

CHEMISTRY OF THERMAL WATER AND ESTIMATED RESERVOIR TEMPERATURES IN SOUTHEASTERN IDAHO, NORTH-CENTRAL UTAH, AND SOUTHWESTERN WYOMING¹

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ABSTRACT

The chemistry of thermal water in southeastern Idaho, north-central Utah, and southwestern Wyoming is quite variable, with dissolved-solids concentrations ranging from about 100 to nearly 40,000 milligrams per liter. Chemical geothermometers were used to estimate the reservoir temperature at the depth where the water was heated. The estimated reservoir temperatures at the sampled sites indicate no uniformity or trend from low to high values. Thermal water in the region possibly results from ground-water circulation both in the basin fill and in the bedrock.

INTRODUCTION

Ground water that has a temperature greater than the shallow ground-water temperature, which normally approximates the mean annual air temperature of the area, is considered to be thermal water. The mean annual air temperature for 1951-80 at four sites in the study area was: 8.1°C at Pocatello, Idaho; 10.8°C at Ogden, Utah; 8.9°C at Logan, Utah; and 3.3°C at Jackson, Wyoming (National Oceanic and Atmospheric Administration, 1982a, 1982b, 1982c). Thus, for southeastern Idaho, north-central Utah, and southwestern Wyoming, the range in shallow ground-water temperature is about 3 to 11°C. Generally, only ground water with a temperature of 5.6°C or 10°F greater than the mean annual air temperature has been included in previous studies of geothermal water.

Ground-water temperature, particularly temperature of spring discharge, can be influenced by seasonal changes in air temperature, and by the depth of the circulation of the water. Some normally cold-water springs have higher water temperatures during the summer (Goode, 1978, p. 6). Water that has circulated to a relatively shallow depth of about 1,000 feet will be about 10°C warmer than the mean air temperature, as predicted by using the average geothermal gradient for the Basin and Range province of 35°C per kilometer (101°F per mile) (Klauck and Budding, 1984, p. 10). Ground-water temperatures that are more

than 10°C warmer than the mean annual air temperature either result from water coming in contact with a subsurface source of heat other than the normal increase in temperature with depth, or water that has circulated to depths greater than about 1,000 feet.

Temperatures and chemical analyses of ground water included in this report were measured at and collected from both springs and wells. Generally, thermal water at depth in the study area is indicated by the existence of hot and warm springs, but thermal water can exist at depth without surface discharge. Some wells have been drilled which unexpectedly produced thermal water, whereas other wells have been specifically drilled as geothermal prospects. A geothermal exploration well was drilled in the lower Bear River valley, northwest of Ogden, to a depth of 11,005 feet by Utah Power and Light Co. (UPL). It had a bottom-hole temperature of 105°C (Goode, 1978, p. 16); this temperature is 23°C less than what would have been predicted from the geothermal gradient. Generally, the only water samples collected from wells are from sites in Cache Valley in Cache County, around Logan, Utah.

Little economic use has been made of the geothermal heat available in the study area. The UPL exploration well was abandoned because the temperature was not high enough and the geothermal resource was perceived to be limited (John Ward, Utah Power and Light Co., oral commun., 1987). Thermal water in the area is used for space heating in a few residences and greenhouses, for aquaculture, and for recreation.

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The structure and stratigraphy of the study area is presented in other papers in this guidebook. Generally, structure and stratigraphy typical of the Basin and Range dominates the western part of the study area, whereas structure and stratigraphy typical of the Overthrust Belt dominates the eastern part of the study area. However, thick deposits of basin fill of Tertiary and Quaternary age, a characteristic of the Basin and Range province, also occur along the Overthrust Belt. Faulting of both the bedrock and basin fill is pervasive throughout the study area. Rocks of Proterozoic, Mesozoic, and Cenozoic age are predominately clastic, whereas Paleozoic-aged rocks are carbonate, commonly dolomitic. No evidence of recent volcanism is present, although there are some canyon-filling lava flows of middle Pleistocene age in the extreme northern part of the study area in Idaho.

The generally accepted conceptual model for low-temperature geothermal systems in the Basin and Range province (and considered applicable for the study area) is one of deep, convective circulation of water of meteoric origin, which increases in temperature with depth due to conductive transfer of heat from the reservoir rock at temperatures controlled by the geothermal gradient (Rush, 1983, p. H4-7). Springs occur where permeable conduits along faults have allowed the deep-circulating, pressurized water to move relatively quickly to the land surface. Locally, however, a fault may be buried under saturated alluvium and no surface discharge of thermal water occurs. Under these conditions, the thermal water ascends along the fault, moves laterally into a more permeable zone of the alluvium, and mixes with the cooler ground water. Generally, the temperature of water produced by a well is higher the closer the well is to the fault.

