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GEOCHEMISTRY OF ACTIVE GEOTHERMAL SYSTEMS IN THE NORTHERN BASIN AND RANGE PROVINCE

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ABSTRACT

Numerous thermal springs occur in the northern Basin and Range Province due primarily to the structure and high regional heat flow. Dilute to slightly saline (200 to 3,000 mg/L TDS) Ca and/or Na-HCO_3 type waters, many associated with travertine, are dominant in eastern and northeastern Nevada. CO_2-charged Na-HCO_3 waters are particularly common along the eastern side of the Sierra Nevada from Long Valley north to Bridgeport. Moderately to very saline (3,000 to 35,000 mg/L TDS) Na-Cl type waters predominate near major topographic lows. Na-SO_4 type waters are common in western Nevada and in northeastern California. Na-mixed anion waters are common along the north side of the Black Rock Desert in northwestern Nevada and the Alvord Desert in southeastern Oregon.

Measured temperatures in deep geothermal wells in the northern Basin and Range Province are about 14°C cooler than the average temperature calculated using two chemical and one isotope geothermometer on waters discharged by nearby thermal springs and shallow wells (<100m). Isotopic data (δD) for thermal springs in the northern Basin and Range have the same general pattern as modern precipitation. However, the few detailed studies of recharge areas for specific systems have generally found local cold waters to be slightly more enriched in deuterium than water currently discharged by the thermal springs. This probably indicates that the water currently being discharged by the hot springs was recharged during colder time periods, perhaps the Pleistocene.

Introduction

Although chemical analyses of a few hot springs in the northern Basin and Range were published in the late 1800's (Peale 1886, Church 1878), the first detailed studies were begun by Don White at Steamboat Springs in the late 40's and continued into the early 60's (White and Brannock, 1950, White and others, 1964). Research activities exploded in the 70's as interest in the geothermal resource increased. Most thermal springs in the northern Basin and Range Province have now been sampled and one or more analyses are available in the literature. Compilations of chemical data for thermal springs in the various states which include parts of the northern Basin and Range Province have been presented by Mundorff (1970), and Goode (1978) for Utah, Garside and Schilling (1979) for Nevada, Majmundar (in press) for California, and U.S. Geological Survey and Oregon Department of Mineral Industries (1979) for Oregon. Locations and temperatures of thermal springs and wells have also been compiled by Waring (1965) and Berry and others (1980). Figure 1 shows the outline of the northern part of the Basin and Range Province (Great Basin) along with physical features mentioned in the text.

Chemical Composition of Water

Chemically, the thermal waters of the Basin and Range Province range from dilute (<1,000 mg/L TDS) Na-HCO_3 or Ca-HCO_3 type waters to very saline (10,000-35,000 mg/L TDS) Na-Cl type waters (Table 1). The chemical constituents in thermal waters are derived primarily from the country rock by dissolution of, or exchange with, the rock-forming minerals (Ellis and Mahon, 1964, 1967). Ideally, concentrations of silica, sodium, potassium, calcium and magnesium are controlled by mineral-water equilibria. However, other constituents such as chloride don't attain concentrations sufficient to reach saturation with respect to any chloride bearing minerals.

Na-Cl type thermal waters of moderate salinity occur in northwestern Nevada and west-southwest of Tonopah (Fig. 2). Na-Cl type thermal waters also discharge along the eastern edge of the Basin and Range Province in Utah and southeastern Idaho. These waters result from the extensive reaction of thermal fluids with sedimentary rocks deposited in a marine environment. Sulfate in the Na-Cl type water of Utah is primarily of marine origin based on both the oxygen and sulfur isotopic compositions of dissolved sulfate (Nehring and Mariner, 1979, Cole, 1982). Locally, chemical and isotopic data indicate some admixture with chloride-rich saline-lake or playa waters may have occurred. High chloride concentrations can also be attained by circulation through some granites (Moore and others, 1983), however, the extent of

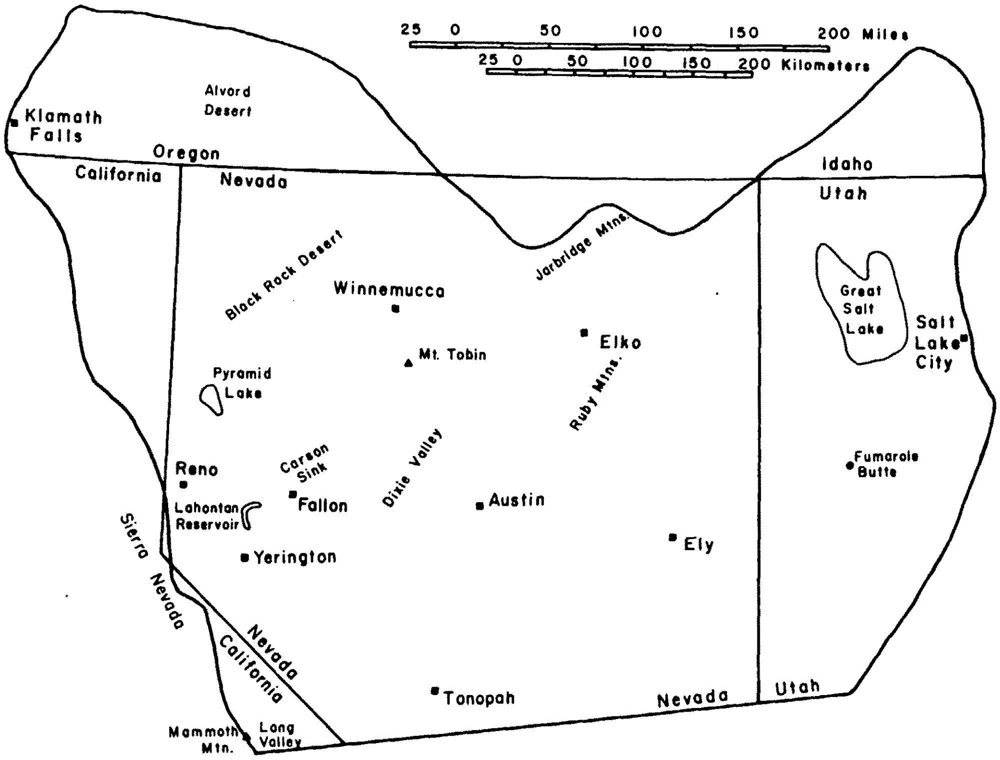

Figure 1. Location map of the major population centers and features mentioned in the text.

this process in the Basin and Range is unknown. High chloride concentrations are an indication that more extensive water-rock reaction has taken place, and this may infer longer flow paths and generally deeper circulation. Most high temperature geothermal wells in the Great Basin have encountered Na-Cl waters.

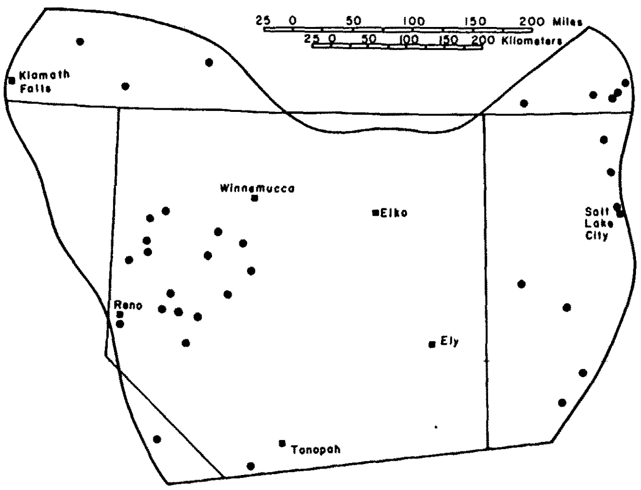

Figure 2. Distribution of Na-Cl waters in the northern Basin and Range Province.

Bicarbonate waters range from dilute to slightly saline depending largely on the source of the dissolved CO_2. If CO_2 is generated at depth and dissolved under pressure in the thermal water, then a high TDS CO_2-charged water will be produced. High TDS CO_2-charged waters are particularly common adjacent to the southern Sierra Nevada. The more saline CO_2-charged waters are slightly radioactive due to their high radium and radon content (Femlee and Cadigan, 1982, and Wollenberg, 1974). Enough calcium is present in most of these waters to form travertine mounds and terraces. Fales and Travertine hot springs, near Bridgeport, California discharge this type of water as does Hyder Hot Springs, in Dixie Valley, Nevada. However, if the CO_2 is dissolved from the atmosphere, or soil gas, then the dissolved carbon concentrations and related total dissolved solids will be very low. Darrough and Soldier Meadows hot springs in central and northwestern Nevada are good samples of dilute Na-HCO_3 waters. Dilute Na-HCO_3 and Ca-HCO_3 type waters are particularly common in central and eastern Nevada (Fig. 3). A dilute Ca-HCO_3 water will be produced if the principal bedrock is a limestone and these waters are common in eastern Nevada where Paleozoic limestones crop out. The dilute Na-HCO_3 waters develop in areas where the rock contains appreciable sodium silicate or sodium aluminosilicate minerals and only small amounts of CO_2 are available.

Dilute to slightly saline Na-SO_4 (± Cl) waters occur principally in northeastern California and the adjacent part of Nevada (Fig. 4). High sulfate concentrations can result from dissolution of gypsum (anhydrite) in sedimentry rocks or dissolution of minerals such as alunite, jarosite, anhydrite, or pyrite from mineralized zones (Hem, 1970). Oxidation of sulfide to sulfate can also produce large sulfate concentrations and acid sulfate waters (White and others, 1971) but these are rare in the Basin and Range Province. The oxygen isotopic compositions of marine and hydrothermal sulfate are quite different (Longinelli and Craig, 1967, and McKenzie and Truesdell, 1977) thus it is relatively easy to differentiate between them. Sulfates in the waters of the western part of the Great Basin generally range from 0 to -10 o/oo in oxygen-18 (Nehring and Mariner, 1979) and have a possible source in the sulfate minerals associated with ore deposits and gossans. Gypsum and anhydrite deposits in Mesozoic marine rocks are also fairly common in western Nevada, however, only one of the hot springs for which isotopic data is available,

Table 1. Chemical Composition of Selected Thermal Waters of the Northern Basin and Range--continued. [Concentrations are in mg/L, temperatures are in °C; sodium (Na) values followed by K represent sodium plus potassium; dashes (-) indicate no data.]

