

THERMAL SPRINGS IN THE BOISE RIVER BASIN, SOUTH-CENTRAL IDAHO

U. S. GEOLOGICAL SURVEY

Water - Resources Investigations 82 - 4006



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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 $\mu\text{g/L}$ (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 μmho (micromhos per centimeter at 25 degrees Celsius). Thermal parameters are reported in "working" units.

<u>Multiply inch-pound unit</u>	<u>By</u>	<u>To obtain SI unit</u>
	<u>Length</u>	
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
	<u>Area</u>	
acre	4047	square meter
square mile (mi ²)	2.590	square kilometer
	<u>Volume</u>	
acre-foot (acre-ft)	1233	cubic meter
	<u>Flow</u>	
gallon per minute (gal/min)	0.06309	liter per second
	<u>Heat Flux</u>	
calorie per second (cal/s)	4.187	watt

Conversion of °C to °F is based on the equation, $^{\circ}\text{F}=(1.8)(^{\circ}\text{C})+32$. All water temperatures are reported to the nearest 0.5 degree.

THERMAL SPRINGS IN THE BOISE RIVER BASIN,
SOUTH-CENTRAL IDAHO

By

R. E. Lewis and H. W. Young

ABSTRACT

The Boise River basin, characterized by steep, rugged mountains and narrow river valleys, drains an area of about 2,680 square miles in south-central Idaho. Granitic rocks of the Idaho batholith predominate in the basin.

Waters from thermal springs in the basin, temperatures of which range from 33 degrees to 87 degrees Celsius, are sodium carbonate type and are slightly alkaline. Dissolved-solids concentrations are less than 280 milligrams per liter. Estimated reservoir temperatures determined by the silica and sodium-potassium-calcium geothermometers range from 50 degrees to 98 degrees Celsius.

Tritium concentrations in sampled thermal springs are near zero and indicate these waters were recharged prior to 1954. Stable-isotope data are not conclusive insofar as indicating a source area of recharge for the thermal springs in the basin.

Thermal springs discharged at least 4,900 acre-feet of water in 1981, and the associated convective heat flux is 11,000,000 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.

This report is the third of three scheduled for central Idaho and describes occurrence and chemistry of thermal springs in the Boise River basin of south-central Idaho. The geothermal studies in Idaho are part of an overall program by the U.S. Geological Survey to understand

better the nature and occurrence of geothermal resources in the Nation. Field work for this phase of the study was accomplished between October 1980 and September 1981.

Purpose and Scope

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

Twenty-eight thermal springs and five selected non-thermal springs were inventoried in the Boise River basin. Water temperatures were measured, and measurements or estimates of discharge were made at the time of inventory. Water samples from 22 thermal springs and 5 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 14 thermal springs and the 5 nonthermal springs. Isotopes analyzed were deuterium and oxygen-18 (19 springs), tritium (6 springs), and sulfate-water isotopes (1 thermal spring).

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 temperature for one selected spring was estimated using the sulfate-water isotope geothermometer.

Previous Investigations

The occurrence of thermal springs in the Boise 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 four thermal springs in their assessment of Idaho's geothermal potential. Using chemical geothermometers, they estimated that reservoir temperatures in the Boise River basin ranged from 70° to 135°C.

Acknowledgments

Many landowners in the Boise River basin cooperated in this study by allowing access to their property, supplying information about their springs, and permitting discharge measurements to be made. The following Geological

Survey personnel contributed significantly to this investigation: A. H. Truesdell and Cathy Janik provided the sulfate-water isotope analysis, and R. H. Mariner aided in the interpretation of geochemical data. To all the above, the authors are grateful.

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 indicates the $\frac{1}{4}$ section (160-acre tract), the $\frac{1}{4}$ - $\frac{1}{4}$ section (40-acre tract), the $\frac{1}{4}$ - $\frac{1}{4}$ - $\frac{1}{4}$ 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 6N-5E-33ADC1S is in the SW $\frac{1}{4}$ SE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 33, T. 6 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 topographic relief. Mean annual precipitation ranges from about 16 in. near Lucky Peak Reservoir to more than 50 in. in the higher mountains (Thomas and others, 1963). Mean annual temperatures, recorded by the National Weather Service, range from 9.4°C at Arrowrock Reservoir Dam to 5.7°C at Atlanta.

