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THE CHEMICAL COMPOSITION AND ESTIMATED MINIMUM THERMAL RESERVOIR TEMPERATURES OF SELECTED HOT SPRINGS IN OREGON

By

R. H. Mariner, J. B. Rapp, L. M. Willey, and T. S. Presser

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ABSTRACT

Thirty-two of the hotter thermal springs were sampled for chemical analysis. The chemical composition of the spring waters suggest aquifer temperatures which range from 43°C to 181°C. Aquifer temperatures exceeding 140°C were estimated by both silica and Na-K or Na-K-Ca geothermometers at nine springs; four of these springs have estimated aquifer temperatures of 150°C or more.

Sodium is the principal cation in all of the spring waters. Most of the springs are sodium-mixed anion waters (Na^{+1}-HCO_3^{-1}-Cl^{-1}-SO_4^{-2}); however, the four sampled hot springs in the Cascade Range are sodium chloride waters.

INTRODUCTION

Interest in geothermal resources has increased markedly in recent years. The chemical composition of thermal spring waters is a valuable aid in exploring for geothermal resources. During the summers of 1972 and 1973 the principal hot springs of Oregon were sampled for detailed chemical analyses. The major element analyses have been completed and this information is being released at this time. The solution-mineral equilibrium, minor element composition, and trace element composition will be released at a later date.

Groh (1966) and Godwin and others (1971) have indicated several areas in Oregon which may have potential for development of geothermal power. Groh (1966) lists and briefly describes 10 areas which may have geothermal potential: (1) Klamath Falls in southwestern Klamath County, (2) Warner Range in southern Lake County, (3) Warner Valley in southern Lake County, (4) Newberry Volcano in Deschutes County, (5) Diamond Craters in Harney County, (6) High Cascade Range, (7) High Plains volcanic belt in Deschutes County and northern Harney County, (8) Harney Basin in northern Harney County, (9) Alvord Valley in southeastern Harney County and southwestern Malheur County, and (10) Jordan Craters in east central Malheur County. Godwin and others (1971) listed seven KGRA's (known geothermal resource areas), Breitenbush Hot Spring, Crump Geyser, Vale Hot Spring, Mt. Hood, Lakeview, Carey Hot Spring (Austin Hot Spring), and Klamath Falls.

SAMPLE SITE SELECTION

Selection of sample sites was based largely on the compilation by Bowen and Peterson (1970). Spring selection was also discussed with G. W. Walker and R. G. Bowen of the U.S. Geological Survey, as well as N. V. Peterson of the Oregon Department of Geology and Mineral Industries. Sampling was generally restricted to springs with a temperature of 50°C or more. However, several warm springs with high rates of flow and temperatures of less than 50°C were sampled in southeastern Oregon.

Table 1 contains the name, location, and topographic map coverage of the 32 thermal springs and wells from which water samples were collected. Spring names were taken from U.S. Geological Survey topographic maps or the report by Bowen and Peterson (1970). Figure 1 shows the distribution of thermal springs and wells covered in this report.

METHODS AND PROCEDURES

Water samples were collected at points as close to the orifices of the thermal springs or wells as possible. Water was collected in a 12-liter stainless steel pressure vessel and immediately pressure filtered through a 0.45μm (micrometer) effective pore diameter membrane filter using nitrogen as a pressure source. The filtered water samples were collected and stored in plastic bottles which had been acid washed to remove any trace contaminants prior to use. Ten milliliters of filtered sample were diluted to 100 ml (milliliters) with distilled deionized water to slow the polymerization of silica.

Field determinations were made of barometric pressure, air temperature, water temperature, conductivity, pH, and alkalinity. Water temperatures were determined with a thermistor probe and a maximum reading mercury in glass thermometer. Conductivity was measured in the spring, using a conductivity bridge with a temperature compensator. Rates of flow were estimated. The pH was measured directly in the spring by the method of Barnes (1964). Alkalinity was measured by the method of Barnes immediately after the sample was withdrawn from the spring.