Name/Location	Temp	pH	SiO_2	Ca	Mg	Na	K	HCO_3	Cl	SO_4	F	Reference
CALIFORNIA Alpine County												
Unn. sprs. on the Carson River SENESE, sec. 34, T. 11 N., R. 20 E.	84	6.63	178	76	6.5	510	40	388	355	550	6.3	Unpub. data, Mariner and others
Unn. sprs. on the Carson River NWSW, sec. 26, T. 11 N., R. 20 E.	65	6.52	110	125	4.0	480.	21	333	295	700	2.4	Unpub. data, Mariner and others
Lassen County												
Amadee Hot Springs NESW, sec. 08, T. 28 N., R. 16 E.	96	8.36	98	15	<.1	235	5.7	57	155	280	4.6	Mariner and others, 1976a
Bassett Hot Springs NWSE, sec. 12, T. 38 N., R. 7 E.	79	8.53	65	30	<.1	220	3.2	32	93	370	2.0	Reed, 1975
Kellog Hot Springs SWSE, sec. 15, T. 38 N., R. 8 E.	78.4	8.63	85	30	<.1	240	5.9	35	110	370	2.6	Reed, 1975
Wendell Hot Springs NESW, sec. 23, T. 29 N., R. 15 E.	95.5	8.26	125	20	<.1	280	8.0	53	185	340	4.2	Mariner and others, 1976a
Zamboni Hot Spring NWNW, sec. 24, T. 24 N., R. 17 E.	41	9.37	36	2.2	.02	66	.57	74	14	57	2.0	Unpub. data, Mariner and others
Modoc County												
Hot Springs Motel NESW, sec. 06, T. 42 N.,R. 17 E.	98	8.40	100	16	<.01	280	5.5	61	200	320	5.1	Reed, 1975
Kelly Hot Springs NENW, sec. 29, T. 42 N., R. 10 E.	91.5	8.08	110	20	<.1	250	6.5	47	160	300	2.1	Reed, 1975
Leonards Hot Springs NENE, sec. 13, T. 43 N., R. 16 E.	61.8	7.82	110	26	.6	330	8.5	84	220	390	5.2	Reed, 1975
Little Hot Springs NWSW, sec. 9, T. 39 N., R. 5 E.	75.7	7.59	87	44	.2	230	5.2	49	120	400	1.9	Reed, 1975
Seyforth Hot Springs NWNW, sec. 12, T. 39 N., R. 5 E.	85	7.66	110	28	<.1	300	9.0	63	220	370	5.4	Reed, 1975
West Valley Reservoir (spring) NWNE, sec. 29, T. 39 N., R. 14 E.	77.3	7.79	130	19	<.1	330	11.	63	150	510	4.0	Reed, 1975
Mono County												
Benton Hot Springs SW, sec. 2, T. 2 S., R. 31 E.	56.5	9.32	63	1.4	<.1	80	1.0	96	22	50	3.8	Mariner and others, 1977
Fales Hot Springs SE, sec. 24, T. 6 N., R. 23 E.	61	6.55	114	41	10	560	37	1130	160	260	4.7	Mariner and others, 1977
Long Valley-Hot Creek Gorge NE, sec. 25, T. 3 S., R. 28 E.	90	6.6	150	1.6	.1	400	24	549	225	100	9.6	Mariner and Wiley, 1976
Mono Lake - North Shore sec. 11, T. 2 N., R. 26 E.	66	7.68	76	13	2.9	430	8.8	454	350	100	4.8	Mariner and others, 1977
- South Shore sec. 18, T. 1 N., R. 27 E.	33	6.38	130	120	61	410	34	1560	105	28	.4	Mariner and others, 1977
Travertine Hot Spring SW, sec. 34, T. 5 N., R. 25 E.	69	6.73	100	64	18	1100	55	1800	200	920	4.5	Mariner and others, 1977
IDAHO Bear Lake County												
Bear Lake Hot Spring SW, sec. 13, T. 15 S., R. 44 E.	47.5	6.6	35	210	55	180	61	256	79	800	7.1	Young and Mitchell, 1973
Cassia County												
RRGE-1 sec. 23, T. 15 S., R. 26 E.	95	8.9	144	58	0.3	505	35	46	896	59	6.2	Nathenson and others, 1982
Franklin County												
Maple Grove Hot Springs NE, sec. 7, T. 13 S., R. 41 E.	76	7.3	55	89	24	490	40	491	630	260	1.1	Young and Mitchell, 1973
Wayland Hot Springs NE, sec. 8, T. 5 S., R. 39 E.	77	7.0	80	160	16	3100	660	699	5400	50	12	Young and Mitchell, 1973
Oneida County												
Woodruff Hot Springs NE, sec. 10, T. 16 S., R. 36 E.	27	7.3	29	130	45	910	87	454	1600	58	.6	Young and Mitchell, 1973

Table 1. Chemical Composition of Selected Thermal Waters of the Northern Basin and Range--continued. [Concentrations are in mg/L, temperatures are in °C; sodium (Na) values followed by K represent sodium plus potassium; dashes (-) indicate no data.]

Name/Location	Temp	pH	SiO_2	Ca	Mg	Na	K	HCO_3	Cl	SO_4	F	Reference
NEVADA												
Carson City												
Carson Hot Springs, SENE, sec. 5, T. 15 N., R. 20 E.	49	9.3	-	2.6	.4	96	-	92	29	96	-	Worts & Malmberg, 1966
Pinyon Hills Well sec. 23, T. 15 N., R. 20 E.	46	8.6	-	275	3	254	-	41	33	135	4.3	CWRR, 1973
Churchill County												
Dixie Valley Hot Springs SE. sec. 5, T. 22 N., R. 35 E.	72	8.6	115	3.2	.02	190	6.5	133	126	111	16.3	Mariner and others, 1974
Dixie Federal 52-18 NE, sec. 18, T. 24 N., R. 37 E.	boiling	8.27 @32°C	383	4.4	.03	385	36	379	307	127	7.0	Unpub. data, Mariner and others
Brady's Hot Spring (well) SW, sec. 12, T. 22 N., R. 26 E.	-	6.78 @24°C	164	45	.32	850	36	111	1140	320	5.8	Unpub. data, Mariner and others
Eagle Salt Works Spring sec. 34, T. 22 N., R. 26 E.			259	32	2	839	-	99	955	334		Adams, 1944
Soda Lake-Upsal Hogback SW, sec. 28, T. 20 N., R. 28 E.	boiling	7.86 @42°C	160	82	2.1	1000	48	144	1500	360	.6	Mariner and others, 1975
Stillwater Area SW, sec. 07, T. 19 N., R. 31 E.	96	7.57	170	108	1.7	1480	42	90	2200	190	5.0	Mariner and others, 1974
Lee Hot Springs Unsurveyed (39°12'N b 118°43'W)	88	7.4	180	44	.6	450	26	114	380	470	7.9	Mariner and others, 1974
Douglas County												
Hobo Hot Spring SESE, sec. 23, T. 14 N., R. 19 E.	46	8.9	47	6	.7	125	1.7	85	74	109	7.1	Glancy and Katzner, 1975
Saratoga Hot Springs SESE, sec. 23, T. 14 N., R. 20 E.	50	9.0	20	172	-	160k	-	18	39	678	9.0	Glancy and Katzner, 1975
Walley's Hot Spring NE, sec. 22, T. 13 N.,R 19 E.	62	8.8	58	10	.01	145	3.6	68	44	235	4.9	Mariner and others, 1974
Elko County												
Nile Spring SW, sec. 30, T. 47 N., R. 70 E.	43	7.2	31	40	11.5	10	5.6	149	8.7	37	.4	Mariner and others, 1974
Trout Creek Ranch Well NWNW, sec. 23, T. 46 N., R. 69 E.	43	8.3	21	16	5.7	24	5.6	120	2	22	.6	Moore and Eakin, 1968
San Jacinto Ranch Spring NWNW, sec. 23, T. 46 N., R. 64 E.	26	8.1	18	25	8.6	13	3.9	132	3.9	11	.5	Moore and Eakin, 1968
Rizzi Ranch Hot Spring sec. 29, T. 45 N., R. 54 E.	41	7.4	23	29	7.7	110	8.3	380	4.4	36	3.4	Moore and Eakin, 1968
Mineral (Contact) Hot Springs sec. 16, T. 45 N., R. 64 E.	60	9.1	83	1.6	<.01	75	2.2	108	15	45	8.9	Mariner and others, 1974
Wild Horse Hot Spring SESE, sec. 4, T. 43 N., R. 55 E.	54	7.2	40	48	12	130	22	482	14	40	5.2	Mariner and others, 1974
Hot Creek Springs NW, sec. 12, T. 28 N., R. 52 E.	26	7.30	20	46	23.5	10	2.1	228	4.6	27	<.1	Mariner and others, 1974
Hot Creek Springs NW, sec. 34, T. 43 N., R. 60 E.	37.5	6.76	139	62	20	23	17	307	3	51	.78	Mariner and others, 1975
Hot Sulphur Spring NE, sec. 8, T. 41 N. , R. 52 E.	92	7.32	165	9.4	.22	160	15	367	16	54	9.6	Mariner and others, 1975
Wine Cup Ranch Well NWNW, sec. 25, T. 41 N., R. 64 E.	59	8.4	-	49	17	139k	-	426	30	69	-	Rush, 1968b
Hot Lake NNW, sec. 25, T. 38 N., R. 46 E.	18	7.2	57	29	5.8	33	7.0	132	22	34	.4	Unpub. data, Mariner and others
Unnamed spring on Rock Creek SWSW, sec. 1,T. 39 N., R. 47 E.	35	6.87	23	41	11	86	14	330	13	62	2.4	Unpub. data, Mariner and others
Humboldt Wells Area SE, sec. 20, T. 38 N., R. 62 E.	60	6.58	110	78	36	300	30	1210	26	24	6.1	Mariner and others, 1975
Hot Hole NE, sec. 21, T. 34 N., R. 55 E.	56	7.21	65	60	15.5	120	39	490	16	72	1.9	Mariner and others, 1974
Hot Spring near Carlin sec. 33, T. 33 N., R. 52 E.	79	7.6	70	60	15	45	16	335	12	52	-	Mariner and others, 1974
Sulphur Hot Spring NW, sec. 11, T. 31 N., R. 59 E.	93	8.53	210	1.0	.03	135	8.9	274	23	40	17.7	Mariner and others, 1974
Smith Ranch (Unn. spr. - Ruby Marsh) NW, sec. 2., T. 27 N., R. 58 E.	65	8.0	50	45	12	58	14	377	6.5	24	-	Mariner and others, 1974
Esmeralda County												
Alkali Springs NW, sec. 26, T. 01 S., R. 41 E.	60	8.1	-	46	4.6	349k	-	348	68	492	-	Rush, 1968a
Silver Peak (Waterworks) Hot Springs SE,sec. 15, T 02 S., R. 39 E.	40	7.18 @19°C	105	540	71	10000	750	559	17000	410	4.1	Unpub. data, Mariner and others
Eureka County												
Beowawe SW, sec. 08, T. 31 N., R. 48 E.	98	8.98	320	1.0	<.1	230	16	383	69	130	17	Mariner and others, 1974
Hot Springs Point NW, sec. 11, T. 29 N., R. 48 E.	54	6.63	67	53	35	230	58	913	1	7	6.6	Mariner and others, 1974
Bruffey's (Mineral Hill) Hot Spring sec. 14, T. 27 N., R. 52 E.	66	7.0	58	52	16	39	8.7	287	14	27	.7	Roberts, Montgomery, and Lehner, 19
Walti Hot Springs SW,sec. 33, T. 24 N., R. 48 E.	72	6.47	68	56	12	44	14	264	12	64	2.5	Mariner and others, 1974
Shipley Hot Springs NESE, sec. 23, T. 24 N., R. 52 E.	39	7.2	40	57	21	29	5.9	279	21	35	.2	Eakin, 1962a
Klobe Hot Springs Bartholomae) SE, sec.28, T. 18 N., R. 50 E.	54	9.25	85	1	<.1	64	.7	144	6.3	18	-	Mariner and others, 1974

