THERMAL SPRINGS IN THE PAYETTE RIVER BASIN,

WEST-CENTRAL IDAHO

By R. E. Lewis and H. W. Young

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CONVERSION FACTORS

For the convenience of those who prefer to use SI (International System of Units) rather than the inch-pound system of units, conversion factors for terms used in this report are listed below. Chemical data are given in mg/L (milligrams per liter) or µg/L (micrograms per liter). These values are, within the range of values presented, numerically equal to parts per million or parts per billion, respectively. Specific conductance is expressed in µmhos (micromhos per centimeter at 25 degrees Celsius). Thermal parameters are reported in "working" units.

Multiply inch-pound unit	By	To obtain SI unit
	Length	
inch (in.)	25.40	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	4047	square meter
square mile (mi^2)	2.590	square kilometer
	Volume	
acre-foot (acre-ft)	1233	cubic meter
	Flow	
gallon per minute (gal/min)	0.06309	liter per second

CONVERSION FACTORS
(Continued)

Multiply working unit	By	To obtain SI unit
	Heat Flux	
calorie per second (cal/s)	4.187	watt
calorie (cal)	4.187	joule

TEMPERATURE

Conversion of °C (degrees Celsius) to °F (degrees Fahrenheit) is based on the equation, °C = 5/9 (°F - 32). All water temperatures are recorded to the nearest one-half degree.

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ABSTRACT

The Payette River basin, characterized by steep, rugged mountains and narrow river valleys, occupies an area of about 3,300 square miles in west-central Idaho. Predominant rock types in the basin include granitic rocks of the Idaho batholith and basalt flows of the Columbia River Basalt Group.

Waters from thermal springs in the basin, temperatures of which range from 34° to 86° Celsius, are sodium bicarbonate type and are slightly alkaline. Dissolved-solids concentrations range from 173 to 470 milligrams per liter. Reservoir temperatures determined from the sodium-potassium-calcium, silicic acid-corrected silica, and sulfate-water isotope geothermometers range from 53° to 143° Celsius.

Tritium, present in concentrations between 0 and 2 tritium units, indicate that sampled thermal waters are at least 100 years and possibly more than 1,000 years old. Stable-isotope data indicate it is unlikely any of the nonthermal waters sampled are representative of precipitation that recharges the thermal springs in the basin.

Thermal springs discharged about 5,700 acre-feet of water in 1979. Associated convective heat flux is 1.1×10^7 calories per second.

INTRODUCTION

Numerous thermal springs (water temperatures greater than 20°C) occur throughout central Idaho, an area encompassing three major basins--the Payette, Salmon, and Boise Rivers. These basins roughly coincide with surface exposures of the Idaho batholith. A map prepared by the National Geophysical and Solar-Terrestrial Data Center (1977) classifies the Idaho batholith and adjacent areas as one of the largest prospectively valuable areas for steam and associated geothermal resources in the western United States.

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This report is the first of three scheduled for central Idaho and describes occurrence and chemistry of thermal springs in the Payette River basin of west-central Idaho. This report is part of an overall program by the U.S. Geological Survey to better understand the nature and occurrence of geothermal resources in Idaho. Work during this phase of study was accomplished during the period October 1978 to September 1979.

Purpose and Scope

Purposes of this report are to: (1) Better define the areal distribution and occurrence of thermal springs in the Payette River basin, (2) evaluate their chemical and isotopic compositions, and (3) quantify the amount of heat and water presently discharging.

Thirty-one thermal springs and four selected nonthermal springs were inventoried in the Payette River basin. Water temperatures were measured, and measurements or estimates of discharge were made at the time of inventory. Water samples from 23 thermal springs and 4 nonthermal springs were collected for chemical analyses, which include common ions, silica, and the minor elements arsenic, boron, lithium, and mercury. Additional water samples for isotope analyses were collected from selected thermal springs and the four selected nonthermal springs. Isotope analyses included deuterium and oxygen-18 (20 springs), tritium (5 springs), and sulfate-water isotopes (6 thermal springs).

Water temperatures and measurements or estimates of discharge were used to determine the amount of thermal water discharging and the associated convective heat flux. Reservoir temperatures were estimated for all sampled thermal springs using the silica and Na-K-Ca (sodium-potassium-calcium) geothermometers. Reservoir temperatures for selected springs were estimated using the sulfate-water isotope geothermometer. Ratios of selected chemical constituents, deuterium and oxygen-18 isotopes, and tritium concentrations were used to characterize and thereby distinguish water from different areas of the basin.

Previous Investigations

The occurrence of thermal springs in the Payette River basin was noted by Stearns, Stearns, and Waring (1937). Ross (1971) summarized existing data, which included several chemical analyses of thermal-spring waters. Young and Mitchell (1973) included chemical analyses of water from 10

thermal springs and 1 warm-water well in their assessment of Idaho's geothermal potential. Using chemical geothermometers, Young and Mitchell (1973) estimated that reservoir temperatures in the Payette River basin ranged from 60° to 150°C. Wilson, Applegate, Chapman, and Donaldson (1976) reported that thermal springs near Cascade were fault controlled. On the basis of the mixed-water silica geothermometer, they suggested that reservoir temperatures near Cascade were about 180°C.

Acknowledgments

Spring-Numbering System

The spring-numbering system (fig. 1) used by the Geological Survey in Idaho indicates the location of springs within the official rectangular subdivision of the public lands, with reference to the Boise base line and meridian. The first two segments of the number designate the township and range. The third segment gives the section number, followed by three letters, a numeral, and the letter "S," which indicate the ¼ section (160-acre tract), the ¼-¼ section (40-acre tract), the ¼-¼-¼ section (10-acre tract), and the serial number of the spring within the tract, respectively. Quarter sections are lettered A, B, C, and D in counterclockwise order from the northeast quarter of each section. Within the quarter sections, 40-acre and 10-acre tracts are lettered in the same manner. Spring 12N-5E-22BBC1S is in the SW¼NW¼NW¼ sec. 22, T. 12 N., R. 5 E., and is the first spring inventoried in that tract.