Table 1.--Location and topographic map coverage of selected hot springs

Spring	Location	Topographic map coverage
	Baker County	
1 Radium Hot Springs (well)	NE 1/4 sec. 28, T. 7S., R. 39E.	Haines, Ore. (7-1/2'); Baker, Oregon-Idaho (2°)
	Clackamas County	
1 Austin Hot Springs	NW 1/4 sec. 30, T. 6S., R. 7E.	Fish Creek Mtn. Ore., (15'); Vancouver, Ore.-Wash. (2°)
	Grant County	
1 Weberg Hot Spring	sec. 18, T. 18S., R. 26E.	; Burns, Oregon (2°)
2 Blue Mountain Hot Springs	S 1/2 sec. 13, T. 14S., R. 34 E.	Prairie City, Ore. (15'); Canyon City, Oregon (2°)
3 Ritter Hot Springs	NW 1/4 sec. 8, T. 8S., R. 30E.	Ritter, Ore. (15'); Canyon City, Oregon (2°)
	Harney County	
1 Unnamed hot spring (Trout Creek)	sec. 16, T. 39S., R. 37E.	; Adel, Oregon (2°)
2 Hot Lake	sec. 15, T. 37S., R. 33E.	; Adel, Oregon (2°)
3 Unnamed hot spring (near Hot Lake)	sec. 15, T. 37S., R. 33E.	; Adel, Oregon (2°)
4 Alvord Spring (Indian Spring)	sec. 33, T. 34S., R. 34E.	; Adel, Oregon (2°)
5 Mickey Springs	sec. 13, T. 33S., R. 35E.	; Adel, Oregon (2°)
6 Unnamed hot spring (near Harney Lake)	sec. 36, T. 27S., R. 29-1/2E.	; Burns, Oregon (2°)
7 Crane Hot Springs	S 1/2 sec. 34, T. 24S., R. 33E.	Crane, Ore. (15'); Burns, Oregon (2°)
	Klamath County	
1 Olene Gap Hot Springs	SW 1/4 sec. 14, T. 39S., R. 10E.	Merrill, Ore.-Calif. (15'); Klamath Falls, Ore.-Calif. (2°)
	Lake County	
1 Fisher Hot Springs	NW 1/4 sec. 10, T. 38S., R. 25E.	Crump Lake, Ore. (7-1/2'); Adel, Oregon (2°)
2 Crump (Charles Crump's Spring)	sec. 27, T. 38S., R. 24E.	; Adel, Oregon (2°)
3 Barry Ranch Hot Springs	SE 1/4 sec. 27, T. 39S., R. 20E.	Lakeview NE, Ore. (7-1/2'); Klamath Falls, Ore.-Calif. (2°)
4 Hunters Hot Springs	NW 1/4 sec. 4, T. 39S., R. 20E.	Lakeview NE, Ore. (7-1/2'); Klamath Falls, Ore.-Calif. (2°)
5 Summer Lake Hot Spring	NE 1/4 sec. 12, T. 33S., R. 17E.	Slide Mtn. Ore. (7-1/2'); Klamath Falls, Ore.-Calif. (2°)

La Grande Baker

Table 1.--Location and topographic map coverage of selected hot springs--Continued

Spring	Location	Topographic map coverage
	Lane County	
1 Belknap Hot Springs	NE 1/4 sec. 11, T. 16S., R. 6E.	McKenzie Bridge, Ore. (15'); Salem, Oregon (2°)
2 Cougar Reservoir Hot Spring	sec. 7, T. 17S., R. 5E.	McKenzie Bridge, Ore. (15'); Salem, Oregon (2°)
	Malheur County	
1 Unnamed hot springs (near McDermitt)	sec. 25, T. 40S., R. 42E.	; Jordan Valley, Ore.-Idaho (2°)
2 Unnamed hot springs (at Three Forks)	sec. 3, T. 35S., R. 45E.	; Jordan Valley, Ore.-Idaho (2°)
3 Unnamed hot spring (near Riverside)	sec. 20, T. 24S., R. 37E.	; Burns, Oregon (2°)
4 Beulah Hot Springs	SE 1/4 sec. 2, T. 19S., R. 37E.	Beulah, Oregon (15'); Burns, Oregon (2°)
5 Neal Hot Springs	NW 1/4 sec. 9, T. 18S., R. 43E.	Jamieson, Oregon (15'); Baker, Idaho-Oregon (2°)
6 Unnamed hot springs (near Little Valley)	NW 1/4 sec. 30, T. 19S., R. 43E.	Harper, Oregon (15'); Boise, Idaho-Oregon (2°)
7 Mitchell Butte Hot Spring	NE 1/4 sec. 12, T. 21S., R. 45E.	Mitchell Butte, Ore. (7-1/2'); Boise, Idaho-Oregon (2°)
	Marion County	
1 Breitenbush Hot Springs	NE 1/4 sec. 20, T. 9S., R. 7E.	Breitenbush Hot Spring, Ore. (15'); Canyon City, Ore. (2°)
	Umatilla County	
1 Lehman Springs	NE 1/4 sec. 12, T. 5S., R. 33E.	Lehman Springs, Ore. (7-1/2'); Pendleton, Ore.-Wash. (2°)
	Union County	
1 Medical Hot Springs	NE 1/4 sec. 25, T. 6S., R. 41E.	Flagstaff Butte, Ore. (7-1/2'); Grangeville, Idaho-Ore.-Wash. (2°)
2 Hot Lake	SE 1/4 sec. 5, T. 4S., R. 39E.	Craig Mtn., Ore. (7-1/2'); Grangeville, Idaho-Ore.-Wash. (2°)
	Wasco County	
1 Kahneeta Hot Springs (Kah-Ne-Tah)	E 1/2 sec. 20, T. 8S., R. 13E.	Eagle Butte, Ore. (7-1/2'); Bend, Oregon (2°)