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Name/Location	Temp	pH	SiO_2	Ca	Mg	Na	K	HCO_3	Cl	SO_4	F	Reference
Humboldt County												
Cordero Mercury Mine well												
SE, sec. 28, T. 47 N., R. 37 E.	60	-	57	36	10	62k	-	195	34	56	-	Visher, 1957
Bog Hot Springs												
SWNW, sec. 07, T. 46 N., R. 28 E.	54	9.05	57	.2	<.1	81	1.0	138	15	45	1.7	Mariner and others, 1974
Baltazor Hot Springs (well)												
NW, sec. 13, T. 46 N., R. 28 E.	90	7.50	150	10	.1	180	8.2	156	47	230	6.8	Mariner and others, 1974
Howard Hot Springs												
NE, sec. 04, T. 44 N., R. 31 E.	56	9.2	85	3	<.1	88	1.7	127	10	62	-	Mariner and others, 1974
Dyke Hot Springs												
SE, sec. 25, T. 43 N., R. 30 E.	66	8.86	85	1.8	<.1	150	4.3	277	21	82	8.0	Mariner and others, 1974
The Hot Springs												
NE, sec. 20, T. 41 N., R. 41 E.	58	8.0	55	10	8	296	36	881	26	36	-	Mariner and others, 1974
Soldier Meadows Hot Springs												
sec. 23, T. 40 N., R. 24 E.	54	8.53	63	3.1	<.1	74	1.1	98	18	41	12	Mariner and others, 1974
Pinto Hot Springs												
ESE,sec. 17, T. 40 N., R. 28 E.	93	7.14	150	14	.4	330	23	497	160	120	12	Mariner and others, 1974
Double Hot Springs												
sec. 4, T. 36 N., R. 26 E.	80	7.93	105	4.8	.1	180	4.5	265	59	120	10	Mariner and others, 1974
Macfarlane's Bath House Spring												
NW, sec. 27, T. 37 N., R. 29 E.,	75	6.61	82	43	11	1350	28	2050	870	210	2.6	Unpub. data, Mariner and others
Well												
SWSE, sec. 03, T. 37 N., R. 39 E.	70	7.4	-	30	7.1	450	26	1240	14	52	-	Cohen, 1962
Golconda Area												
SE, sec. 29, T. 36 N., R. 40 E.	74	6.53	66	33	6.8	130	22	429	18	56	1.8	Mariner and others, 1974
Hot Pot												
SW, sec. 11, T. 35 N., R. 43 E.	57	6.95	39	18	5.3	660	28	1625	61	155	9.4	Unpub. data, Mariner and others
Hot Spring Ranch (Tipton)												
SE, sec. 05, T. 33 N., R. 40 E.	85	8.36	125	16	.9	200	18	385	41	140	-	Mariner and others, 1974
Lander County												
Buffalo Valley Hot Springs												
SE, sec. 23, T. 28 N., R. 41 E.	49	6.53	80	45	4.9	250	34	813	29	110	4.8	Mariner and others, 1974
" " " " " " " " "	73	-	71	43	5.2	295	33	-	29	104	4.6	Unpub. data, Mariner and others
Hot Springs Ranch (Valley of the Moon)												
NE, sec. 23, T. 27 N., R. 43 E.	53	8.0	40	20	9	118	21	333	21	64	-	Mariner and others, 1974
South Smith Creek Valley												
NE, sec. 25, T. 17 N., R. 39 E.	86	7.72	110	4.8	.06	170	8.4	256	22	102	8.9	Mariner and others, 1974
Spencer Hot Springs												
SE, sec. 13, T. 17 N., R. 45 E.	72	6.49	77	43	9.4	200	36	672	22	51	4.7	Mariner and others, 1974
Unnamed spring near Walti Hot Springs												
Unsurveyed 39°56.6'N by 116°40.8'W	64	6.51	83	66	11	135	42	559	32	58	4.1	Unpub. data, Mariner and others
Lyon County												
Hazen Area												
SW, sec. 18, T. 20 N., R. 26 E.	86	7.05	150	70	1.5	620	38	100	820	400	4.2	Mariner and others, 1975
Wabuska Hot Springs												
SE, sec. 16, T. 15 N., R. 25 E.	94	8.06	110	39	.1	300	14	74	55	620	8.2	Mariner and others, 1975
Hind's (Nevada) Hot Springs												
SE, sec. 16, T. 12 N., R. 23 E.	61	8.65	52	4.5	.01	102	2.5	69	17	169	3.1	Mariner and others, 1974
Wedell Springs												
SW, sec. 07, T. 12 N., R. 34 E.	60	7.83 @50°C	153	13	.2	270	9.2	214	78	315	12	Unpub. data, Mariner and others
Nye County												
Diana's Punch Bowl												
SE, sec. 22, T. 14 N., R. 47 E.	59	7.14	46	50	11	55	15	277	8	59	2.8	Mariner and others, 1974
Darrough's Hot Spring												
sec. 08, T. 11 N., R. 43 E.	95	8.29	98	1.3	.1	110	2.6	152	12	53	14	Mariner and others, 1974
Hot Creek Ranch Springs												
sec. 29, T. 08 N., R. 50 E.	63	8.0	135	51	15.1	197	13.4	545	42	86.4	8	Sanders and Miles, 1974
Upper Hot Creek Ranch Springs												
NESE, sec. 29, T. 08 N., R. 50 E.	67	8.1	161	33	9.5	193	1.4	501	37	64	8.3	USGS, 1977
Warm (Nanny Goat) Spring												
NWSW, sec. 20, T. 04 N., R. 50 E.	61	8.1	60	43	24	175	24	714	32	120	-	Mariner and others, 1974
Pershing County												
Colado (wells)												
SE, sec. 33, T. 28 N., R. 32 E.	60	7.56 @38°C	85	110	6.5	1450	120	199	2400	120	4.6	Mariner, Brook, Swanson and Mabey, 1978
Kyle Hot Springs												
SW, sec. 01, T. 29 N., R. 36 E.	77	6.50	150	95	25.5	540	80	544	770	51	5.7	Mariner and others, 1974
Trego Area												
40° 46'N by 119° 7'W	84.5	7.93	79	11	.4	430	8.6	163	500	180	4.1	Mariner and others, 1976
Leach Hot Springs												
SE, sec. 36, T. 32 N., R. 38 E.	92	7.4	135	8.8	.5	160	13	368	29	53	7.8	Unpub. data, Mariner and others
Humboldt House (Rye Patch)												
SE, sec. 21, T. 31 N., R. 33 E.	-	-	340	43	3.6	1350	240	202	2250	18	6.2	Unpub. data, Mariner and others
art. well	77	-	162	120	7.2	1400	240	380	2300	39	5.3	Unpub. data, Mariner and others
	-	-	440	90	1.0	2000	240	43	3600	90	-	Benoit, 1978
Sou Hot Springs												
SE, sec. 29, T. 26 N., R. 38 E.	70	7.3	64	106	19.8	167	26	324	77	354	5.5	Sanders and Miles, 1974
Hyder Hot Springs												
SW, sec. 28, T. 25 N., R. 38 E.	78	6.77	63	41	10	390	20	926	45	120	8.6	Mariner and others, 1976

Table 1. Chemical Composition of Selected Thermal Waters of the Northern Basin and Range--continued. [Concentrations are in mg/L, temperatures are in °C; sodium (Na) values followed by K represent sodium plus potassium; dashes (-) indicate no data.]

Name/Location	Temp	pH	SiO_2	Ca	Mg	Na	K	HCO_3	Cl	SO_4	F	Reference
Washoe County												
Fly Ranch (Ward's)												
sec. 02, T. 34 N., R. 23 E.	80	7.91	82	31	4.2	340	17	466	240	46	7.0	Mariner and others, 1974
Great Boiling Spring												
NW, sec. 15, T. 32 N., R. 23 E.	86	7.15	165	68	1.2	1400	130	83	2200	400	4.5	Mariner and others, 1974
San Emidio Desert												
Unsurveyed - 40°23'N 119°24'W	89	6.57	205	160	2.2	1400	110	102	2300	220	5.1	Mariner and others, 1976
The Needle Rocks												
NWSWSW, sec. 06, T. 26 N., R. 21 E.	56	8.43	110	260	.1	1100	160	24	1900	340	3.0	Mariner and others, 1974
Lawton Hot Springs												
SWNE, sec. 13, T. 19 N., R. 18 E.	49	9.0	46	6.2	.1	117	5.4	52	57	144	2.5	Cohen and Loeltz, 1964
Moana Springs Area (Biglin well)												
NESE, sec. 26, T. 19 N., R. 19 E.	85	8.0	106	23	.08	236	8.0	86	48	455	5.1	Bateman and Scheibach, 1975
Steamboat Springs												
NE, sec. 33, T. 18 N., R. 20 E.	94	7.19	270	16	.7	680	66	368	837	73	2.1	Mariner and others, 1974
Bowers Mansion Hot Springs												
NW, sec. 03, T. 16 N., R. 19 E.	46	9.36	47	2.9	.2	50	0.6	76	6.3	38	2.8	Mariner and others, 1975
White Pine County												
Cherry Creek Hot Springs												
sec. 6, T. 23 N., R. 63 E.	61	7.77	105	12	.3	150	4.8	380	16	1	1.2	Mariner and others, 1975
Monte Neva Hot Springs												
sec. 24, T. 21 N., R. 63 E.	79	6.35	52	63	21	16	5.6	303	5.0	26	1.0	Mariner and others, 1975
OREGON												
Harney County												
Alvord (Indian) Hot Springs												
SE, sec. 33, T. 34 S., R. 34 E.	78.5	6.90	128	12	2.2	1000	63	1230	770	180	11	Mariner and others, 1974
Crane Hot Springs												
SW, sec. 34, T.24 S., R. 33 E.	78	8.1	83	3.7	.1	170	3.9	208	79	86	9.0	Mariner and others, 1974
Mickey Hot Springs												
sec. 13, T.33 S., R. 35 E.	86	8.31	214	1.0	.1	550	30	814	240	220	17	Mariner and others, 1974
Trout Creek Hot Springs												
sec. 16,T. 39 S., R. 37 E.	52	6.77	105	18	.8	270	10.8	441	24	204	12.8	Mariner and others, 1974
Unn. Sprs. near Hot Lake												
SE, sec. 36, T. 27 S., R. 29 E.	96	7.30	160	14	.3	450	28	382	250	434	7.2	Mariner and others, 1974
Unn. Sprs. near Harney Lake	68	7.26	92	12	1.8	630	13	568	590	140	3.3	Mariner and others, 1974
Lake County												
Barry Ranch Hot Springs												
SE, sec. 27, T. 39 S., R. 20 E.	88	7.76	130	8.8	.1	280	9.0	236	170	240	5.4	Mariner and others, 1974
Crump												
SW, sec. 34,T. 38 S., R. 24 E.	78	7.26	180	16	.2	280	11	155	240	200	4.9	Mariner and others, 1974
Fisher Hot Springs												
NW, sec. 10, T. 38 S., R. 25 E.	68	7.93	77	8.4	1.0	92	7.9	107	56	59	3.5	Mariner and others, 1974
Hunters Hot Springs												
NW, sec. 04, T.39 S., R. 20 E.	96	7.77	140	13	<.1	210	8.5	81	120	260	4.4	Mariner and others, 1974
Summer Lake Hot Springs												
NE, sec. 12, T. 33 S., R. 17 E.	43	8.43	94	2.1	.1	390	4.6	426	280	120	2.2	Mariner and others, 1974
UTAH												
Beaver County												
Roosevelt Seep												
NWSWSW, sec. 34, T. 26 S., R. 9 W	25	5.60	165	110	22	1800	260	298	3150	110	3.5	Unpub. data, Mariner and others
Roosevelt Steam Well												
NWSWNE, sec. 03, T. 27 S., R. 9 W.	-	5.80 @24°C	590	7.0	0.1	1950	400	200	3400	61	5.7	Unpub. data, Mariner and others
Thermo Hot Springs												
sec. 28, T. 30 S., R. 12 W.	89.5	7.98	113	71	10	380	52	360	255	480	6.6	Mariner and others, 1977
Box Elder County												
Crystal (Madsen's) Hot Springs												
SE, sec. 29, T. 11 N., R. 2 W.	56	7.3	26	784	186	13600	654	371	22600	444	19	Mundorff, 1970
Udy Hot Springs												
NW, sec. 23, T. 13 N., R. 3 W.	43	7.9	26	212	55	2690	118	366	4470	90	1.5	Mundorff, 1970
Juab County												
Baker Hot Springs												
SE, sec. 10, T. 14 S., R. 8 W.	85	7.36 @61°C	66	360	54	860	58	150	1550	720	2.9	Mariner and others, 1977
Millard County												
Meadow Hot Springs												
SW, sec. 26, T. 2 S., R. 6 W.	41	7.5	47	433	144	1040	13.8	408	1800	1130	-	Mundorff, 1970
Salt Lake County												
Becks Hot Spring												
SE, sec. 14, T. 1 N., R. 1 W.	56	7.4	32	746	131	4250	156	221	7470	985	3.3	Mundorff, 1970
Toole County												
Wilson Springs												
sec. 33, T. 10 S., R. 14 W.	61	7.4	33	741	224	7090	18	178	11900	1560	4.0	Mundorff, 1970
Weber County												
Ogden Hot Springs												
SW, sec. 23, T. 6 N., R. 1 W.	56	6.87	52	330	7.2	2700	350	196	4950	93	3.3	Unpub. data, Mariner and others
Utah Hot Springs												
SE, sec. 14, T. 7 N., R. 2 W.	57	6.28	38	890	24	5900	790	206	11500	180	3.7	Unpub. data, Mariner and others