HYDROLOGIC AND GEOLOGIC SETTING

Climate in the study area ranges from semiarid at the lower end of the basin to subhumid in the mountains. The variation in climatic conditions is caused primarily by
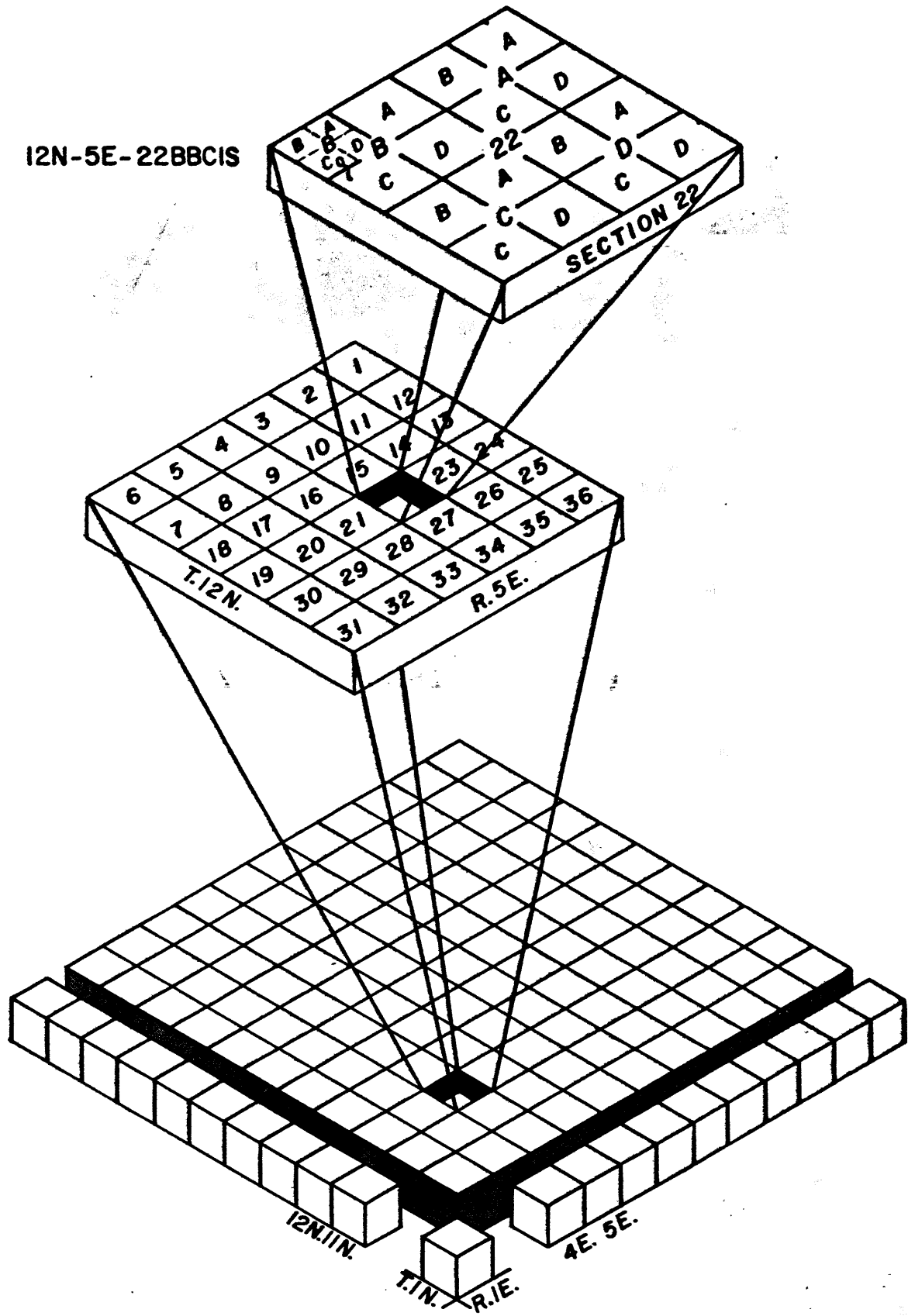
Figure 1.-- Spring-numbering system.

12N-5E-22BBCIS

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topographic relief. Mean annual precipitation ranges from about 12 in. near Payette to more than 50 in. in the mountains (Thomas and others, 1963). Mean annual temperatures, recorded by the National Weather Service, range from 10.5°C at Payette to 3.5°C at Deadwood Reservoir.

Topography of the basin is characterized by rugged mountains and narrow river valleys. Two prominant structural features (grabens) are located within the Payette River basin: the Cascade-Long Valley area on the North Fork Payette River, and the western Snake River Plain, where the Payette River joins the Snake River.

Drainage within the basin is provided mainly by the North, Middle, and South Forks of the Payette River, Squaw Creek, and Deadwood River (pl. 1). The North and Middle Forks of the Payette River, Deadwood River, and Squaw Creek flow generally southward. The South Fork flows westward to near Crouch, where it is joined by the Middle Fork to form the Payette River. From Crouch, the Payette River flows southward to Horseshoe Bend, then westward to the Snake River. The Payette River drains an area of approximately 3,300 mi².

Geologic formations in the Payette River basin are divided into: (1) Precambrian metamorphic rocks; (2) Cretaceous intrusive and metamorphosed granitic rocks; (3) Eocene intrusive rocks; (4) Miocene basalt flows; (5) Tertiary sedimentary rocks; and (6) Quaternary sedimentary rocks. Areal distribution and descriptions of these rocks are shown on plate 2.

The Cretaceous granitic rocks (Idaho batholith) are the predominant unit and are exposed throughout the mountainous parts of the basin. Miocene basalt flows, principally basalts of the Columbia River Basalt Group, are an important unit in the southwestern part of the basin.

Several major north- and northeast-trending fault systems have been mapped in the basin (pl. 2). Most of the faults appear to be high angle and have dip-slip movement. Faults at the western end of the basin trend northwest and are associated with faulting along the margin of the Snake River Plain.

WATER CHEMISTRY

Water samples from 23 thermal and 4 nonthermal springs in the Payette River basin were obtained for water-quality analyses. Results of the chemical analyses, which include

common ions, silica, and the minor elements arsenic, boron, lithium, and mercury, are given in table 1. In addition, chemical analyses of water from three thermal springs sampled by Young and Mitchell (1973) and five thermal springs for which only partial analyses are available are included. Spring locations are shown on plate 1.

Chemical Character

All the thermal springs discharge fresh water (less than 1,000 mg/L dissolved solids) of a sodium bicarbonate type, at temperatures between 34° and 86°C. These waters are slightly alkaline--pH ranges from 8.0 to 9.6. Generally, the higher pH values are associated with waters having lower concentrations of dissolved solids. Concentrations of chloride and fluoride are variable and show no definite correlation with temperature. Concentration of boron is low compared with other thermal waters in Idaho, and is, to a degree, correlative with water temperature.

Nonthermal spring waters are either a calcium or sodium bicarbonate type. Water temperature measured in these springs is 7.0°C or less and, generally, is representative of local, ambient conditions. Concentrations of dissolved solids in these near-neutral waters (pH ranges from 6.2 to 7.3) are 90 mg/L or less.

Chemical Geothermometers

Aquifer temperatures in the Payette River basin were estimated using the silica geothermometer (Fournier and Rowe, 1966) and the Na-K-Ca geothermometer (Fournier and Truesdell, 1973). Temperatures estimated by these chemical geothermometers are valid only for hot-water systems and only if the following basic assumptions are met (Fournier, White, and Truesdell, 1974): (1) The chemical reactions at depth are temperature dependent; (2) an adequate supply of chemical constituents used for the thermometry is present in the aquifer; (3) chemical equilibrium is established at depth between the hot water and the specific aquifer minerals; (4) there is negligible reequilibration of the chemical composition of the hot water as it rises to the surface; and (5) hot water rises rapidly to the surface with no dilution or mixing of hot and cold waters.