Only thermal waters with surface temperatures equal to or greater than 21°C, about 10°C greater than the mean air temperature, are discussed in this report. These waters are considered to have circulated to depths of greater than about 1,000 feet and are not part of a local, shallow ground-water flow system. No thermal water in the study area is known to be associated with recent volcanic activity.

PREVIOUS WORK

Young and Mitchell (1973) obtained chemical analyses of water samples from 124 thermal springs and wells throughout Idaho. They used silica and sodium-potassium-calcium (Na-K-Ca) chemical geothermometers to estimate reservoir temperatures. Young and Lewis (1981) applied the magnesium correction of Fournier and Potter (1979) to the temperatures determined by the Na-K-Ca method by Young and Mitchell (1973) to estimate reservoir

temperatures for the magnesium-enriched thermal waters of southeastern Idaho.

In Utah, data from chemical analyses of thermal water were compiled by Mundorff (1970) and Goode (1978); Goode generally updated Mundorff's report. Studies of the geothermal potential of parts of north-central Utah were completed by DeVries (1982) for Cache Valley in part of Cache County, by Klauk and Budding (1984) for parts of Box Elder County, by Klauk and Prawl (1984) for parts of Davis and Weber Counties, and by Murphy and Gwynn (1979) for the northern Wasatch Front in parts of Box Elder and Weber Counties.

No compilation of water-chemistry data has been made for thermal water in southwestern Wyoming. Two thermal springs were sampled, however, for water chemistry as part of an areal ground-water study in Wyoming (Lines and Glass, 1975).

WATER CHEMISTRY

Analyses included in this report are for samples collected and analyzed by the U.S. Geological Survey, the Earth Science Laboratory at the University of Utah, and by DeVries (1982). The complete analyses for most of these samples have been published in reports referenced in table 1. Repeat samples of thermal water have been collected and analyzed in north-central Utah. Therefore, if a site had more than one analysis, only the most recent analysis by the Geological Survey is listed in table 1. Analyses by the Earth Science Laboratory that indicated the concentration of a common constituent was less than the detection limit are not included in table 1. Selected sites were chosen in areas having numerous sites with analyses. The sample for the spring in the SE $\frac{1}{4}$ NE $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 22, T.7N., R.1E. (number 34 in table 1) was collected by the author.

The water chemistry of thermal water is quite variable (table 1). The range of dissolved-solids concentration is from about 100 to nearly 40,000 milligrams per liter. Nearly all the water samples with dissolved-solids concentrations that exceeded 10,000 milligrams per liter were from sites in the Bear River valley, north of Brigham City, Utah. Generally, the more dilute water is a calcium bicarbonate type, whereas water with dissolved solids exceeding 3,000 milligrams per liter is a sodium chloride type.

Due to conductive loss of heat from the water to the cooler reservoir rock during the ascent of the water, and in some cases dilution with cooler water, the measured water temperature at thermal springs and shallow wells usually is lower than the maximum temperature the water attained at depth. The maximum temperature of the water at depth