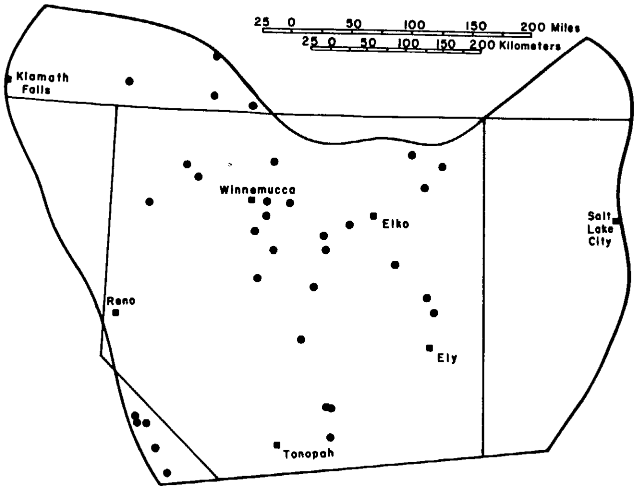

Figure 3. Distribution of Na-HCO$_3$ waters in the northern Basin and Range Province.

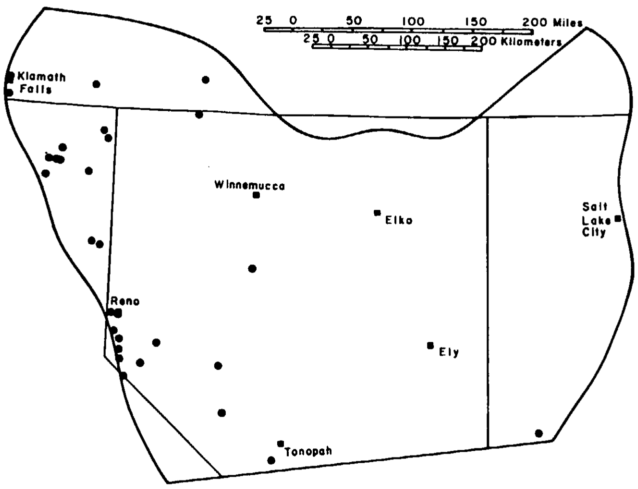

Figure 4. Distribution of Na-SO$_4$ waters in the northern Basin and Range Province.

discharges sulfate as enriched in oxygen-18 as gypsum of marine origin (+15 o/oo). Either marine gypsum is not available in areas where thermal springs develop or, more likely, the oxygen isotopic composition of the sulfate is being or has been reset in high temperature thermal-environments such as the intrusion of the Sierra Nevada Batholith or the development of mineralized zones. Sulfate-rich waters in some areas, such as northeastern California, are very constant in chemical composition (Table 1). The dissolved sulfate concentration in the water is apparently controlled by the solubility of a common mineral, probably hydrothermal anhydrite.

Mixed anion waters commonly develop in areas where the predominant bedrock or depth of circulation is changing. For instance, the Na-mixed anion waters common in northwestern Nevada west and northwest of the Black Rock Desert, represent a transition zone where rock type and depth of circulation of the thermal waters is changing. Instead of deep circulation in Mesozoic marine strata, which is common to the east and southeast, shallower circulation in predominantly unaltered volcanic rocks of Cenozoic age is more prevalent. The supposition of shallower circulation is evidenced by cooler spring temperatures and lower geothermometer temperatures. Sulfate is a major anion only locally where faults intersect mineralized areas, probably in the Mesozoic rock.

Many of the springs in the Basin and Range Province have been analyzed several times over the last 100 years. These analyses are always slightly different and it is not possible to determine how much of the variation is due to improved analytical techniques and how much to actual changes in the chemical composition with time. Cole (1982) demonstrated that the major constituents of Becks Hot Springs and Wasatch Hot Springs in Utah varied by as much as 15 % during a single year. This variation was caused by dilution on six and three month cycles. Long-term variations certainly occur in many hot springs but these have not been documented.

Chemical Compositions of Gases

Most thermal springs discharge gas along with the water at rates which range from low to high. Chemically these discharges include nitrogen and/or carbon dioxide with lesser amounts of argon, methane, hydrogen, helium, and hydrogen sulfide (Table 2). These gases probably originate from the atmosphere (N$_2$ and and Ar$_2$), soil (CO$_2$), radiogenic processes (He and Ar), and metamorphic or volcanic processes (CO$_2$). Ratios of nitrogen to argon range from 137/1 to 33/1 although most have N$_2$/Ar ratios are near the 50/1 expected from an atmospheric source. Organic decay product nitrogen is present in at least one sample (Wedell Spring - N$_2$/Ar = 131/1). Methane concentrations are low, indicating that breakdown of organic material is contributing relatively little at most springs. Hydrogen concentations are occasionally well above that expected from an atmospheric source and indicate that hydrogen is being generated at depth. Detectable(>0.005 %) hydrogen concentrations occur only where high temperature systems are indicated by geothermometry. Helium concentrations are more than an order of magnitude higher than expected from an atmospheric source in most springs and are almost certainly due to radiogenic decay of uranium, thorium, and/or their daughter products. Carbon dioxide makes up 99% or more of the gas phase in the CO$_2$-charged slightly to moderately saline Na-HCO$_3$ (± Cl) waters.

Table 2. Compositions of gas discharging from thermal springs, fumaroles and wells in the Northern Basin and Range.

[Compositions reported in volume %]

Name	O_2	Ar	N_2	CO_2	CH_4	C_2H_6	He	H_2	H_2S	Total
CALIFORNIA										
Alpine County										
Unnamed Spr. E. Fk. of the Carson River (9/3/81)	.31	.33	30.51	68.59	.52	<.01	.03	<.005	-	100.29
Lassen County										
Zamboni Hot Springs (9/3/81)	.93	1.26	97.45	.007	.34	<.01	.025	<.005	-	100.01
Mono County										
Hot Creek Gorge (5/29/80)	<.02	.02	1.00	99.83	.02	<.01	.005	.005	<.04	100.88
Fales Hot Springs (11/5/77)	.23	.08	4.27	94.86	<.005	<.05	<.02	<.01	-	99.44
Mammoth Mountain fumarole (7/28/82)	.01	.11	8.27	91.22	.008	<.01	<.005	.010	<.02	99.63
Travertine Hot Springs (11/5/77)	.02	<.02	.15	99.17	<.005	<.05	<0.02	<.01	-	99.34
Unn. Spring S. Mono Lake (11/5/77)	.18	.02	1.05	99.27	<.005	<.05	<0.02	<.01	-	100.52
NEVADA										
Churchill County										
Brady #8 (7/6/79)	.1	1.31	90.14	2.48	2.63	.03	.01	2.94*	<.01	99.54
Dixie Valley well Lamb 4 (5/29/80)	<.02	.04	2.15	97.14	.99	.03	.005	.05	.13	100.80
Elko County										
Hot Sulphur Springs (Tuscarora) (5/30/80)	<.02	.12	3.95	95.54	.34	<.01	.005	.02	-	100.71
Sulphur Hot Springs (Elko) (5/31/80)	<.44	.46	25.31	74.58	.60	<.01	.02	<.005	<.04	100.41
Unnamed Spring on Mary's River (8/11/82)	.03	.91	60.88	37.84	.014	<.01	.170	<.005	-	99.84
Eureka County										
Beowawe (7/31/82)	<.02	1.69	85.40	7.67	4.72	.11	.130	.290	<.02	100.01
Hot Spring near Walti (7/31/82)	.03	.54	27.85	70.71	.47	<.01	.020	<.005	-	99.62
Humboldt County										
Golconda Hot Spring (8/4/82)	.15	.84	39.58	58.09	.97	<.01	.030	<.005	-	99.66
Hot Pot (8/3/82)	.07	.74	48.74	50.06	.16	<.01	.11	<.005	-	99.88
Macfarlanes Hot Spring (8/3/82)	.02	<.02	.09	99.26	.034	<.01	.005	.005	-	99.40
Lander County										
Smith Creek Valley (7/31/82)	.20	1.95	90.31	6.13	1.32	<.01	.050	.045	-	100.00
Mineral County										
Wedell Springs @ (7/30/82)	<.5	.7	92	8.1	.95	<.2	.08	<.05	-	101.83
Pershing County										
Leach Hot Springs (5/--/77)	.03	1.57	73.49	24.53	.90	<.05	.05	<.01	-	100.57

@ Very low pressure sample

* Hydrogen probably from high temperature steam reaction with steel pipe

''Fumaroles'' occur along the west side of Dixie Valley, at Fumarole Butte near Baker Hot Springs in Utah, and at Mammoth Mountain and Casa Diablo in Long Valley, California (Berry and others, 1980). The fumaroles in Dixie Valley in Nevada discharge water vapor mixed with air (Mariner and Evans, unpublished data). The fumarole on Mammoth Mountain discharges mostly CO_2 with minor amounts of nitrogen and traces of hydrogen (Table 2). Chemically the gas discharged by the ''fumarole'' is more like the gases discharged from hot springs in the Hot Creek Gorge part of Long Valley than a fumarole associated with a volcano (analysis of a fumarole on Mt. Hood is included in Table 2 for comparison).