Dissolved silica (SiO_2) reported in chemical analyses is actually present as silicic acid (H_4SiO_4) and various dissociated species, particularly $H_3SiO_4^-$. In neutral to slightly acid waters, dissolved silica ($H_4SiO_4 + H_3SiO_4^-$) consists mostly of H_4SiO_4, and, under these conditions,

Table 1. Chemical analyses of water from thermal and selected nonthermal springs

[Chemical constituents in milligrams per liter, except where noted]

-- = Constituents not analyzed for.
< = Less than.

Spring no.	Date of collection	Flow rate (gal/min)[1]	Specific conductance (umhos)	pH	Water temperature (°C)[2]	Hardness as CaCO₃	Noncarbonate hardness	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Percent sodium	Sodium-adsorption ratio (SAR)	Potassium (K)	Bicarbonate (HCO₃)[3]	Carbonate (CO₃)[3]	Alkalinity as CaCO₃	Sulfate (SO₄)	Chloride (Cl)	Fluoride (F)	Silica (SiO₂)	Dissolved solids (calculated)	Nitrite plus nitrate as N (NO₂+NO₃)[3]	Phosphorus, total as P	Arsenic (As) (µg/L)	Boron (B) (µg/L)	Lithium (Li) (µg/L)	Mercury (Hg) (µg/L)
Nonthermal																											
17N- 2E-15BABIS	6-28-79	2	85	7.3	7.0	31	0	7.8	2.9	3.9	20	0.3	1.8	51	0	42	2.6	0.4	.1	45	90	0.11	0.02	0	2	<4	<.01
15N- 5E-23DACIS	6-27-79	2	20	6.2	4.0	5	1	1.7	.2	2.4	58	.5	.3	12	0	10	.7	.3	.2	17	29	<.01	.02	1	0	<4	<.01
13N- 5E-21CAAIS	6-26-79	4	21	6.1	6.5	3	0	.7	.1	1.9	58	.5	.2	7	0	6	1.4	.4	.1	13	22	<.01	.02	0	0	<4	<.01
9N- 9E-32BADIS	8-31-79	2	52	6.6	4.5	17	0	3.8	1.9	3.1	27	.3	.6	29	0	24	1.9	.4	.1	14	42	.13	.02	0	10	10	<.01
Thermal																											
16N- 4E-35CCBIS	6-27-79	94	304	9.5	50.0	3	0	1.1	<.1	70	98	18	.7	85	36	130	12	11	9.0	63	245	<.01	.01	11	50	30	<.01
15N- 3E-13SBCIS	8- 2-72	798	279	--	34.0	4	0	1.1	<.1	60	97	14	.5	17	36	89	43	16	2.6	60	210	--	--	3	10	8	--
15N- 4E-21DCCIS	6-27-79	31	206	9.6	36.0	4	0	1.3	<.1	43	96	9.8	.9	66	34	111	7.8	2.5	3.1	48	173	<.01	.01	21	310	40	<.01
13N- 3E-13ADAIS	6-26-79	20	433	9.3	49.0	3	0	1.2	<.1	85	98	21	1.0	90	34	110	24	28	5.3	61	284	<.01	.01	3	10	60	<.01
13N- 4E-31CABIS	6-26-79	70	514	9.0	71.0	4	0	1.5	<.1	110	97	25	2.1	94	25	119	43	40	11	72	351	<.01	.01	39	400	60	.1
13N- 6E-29DABIS	7- 7-79	50	334	9.5	53.0	4	0	1.6	.1	64	96	13	1.3	68	36	116	31	7.8	15	80	270	<.01	.01	6	50	30	<.01
12N- 5E- 2CCCIS	7- 8-79	12	--	--	46.5	4	0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	6	60	10	--
2DACIS	7- 8-79	10	337	9.3	50.0	3	0	1.3	.1	65	97	16	1.1	68	34	112	16	6.5	16	73	247	<.01	.01	6	10	10	<.01
10DDDIS	7- 8-79	22	--	--	66.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	10	90	80	.2
22BBCIS	6- 5-79	134	331	8.9	86.0	4	0	1.4	.1	74	96	16	1.9	110	18	120	12	11	12	86	271	<.01	.01	10	90	80	.2
11N- 36DBAIS	8- 8-79	334	266	8.9	38.0	7	0	2.8	<.1	54	94	8.9	.9	82	5	76	26	5.8	12	54	201	.03	.02	5	50	50	<.01
11N- 5E-29CDBIS	8- 8-79	90	293	8.8	49.0	8	0	1.1	<.1	97	96	4.8	.9	100	4	89	24	9.6	13	74	278	.01	.01	14	70	90	<.01
11N- 7E-16AABIS	7-24-79	50	315	9.3	65.0	5	0	1.8	<.1	65	96	13	1.8	49	35	98	36	3.9	15	82	265	.02	.03	9	50	80	.01
10N- 4E-33CBDIS	11-27-78	500	402	8.4	75.0	5	0	1.9	<.1	90	96	17	3.2	130	2	110	27	19	13	110	331	.01	.01	1	120	100	.2
10N-10E-31BCCIS	3-13-79	360	378	9.1	84.0	4	0	1.5	<.1	77	96	17	3.2	57	38	97	50	8.0	17	91	314	<.01	<.01	1	70	110	<.01
10N-11E-11ADDIS	5- 7-79	75	381	9.6	67.0	5	0	1.9	.1	77	95	15	2.6	43	45	110	46	9.5	15	82	301	.02	<.01	2	90	110	.1
9N- 2E-29BACIS	11-22-78	32	622	8.0	79.5	16	0	6.1	.1	120	92	13	5.3	160	0	131	88	39	12	120	470	.01	<.01	5	240	150	<.01
9N- 7E-35AAAIS	5- 7-79	3	287	8.0	37.0	4	--	1.4	<.1	79	97	18	1.8	72	31	111	39	5.7	20	83	297	.01	<.01	2	20	120	<.01
9N- 8E-31ACAIS	3-13-79	20	369	9.2	63.5	4	0	1.9	<.1	70	96	14	1.3	59	29	97	39	3.9	16	67	257	.02	<.01	2	50	110	<.01
32CBAIS	2-27-79	350	321	9.1	64.0	5	0	1.9	<.1	—	96	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
9N- 9E-22DCAIS	7-29-79	13	--	--	54.0	6	0	2.4	.1	66	95	11	.9	85	--	71	42	5.1	11	48	216	.01	<.01	6	110	120	--
8N- 5E- 1BCCIS	6- 8-72	1.5	317	--	40.0	6	0	2.9	.1	77	95	11	1.2	88	20	105	37	7.8	15	75	279	.01	<.01	6	110	130	<.01
6DCBIS	11-23-78	14	359	9.0	42.0	8	0	2.9	<.1	72	92	8.9	1.3	83	22	105	36	7.8	15	63	263	.01	<.01	6	110	130	<.01
6DCCIS	2-26-79	75	343	9.1	51.0	12	0	5.0	<.1	76	92	8.9	1.3	78	19	96	40	5.7	14	78	275	.01	.01	4	90	80	<.01
10ADDIS	11-22-78	10	344	9.0	54.0	5	0	2.0	<.1	—	96	15	1.2	78	—	—	—	5.7	—	—	—	—	—	—	—	—	—
10BDDIS	11-27-78	90	345	9.1	54.5	5	0	2.0	<.1	75	96	14	1.0	72	23	97	38	5.7	14	74	268	.01	<.01	4	70	70	<.01
11BAAIS	2-26-79	35	352	9.1	60.0	5	0	1.8	<.1	78	96	16	1.4	77	28	110	41	5.4	17	66	277	.01	.01	5	90	160	<.01
11BACIS	7-25-79	175	346	9.2	56.5	--	--	--	--	--	--	--	--	70	26	101	38	6.7	17	63	266	.01	<.01	1	80	100	<.01
8N- 6E- LADBIS	2-27-79	50	343	9.2	59.5	22	0	8.4	.2	75	92	15	1.1	68	29	104	120	61	16	110	573	<.01	<.01	6	710	220	<.01
7N- 1E- 8DDAIS	8- 4-72	20	780	8.0	64.0	--	--	--	2.4	160	92	15	8.0	180	0	148	120	61	8	63	266	.01	.01	10	80	100	<.01
9CDCIS	—	—	529	--	45.0	47	0	15	2.4	99	80	6.3	5.3	169	0	139	57	30	—	94	397	--	--	—	—	—	<.01