Topography of the basin is characterized by rugged mountains and narrow river valleys. Drainage within the basin is provided mainly by the North, Middle, and South Forks of the Boise River (fig. 2). Larger tributaries to the Boise River system include Grimes, Mores, and Big and Little Smoky Creeks and Crooked River. The North and Middle Forks of the Boise River flow generally southwestward to their confluence near Arrowrock Reservoir and continue in this direction to Lucky Peak Reservoir. The South Fork of the Boise River flows generally west, then south, and west again, where it joins the North and Middle Forks at Arrowrock Reservoir. The Boise River drains an area of about 2,680 mi² above Lucky Peak Reservoir.

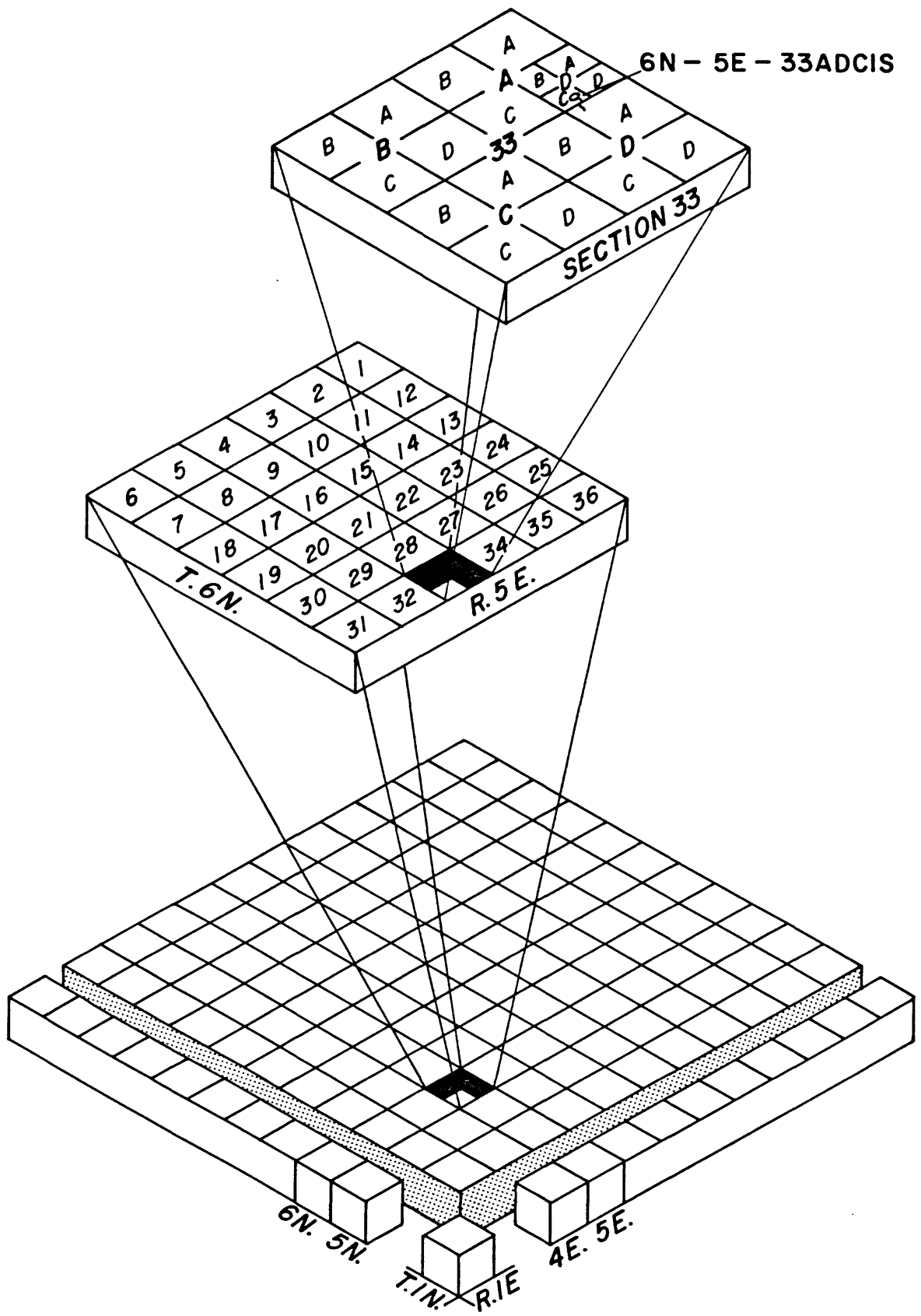
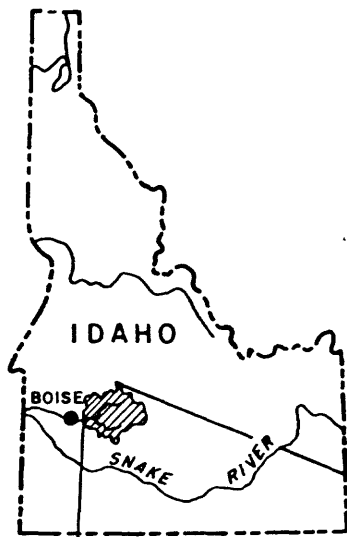