Chemical Geothermometers

The primary use of chemical data in geothermal exploration has been to estimate the temperature of the deep thermal-aquifer associated with a hot spring. The most useful geothermometers for estimating aquifer-temperatures are either the quartz geothermometer of Fournier and Rowe (1966), the Na-K-Ca geothermometer of Fournier and Truesdell (1973), or the Mg-corrected Na-K-Ca geothermometer of Fournier and Potter (1979). Other means of estimating aquifer-temperatures include the sulfate-water isotope geothermometer (McKenzie and Truesdell, 1977), the gas geothermometer (D'Amore and Panichi, 1980), the Na/K geothermometer (Fournier, 1979), and in a very few systems, the solubilities of minerals such as anhydrite (Sakai and Matsubaya, 1974).

Geothermometer temperatures based on the chemical composition of water discharged from hot springs and shallow wells are shown on Table 3. The high temperature areas in the northern Basin and Range Province (>150°C in Table 3) include: Long Valley, Seyferth Hot Springs, unnamed springs on the East Fork of the Carson River in California; Raft River, Idaho; Baltazor Hot Springs, Beowawe, Great Boiling Springs, Hazen, Hot Springs Ranch (Tipton), Hot Sulphur Spings (Tuscarora), Humboldt House, Leach Hot Springs, Lee Hot Springs, Pinto Hot Springs, San Emidio Desert, Soda Lake-Upsal Hogback, Steamboat Springs, Stillwater and Sulphur Hot Springs in Nevada; Alvord Hot Springs, Crump, Hot Lake, Hunters Hot Springs, and Mickey Hot Springs in Oregon; and Roosevelt Hot Springs in Utah. By types of waters, 10 are Na-Cl, 8 are $Na-HCO_3$, 4 are Na-mixed anion waters, and 3 are $Na-SO_4$ waters. '' Successful'' geothermal wells have been drilled at roughly half of the Na-Cl discharging springs but only at one of the $Na-HCO_3$ discharging springs (Table 4). ''Successful'' high-temperature geothermal wells have not been drilled near any of the Na-mixed anion or $Na-SO_4$ springs.

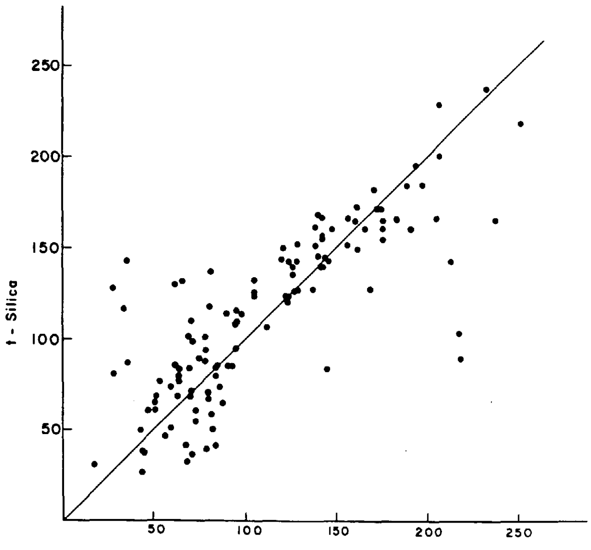

Figure 5. Comparison of temperatures estimated from ^{t}silica and ^{t}Na-K-Ca.

Plots of ^{t}silica and ^{t}Na-K-Ca (Fig.5) show generally good agreement, with relatively few large disparities. Arbitrarily, the quartz geothermometer was used when the Na-K-Ca geothermometer indicated a temperature of 100°C or more, the chalcedony geothermometer was used when the Na-K-Ca geothermometer indicated a temperature of less than 100°C. The few large disparities occur where waters discharge from silicic tuffs, CO_2-charged waters, waters contaminated with high-chloride saline lake or playa waters, and dilute high-pH waters. Springs issuing from silicic tuffs such as Hot Creek Ranch Springs in Nye County, Nevada and CO_2-charged water such as the water discharged by Travertine and Fales hot springs in California have higher temperatures estimated from the silica geothermometer than from the Na-K-Ca geothermometer. Silica is apparently being taken into solution faster than quartz or chalcedony can be precipitated, supersaturation with respect to quartz or chalcedony is maintained and the quartz (or chalcedony) geothermometer give excessively high subsurface temperature estimates. The magnesium corrected Na-K-Ca geothermometer in these waters generally gives estimated aquifer-temperatures within 25°C of the measured spring temperature. High CO_2 concentrations generally require high temperatures for generation, but these conditions may be very deep (Barnes and others, 1978). Some of the Na-Cl waters issue near saline lakes or playas and may contain some admixed saline lake waters (Utah Hot Springs adjacent to Great Salt Lake is an example). Since the saline water contains almost no calcium or magnesium, abnormally high Na-K-Ca geothermometer temperatures are calculated. The Na/K geothermometer is no better since the proportion of Na to K in the saline water was controlled initially by reactions which included calcium. Finally, the dilute high-pH waters

Table 3. Geothermometer temperatures for springs of the Northern Basin and Range.

[All temperatures in °C.]

	Geothermometers			Measured	
Name	Silica	Na-K-Ca	SO_4-H_2O	Surface	Depth
CALIFORNIA					
Alpine County					
Unn. sprs. on the Carson River	172	175		84	
Unn. sprs. on the Carson River	146	140		65	
Lassen County					
Amadee Hot Springs	109	95		96	
Bassett Hot Springs	86	62		79	
Kellog Hot Springs	101	78		78	
Wendell Hot Springs	150	121		96	122
Zamboni Hot Springs	(65)	51		41	
Modoc County					
Hot Springs Motel	110	96	200	98	
Kelly Hot Springs	116	95	198	92	
Leonards Hot Springs	143	124		62	
Little Hot Springs	102	69		79	
Seyforth Hot Springs	143	129	205	85	
West Valley Reservoir	152	129	247	77	
Mono County					
Benton Hot Springs	40	79		56	
Fales Hot Springs	118	81	684	61	
Long Valley-Hot Creek Gorge	161	191	224	90	
Mono Lake - North Shore	94	79		66	
- South Shore	126	28		33	
Travertine Hot Springs	110	71	173	69	
IDAHO					
Bear Lake County					
Bear Lake Hot Springs	55	73		48	
Unn. spring	39	44		42	
Cassia County					
RRGE-1	159	171		145	142
Franklin County					
Maple Grove Hot Springs	77	64		76	
Wayland Hot Springs	125	105		77	
Oneida County					
Woodruff Hot Springs	47	57		27	
NEVADA					
Carson City					
Carson Hot Springs	insufficient data			49	
Pinyon Hills Well	insufficient data			46	
Churchill County					
Brady's Hot Spring (well)	167	157	165	-	188
Dixie Valley Hot Springs	145	144	127	72	
Dixie Federal 52-18	229	207	268	191 gas geot.	
Eagle Salt Works Spring	198	-		-	
Lee Hot Springs	173	162	282	88	
Soda Lake-Upsal Hogback	165	161	127	100	188
Stillwater Area	169	140	177	96	178

Table 3. Geothermometer temperatures for springs of the Northern Basin and Range - continued.

[All temperatures in ^{o}C.]

Name	Geothermometers			Measured	
	Silica	Na-K-Ca	SO_4-H_2O	Surface	Depth
<u>Douglas County</u>					
Hobo Hot Spring	69	70		46	
Saratoga Hot Springs	31	-		50	
Walley's Hot Spring	80	84		62	
<u>Elko County</u>					
Hot Creek Springs	31	17		26	
Hot Creek Springs	132	66		37	
Hot Hole	86	85		56	
Hot Lake	79	67		18	
Hot Spring near Carlin	90	75		79	
Hot Sulphur Spring	167	183	175	92	117
Humboldt Wells Area	117	34		60	
Mineral (Contact) Hot Springs	127	129		60	
Nile Spring	50	43		43	
Rizzi Ranch Hot Spring	37	71		41	
San Jacinto Ranch Spring	27	44		-	
Sulphur Hot Spring (Ruby Valley)	183	181	161	93	
Smith Ranch	72	71		65	
Trout Creek Ranch Well	33	69		43	
Unnamed spring (Rock Creek)	37	69		35	
Wild Horse Hot Spring	61	73		54	
Wine Cup Ranch Well	insufficient data			59	
<u>Esmeralda County</u>					
Alkali Springs	insufficient data			60	
Silver Peak (Waterworks) Hot Springs	140	142		40	
<u>Eureka County</u>					
Beowawe	196	194	251	98	201
Bruffey's (Mineral Hill) Hot Spring	80	64		66	
Hot Springs Point	87	36		54	
Klobe Hot Springs	69	72		54	
Shipley Hot Springs	61	48		39	
Walti Hot Springs	88	78		72	
<u>Humboldt County</u>					
Baltazor Hot Springs (well)	161	148	158	90	
Bog Hot Springs	65	88		54	
Cordero Mercury Mine well	108	-		60	
Double Hot Springs	140	126		80	
Dyke Hot Springs	128	137		66	
Golconda Area	86	92		74	
Hot Pot	59	81		57	
Hot Spring Ranch (Tipton)	150	162		85	
Howard Hot Springs	71	80		56	
Macfarlane's Bath House Spring	99	71		75	
Pinto Hot Springs	161	176	207	93	
Soldier Meadows Hot Springs	84	64		54	
The Hot Springs	77	54		58	
Well	-	81		70	
<u>Lander County</u>					
Buffalo Valley Hot springs	119	126	140	73	
Hot Springs Ranch(Valley of the Moon)	61	51		53	
South Smith Creek Valley	143	156	143	86	
Spencer Hot Springs	95	95		72	
Unn. spring near Walti Hot Spring	127	129		64	

Table 3. Geothermometer temperatures for springs of the Northern Basin and Range - continued.

[All temperatures in °C.]

Name	Geothermometers Silica	 Na-K-Ca	 SO_4-H_2O	Measured Surface	 Depth
Lyon County					
Hazen Area	161	166	220	86	
Hind's (Nevada) Hot Springs	74	86		61	
Wabuska Hot Springs	143	146	140	94	108
Wedell Springs	162	139		60	
Nye County					
Darrough's Hot Spring	136	126		95	129
Diana's Punch Bowl	67	80		59	
Hot Creek Ranch Springs	130	62		63	
Upper Hot Creek Ranch Springs	143	36		67	
Warm (Nanny Goat) Spring	81	29		61	
Pershing County					
Colado	128	169		61	155
Humboldt House (Rye Patch Reserv.)	219	252	176	-	156
- artesian well	166	238		77	
Hyder Hot Springs	84	70		78	
Kyle Hot Springs	137	81	154	77	
Leach Hot Springs	155	176	176	92	126
Sou Hot Springs	85	84		70	
Trego Area	124	124		84	
Washoe County					
Bowers Mansion Hot Springs	38	45		46	
Fly Ranch (Ward's)	126	105		80	
Great Boiling Spring	167	205	93	86	
Lawton Hot Springs	84	145		49	
Moana Springs Area (Biglin well)	114	98		85	
San Emidio Desert	185	189		89	115
Steamboat Springs	201	207	207-220	94	208
The Needle Rocks	143	214		56	
White Pine County					
Cherry Creek Hot Springs	114	90		61	
Monte Neva Hot Springs	74	60		79	
OREGON					
Harney County					
Alvord (Indian) Hot Springs	152	157	231	78	
Crane Hot Springs	124	124		78	
Mickey Hot Springs	185	197	273	86	
Trout Creek Hot Springs	140	143	235	52	
Unn. spr. near Hot Lake	165	176	231	96	
Unn. spr. near Harney Lake	133	105		68	
Lake County					
Barry Ranch Hot Springs	152	139		88	
Crump	172	173	202	78	
Fisher Hot Springs	123	123		68	
Hunters Hot Springs	157	143	158	96	
Summer Lake Hot Springs	107	112	189	43	
UTAH					
Beaver County					
Roosevelt Seep	167	142	216	25	208
Roosevelt Steam Well	238	234Na-K	278	208	
Thermo Hot Springs	144	120	142	90	

Table 3. Geothermometer temperatures for springs of the Northern Basin and Range - continued.