[1]Flow rate is for entire spring complex.
[2]Water temperature is highest temperature at spring vents or temperature of sampled vent.
[3]Total alkalinity distributed as carbonate and bicarbonate at the spring temperature and pH.
[4]Analyses taken from Young and Mitchell (1973).
[5]Temperature may be higher because vents were underwater.
[6]Shown in Young and Mitchell (1973) as BCBIS.

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silica geothermometers give good estimates of reservoir temperatures. In alkaline waters, hydroxide (OH^-) reacts with silicic acid to reduce the proportion of silicic acid to total dissolved silica. The total concentration of dissolved silica measured in the laboratory (H_4SiO_4 + $H_3SiO_4^-$) must therefore be reduced by the concentration of $H_3SiO_4^-$ occurring at the pH level of the spring water, to obtain an accurate estimate of the reservoir temperature.

For thermal waters having pH greater than 8.2, reported values for dissolved silica were corrected for dissociation of silicic acid at the spring temperature, and reservoir temperatures were estimated assuming equilibrium with both quartz and chalcedony (table 2). The pH of water in the thermal aquifer would be slightly lower than the pH measured at the spring, and calculation of aquifer pH might increase the H_3SiO_4 -corrected quartz temperature by 5° or 10°C (R. H. Mariner, written commun., 1980). Calculation of aquifer pH requires consideration of acid-base equilibria, distribution of acidic gases between steam and water, and the effect of temperature on the equilibria (Ellis and Mahon, 1977). Most of the calculations are time consuming and require computer methods, such as those presented by Truesdell and Singers (1973).

Concentration of magnesium in thermal waters sampled generally was 0.1 mg/L or less, so corrections for magnesium in the Na-K-Ca geothermometer suggested by Fournier and Potter (1979) were not applied. Applying the magnesium correction to the Na-K-Ca geothermometer for one thermal spring having a magnesium concentration of 2.4 mg/L increased the estimated reservoir temperature by 6° to 90°C.

Reservoir temperatures calculated from water analyses for 26 thermal springs in the Payette River basin are given in table 2, along with selected chemical reaction coefficients. In applying the H_3SiO_4 -corrected silica geothermometer for thermal springs having water temperature at the land surface generally greater than 65°C, best estimates were obtained by assuming that quartz was controlling the SiO_2 concentration. For springs having temperatures at the surface generally less than 65°C, better estimates of reservoir temperature were obtained by assuming that chalcedony was controlling the SiO_2 concentration. If, however, the calculated free energy of formation showed the waters were unsaturated with chalcedony; or, if the estimated temperature was less than the temperature of the spring, then quartz was assumed to be controlling the SiO_2 concentration.

Using a plot of reservoir temperatures estimated by the silica and the Na-K-Ca geothermometers, Fournier, Sorey, Mariner, and Truesdell (1979) showed waters that plot on or

Spring No.	Water temperature at the surface (°C)	Estimated aquifer temperatures based on geothermometers					Free energy of formation[1]				Reference No. (fig. 2)
		Silica quartz-conductive (°C)	Silica quartz-conductive H_3SiO_4 corrected (°C)	Sodium-potassium-calcium (°C)	Silica-chalcedony (°C)	Silica-chalcedony H_3SiO_4 corrected (°C)	Aragonite	Calcite	Chalcedony	Quartz	
6N- 4E-35CCB1S	50.0	113	69	71	84	37	0.1	0.2	-0.2	0.3	1
5N- 3E-13BBC1S	34.0	110	61	61	81	28	-.1	0	-.1	.5	2
5N- 4E-21DCC1S	36.0	100	62	53	70	30	0	.1	-.1	.5	3
3N- 3E-13ADA1S	49.0	111	79	83	82	47	0	.1	0	.5	4
3N- 4E-31CAB1S	71.0	120	91	117	91	61	.1	.2	-.1	.3	5
3N- 6E-29DAB1S	53.0	125	76	82	97	45	.2	.3	-.1	.4	6
2N- 5E- 2DAC1S	50.0	120	86	81	92	55	0	0	.1	.6	7
22BBC1S	86.0	129	101	100	101	71	.3	.4	-.2	.2	8
36DBA1S	38.0	105	93	57	76	62	-.3	-.2	.3	.9	9
1N- 5E-29CDB1S	49.0	121	107	61	93	77	-.1	0	.4	.9	10
1N- 7E-16AAB1S	65.0	126	84	91	99	52	.3	.4	-.2	.3	11
0N- 4E-33CBD1S	75.0	143	132	138	116	105	-.3	-.2	.4	.8	12
0N-10E-31BCC1S	84.0	132	81	145	105	50	.5	.6	-.5	-.1	13
0N-11E-31ADD1S	67.0	126	63	134	99	31	.6	.7	-.5	-.1	14
9N- 3E-25BAC1S	79.5	148	143	144	122	116	.1	.2	.5	.9	15
9N- 8E-31ACA1S	63.5	127	90	99	99	60	.1	.2	0	.4	16
32CBA1S	64.0	116	86	79	87	55	.2	.3	-.1	.4	17
8N- 5E- 1BCC1S	40.0	100	89	62	70	59	-.5	-.4	.3	.8	18
6DCB1S	42.0	122	104	69	94	74	.1	.1	.4	1.0	19
6DCC1S	51.0	113	88	60	84	58	.6	.7	.1	.6	20
10ADD1S	54.0	124	101	76	96	71	-.1	0	.2	.8	21
10BDD1S	54.5	121	89	70	93	58	.1	.2	.1	.6	22
11BAA1S	60.0	115	87	84	86	56	.2	.2	0	.4	23
8N- 6E- 1ADB1S	59.5	113	80	74	84	49	.3	.3	-.1	.3	24
7N- 1E- 8DDA1S	64.0	143	138	152	116	112	0	.1	.6	1.1	25
9CDC1S	45.0	134	133	[2]90	107	106	-.5	-.4	.8	1.3	26

Values are departure from theoretical equilibrium in kilocalories; (+) values indicate super-
saturation, (-) values indicate unsaturated. Calculations from computer program SOLMNEQ
(Kharaka and Barnes, 1973).
[2]Magnesium corrected (Fournier and Potter, 1979).