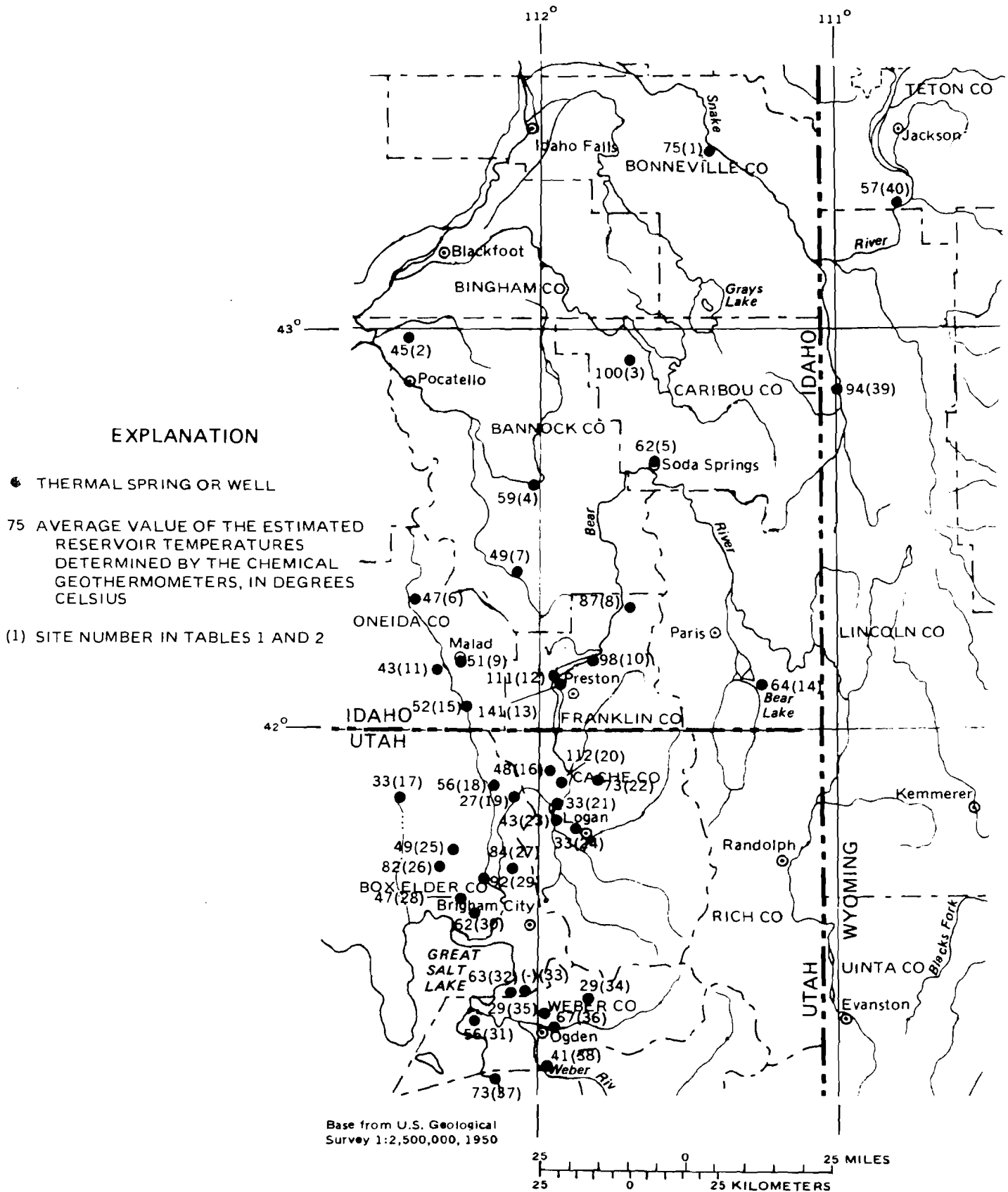


Figure 1 — Location of selected thermal springs or wells and the estimated reservoir temperature.

can be approximated by chemical-geothermometer methods as discussed in the following section.

CHEMICAL GEOTHERMOMETERS

Chemical equilibrium of geothermal fluids is, to a great extent, temperature dependent. A number of empirical correlations (chemical geothermometers) have been determined between cation concentrations of aqueous fluids and the equilibrium temperature of the fluid. The principal assumptions of the physical and chemical environment for application of the chemical geothermometers are given by Fournier, White, and Truesdell (1974).

Three chemical geothermometers were used to estimate reservoir temperature in the study area. The silica-geothermometer methods (Fournier and Rowe, 1966; Arnorsson, 1975) calculate the reservoir temperature from the silica concentration. Because the solubility of either quartz or chalcedony will usually govern the concentration of disassociated silica, two temperatures can be calculated. Arnorsson (1975, p. 769) determined that, at reservoir temperatures higher than 180°C, correlation of reservoir temperature and quartz-controlled silica concentration was best. At temperatures lower than 110°C, it was determined that chalcedony solubility probably controls silica concentration. The last geothermometer is based on relations between sodium, potassium, calcium, and magnesium concentrations. This Mg-corrected, Na-K-Ca chemical geothermometer was devised by Fournier and Potter (1979).

Using the water-chemistry data presented in table 1, estimated reservoir temperatures were calculated by the chemical geothermometer methods. The results are presented in table 2. Because not all the geothermometers are applicable to a water sample, as partly discussed above, the results need to be evaluated within the context of the hydrologic, chemical, and geologic setting. A number of temperatures determined by the geothermometers were either rejected by evaluation criteria given for the method or because the calculated temperature was lower than the measured temperature of the water at land surface. Because each geothermometer could not be fully evaluated for its suitability at each site, the average of the possible estimated temperatures is given in table 2. The average values are plotted by location in figure 1.