[All temperatures in °C.]

Name	Geothermometers			Measured	
	Silica	Na-K-Ca	SO_4-H_2O	Surface	Depth
Box Elder County					
Crystal (Madsen's) Hot Springs	42	84		56	
Udy Hot Springs	42	68		43	
Juab County					
Baker Hot Springs	86	91	22	85	
Millard County					
Meadow Hot Springs	69	63		41	
Salt Lake County					
Beck's Hot Springs	51	82		56	
Toole County					
Wilson Hot Springs	52	60		61	
Weber County					
Ogden Hot Springs	104	218		56	
Utah Hot Springs	90	219		57	

Table 4. Geothermal Systems with Estimated Reservoir-Temperatures >150°C

Na-HCO_3 Waters

*Beowawe
Hot Springs Ranch
Hot Sulphur Springs (Tuscarora)
Leach Hot Springs
Long Valley
Mickey Hot Springs
Pinto Hot Springs
Sulphur Hot Springs (Ruby Valley)

Na-Mixed Anion Waters

Alvord Hot Springs
Hot Lake (Alvord Desert)
Lee Hot Springs
Unn. Springs-Carson River

Na-SO_4 Waters

Baltazar Hot Springs
Hunters Hot Springs
Seyferth Hot Springs

Na-Cl Waters

Crump
Great Boiling Spring
Hazen
*Humboldt House
*Raft River
*Roosevelt
San Emidio Desert
*Soda Lake-Upsal Hogback
*Steamboat Springs
*Stillwater

*Locations of "successful" geothermal wells.

such as Zamboni or Benton hot springs which discharge from granites near the contact of the Basin and Range with the Sierra Nevada contain unusually large silica concentrations due to dissociation of silicic acid (H_4SiO_4 to $H_3SiO_4^-$ and $H_2SiO_4^=$). With one of the computer codes such as SOLMINEQ (Kharaka and Mariner, 1977) the temperature at which the thermal water is in equilibrium with chalcedony or quartz, as appropriate, can be determined. These values are enclosed in parentheses in Table 3.

The apparent agreement between the temperatures estimated from the silica and cation geothermometers in most waters of the Great Basin could be fortuitous. A more important question is, how do the estimated temperatures compare with measured temperatures in geothermal wells? Deep-well temperature data are available for only 15 systems (Table 5). Surprisingly, when measured and estimated temperatures are compared for all 15, the measured temperatures are, on the average, only 14°C cooler than the estimated temperatures. The standard deviation is however,

Table 5. Expected and Measured Temperatures of Geothermal Systems in the Northern Basin and Range.

Name	Temperatures Expected*	Temperatures Measured
High Discharge Springs		
Beowawe	214	201
Hot Sulfur Springs (Tuscarora)	175	117
Leach Hot Springs	167	126
Long Valley	196	170
Steamboat Springs	205	204
Wendel Hot Springs	136	122
Low Discharge Springs		
Humboldt House	184	156
Roosevelt Hot Springs	175	208
San Emidio Desert	187	115
Wells		
Brady's Hot Springs	162	155
Colado	148	155
Raft River	161	150
Soda Lake	151	188
Stillwater	162	178
Wabuska	143	108

*Average of ^{t}silica, ^{t}cation, and $^{t}SO_4-H_2O$ when available.

rather large (± 28 C). The estimated temperature for each system is an average which includes values from the quartz or chalcedony geothermometer, as appropriate, the Na-K-Ca geothermometer, and when available, the SO_4-H_2O isotope geothermometer. Surprisingly, the average difference between expected temperatures calculated from geothermometry and the measured temperatures for low discharge rate (<100 L/min) and high discharge rate hot springs are nearly the same (22°C vs 26°C). Normally, high discharge rate springs should give better estimates of subsurface temperature than low discharge rate springs (Fournier and others, 1974). This apparent anomaly may be due, in part, to the small number of systems for which data is available, and, in part, may indicate that the accessible part of the thermal reservoirs may be smaller than previously thought. Long Valley is the best example of an area where recent drilling has shown that the accessible part of the thermal reservoir is smaller than predicted in the last assessment of high-temperature of geothermal resources of the United States (Brook and others, 1978). If geothermal reservoirs are appreciably smaller than anticipated by Brook and others (1978), geothermal development in the northern Great Basin may be seriously curtailed. The six areas where thermal waters were collected from shallow wells (50 - 1000 feet deep) gave remarkably good agreement between estimated and measured temperatures (less than 2°C average difference). The disparity between estimated and observed temperatures is considerably larger for the areas where data is available only from hot springs, measured temperatures in geothermal wells average 24°C cooler than the estimated temperatures.

Isotopic Data

Craig (1963) demonstrated that for high-temperature chloride-rich waters or steam discharges, the deuterium content is approximately equal to that of the local meteoric water. Nehring (1979) reached a similar conclusion in a restudy of the high-temperature chloride-rich system at Steamboat Springs as did Mariner and Wiley (1976) in a study of the Long Valley area. However, other detailed studies of recharge areas for specific systems in the northern Basin and Range Province have generally had difficulty locating cold spring waters in the adjacent highlands which were as depleted isotopically as water discharged by the thermal springs. Welch and others (1981) concluded that the water discharged at Leach Hot Springs was paleo-water which recharged during a colder time-period since it was more depleted in terms of deuterium than any of the water discharged by cold springs in the adjacent mountain ranges. Summit Spring (Table 6; $\delta D = -126.8$ o/oo), a perenial spring on the north side of Mt. Tobin near Leach Hot Springs, is as depleted in deuterium as the thermal water discharging at Leach if you assume that the small oxygen shift (+0.3 o/oo $\delta^{18}O$) observed in the cold spring water is due to nonequilibrium evaporation (Fig. 6). This evaporation could have taken place prior to recharge, or in an unconfined aquifer. Although Mt. Tobin is the highest mountain in the region, and could be the recharge area for Leach Hot Springs, this interpretation forces the data to the limits of credibility, only a small summit area on Mt. Tobin exists as a catchment basin and, most damaging, two travertine depositing springs, Buffalo Valley Hot Springs east of Mt. Tobin and Hyder Hot Springs in Dixie Valley south of Mt. Tobin are even more depleted in deuterium (-132 per mil and -133 per mil, respectively).

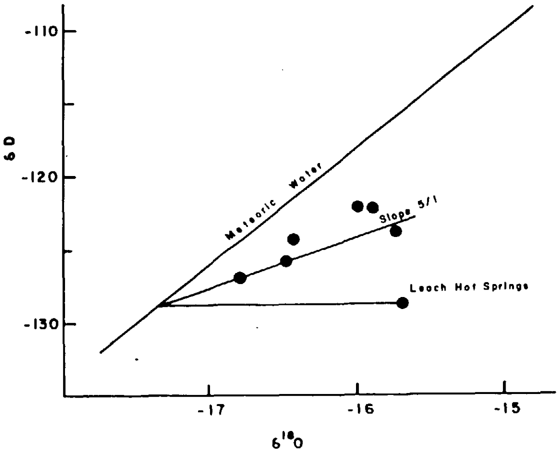

Figure 6. Isotopic composition of thermal and cold waters in the Leach Hot Springs Area.

A detailed study of the Tuscarora Area (Hot Sulphur Springs) at the west end of the Jarbridge Mountains (Bowman and Cole, 1982) also did not find any cold springs as depleted in deuterium as the hot springs. Most of the cold spring water however, appear to have undergone some nonequilibrium evaporation. A study of Ogden and Utah hot springs near Great Salt Lake by Cole (1982) also showed that the thermal waters were more depleted in deuterium than nearby cold springs.

Are these cases the exception or the rule? When the deuterium contents of hot springs in the northern Basin and Range Province (Table 6) are plotted and contoured, the map produced (Fig. 7) is similar to the map for meteoric waters of North America as presented in Taylor (1974). However, based on the map of Taylor (1974), most precipitation in the northern Great Basin should range in deuterium composition from about -110 to -130 o/oo. Most of the hot springs however are in the -120 to -140 o/oo range (figure 7), and a few near Elko are even more depleted (-145 o/oo δD). Appealing to the presence of regional aquifers is not valid since the nearest area with precipitation as depleted as -145 o/oo is in western Montana. Since the isotopic composition of precipitation is a function of temperature, $\delta D = 5.56t - 98.5$ (Dansgaard, 1964), the water being discharged by most of the hot springs in the northern Basin and Range Province apparently recharged during times of colder climate (2 to 3°C colder than at present). Although there have been recent fluctuations in mean annual air temperature with a maximum about 1930, and several recent periods of colder climates (1900-1800, 1700-1575, and 1525-1400) the temperatures were not cold enough to account for the 15 o/oo difference in deuterium observed in most of the Basin and Range. The work of Dansgaard and others (1969) and Johnson and others (1970) has shown that the isotopic composition of precipitation changed from more depleted values to roughly modern values abruptly about 10,000 years ago at the "end" of the Pleistocene. Thus most of the water currently discharged by hot springs in the northern Great Basin, apparently recharged at least 10,000 years ago.

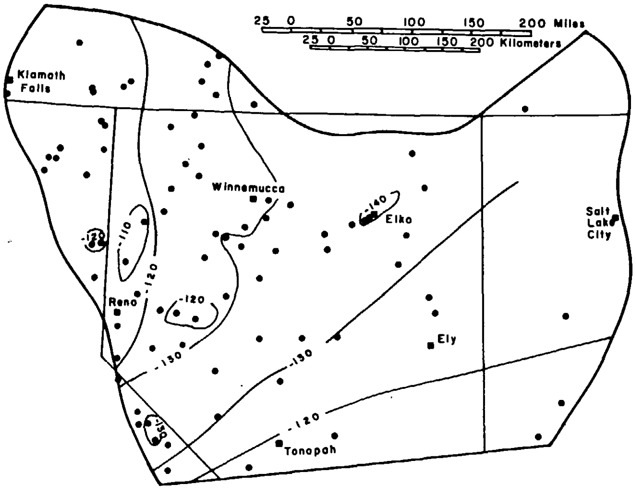

Figure 7. Contour map of the deuterium composition of thermal springs in the northern Basin and Range Province.

Unfortunately, times of circulation for geothermal waters are generally unknown, due in part to the difficulty and uncertainty in interpreting tritium or carbon-14 values. Tritium has a half-life of only 12.3 years and generally concentrations of tritium in thermal waters are less than 0.1 TU. This merely shows that the waters are more than 60 years old (Barnwell, 1963; Wilson, 1963). Carbon-14 has a half-life of 5,670 years and should be much more useful than tritium. However, carbon-14 readily exchanges with reservoir carbon at high temperatures (Craig, 1963).