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near the equal-temperature line ($T^{\circ}_{SiO_2} = T^{\circ}_{Na-K-Ca}$; slope = 1) are likely to be unmixed waters or waters that have reequilibrated with the aquifer minerals after mixing. Waters that plot significantly above the equal-temperature line probably contain anomalous concentrations of silica, owing to evaporation or to dissolving amorphous silica from the aquifer material. The Na-K-Ca geothermometer uses ratios of constituents and is less sensitive to concentration changes that occur during evaporation than is the silica geothermometer.

Waters that plot significantly below the equal-temperature line may be due to: (1) Mixing with another type water without sufficient time to equilibrate with the surrounding rock (in mixed waters, silica-estimated temperatures are generally decreased more than Na-K-Ca estimated temperatures); (2) precipitation of silica during cooling, whereas Na-K-Ca proportions remain unchanged; or (3) precipitation of calcite or aragonite due to loss of carbon dioxide without adjustment of sodium and potassium through reaction with clays, zeolites, or other minerals (Fournier and others, 1979).

Figure 2 is a plot of reservoir temperatures estimated using silica and Na-K-Ca geothermometers for thermal springs in the Payette River basin. Most thermal springs plot on or near the equal-temperature line. As suggested by Fournier and others (1979), these waters are probably unmixed waters that have lost some heat through conduction or are mixed waters that have had time to reequilibrate. Several springs (samples 5, 7, 13, and 14) plot significantly below the equal-temperature line and may indicate a mixed water or water from which calcite and aragonite have precipitated. Table 2 shows that, with the exception of sample 7, waters from these springs are supersaturated with calcite or aragonite, which may indicate a possible loss of calcium without an adjustment of the sodium and potassium concentrations. For these samples, the silica geothermometer probably gives the better estimate of reservoir temperature.

Only two springs (samples 10 and 26) plot significantly above the equal-temperature line in figure 2. These waters are thought to have dissolved amorphous silica from the aquifer materials (calculated free energy of formation of amorphous silica is 0, which indicates equilibrium with this phase). For these springs, the Na-K-Ca geothermometer probably gives the better estimate of reservoir temperature.

Estimated reservoir temperatures determined from the silica and Na-K-Ca geothermometers are highly variable and range from 53° to 143°C. Along the North Fork of the
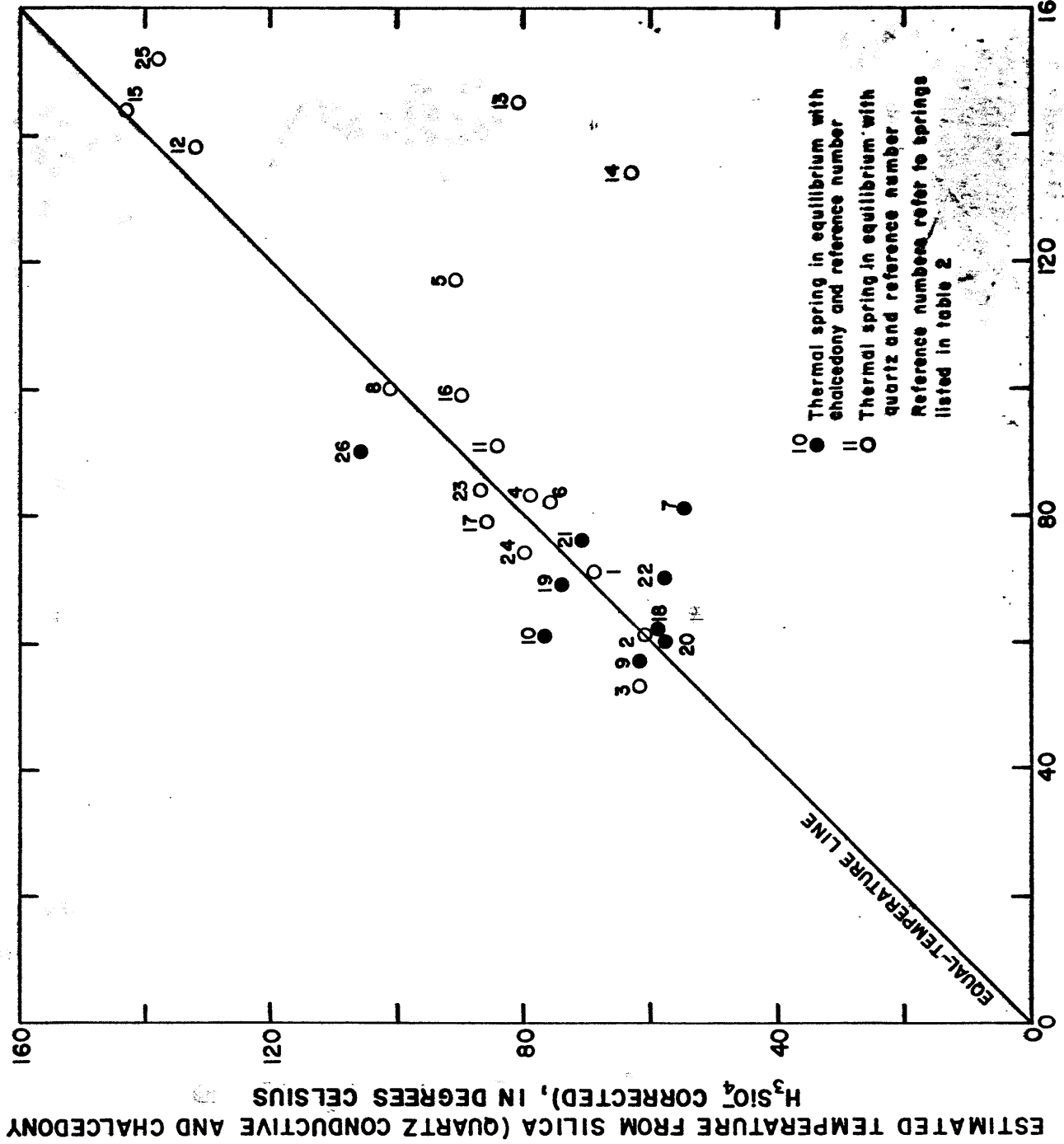
Figure 2.-- Comparison of reservoir temperatures estimated by the silica, and sodium-potassium-calcium geothermometers

ESTIMATED TEMPERATURE FROM SILICA (QUARTZ CONDUCTIVE AND CHALCEDONY
$H_3SiO_4^-$ CORRECTED), IN DEGREES CELSIUS

ESTIMATED TEMPERATURE FROM SODIUM-POTASSIUM-CALCIUM, IN DEGREES CELSIUS

Payette River, estimated reservoir temperatures range from 53° to 91°C. Along the Middle and South Forks of the Payette River, estimated reservoir temperatures range from 57° to 138°C and 58° to 99°C, respectively. Estimated reservoir temperatures along the Payette River from Banks, Idaho, range from 90° to 143°C.