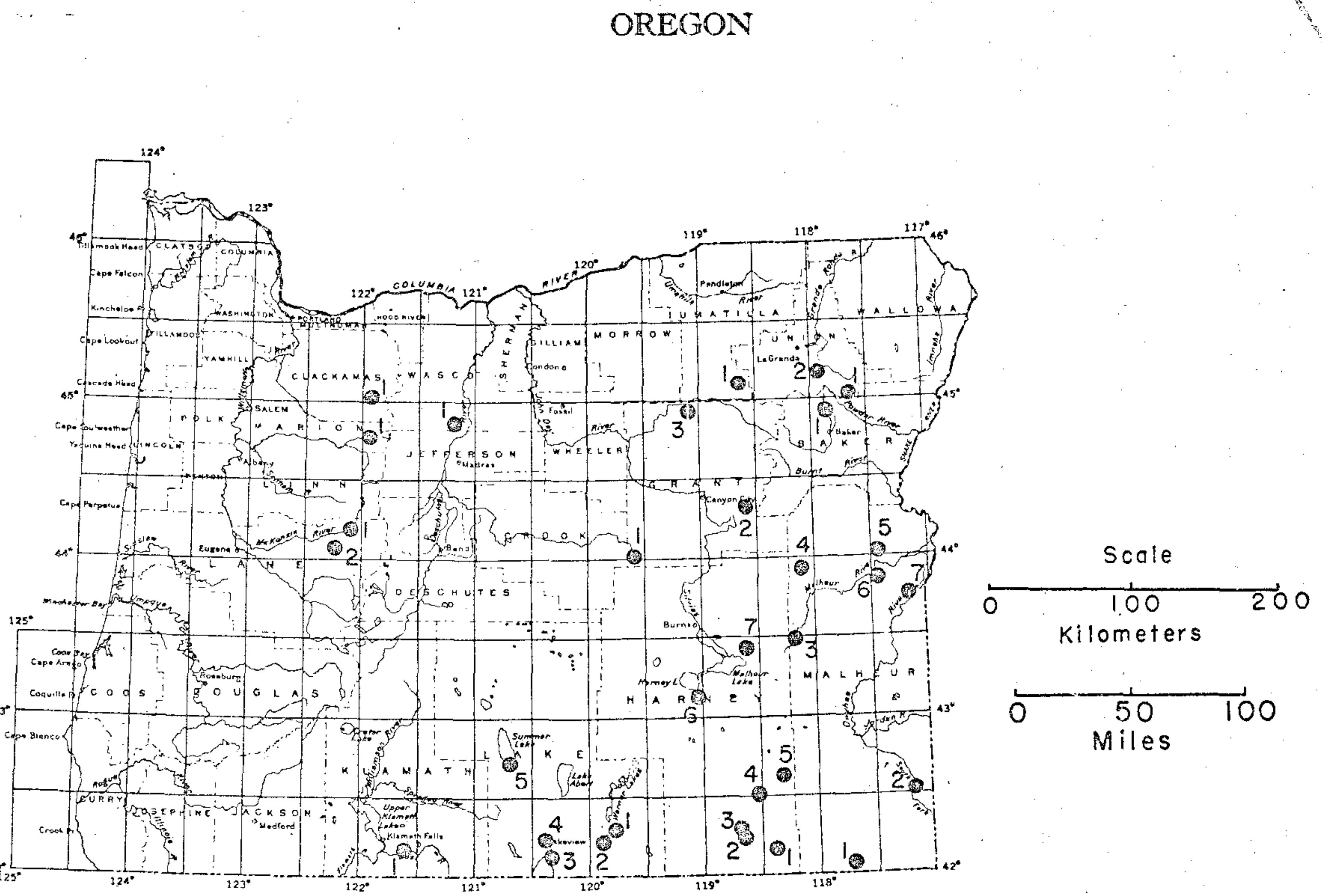

Figure 1. Map of the State of Oregon showing the location of sampled thermal springs and wells. The numbered dots correspond to sampled springs listed by county in tables 1, 2, 3, and 4 of the text.

WATER CHEMISTRY

Major chemical constituents of the sampled springs and wells, table 2, shows that all of the hot springs have sodium as the principal cation. Chloride is the principal anion of all four hot springs in the Cascade Range. Bicarbonate is the principal anion at Weberg, Blue Mountain, Ritter, Crane, and the two unnamed hot springs in southern Malheur County. Sulfate is the principal anion at Olene Gap and Medical Hot Springs. The other springs are mixed anion waters with varying proportions of bicarbonate, sulfate, and chloride. The thermal waters from the Cascade Range and southern Harney County are the most saline. Alvord Hot Spring in southern Harney County and Belknap Hot Spring in the Cascade Range are very saline with total dissolved solids of 2,980 and 3,020 mg/l (milligrams per liter), respectively. The pH's range from 6.53 at Weberg Hot Spring to 9.68 at Ritter Hot Spring; both springs are in Grant County. Lithium, boron, and to a lesser extent, fluoride concentrations are high in thermal waters from southern Harney County. Kah-Ne-Tah Hot Spring in Wasco County is very high in fluoride, 20.5 mg/l.