In contrast to deuterium, which generally does not change in concentration during passage through a geothermal system (boiling excepted), the oxygen isotopic composition of the water

Table 6. Isotopic data for thermal springs of the northern Basin and Range.

	del D	del 180
CALIFORNIA		
Alpine County		
Unn. sprs. E.Fk. Carson River		
(84°C spring)	-126.5	-15.56
(65°C spring)	-125.3	-15.54
Lassen County		
Amadee Hot Springs	-120.0	-
Bassett Hot Springs	-115.1	-13.54
Kellog Hot Springs	-115.5	-14.09
Wendell Hot Springs	-120.8	-14.04
Zamboni Hot Springs	-118.1	-15.34
Modoc County		
Lake City Mud Eruption	-113.0	-14.79
Kelly Hot Springs	-115.1	-13.54
Little Valley Hot Springs	-116.9	-14.20
Hot Springs Motel (well)	-117.0	-13.81
Menlo Hot Springs	-112.3	-15.30
Seyforth	-121.2	-14.05
Mono County		
Benton Hot Springs	-135.5	-17.46
Fales Hot Springs	-132.8	-17.46
Long Valley (Hot Creek Gorge)	-120.3	-14.83
- LDMW	-115 to -130	
Mono Lake - North Shore	-126.6	-16.91
- South Shore	-126.9	-15.69
The Hot Springs	-137.3	-16.29
Travertine Hot Springs	-139.3	-16.64
NEVADA		
Churchill County		
Brady's Hot Spring (well)	-121.2	-14.22
Dixie Federal 52-18	-133.9	-14.72
Dixie Valley Hot Springs	-126.1	-15.89
- LDMW	-120.0	-15.22
Lee Hot Springs	-125.8	-13.34
Stillwater Area (well)	-110.0	-12.36
Douglas County		
Walley's Hot Springs	-119.5	-15.55
Elko County		
Hot Creek	-126.7	-16.28
- LDMW	-121.4	-15.69
Hot Creek Springs	-135.7	-17.40
- LDMW	-128.9	-16.20
Hot Hole	-144.7	-15.31
Hot spring near Carlin	-132.7	-16.64
Hot Sulfur Spring (Tuscarora)	-138.6	-16.65
Humboldt Wells	-134.7	-
- LDMW	-122.1	-15.81
Mineral (Contact) Hot Spring	-139.0	-17.61
Nile Spring	-139.1	-18.24
Smith Ranch Hot Spring	-132.8	-16.24
Sulphur Hot Spring (Ruby V.)	-130.1	-16.09
- LDMW	-124.6	-16.87
Sulphur Hot Spring (Elko)	-145.9	-17.67

Table 6. Isotopic data for thermal springs of the northern Basin and Range--continued.

	del D	del 180
Esmeralda County		
Silver Peak (Water Works spr.)	-118.2	-13.50
Eureka County		
Beowawe	-130.0	-14.76
Hot Springs Point	-136.1	-15.97
Klobe Hot Springs	-127.9	-16.28
Walti Hot Springs	-129.8	-16.87
Humboldt County		
Baltazor Hot Springs	-125.3	-15.26
Bog Hot Springs	-124.3	-15.30
Double Hot Springs	-128.8	-15.93
Dyke Hot Springs	-128.0	-16.29
Hot Pot	-136.7	-16.70
Hot Springs Ranch (Tipton)	-131.4	-15.74
Howard Hot Spring	-127.1	-16.17
Macfarlanes Hot Springs	-127.2	-12.54
Pinto Hot Springs	-129.2	-14.48
Soldier Meadows Hot Springs	-129.2	-16.56
The Hot Springs	-134.6	-16.44
Lander County		
Buffalo Valley Hot Springs	-131.6	-15.85
	-135.2	-13.61
- LDMW	-117.3	-14.95
Hot Springs Ranch (Valley of the Moon)	-127.8	-16.28
Smith Creek Valley	-130.4	-16.68
Spencer Hot Spring	-135.8	-16.01
Unn. Spr. (Grass V. nr Walti)	-134.8	-16.73
Lyon County		
Hazen Area	-121.5	-13.30
Hinds (Nevada) Hot Springs	-123.2	-16.01
Wabuska Hot Springs	-129.7	-15.38
Wedell	-131.9	-15.90
Mineral County		
Soda Springs	-130.3	-16.13
Nye County		
Diana's Punchbowl	-124.9	-16.24
Darroughs Hot Springs	-122.5	-15.50
Pershing County		
Colado	-125.5	-14.01
Hyder Hot Springs	-133.2	-15.66
Humboldt House - deep well	-130.6	-14.64
- shallow well	-127.2	-14.09
- LDMW	-119.9	-15.25
Kyle Hot Springs	-130.0	-15.50
- LDMW	-121.1	-14.71
Leach Hot Springs	-128.6	-15.70
Summit Spring - LDMW	-126.8	-16.80
Trego Hot Springs	-124.5	-14.40

Table 6. Isotopic data for thermal springs of the northern Basin and Range--continued.

	del D	del 180
Washoe County		
Bowers Mansion Hot Springs	-102.3	-14.79
Fly Ranch	-120.7	-14.72
Great Boiling Springs	-100.5	-10.83
San Emidio Desert	-108.3	-12.05
Steamboat Springs	-116.7	-12.16
The Needle Rocks	-106.5	- 6.33
White Pine County		
Cherry Creek Hot Springs	-127.8	-16.20
Monte Neva Hot Springs	-127.8	-16.68
OREGON		
Harney County		
Alvord (Indian) Hot Springs	-123.6	-13.23
Crane Hot Springs	-133.3	-16.17
Mickey Hot Springs	-124.3	-13.42
Pike Creek - LDMW	-108.4	-14.05
Trout Creek Hot Spring	-127.4	-16.17
Trout Creek- LDMW	-115.3	-15.50
Unn. Sprs. near Hot Lake	-125.4	-14.36
Unn. H. Sprs near Harney Lake	-128.5	-
Lake County		
Barry Ranch Hot Springs	-119.4	-13.72
Crane Creek- LDMW	-101.2	-13.40
Crump	-115.5	-13.28
Deep Creek - LDMW	-106.6	-13.46
Fisher Hot Springs	-117.0	-
Hunters Hot Springs	-119.0	-14.32
Summer Lake Hot Springs	-115.0	-13.32
Malheur County		
Unn. Spr. nr. McDermitt	-134.6	-16.95
UTAH		
Beaver County		
Roosevelt Seep	-113.0	-12.95
Thermo Hot Springs	-118.3	-14.32
Steam Well at Roosevelt H.S.	-115.9	-12.99
Juab County		
Crater (Baker,Abraham) Hot S.	-126.3	-16.0

changes due to exchange with minerals in the confining rock (Craig, 1963). In the northern Great Basin, dilute Na-HCO$_3$ waters and Na-SO$_4$ waters generally have less oxygen enrichment than Na-Cl waters (Figs. 8, 9, and 10). Bicarbonate-rich waters, however, occasionally have very large oxygen shifts (up to 4 o/oo; Fig. 8). Carbonates in limetsones are usually +20 to +30 per mil in $\delta^{18}O$ while silicates in most igneous rocks range from +5 to +15 o/oo. Larger oxygen shifts are observed in water associated with limestones than in waters associated with silicate rocks because of the concentration difference and the faster exchange rates between carbonates and waters. The lack of correlation between oxygen shift and amount of dissolved solids in the Na-Cl waters is an indication that although these waters generally occur where most water-rock reaction has taken place, the chloride concentration is at least, in part, a function of chloride availability.

The oxygen isotopic compositions of a few sulfates in thermal waters of the Basin and

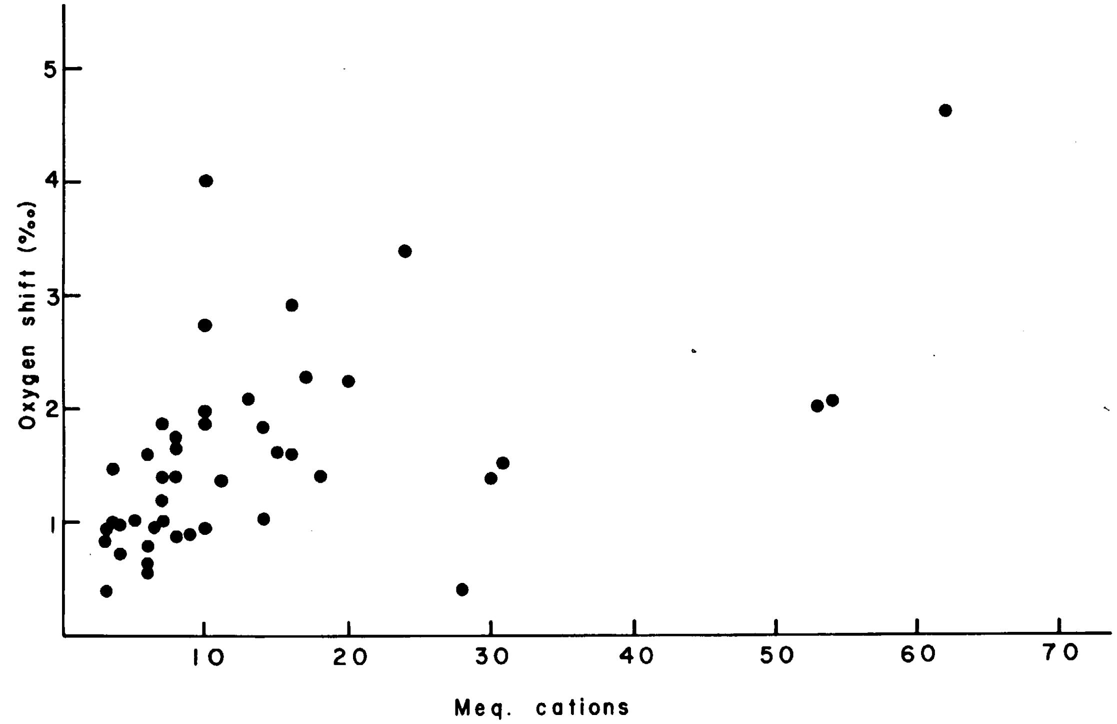

Figure 8. Oxygen shift of HCO_3-rich thermal water as a function of milliequivalents cations (specific conductivity).