DISCUSSION

The estimated reservoir temperatures varied from more than 200°C to less than the measured surface temperature. The maximum estimated reservoir temperatures determined were: 153°C by the silica-quartz geothermometer; 128°C by the silica-chalcedony geother-

meter; and 230°C by the Mg-corrected, Na-K-Ca geothermometer. Because the estimated reservoir temperatures generally were lower than 120°C, the silica-quartz geothermometer was rarely applicable. The average of the temperatures determined from the geothermometers at each site was used for the estimation of the reservoir temperature because the average value would temper anomalous geothermometer temperatures resulting from chemical disequilibrium.

No uniformity or trend across the area from low to high values is indicated by the reservoir temperatures estimated by the average of the geothermometer temperatures (fig. 1). The highest reservoir temperatures, determined for ground water northwest of Preston, Idaho, probably are anomalous due to precipitation of calcium (Young and Lewis, 1981, p. 147), although the silica geothermometers also indicated a relatively high temperature. Water from the one site near Logan, Utah, with an estimated reservoir temperature greater than 100°C, had an unusually high concentration of silica. The lowest estimated reservoir temperatures occurred around Logan, Utah, where a few samples were collected from wells. Some mixing with cooler, non-thermal water probably occurred at those sites.

Definition of the ground-water flow systems responsible for the thermal water in the area is not possible. The presence of highly mineralized thermal water in the area indicates ground-water circulation on a regional scale through bedrock such as occurs in the Basin and Range province of west-central Utah (Gates and Kruer, 1981, p. 22-38). However, this assumes that the degree of mineralization is mostly related to the length of the flow path, which is not necessarily the case. The less mineralized thermal water may be moving through a relatively short flow system, most likely occurring in the semiconsolidated to unconsolidated basin fill. It is conceivable that both scales of flow system are responsible for the thermal water.

There is little evidence of thermal water in the eastern part of the study area in Utah or the southern part of the study area in Wyoming. These areas generally are topographically higher than the sample locations and probably are areas where recharge of the ground-water system occurs.

SUMMARY

The chemistry of thermal water in southeastern Idaho, north-central Utah, and southwestern Wyoming is quite variable, with a dissolved-solids concentration ranging from about 100 to nearly 40,000 milligrams per liter. Estimated reservoir temperatures calculated from chemical

Table 1. Selected chemical analyses of thermal ground water

[Analyses from DeVries, 1982; Goode, 1978; Klauk and Budding, 1984; Klauk and Prawl, 1984; Mundorff, 1970; unpublished U.S. Geological Survey data; and Young and Mitchell, 1973]

DS: dissolved solids--U.S. Geological Survey analyses are calculated as the sum of constituents, whereas Earth Science Laboratory (University of Utah) and DeVries analyses are residue on evaporation.

Laboratory analyzing sample: GS, U.S. Geological Survey; ESL, Earth Science Laboratory (University of Utah); DV, DeVries (1982).