CHEMICAL GEOTHERMOMETERS

The chemical composition of thermal spring waters can be used to give estimates of the aquifer temperature. Qualitative geochemical indicators include Ca and HCO_3 contents of near neutral waters (Ellis, 1970); Mg or Mg/Ca ratios: low values indicate high thermal aquifer temperatures (White, 1970); Na/Ca ratios: high ratios may indicate high temperatures (Mahon, 1970); $Cl/(HCO_3 + CO_3)$: highest ratios

Table 2.--Chemical analyses of selected hot springs

Spring	Temperature (°C)	pH	Specific conductance	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Lithium (Li)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Boron (B)
Baker County															
1 Radium Hot Springs (well)	58	9.56	290	78	1.5	0.1	58	1.1	0.01	86	27	34	17	1.3	0.42
Clackamas County															
1 Austin Hot Springs	86	7.63	1,720	81	35	.1	300	7.1	.4	56	<1	140	430	1.4	2.5
Grant County															
1 Weberg Hot Spring	46	6.53	2,570	82	38	7.8	610	36	.7	1,710	1	13	50	3.9	15
2 Blue Mountain Hot Springs	58	7.96	610	47	2.2	.2	140	3.3	.07	323	3	11	15	10.6	1.6
3 Ritter Hot Springs	41	9.68	319	70	1.4	<.05	72	.82	.01	86	28	9	29	4.0	2.6
Harney County															
1 Unnamed hot spring (Trout Creek)	52	6.77	1,168	105	18	.8	270	10.8	.68	439	1	204	24	12.8	.89
2 Hot Lake	36	7.28	2,410	190	16	.3	500	31	.65	420	<1	350	300	9.0	16.6
3 Unnamed hot spring (near Hot Lake)	96	7.30	2,020	160	14	.3	450	28	.51	374	4	434	250	7.2	15
4 Alvord Spring (Indian Spring)	76	6.73	4,590	120	13	2.2	960	69	2.1	1,196	1	220	780	10.2	30
5 Mickey Springs	73	8.05	2,490	200	.9	.1	550	35	1.1	774	11	230	240	16	10.5
6 Unnamed hot spring (near Harney Lake)	68	7.26	2,970	92	12	1.8	630	13	.45	566	1	140	590	3.3	11.3
7 Crane Hot Springs	78	8.10	810	83	3.7	.1	170	3.9	.09	202	3	86	79	9.0	7.9
Klamath County															
1 Olene Gap Hot Springs	74	7.68	1,140	98	40	.2	190	7.2	.15	53	<1	400	59	1.2	1.0
Lake County															
1 Fisher Hot Springs	68	7.93	513	77	8.4	1.0	92	7.9	.04	105	1	59	56	3.5	2.2
2 Crump (Charles Crump's Spring)	78	7.26	1,490	180	16	.2	280	11	.4	153	<1	200	240	4.9	13.6
3 Barry Ranch Hot Springs	88	7.76	1,370	130	8.8	.1	280	9.0	.15	232	2	240	170	5.4	11.2
4 Hunters Hot Springs	96	7.77	1,120	140	13	<.1	210	8.5	.15	79	<1	260	120	4.4	6.9
5 Summer Lake Hot Spring	43	8.43	1,790	94	2.1	.1	390	4.6	.15	406	10	120	280	2.2	6.9