Figure 1.-- Spring - numbering system.



MAP OF STUDY AREA

EXPLANATION

- 32DACIS ● Nonthermal spring and number for which water-quality analysis is given (table I)
- 33ABCIS ○ Thermal spring and number for which water-quality analysis is given (table I)
- 35DDBIS ○ Thermal spring and number for which partial water-quality analysis is given (table I)
- 7ADCIS ○ Thermal spring and number for which reported location and temperature are given (table I)
- Basin boundary

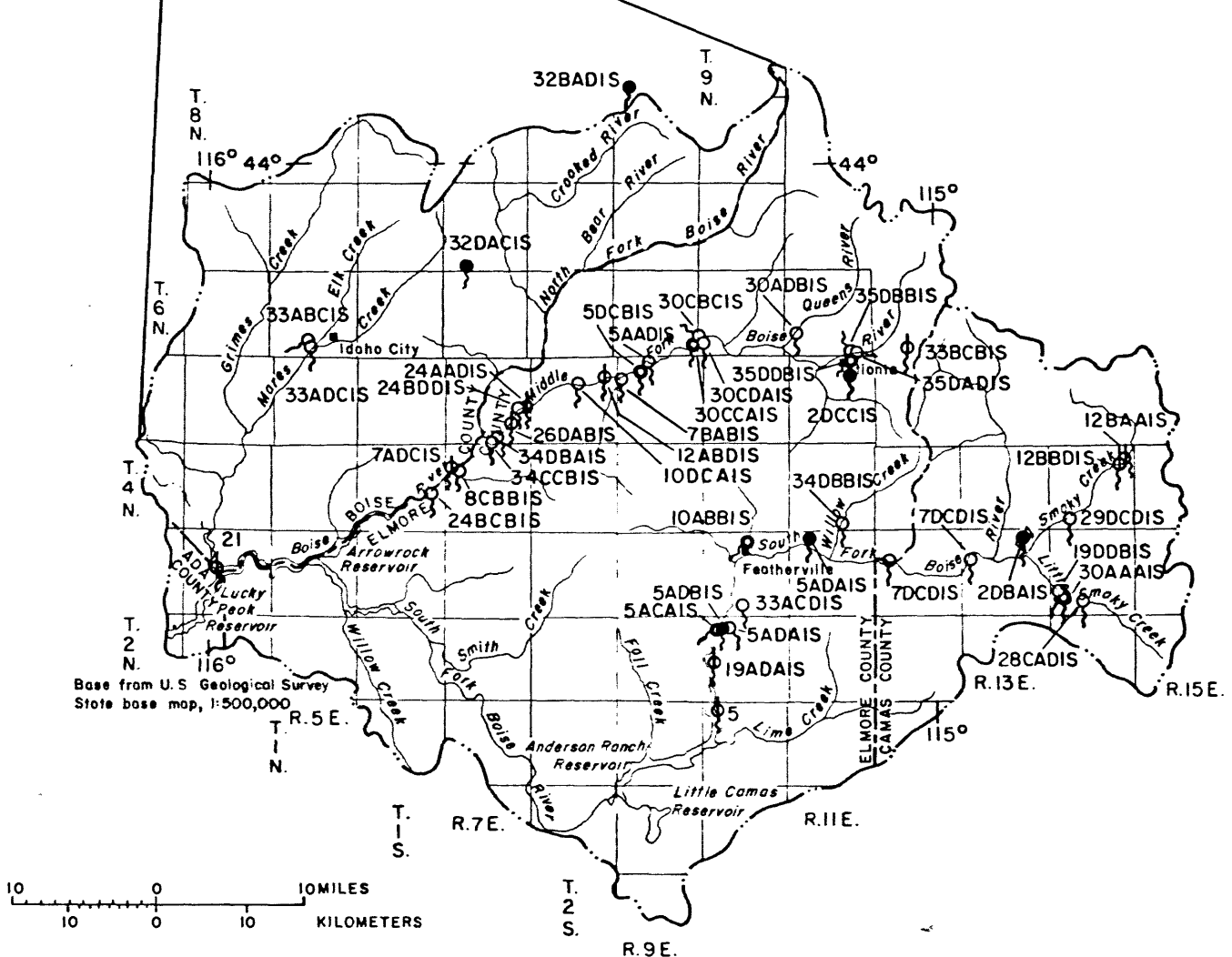


Figure 2.--Locations of sampled thermal springs and selected nonthermal springs, Boise River basin, south-central Idaho.

Geologic formations in the Boise River basin are divided into: (1) Quaternary sedimentary rocks; (2) Tertiary volcanic rocks; (3) Eocene intrusive rocks; (4) Cretaceous intrusive granitic rocks; (5) Cretaceous metamorphosed granitic rocks, and (6) Paleozoic sedimentary rocks. Areal distribution and descriptions of these rocks are shown in figure 3.

The Cretaceous granitic rocks (Idaho batholith) predominate throughout the mountainous parts of the basin. Eocene intrusive rocks also are widely distributed in the mountainous parts of the basin.

Several major north-, northwest-, and northeast-trending fault systems have been mapped in the basin. Most of the faults appear to be high angle and have dip-slip movement.

WATER CHEMISTRY

Water samples from 22 thermal and 5 nonthermal springs in the Boise 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, the chemical analysis of water from one nonthermal spring sampled by Lewis and Young (1980) is included in table 1. Partial analyses for 6 thermal springs and reported locations and temperatures for 11 thermal springs also are included in table 1. Spring locations are shown in figure 2.

Chemical Character

Thermal springs in the Boise River basin discharge fresh water (less than 280 mg/L dissolved solids) at temperatures between 33° and 87°C. These waters are slightly alkaline--pH values range from 9.1 to 9.8--and are typically a sodium carbonate type. All sampled waters are fairly uniform in their chemical composition. Concentrations of chloride are low (12 mg/L or less) compared to other thermal waters in Idaho. Fluoride concentrations range from 2.9 to 15 mg/L and are comparable with most thermal waters in Idaho.

Sampled nonthermal spring waters are a calcium bicarbonate type. Water temperatures measured in these springs are 10.0°C or less and are probably representative of the local ambient (surrounding) conditions. Concentrations of dissolved solids in these near-neutral waters (pH ranges from 5.9 to 8.0) are 132 mg/L or less.