Site number	Flow rate (gal/min)	pH (standard units)	Water temp (°C)	Milligrams per liter							Laboratory DS analyzing sample		
				Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO ₃)	Sulfate (SO ₄)	Chloride (Cl)		Silica (SiO ₂)	
IDAHO													
1	70	6.3	25.0	440	96	1,110	120	1,200	390	1,900	11	4,650	GS
2	15	7.7	40.5	70	25	150	21	478	95	87	20	706	GS
3	1,300	6.8	42.0	660	260	94	240	2,500	980	40	24	3,530	GS
4	--	6.6	44.5	120	32	170	39	542	110	190	32	962	GS
5	--	6.3	31.0	640	170	12	23	2,290	800	5	29	3,120	GS
6	189	6.7	24.0	56	19	15	4	226	18	35	33	295	GS
7	490	6.7	43.0	43	15	20	9	214	18	20	29	262	GS
8	350	7.3	76.0	89	24	490	110	491	260	630	55	1,900	GS
9	44	6.5	25.0	240	79	1,200	210	958	25	2,100	19	4,350	GS
10	--	7.3	44.5	25	7	360	24	524	15	320	80	1,110	GS
11	3,810	6.8	25.0	110	33	280	29	331	110	470	21	1,220	GS
12	900	7.0	77.0	160	16	3,100	660	699	50	5,400	80	9,830	GS
13	25	7.8	82.0	250	23	4,300	880	733	54	7,700	130	13,700	GS
14	--	6.6	47.5	210	55	180	61	256	800	79	35	1,560	GS
15	--	7.3	27.0	130	45	910	87	454	58	1,600	29	3,090	GS
UTAH													
16	--	7.6	31.0	132	46	1,400	110	548	71	2,280	23	4,380	GS
17	--	7.9	28.0	56	24	636	22	329	84	895	19	2,010	GS
18	200	7.2	51.0	220	70	2,900	120	360	98	4,800	29	8,420	GS
19	10	7.6	23.0	84	43	620	22	320	65	1,000	17	2,120	GS
20	--	8.1	49.0	34	30	1,140	71	622	1	1,690	81	3,280	GS
21	300	--	28.0	44	31	182	6	358	1	255	24	720	GS
22	60	6.9	51.0	79	30	1,300	78	588	2	2,120	69	3,780	GS
23	--	7.4	23.0	67	21	92	2	257	1	210	21	542	DV
24	--	7.2	25.0	51	20	22	6	247	21	20	18	290	DV
25	--	6.7	21	89	41	182	9	234	70	314	47	984	ESL
26	--	6.2	46	644	159	13,860	566	442	377	19,600	24	34,850	ESL
27	1,800	7.3	53.0	784	186	13,600	654	371	444	22,600	26	38,500	GS
28	450	7.0	42.0	630	230	13,000	450	400	500	22,000	28	37,000	GS
29	--	7.7	25.5	94	45	3,900	160	452	170	6,200	80	10,800	GS
30	--	7.1	47.0	652	431	9,780	492	426	152	17,200	41	29,000	GS
31	90	7.9	34.0	8	6	145	6	308	1	87	36	458	GS
32	42	7.8	25.0	21	4	49	7	193	4	10	28	221	GS
33	--	7.0	57.0	1,040	79	6,870	932	190	293	13,300	34	22,700	GS
34	--	7.2	24.0	14	6	12	2	61	10	10	13	104	GS
35	--	6.8	21	93	49	118	25	551	40	112	21	712	ESL
36	--	7.7	56.5	320	49	2,690	347	192	121	4,990	45	8,680	GS
37	--	7.6	48.0	506	91	2,350	256	224	38	4,840	30	8,230	GS
38	--	7.2	23	62	15	19	2	225	21	22	20	269	ESL
WYOMING													
39	38	6.6	55.0	420	69	1,400	150	830	1,300	1,900	40	5,690	GS
40	350	7.3	39.0	180	46	120	14	295	540	88	27	1,160	GS

Table 2. Estimated reservoir temperatures using chemical geothermometers

Site number	Measured water temp (°C)	Estimated reservoir temperature (°C) by chemical geothermometer			Average value of the estimated temperatures (°C)
		Silica quartz ¹	Silica chalcedony	Magnesium corrected Na-K-Ca	
IDAHO					
1	25.0	--	(2)	75	75
2	40.5	--	(2)	45	45
3	42.0	--	(2)	100	100
4	44.5	--	51	68	59
5	31.0	--	47	77	62
6	24.0	--	52	41	47
7	43.0	--	47	50	49
8	76.0	--	77	98	87
9	25.0	--	30	72	51
10	44.5	125	97	73	98
11	25.0	--	33	54	43
12	77.0	125	97	(3) 230	111
13	82.0	153	128	(3) 229	141
14	47.5	--	55	73	64
15	27.0	--	47	57	52
UTAH					
16	31.0	--	37	59	48
17	28.0	--	29	36	33
18	51.0	--	(2)	56	56
19	23.0	--	25	28	27
20	49.0	126	98	(2)	112
21	28.0	--	39	(4) 28	33
22	51.0	--	89	57	73
23	23.0	--	33	53	43
24	25.0	--	27	39	33
25	21	--	69	28	49
26	46	--	(2)	82	82
27	53.0	--	(2)	84	84
28	42.0	--	45	50	47
29	25.5	125	97	55	92
30	47.0	--	62	(2)	62
31	34.0	--	56	(2)	56
32	25.0	--	45	81	63
33	57.0	--	(2)	(3) 178	--
34	24.0	--	(2)	29	29
35	21	--	33	24	29
36	56.5	--	67	(3) 132	67
37	48.0	--	48	99	73
38	23	--	31	52	41
WYOMING					
39	55.0	--	61	128	94
40	39.0	--	44	70	57

- (1) The value is not shown when the estimated reservoir temperature is lower than 110 °C, because the quartz-controlled silica concentration probably would not correlate well with reservoir temperature (Arnorsson, 1975, p. 769).
- (2) Estimated temperature is lower than measured water temperature.
- (3) Temperature is much higher than the silica-geothermometer-determined temperature and is not considered in the average value.
- (4) The R value (Fournier and Potter, 1979, p. 1548) is greater than 50, indicating that the reservoir temperature probably is about equal to the measured water temperature.

geothermometers indicated no uniformity or trend from low to high values that might have helped define the ground-water flow systems responsible for the thermal water. Thermal water in the region possibly results from both shallow circulation in the basin fill and deeper circulation in the bedrock.

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