Table 2.--Chemical analyses of selected hot springs--Continued

Spring	Temperature (°C)	pH	Specific conductance	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Lithium (Li)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Boron (B)
Lane County															
1 Belknap Hot Springs	71	7.62	4,300	96	210	.2	690	15	.95	17	<1	170	1,300	1.2	6.4
2 Cougar Reservoir Hot Spring	44	7.76	2,890	50	225	.1	392	6.3	.52	19	<1	260	788	.8	5.1
Malheur County															
1 Unnamed hot springs (near McDermitt)	52	8.79	598	72	.6	<.1	130	1.0	.06	237	13	52	14	6.6	1.1
2 Unnamed hot springs (at Three Forks)	34	8.11	338	40	10.5	.7	61	1.2	.04	108	1	34	18	4.2	.11
3 Unnamed hot spring (near Riverside)	63	7.43	1,330	110	34	.5	240	9.7	.27	160	<1	290	140	4.8	6.6
4 Beulah Hot Springs	60	7.56	1,090	170	24	.2	200	6.0	.24	161	1	290	55	4.7	4.7
5 Neal Hot Springs	87	7.32	1,010	180	8.8	.2	190	16	.3	198	<1	120	120	9.4	4.1
6 Unnamed hot springs (near Little Valley)	70	8.71	740	115	3.2	<.05	160	3.2	.11	127	1	110	74	6.8	4.7
7 Mitchell Butte Hot Spring	62	8.69	559	94	4.6	<.1	110	1.6	.03	72	3	130	28	10.4	.49
Marion County															
1 Breitenbush Hot Springs	92	7.31	4,030	83	100	1.3	720	31	1.8	142	<1	140	1,300	3.4	4.1
Umatilla County															
1 Lehman Springs	61	9.18	252	44	.9	.1	53	.7	.03	101	13	23	5.4	2.1	.12
Union County															
1 Medical Hot Springs	60	8.23	1,173	80	72	.2	190	7.0	.05	26	<1	400	77	1.2	2.2
2 Hot Lake	80	9.21	688	48	4.9	<.1	130	2.7	.03	75	12	56	140	1.7	2.9
Wasco County															
1 Kahneeta Hot Springs (Kah-Ne-Tah)	52	8.32	1,370	104	3.2	<.05	325	3.4	.52	493	9	34	155	21	2.6

in waters from the same thermal system indicate the highest subsurface temperatures (Fournier and Truesdell, 1970); and Cl/F: high ratios may indicate high temperature (Mahon, 1970). Quantitative estimates of aquifer temperatures can be obtained from geothermometers based on silica and Na/K or Na-K-Ca.

The basic assumptions in using quantitative geothermometers have been enumerated by Fournier, White, and Truesdell (1974):

"1. Temperature dependent reactions occur at depth.

2. There is an adequate supply of the constituents that are used as a basis for geothermometry.

3. Water-rock equilibrium occurs at the reservoir temperature.

4. There is negligible re-equilibrium at lower temperatures as the water flows from the reservoir to the surface.

5. There is no dilution or mixing of the hot water coming from depth with shallow water."

The silica geothermometer is based on the solubility of quartz (Fournier and Rowe, 1966) while the cation geothermometers are based on exchange reactions between silicates and the aqueous phase. The Na/K ratio should be used only for near-neutral and alkaline waters that do not deposit travertine and/or waters with $\sqrt{Ca}/Na$ ratios equal to or less than one (Fournier and Truesdell, 1973). Fournier and Truesdell (1973) have shown that data for most geothermal waters cluster near a straight line when the function log (Na/K) + β log ($\sqrt{Ca}/Na$) is plotted versus the reciprocal of absolute temperature. Beta (β) is 4/3 for waters which have equilibrated below 100°C and 1/3 for waters which have equilibrated above 100°C.

Fournier, White, and Truesdell (1974) present a set of guidelines for determining which subsurface temperature estimates may give the best indication of the aquifer temperature. They recommend a procedure based on the temperature and flow rate of the spring. A large rate of flow is taken to be 100 liters per minute or more while a small rate of flow is less than about 20 liters per minute. Boiling springs with large rates of flow may be considered to have cooled adiabatically, while boiling springs with small rates of flow may have cooled by conduction. Springs with temperatures below boiling are difficult to interpret if the flow rates are small. They may either be a mixed water or they may have cooled by conduction. These nonboiling springs of small flow rate give only qualitative estimates of the thermal aquifer temperatures. Springs of large flow rate with temperatures below boiling may be mixed waters or water which has equilibrated near the spring temperature. If the Na-K-Ca geothermometer indicates a temperature of more than 25°C above the measured spring temperature, the water should be treated as a mixed water by the method of Fournier and Truesdell (1974). Springs preceded by an asterisk (*) in table 3 may be mixed waters and will be discussed in a later report. The subsurface temperature estimates for these mixed waters, table 3, represent minimum thermal aquifer temperatures. The underlined numbers in table 3 represent the "best" estimates of aquifer temperature. Hot Lake in the Alvord region was assumed to have cooled adiabatically because of the very large flow rate, extremely large cooling surface, and the questionable temperature data. The temperature reported in table 3 was measured in the edge of the lake near the outlet channel, not in the throat of the spring which is not accessible. Eleven of the 32 sampled springs may be mixed waters.

Five of these 11 possible mixed waters have estimated aquifer temperatures of more than 140°C without considering mixing. The water chemistry at Breitenbush Hot Spring in Marion County may have been altered by precipitation of calcite. Therefore, Breitenbush Hot Spring may be either a mixed water or a high flow rate spring which has equilibrated with rock at temperatures only slightly above 100°C. Weberg, Fisher, Crump, and Summer Lake hot springs are low to intermediate flow rate springs which may be mixed waters or may have cooled by conduction.

