied were noted to be closely associated with nearby normal faulting. Therefore, it is believed that all of the hot springs in the Black Rock Desert area are structurally controlled with hot water migrating up the fault zones. The rising hot water moves rapidly enough up these fault zones to reach the surface at temperatures greater than 94°C. Some of the rising hot water must also move laterally, and mix with shallow cold groundwater in some of the aquifers, since a wide range of temperatures was noted in most spring clusters.

The trilinear plots (figs. 5 and 6) suggest that the hot water of the various hot springs has a common source. All show high concentrations of Na and low concentrations of Ca and Mg. On the basis of these plots it is hypothesized that the source of the hot water is surface runoff (nonthermal groundwater). Na-HCO water flows from the upper ridges of the adjacent mountain areas and enters the basin through joints, fractures, and faults, or through the porous alluvial slopes that flank the mountains. The deeper the water migrates, and the longer its contact with the basin fill, the more saline it becomes. Therefore, the hot springs with Na-HCO type water are hypothesized to be derived from a shallow thermal reservoir which undergoes extensive mixing with shallow cold groundwater. The hot spring areas with Na-HCO type water are Soldier Meadows, Double Hot springs, and the Fly Ranch hot springs.

All of the hot spring areas that show chemical evidence of commercial subsurface temperatures are characterized by Na-Cl type water, and are thought to be associated with the deeper sections of their related basins. The hot spring areas with Na-Cl water are Black Rock spring, Trego hot spring, Great Boiling springs and Mud springs at Gerlach, San Emidio Desert springs, and the springs at the Needles area of Pyramid Lake.

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