Assuming conductive heat loss, reservoir temperatures for six thermal springs were estimated using the sulfate-water isotope geothermometer described by McKenzie and Truesdell (1977): 16N-4E-35CCB1S, 71°C; 13N-4E-31CAB1S, 75°C; 13N-6E-29DAB1S, 71°C; 9N-3E-25BAC1S, 139°C; 9N-8E-32CBA1S, 88°C; and 8N-5E-10BDD1S, 76°C. Additional temperatures of 89° and 94°C were estimated for thermal springs 12N-5E-22BBC1S and 10N-10E-31BCC1S, respectively, by Nehring and others (1979).

Isotopes

Samples of thermal and nonthermal water from selected springs in the Payette River basin were collected for analyses of oxygen-18, deuterium, and tritium. In this report, isotope data are presented in tabular and graphical format (tables 3 and 4 and fig. 3); interpretations concerning age or relation of the various waters are offered only insofar as they apply to the Payette River basin and are considered preliminary. A discussion of the isotopic composition and possible relations of thermal waters in the Payette, Salmon, and Boise River basins will be presented in a final report.

Tritium

Tritium (H³) is produced naturally in small quantities in the upper atmosphere during bombardment by subatomic particles. The tritium, incorporated in water molecules, enters the water cycle in rain and snow. Having a half life of about 12.3 years, tritium can be used to determine how long a particular water may have been stored out of contact with the atmosphere. The transit or residence time can be determined from the concentration of tritium in the discharge water, if the amount of tritium in the recharge water and the nature of the subsurface flow regime are known.

Before extensive thermonuclear testing began in 1954, tritium in the atmosphere ranged from 10 to 20 TU (tritium unit). One TU equals a ³H/H ratio of about 10, or about 3.2 picocuries per liter. By 1963, worldwide tritium levels had increased several orders of magnitude. Tritium levels in precipitation have since declined and now (1980) average about 50 TU.

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Table 3. Tritium in water from
selected springs

Spring No.	Water temperature at surface (°C)	Tritium (TU)
Nonthermal		
15N-5E-23DAC1S	4.0	46.8 $\pm$2.1
13N-5E-21CAA1S	6.5	60.2 $\pm$2.7
Thermal		
13N-6E-29DAB1S	53.0	0.1 $\pm$0.1
9N-8E-32CBA1S	64.0	0.0 $\pm$0.1
8N-5E- 6DCC1S	51.0	2.0 $\pm$0.1

Table 4. Stable isotope analyses from selected springs

| Spring No.	t°C	δD_{SMOW}	$\delta^{18}O_{SMOW}$	$\Delta^{18}O$	Reference symbol (fig. 3)
Nonthermal					
17N- 2E-15BAB1S	7.0	-127	-17.1	0.0	27
15N- 5E-23DAC1S	4.0	-124	-17.7	--	28
13N- 5E-21CAA1S	6.5	-128	-17.3	-0.05	29
9N- 9E-32BAD1S	4.5	-131	-17.7	-0.05	30
Thermal					
16N- 4E-35CCB1S	50.0	-135	-18.0	+0.12	1
13N- 4E-31CAB1S	71.0	-138	-17.3	+1.20	2
13N- 6E-29DAB1S	53.0	-137	-18.2	+0.15	3
12N- 5E- 2DAC1S	50.0	-136	-18.1	+0.15	4
12N- 5E-22BBC1S	86.0	-134	-17.7	+0.28	5
11N- 5E-29CDB1S	49.0	-132	-17.7	+0.04	6
11N- 7E-16AAB1S	65.0	-138	-18.4	+0.20	7
10N- 4E-33CBD1S	75.0	-136	-18.2	+0.04	8
10N-10E-31BCC1S	84.0	-140	[1]-18.1	+0.63	9
10N-11E-31AAD1S	67.0	-140	-18.7	+0.04	10
9N- 3E-25BAC1S	79.5	-136	-17.2	+1.03	11
9N- 8E-32CBA1S	64.0	-135	-17.9	+0.22	12
8N- 5E- 6DCC1S	51.0	-136	-18.0	+0.23	13
8N- 5E-10BDD1S	54.5	-137	-18.3	+0.06	14
8N- 6E- 1ADB1S	59.5	-138	-18.5	0.0	15
7N- 1E- 8DAA1S	64.0	-134	-15.6	+2.43	16