Aquifer temperatures estimated from the chemical composition indicate several regions where the hot spring waters have circulated through rock at 140°C or more. The Wild Horse Valley (Alvord area) of southeastern Oregon contains four principal hot springs which have chemical compositions indicating a subsurface temperature of at least 148°C. Barry Ranch Hot Spring and Hunters Hot Spring near Lakeview in southern Lake County, Neal Hot Spring and an unnamed hot spring (near Riverside) in Malheur County, and the unnamed hot spring (Trout Creek) in southern Harney County all have estimated aquifer temperatures of at least 140°C.

Table 3.--Geologic setting and estimated thermal aquifer temperatures of selected hot springs

Spring	Spring temperature (°C)	Flow (lpm)	Gas	Spring deposits		Rock type of the spring	Estimated thermal aquifer temperature				
				$CaCO_3$	Silica		Silica conductive	Silica adiabatic	Na-K	Na-K-1/3Ca	Na-K-4/3Ca
Baker County											
1 Radium Hot Springs (well)**	58	1,100	X	--	--	Alluvium, quartzdiorite, and basalt	123	122	48	109	77
Clackamas County											
1 Austin Hot Springs***	86	950	T	T	--	Olivine basalt, basaltic andesite and pyroxene andesite	124	123	61	118	88
Grant County											
1 Weberg Hot Spring	46	40	X	T	--	Arkosic sandstone	125	124	130	170	162
2 *Blue Mountain Hot Springs	58	250	--	T	--	Andesite	99	101	61	126	118
3 Ritter Hot Springs**	41	130	--	--	--	Basalt	118	117	20	92	71
Harney County											
1 *Unnamed hot spring (Trout Creek)	52	200	T	--	--	Andesite, basalt, and rhyolite	140	135	97	144	118
2 Hot Lake	36	3,500	T	--	X	Alluvium, andesite, and basalt	176	165	134	176	181
3 Unnamed hot spring (near Hot Lake)	96	15	X	T	X	Alluvium, andesite, and basalt	165	156	134	176	178
4 *Alvord (Indian) Hot Spring	76	500	T	T	X	Rhyodacite, andesite, and basalt	148	142	148	199	254
5 *Mickey Springs	73	100	X	T	X	Andesitic tuff-breccia	179	168	136	207	330
6 *Unnamed hot spring (near Harney Lake)	68	550	T	T	--	Basaltic tuff, and olivine basalt	132	129	52	130	151
7 Crane Hot Springs	78	550	T	--	--	Augite andesite	127	125	59	124	114
Klamath County											
1 Olene Gap Hot Springs**	74	200	T	--	--	Andesite, basalt, and andesitic tuff-breccia	136	132	93	130	80
Lake County											
1 Fisher Hot Springs	68	70	T	T	--	Alluvium and olivine basalt	123	121	167	170	112
2 Crump (Charles Crump's Spring)	78	0-50	T	T	X	Alluvium and olivine basalt	173	162	96	144	123
3 *Barry Ranch Hot Springs	88	200	X	T	T	Andesite, andesitic tuff-breccia, and rhyolite	153	146	81	140	131
4 Hunters Hot Springs	96	2,300	T	T	T	Alluvium, andesite, and andesitic tuff-breccia	157	149	98	143	114
5 *Summer Lake Hot Spring***	43	75	T	T	--	Alluvium, andesite, andesitic tuff-breccia	134	130	22	112	149

Table 3.--Geologic setting and estimated thermal aquifer temperatures of selected hot springs--Continued

Spring	Spring temperature (°C)	Flow (lpm)	Gas	Spring deposits: $CaCO_3$	Spring deposits: Silica	Rock type at the spring	Estimated thermal aquifer temperature: Silica conductive	Silica adiabatic	Na-K	Na-K-1/3ca	Na-K-4/3ca
						Lane County					
1 Belknap Hot Springs**	71	300	--	--	--	Olivine basalt	135	131	56	114	82
2 Cougar Reservoir Hot Spring**	44	200	--	--	--	Andesite, basalt, and basic tuff-breccia	89	92	38	95	49
						Malheur County					
1 *Unnamed hot springs (near McDermitt)	52	750	T	--	--	Basalt	118	118	3	91	105
2 Unnamed hot springs (at Three Forks)**	34	4,000	--	--	--	Basalt	95	97	52	100	44
3 *Unnamed hot springs (near Riverside)	63	200	T	T	--	Andesite	142	137	98	138	97
4 Beulah Hot Springs	60	50	T	T	X	Vitric tuff	169	159	76	125	86
5 Neal Hot Springs	87	90	T	T	X	Basalt	173	162	164	181	151
6 *Unnamed hot springs (near Little Valley)***	70	550	T	T	T	Basalt and andesite	145	139	51	119	109
7 Mitchell Butte Hot Spring**	62	60	--	T	--	Volcanic arkose	133	130	33	100	72
						Marion County					
1 Breitenbush Hot Springs	92	3,400	--	X	--	Andesite	127	124	103	149	128
						Umatilla County					
1 Lehman Springs***	61	275	X	T	--	Andesite	98	98	28	97	73
						Union County					
1 Medical Hot Springs**	60	200	X	T	--	Basalt	125	123	91	125	67
2 Hot Lake	80	1,500	T	T	--	Basalt and mylonite	102	103	53	115	90
						Wasco County					
1 *Kahneeta Hot Springs (Kah-Ne-Tah)	52	200	T	T	--	Rhyolite, andesite, basalt, and tuffs	139	135	17	103	121