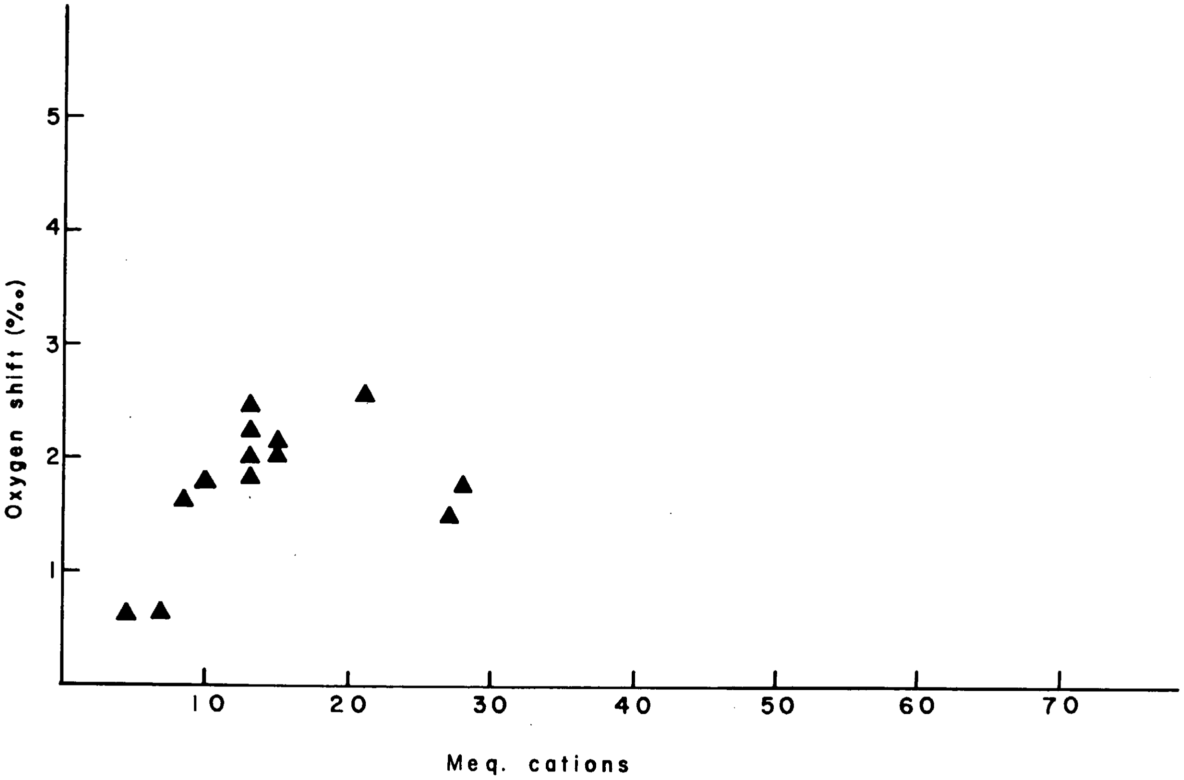

Figure 9. Oxygen shift of SO_4-rich thermal waters as a function of milliequivalents cations (specific conductivity).

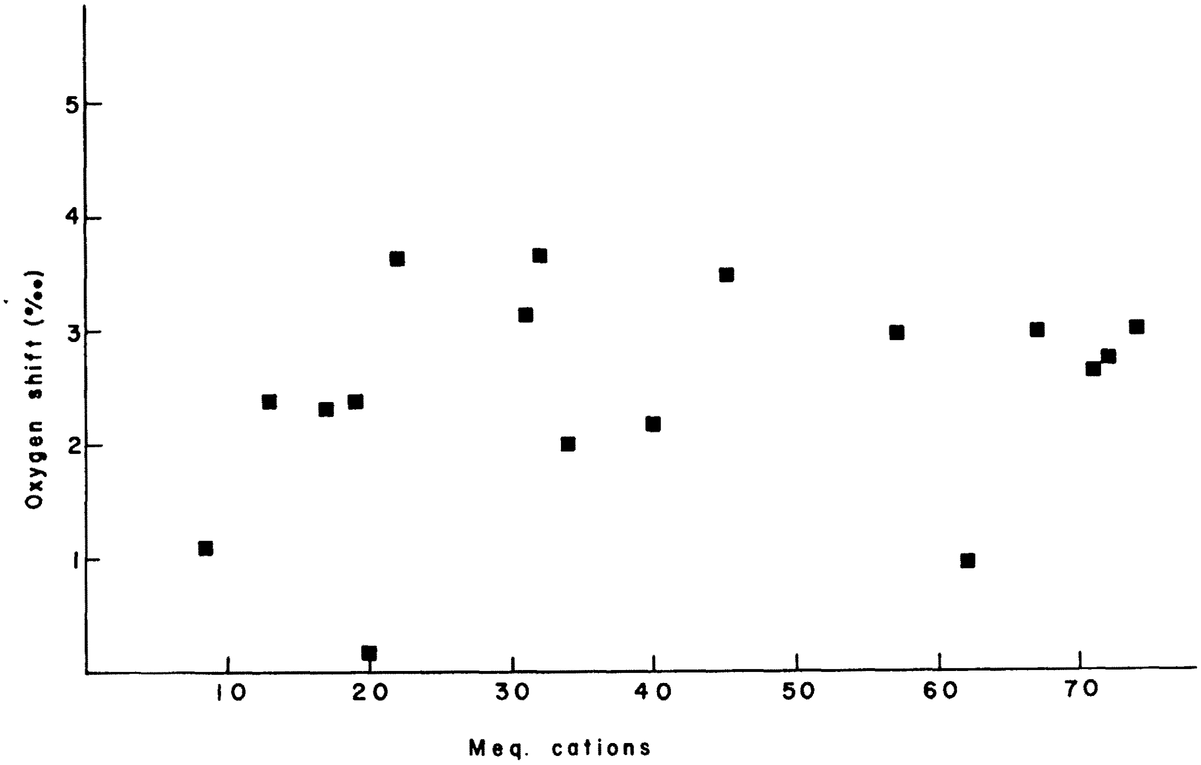

Figure 10. Oxygen shift of Cl-rich thermal waters as a function of milliequivalents cations (specific conductivity).

Range Province have been reported by Nehring and Mariner (1979). Our intent was to estimate the thermal-aquifer temperature using the sulfate-water isotope geothermometer of McKenzie and Truesdell (1977). The sulfate-water isotope geothermometer generally gives calculated temperatures that are slightly hotter than those obtained from the quartz or Na-K-Ca geothermometers. However, in some areas, the sulfate-water isotope geothermometer gives temperatures considerably lower than the measured surface temperatures or considerably higher than the temperatures estimated from the other geothermometers (Table 3). It is possible for sulfate to be dissolved from the country rock after the thermal fluid leaves the thermal aquifer or the thermal fluid may mix with sulfate-rich nonthermal water before it discharges at the surface. This added sulfate probably will have a different original isotopic composition and could significantly change the isotopic composition of the total sulfate in the discharge.

In the northern Basin and Range Province, the sulfate-water isotope geothermometer indicates aquifer-temperatures which are generally 50 to 100°C higher than those estimated from the silica or cation geothermometers. A possible explanation for these higher apparent temperatures is that the depleted sulfate is from dissolution of minerals formed during previous high temperature hydrothermal or metamorphic events. However, these minerals must be situated along the flow path from the reservoir to the surface or the residence times of fluids in the thermal reservoir must be very short. The latter possibility does not appear likely due to the old apparent age of most of the waters. However, in mineralized areas, there is the possibility of dissolving isotopically depleted sulfate which does not have enough time to attain equilibrium with the dissolving fluid. For example, pickeringite (ideal formula $MgAl_2(SO_4)_4\ 22H_2O$) from a site near Lahontan Reservoir west of Fallon was -6.53 o/oo $\delta^{18}O$. Dissolution of such a mineral without concomitant reequilibration would result in excessively high apparent SO_4-H_2O isotopic equilibrium temperatures. Sulfate minerals are often associated with ore deposits in western Nevada and so isotopically depleted sulfate is readily available.

Alternatively, although the sulfate-water isotope temperatures are no closer to the measured temperatures in the deep wells then the temperatures calculated from the cation or silica geothermometers, the apparent sulfate-water equilibrium temperatures could be correct. Calculations with the computer code SOLMNEQ (Kharaka and Barnes, 1973, as modified by Kharaka and Mariner, 1977) indicate saturation with respect to anhydrite ($CaSO_4$) at temperatures near those estimated from the sulfate-water isotope geothermometer in several of the systems in northeastern California (Table 7). This may be an indication that the temperatures calculated from the sulfate-water isotope geothermometer are accurate in this area. The cooler temperatures estimated from the quartz and Na-K-Ca geothermometer may indicate that chemical equilibrium was approached in a shallow aquifer at temperatures near the spring temperature but the isotopic composition remained unchanged. Anhydrite saturation temperatures (Table 7) for Travertine Hot Springs, Hot Lake (Oregon), Stillwater, Soda Lake-Upsal Hogback, Hazen and Alvord Hot Springs are also reasonably near the sulfate-water isotope equilibrium temperatures. The differences in temperatures estimated from theoretical anhydrite saturation (175°C) and sulfate-water isotopic data (127°C) at the Soda Lake-Upsal Hogback area may indicate that reequilibration or mixing has taken place in a shallow aquifer since deep wells have encountered temperatures more than 50°C hotter. Lee Hot Springs, located south of Fallon, has an apparent anhydrite saturation temperature of only 173°C, almost 100°C cooler than the sulfate-water isotopic equilibrium temperature. The sulfate at Lee must be from a near surface hydrothermal mineral source. At the other extreme, Abraham Hot Springs in Utah had a sulfate-water isotopic equilibrium temperature less than the measured spring temperature. Apparently, the sulfate discharged at Abraham Hot Springs is of marine origin (initially about +15 o/oo in $\delta^{18}O$) and it never attained, isotopic equilibrium with the thermal water.

Summary

Thermal waters in the Basin and Range Province range from dilute $Na\text{-}HCO_3$ and $Ca\text{-}HCO_3$ waters to very saline Na-Cl waters. The most saline Na-Cl waters occur near Great Salt Lake or near the sinks and playas of northwestern Nevada. Slightly saline CO_2-charged $Na\text{-}HCO_3$ waters are common near the Sierra Nevada. $Na\text{-}SO_4$ (± Cl) waters occur in northeastern California and western Nevada. Sulfate in these waters may be from sulfate minerals, initially deposited during previous hydrothermal events.

Meteoric waters in the probable recharge areas for most hot springs in the Northern Basin and Range Province are generally not as depleted in deuterium as the waters currently discharged by the hot springs. This difference is largest for waters associated with travertine and is almost certainly an indication that the thermal waters recharged during times of colder climate, probably the Pleistocene.

Measured temperatures in deep wells are, on the average, 14°C cooler than expected from the chemical geothermometry on waters from nearby

Table 7. Anhydrite saturation temperatures and sulfate-water isotope equilibrium temperatures for thermal waters of the northern Basin and Range.

Name of Sample	T - Anhydrite Saturation	T - SO_4-H_2O
California		
Fales Hot Springs	310	184
Hot Springs Motel (Surprise Valley)	211	200
Kelly Hot Springs	193	198
Seyferth Hot Springs	189	205
Travertine Hot Springs	190	173
West Valley Reservoir (Hot Spring)	220	247
Nevada		
Hazen (Hot Springs)	185	220
Lee Hot Springs	173	282
Soda Lake - Upsal Hogback (well)	125	127
Stillwater (well)	180	177
Wabuska (shallow well)	176	140
Oregon		
Alvord Hot Springs	275	231
Spring near Hot Lake (Alvord Desert)	215	230
Utah		
Abraham (Baker) Hot Springs	159	22
Thermo Hot Springs	172	142

hot springs and shallow wells. The measured temperatures in the geothermal reservoirs are, on the average, 22°C cooler than expected when spring waters are used to estimate the deep aquifer-temperature, however measured temperature are only 2°C lower than expected when waters from shallow wells are used to estimate the temperature of the deep aquifer.

Anhydrite saturation temperatures are similar to sulfate-water isotope equilibrium temperatures for the more saline thermal waters of the northern Basin and Range Province. However, some systems in northeastern California have aquifer-temperatures of 200 to 220 C based on anhydrite saturation and SO_4-H_2O isotopic equilibrium temperatures. These temperatures are roughly 100°C above the temperatures estimated from silica or Na-K-Ca geothermometers.

The oxygen-18 enrichment of Na-HCO_3 thermal waters generally increases as the total dissolved solids increase. Concentrations of dissolved solids in Na-Cl waters generally are higher than either Na-HCO_3 or Na-SO_4 waters. Although Na-Cl waters are generally more enriched in oxygen-18, no correlation seems to exist between their oxygen-18 enrichment and amount of dissolved solids.

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