[1] ^{18}O from Nehring and others (1979)
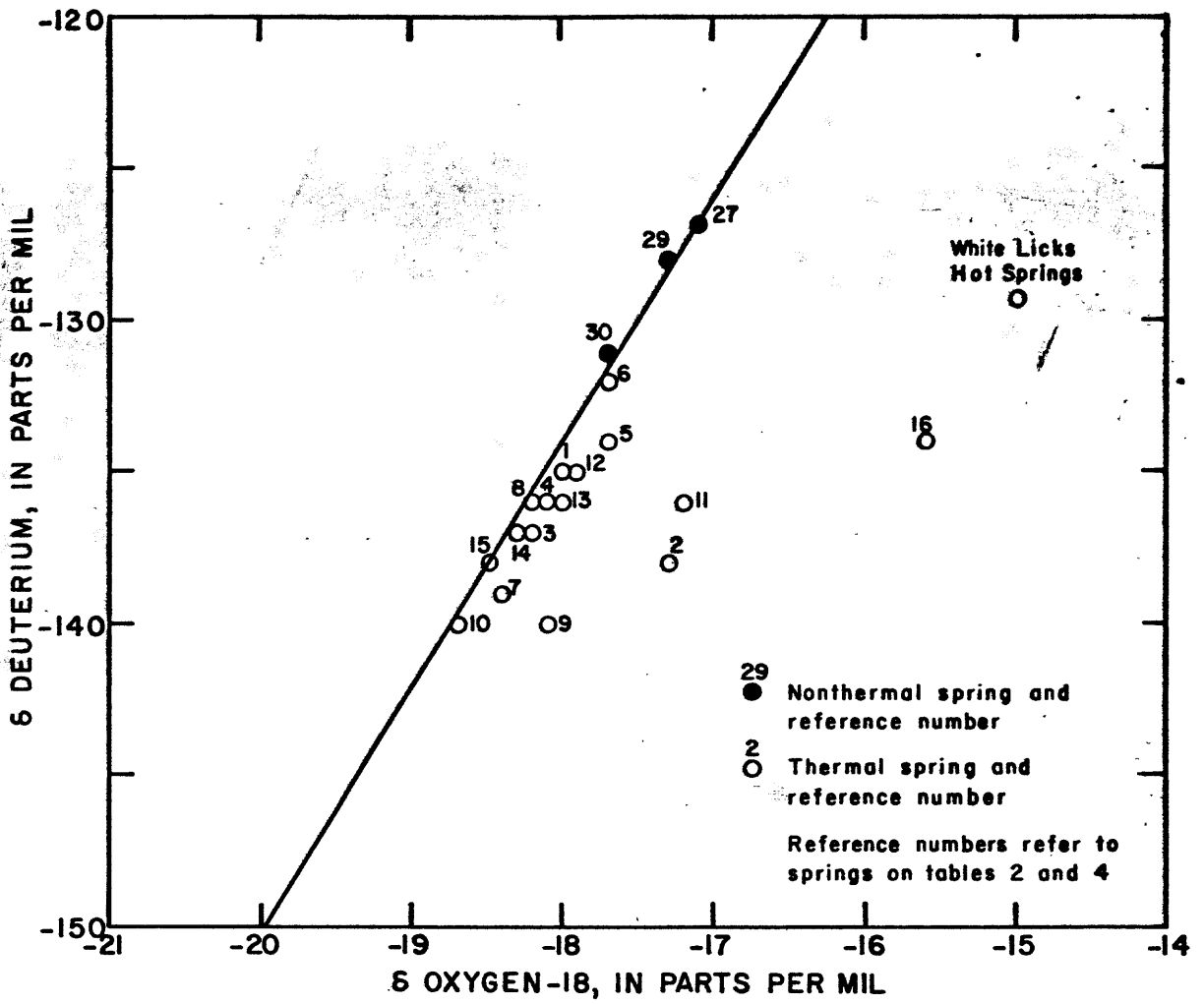
Figure 3.-- Relation between concentration of deuterium and oxygen-18.

Tritium content in a ground-water system is a function of tritium content in the recharge water and the residence time and nature of flow in the system. Two basic types of flow models are discussed in detail by Nir (1964): (1) The piston-flow model, which has parallel flow lines of constant and equal velocity, so that a water sample taken at some point would include only water originating at the point of recharge; and (2) the well-mixed reservoir model, where it is assumed that the recharge water is continually and instantly mixing throughout the entire system.

Water samples were obtained from two nonthermal and three thermal springs and were analyzed for concentrations of tritium by the U.S. Geological Survey laboratory in Reston, Va. Samples were predistilled and enriched by electrolysis, and the enriched samples were counted by a gas proportional counter. Results of tritium analyses are shown in table 3. All samples were corrected for tritium decay to the collection date, using a half life of 12.361 years.

As shown in table 3, concentrations of tritium in thermal water from springs are relatively low. Thermal waters containing essentially no tritium probably contain no water younger than about 100 years. Assuming pre-1954 tritium levels of about 20 TU and piston flow or a well-mixed dispersive system, these waters would have an age of between about 100 to more than 1,000 years, respectively. Water from spring 8N-5E-6DCC1S could be an old (more than 1,000 years), tritium-depleted water mixed with about 4 percent young water, or may be an unmixed water ranging in age from about 40 to more than 1,000 years.

Tritium in samples from the two nonthermal springs (table 3) is relatively high. Such levels could occur in recent precipitation (less than 2 years) or could be influenced by 1954-64 precipitation. They indicate a water-residence time of about 25 years, assuming a piston-flow system, or about 100 years, assuming a well-mixed system.

Deuterium and Oxygen-18

Concentration of the stable isotopes, deuterium (D) and oxygen-18 (^{18}O) in water from different sources is used to characterize and indicate the origin and mixing patterns of individual waters. Atmospheric water derived from the ocean is depleted in ^{18}O and D. Isotopic composition of precipitation depends on the fraction of water remaining in and temperature of the air mass from which the rain or snow is derived.

Isotopic compositions of water from thermal and non-thermal springs are listed in table 4. Data are expressed in the δ notation,

$$\delta_x = \left[\frac{R_x - R_{std}}{R_{std}}\right] 10^3,$$

where $R_x = (D/H)_x$ or $(^{18}O/^{16}O)_x$ of the sample, and R_{std} is the corresponding ratio for standard mean ocean water (SMOW).

A plot of D versus ^{18}O, along with the SMOW line, is shown in figure 3. Because of a lack of data from adjacent drainages, a full discussion of the $D-^{18}O$ relations in waters from thermal springs in the Payette River basin is unwarranted. However, several observations can be made. Stable-isotope compositions of water from the nonthermal springs are enriched in D and, to a lesser extent, in ^{18}O, relative to the thermal waters, and it is unlikely the nonthermal waters represent precipitation that recharges thermal springs in the Payette River basin.

As shown in figure 3, concentrations of D in the nonthermal springs (about -128 parts per mil) and in White Licks hot spring (-129 parts per mil, Nehring and others, 1979) are similar and may indicate a common recharge source for these springs. Enrichment of ^{18}O relative to the SMOW line (about 2.3 parts per mil) is indicative of increased temperatures, which probably are due to deep circulation, and reaction with ^{18}O in the rocks.

Deuterium compositions of the nonthermal and thermal springs in the Payette River basin are sufficiently different (7 to 12 parts per mil) to indicate that direct communication and a single area of recharge for both types of springs are not likely. Recharge from at least two different sources and some mixing are implied from the stable-isotope data; however, additional sampling of both thermal and nonthermal springs in the adjacent Salmon and Boise River basins is needed to adequately discuss the relations of thermal waters in the Idaho batholith.

THERMAL GROUND-WATER DISCHARGE AND ASSOCIATED HEAT FLUX

Annual thermal water discharge in the Payette River basin was estimated for 31 thermal springs. Although most of these springs are unused, several supply water for swimming pools, bathhouses, and some space heating of private residences and greenhouses. For purposes of this report, all water discharging from the springs is assumed to be

consumptively used. Discharge for each spring was estimated or measured during inventory and annual discharge computed (table 1). Thermal ground-water discharge in the Payette River basin in 1979 totaled about 5,700 acre-ft.

Heat from the Payette River basin is removed convectively by hot water, which discharges from the thermal springs. The convective heat flux from the basin can be calculated as the product of the volume rate of discharge and the enthalpy (heat content) of the water in excess of the ambient (surrounding) air temperature, or:

$$H = M (h_r - h_o)$$

where,

H = heat loss, by convection, in calories per second,
M = mass discharge,
h_r = enthalpy of the hot water, and
h_o = enthalpy of cold recharge water (4° to 10°C, depending on spring location).