* Mixed waters

** Temperature estimates based on the solubility of cristobalite improve the agreement between the silica and cation geothermometers at Radium Hot Springs (72°C), Ritter Hot Springs (70°C), Olene Gap Hot Springs (84°C), Belknap Hot Springs (84°C), Cougar Reservoir Hot Springs (51°C), the unnamed hot springs near Three Forks (39°C), Mitchell Butte Hot Springs (83°C), and Medical Hot Springs (74°C). Solubility data from Fournier and Rowe (1962).

***Temperature estimates based on the solubility of chalcedony improve the agreement between the silica and cation geothermometers at Austin Hot Springs (95°C), the unnamed hot springs near Little Valley (112°C), Summer Lake Hot Springs (107°C), and perhaps, Lehman Hot Springs (68°C). Solubility data from Fournier (1973).

GENERALIZED GEOLOGIC SETTING

Areas of Oregon which have thermal springs are underlain principally by Cenozoic volcanic rocks (basalts or andesites), as well as related tuffs and sedimentary rocks. Late Cenozoic basalt and andesite flows crop out in the Cascade Range. Southeastern Oregon, part of the Basin and Range Province, consists chiefly of flows of basalt and andesite with some rhyolitic flows and domes interbedded with ash-flow tuffs and continental sedimentary rocks. The principal valleys all contain Quarternary alluvium and lake sediments, usually with some fluvial glacial deposits and pumice. Rocks exposed in the northeastern part of the state are largely Cenozoic basalts and andesites with some interbedded sedimentary rocks. A window of Mesozoic and Paleozoic rock crops out in Grant County. These pre-Cenozoic rocks include gabbro and granite in addition to sedimentary and volcanic rocks. Some of the sedimentary and volcanic rocks have been strongly metamorphosed. A similar window of pre-Cenozoic rocks is exposed in southwestern Oregon (Corcoran, 1969).

Rock types which crop out near the spring or may be present at depth are listed in table 4. Recent papers on the geology around the various springs are listed for reference in table 4. Almost all of the springs issue along faults. Generally the springs are located at or near the edge of an alluvium-filled valley.

Table 4.--Age of bedrock and geologic coverage of each spring

Spring	Age of bedrock	Geologic reference
	Baker County	
1 Radium Hot Springs (well)	Quaternary alluvium, Late Cretaceous diorite, and Permian greenstone	Gilluly (1937)
	Clackamas County	
1 Austin Hot Springs	Pliocene to Holocene mafic flows and perhaps pyroclastic rocks	Peck, Griggs, Schlicker, Wells, and Dole (1964)
	Grant County	
1 Weberg Hot Spring	Lower and Middle Jurassic sandstone and volcanic rocks	Brown and Thayer (1966)
2 Blue Mountain Hot Springs	Miocene and Pliocene andesite flows	Brown and Thayer (1966)
3 Ritter Hot Springs	Miocene and Pliocene basalt flows	Brown and Thayer (1966)
	Harney County	
1 Unnamed hot spring (Trout Creek)	Quaternary alluvium, Miocene to Pliocene basalt, andesite, and rhyolite flows	Walker and Repenning (1965)
2 Hot Lake	Quaternary alluvium and playa deposits	Walker and Repenning (1965)
3 Unnamed hot spring (near Hot Lake)	Quaternary alluvium and playa deposits	Walker and Repenning (1965)
4 Alvord (Indian) Spring	Miocene rhyodacite, basalt, and andesite	Walker and Repenning (1965)
5 Mickey Springs	Miocene andesitic tuff-breccia, basalts, and andesites	Walker and Repenning (1965)
6 Unnamed hot spring (near Harney Lake)	Pliocene basalts, tuffs, and welded tuffs	Walker and Swanson (1967); Greene, Walker and Corcoran (1972)
7 Crane Hot Springs	Quaternary alluvium, Pliocene and Pleistocene pyroclastic rocks, and Pliocene basalt and andesite	Leonard (1970); Greene, Walker, and Corcoran (1972)
	Klamath County	
1 Olene Gap Hot Springs	Pliocene and Pleistocene basalts and associated pyroclastic rocks	Peterson and Groh (1967)
	Lake County	
1 Fisher Hot Springs	Quaternary alluvium and Miocene to Pliocene olivine basalt	Walker and Repenning (1965)
2 Crump (Charles Crump's Spring)	Quaternary alluvium and Miocene to Pliocene olivine basalt	Walker and Repenning (1965); Peterson (1959)
3 Barry Ranch Hot Springs	Oligocene(?) and Miocene basalt or andesite flows, tuff-breccia, tuff, and tuffaceous rocks	Walker (1963)