CORRELATION OF MAP UNITS

DESCRIPTION OF MAP UNITS

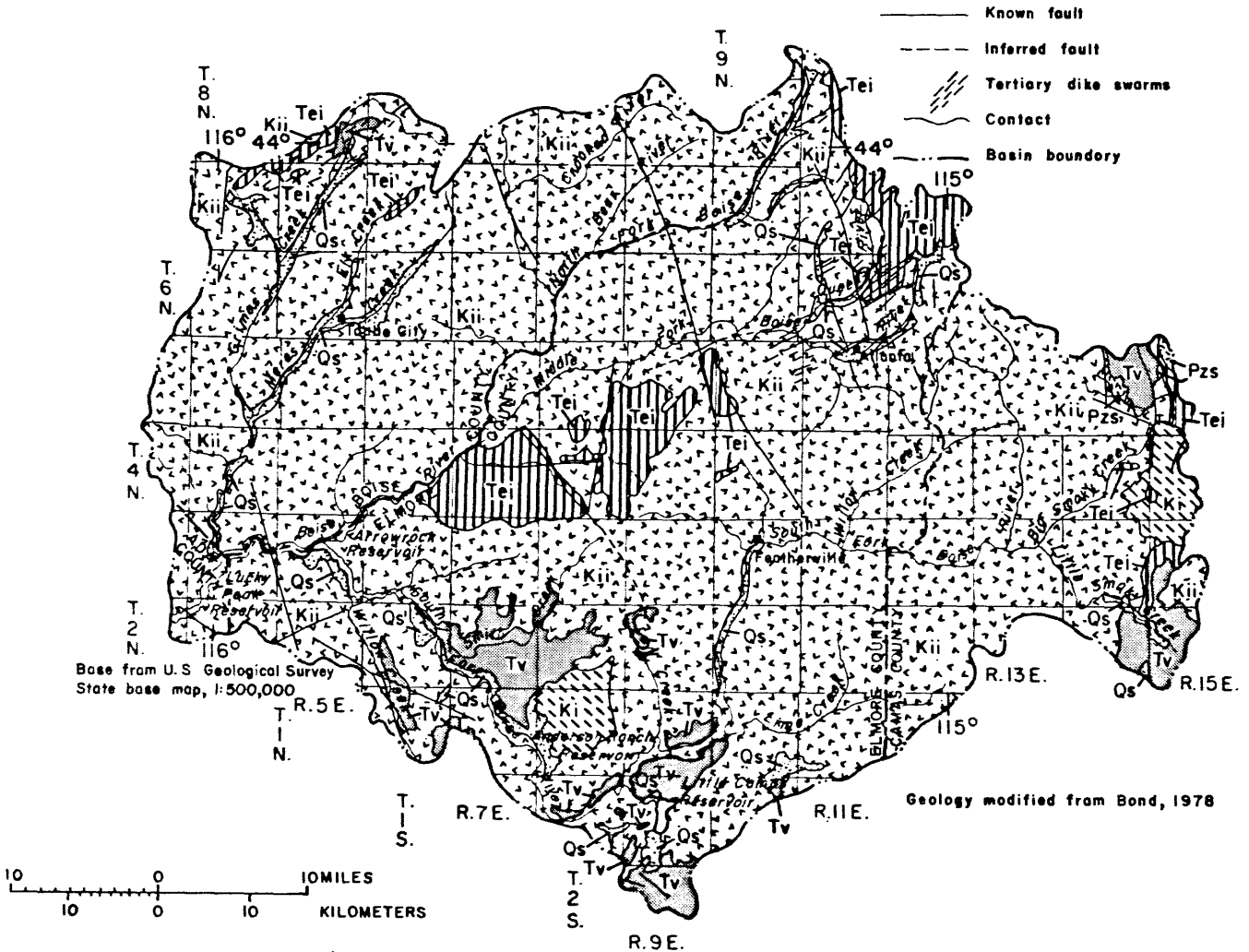
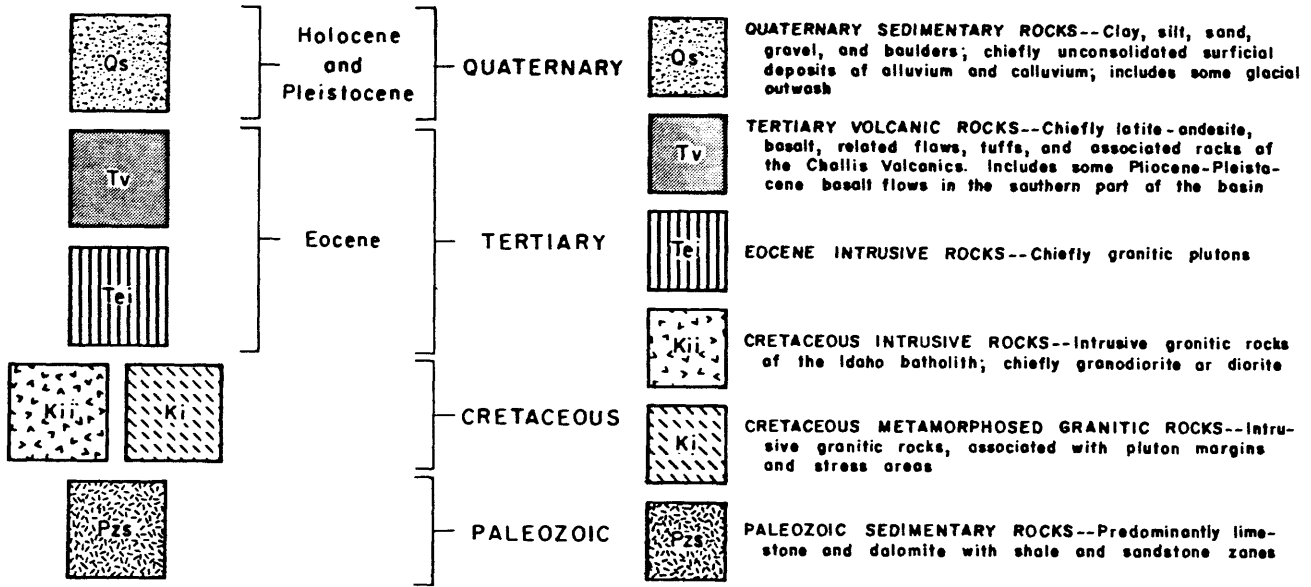