To estimate the total convective heat flux, the volume of discharge in 1979 for each thermal spring was converted to an instantaneous flow rate, and the mass discharge, M, was calculated. In the convective heat flow equation, h_o is approximately equal to the mean annual air temperature. Subsequent percolation of spring water after discharge is considered negligible, and no heat is returned to the system. Total convective heat flux from the Payette River basin in 1979 was estimated to be 1.1×10^7 cal/s.

Significant changes in discharge or temperature will affect calculation of the amount of heat convectively discharged from the system. To determine the magnitude of any changes, equipment to continuously monitor temperature and discharge was installed at spring 12N-5E-22BBC1S (Boiling Springs) in August 1978. From the multiple vents at the spring, one of moderate size that discharged the hottest water was selected, and a thermistor probe was installed and wired into the recording equipment. A V-notch weir and bubbler gage were installed below the spring. Several vents below the weir discharged some thermal water that could not be measured, but about 90 percent of the discharge from Boiling Springs was captured and passed through the weir.

A record of water temperature and discharge at Boiling Springs is shown in figure 4. Discharge records from late 1978 and early 1979 were sporadic and incomplete due to malfunctioning of the gas-bubbler gage. Records after May 1979 were complete, but no attempt was made in this report to correlate discharge with temperature or precipitation. Seasonal variation in temperature of about 1°C was apparent
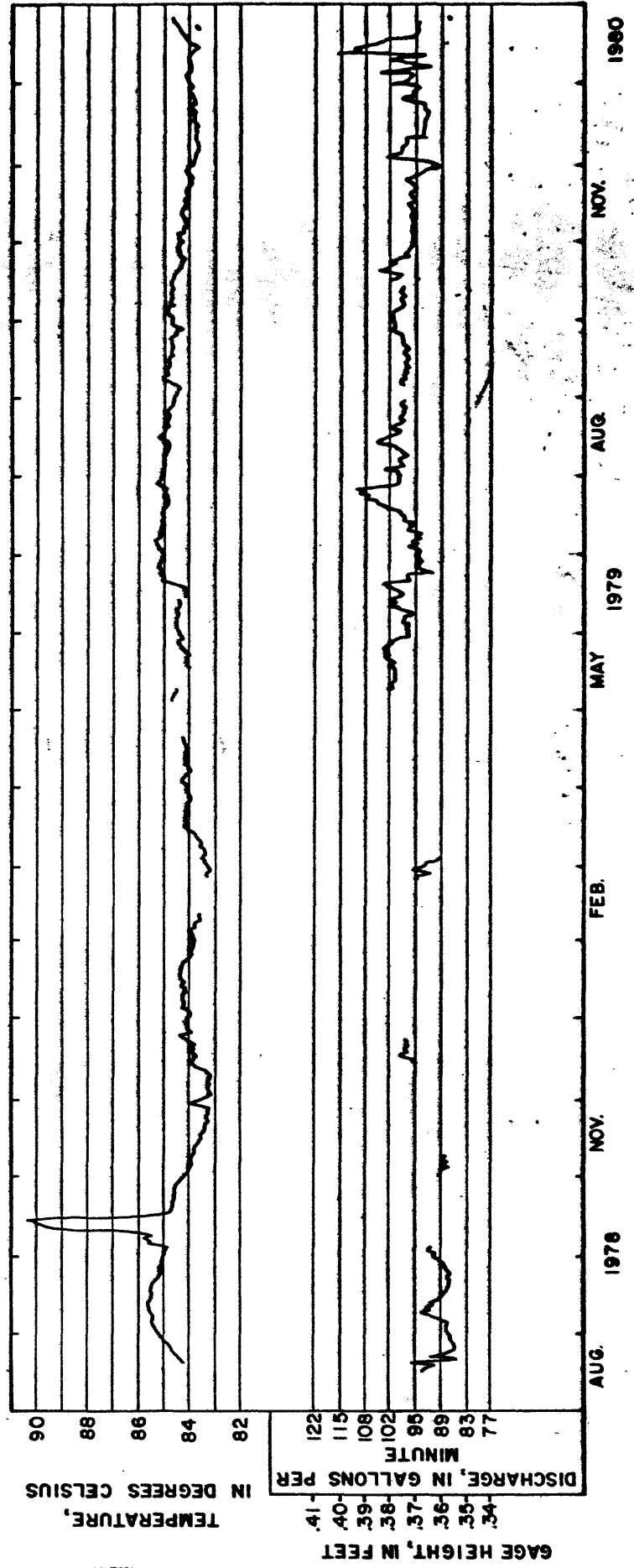
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Figure 4.--Fluctuations in water temperature and discharge at spring 12N-5E-22BBCIS (Boiling Springs).

between June and July to November 1979. A short-term temperature increase of about 5°C occurred in early October 1978; however, correlative discharge data were lacking for this period. From the data, it could not be determined whether the temperature increase was caused by a surge of hotter water or a temporary decrease in a nonthermal water mixing fraction. Monitoring of temperature and discharge at Boiling Springs will continue into 1981, and a discussion of the records will be included in a final report.

SUMMARY

The Payette River drains an area of about 3,300 mi² in west-central Idaho. The basin is characterized by steep, rugged mountains and narrow river valleys. Granitic rocks of the Idaho batholith of Cretaceous age are predominant within the basin. Basalt flows of the Columbia River Basalt Group of Miocene age are important in the southwestern part of the basin.

Water temperatures of thermal springs range from 34° to 86°C. The waters are a sodium bicarbonate type and are slightly alkaline--pH values range from 8.0 to 9.6. Concentrations of dissolved solids in thermal springs are low and range from 173 to 470 mg/L. Concentrations of fluoride and chloride are variable and range from 2.6 to 20 and 2.5 to 61 mg/L, respectively.

Estimated reservoir temperatures determined from the Na-K-Ca and $H_3SiO_4^-$-corrected silica geothermometers range from 53° to 143°C. Estimated reservoir temperatures using the sulfate-water isotope geothermometer range from 71° to 139°C. Estimated temperatures for most springs are in good agreement among the chemical geothermometers, indicating the waters are probably unmixed or have reequilibrated in the system.

Tritium, present in concentrations between 0 and 2 TU in thermal waters, indicates the presence of little or no water younger than about 100 years. On the basis of a tritium concentration of 20 TU in the recharge water, thermal waters sampled are at least 100 years and possibly more than 1,000 years old.

Stable-isotope data indicate it is unlikely any of the nonthermal waters sampled are representative of precipitation that recharges thermal springs in the Payette River basin, and recharge from at least two different sources is implied.

Annual (1979) thermal ground-water discharge in the Payette River basin was about 5,700 acre-ft, and the heat convectively discharging from the springs is about 1.1×10^7 cal/s. Annual variation in temperature measured at Boiling Springs is about 1°C.

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