Table 4.--Age of bedrock and geologic coverage of each spring--Cont'd

Spring	Age of bedrock	Geologic reference
4 Hunter Hot Springs	Quaternary alluvium, Quaternary to late Tertiary basalts and andesites, middle Tertiary tuffs	Walker (1963)
5 Summer Lake Hot Spring	Tertiary and Quaternary sedimentary rocks overlying Tertiary andesite flows	Walker (1963)
	Lane County	
1 Belknap Hot Springs	Pliocene to Holocene basic volcanic flows and pyroclastic rocks	Peck, Griggs, Schlicker, Wells, and Dole (1964)
2 Cougar Reservoir Hot Spring	Miocene mafic to intermediate flows, tuffs, and tuff-breccias	Peck, Griggs, Schlicker, Wells, and Dole (1964)
	Malheur County	
1 Unnamed hot springs (near McDermitt)	Quaternary alluvium, Tertiary and Quaternary pediment gravels, and Miocene volcanic rocks	Walker and Repenning (1966)
2 Unnamed hot springs (at Three Forks)	Miocene and Pliocene volcanic flows and tuffs	Walker and Repenning (1966)
3 Unnamed hot springs (near Riversdie)	Miocene basalt	Walker and Repenning (1965)
4 Beulah Hot Springs	Miocene and Pliocene vitric tuff	Greene, Walker, and Corcoran (1972); Bowen (1956)
5 Neal Hot Springs	Miocene(?) volcanic flows	Walker (1973)
6 Unnamed hot springs (near Little Valley)	Pliocene basalt and sedimentary volcanic rocks	Corcoran, Doak, Porter, Pritchett, and Privrasky (1962)
7 Mitchell Butte Hot Spring	Pliocene conglomerate, sandstone, and siltstones	Corcoran, Doak, Porter, Pritchett, and Privrasky (1962)
	Marion County	
1 Breitenbush Hot Springs	Miocene basalt flows, tuff-breccias, and tuffs, near an area of propylitically altered rock	Peck, Griggs, Schlicker, Wells, and Dole (1964)

Table 4.--Age of bedrock and geologic coverage of each spring--Cont'd

Spring	Age of bedrock	Geologic reference
	Umatilla County	
1 Lehman Springs	Miocene basalt	Wagner (1954)
	Union County	
1 Medical Hot Springs	Miocene basalts and andesites, Permian and Triassic metavolcanic and metasedimentary rocks	Walker (1973)
2 Hot Lake	Miocene basalt	Hampton and Brown (1964)
	Wasco County	
1 Kahneeta Hot Springs (Kah-Ne-Tah)	Oligocene and Miocene rhyolites and tuffs	Waters (1968); Hodge (1941)

TYPES OF THERMAL SYSTEMS

The Geysers in California, Larderello in Italy, and the Matsukawa area of Japan are vapor-dominated (dry steam) systems which have been developed as electric-power producing regions. Geothermal areas underlain by vapor-dominated systems have thermal springs with low discharges (100 liters per minute or less) of sulfate waters (White, Muffler, and Truesdell, 1971). These sulfate waters are low in chloride and often strongly acidic (pH 2 to pH 3). The few thermal springs with pH's near neutral are rich in sodium and bicarbonate and have chloride contents of less than 20 mg/l.

Hot-water dominated systems have been found in permeable sedimentary rocks, volcanic rocks, and rocks such as granite. Springs issuing from hot-water dominated systems are characterized by high total discharges (several hundred to several thousand liters per minute) and high contents of alkalis, chloride, and silica. Individual springs have discharges of a few liters per minute to several hundred liters per minute (White, Muffler, and Truesdell, 1971).

The sampled thermal springs in Oregon have chemical compositions characteristic of hot-water dominated systems. Several of the warm springs of low specific conductance have less than 20 mg/l chloride and are neutral to alkaline in pH. Local meteoric water have similar compositions.

SUMMARY

Nine of the sampled thermal springs have chemical compositions which indicate aquifer temperatures of at least 140°C. Possible contamination with meteoric water of low specific conductance is not considered and therefore the estimated thermal aquifer temperatures are minimum values. The chemical compositions of the springs are typical for springs associated with hot-water dominated systems. Specific conductances for the springs with estimated aquifer temperatures of at least 140°C are high to very high. Areas underlain by thermal aquifers of 140°C or more include the Alvord area of southern Harney County, the Lakeview area of southern Lake County, and the Vale area of northern Malheur County.

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