Figure 3.-- Generalized geology of the Boise River basin, south-central Idaho.

Table 1.--Chemical analyses of water from thermal and selected nonthermal springs
(Chemical constituents in milligrams per liter, except where noted)

[--, undetermined; >, less than]

Spring No.	Date of collection	Flow rate ¹ (gal/min)	Specific conductance (µmho)	pH	Water temperature ² (°C)	Hardness as CaCO ₃	Noncarbonate hardness	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Percent sodium	Sodium-adsorption ratio (SAR)	Nonthermal						Thermal								
													Bicarbonate ³ (HCO ₃)	Carbonate ³ (CO ₃)	Alkalinity as CaCO ₃	Sulfate ⁴ (SO ₄)	Chloride (Cl)	Fluoride (F)	Silica (SiO ₂)	Dissolved solids (calculated)	Nitrate plus nitrite as N (NO ₃ +NO ₂)	Phosphorus, total as P	Arsenic (As) (µg/L)	Boron (B) (µg/L)	Lithium (Li) (µg/L)	Mercury (Hg) (µg/L)	
9N-9E-32BAD1S	8-31-79	2	52	6.6	4.5	17	0	3.8	1.9	3.1	27	0.3	0.6	29	0	24	1.9	0.4	0.1	14	42	0.13	0.02	0	10	<0.1	
7N-7E-32DAC1S	9-15-81	1	26	6.6	6.0	7	0	2.3	4.4	2.1	39	.4	0	15	0	12	5.0	.1	0	14	31	.12	.01	0	0	<4	
5N-11E-2DCCL1S	9-1-81	---	102	6.7	7.5	40	0	14	1.1	3.4	16	.2	.5	51	0	42	5.0	.3	.5	15	65	.20	.01	0	0	<4	
3N-11E-5ADAL1S	7-15-81	---	211	8.0	10.0	94	0	33	2.8	10	19	.5	.6	120	0	98	5.0	.9	.1	19	132	1.9	.01	1	0	30	
3N-13E-2DBAL1S	7-14-81	---	205	6.9	6.0	100	5	36	3.0	4.6	9	.2	1.0	120	0	98	2.0	1.0	.2	12	119	.95	.01	1	0	30	
2N-10E-5ADB1S	8-4-81	---	136	6.7	9.5	54	0	18	2.3	6.8	21	.4	.8	78	0	64	1.0	.5	.5	24	92	<.01	.19	2	10	8	
6N-5E-33ABC1S	5-11-81	6	292	9.5	40.5	4	0	1.5	0.1	65	96	12	0.8	41	36	94	22	2.7	13	58	220	0.05	0.04	48	50	30	
33ABC1S	5-11-81	200	317	9.5	42.0	5	0	2.0	1.1	65	96	12	.8	41	36	94	22	2.7	13	57	219	.02	.04	35	50	30	
6N-10E-30CBC1S	9-2-81	7	---	---	45.0	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
30CBC1S	9-2-81	150	282	9.5	64.0	8	0	3.0	.3	58	93	9.2	1.2	7	38	69	41	2.5	7.9	67	222	.10	.02	10	20	80	
6N-11E-30ADB1S	9-2-81	60	231	9.6	50.5	8	0	3.2	<.1	48	92	7.4	.8	5	34	61	29	3.0	7.8	58	186	.1	.01	5	30	80	
35ADB1S	9-1-81	60	317	9.7	60.0	5	0	1.9	<.1	67	96	13	1.5	2	46	78	41	4.6	13	74	240	.1	.01	3	50	240	
35DBB1S	9-1-81	100	305	9.2	53.0	6	0	2.2	<.1	82	94	11	1.8	30	25	66	41	4.4	13	79	250	.1	.01	4	30	230	
35DBB1S	9-1-81	65	362	---	53.5	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
6N-12E-33BCB1S	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
5N-7E-24AAD1S	---	---	---	---	42.0	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
24BDD1S	8-3-81	424	297	9.4	76.0	4	0	1.6	---	64	96	14	1.7	16	46	90	28	2.4	9.2	100	261	<.01	.16	1	40	90	
26DAB1S	---	---	---	---	68.0	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
34CBB1S	8-3-81	100	210	9.5	60.0	6	0	2.3	<.1	44	94	8.0	.7	15	32	66	18	2.0	5.4	64	176	.01	.17	3	30	50	
34DBA1S	5-27-81	15	197	9.6	55.0	6	0	2.4	<.1	42	93	7.6	1.0	4	36	63	21	11	4.7	70	190	<.01	.01	1	0	40	
5N-8E-10DCA1S	9-2-81	50	245	9.4	51.0	5	0	1.8	<.1	52	95	11	1.3	37	31	82	25	1.3	6.6	77	214	.1	.01	6	20	100	
12ABD1S	---	---	---	---	62.0	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
5N-9E-5AAD1S	5-28-81	100	241	9.4	56.0	5	0	1.9	<.1	52	95	10	1.3	18	34	71	26	1.7	7.1	68	201	<.01	.02	11	10	70	
50CB1S	9-2-81	20	255	9.5	54.0	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
78AB1S	5-28-81	300	250	9.6	65.0	4	0	1.6	<.1	57	96	12	1.2	15	38	76	27	1.8	8.3	70	212	<.01	.01	11	10	80	
4N-6E-24BCB1S	5-27-81	300	236	9.5	67.0	5	0	1.7	.1	49	94	9.9	1.3	9	43	79	21	1.6	4.1	86	212	<.01	.01	16	30	40	
7ADCL1S	---	---	---	---	41.0	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
8CBB1S	5-27-81	8	223	9.5	61.0	6	0	2.5	<.1	50	93	8.7	1.2	20	41	85	20	1.8	4.6	84	215	.28	.01	19	20	50	
4N-11E-34DBB1S	7-16-81	60	221	9.5	53.0	5	0	2.1	<.1	46	94	9.0	1.0	24	32	73	23	3.2	5.1	63	187	.03	.01	4	20	90	
4N-14E-12BAAL1S	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
12BBD1S	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
29DCC1S	7-15-81	150	285	9.4	64.5	9	0	3.4	<.1	60	93	9.0	1.5	38	25	73	31	4.9	14	71	230	.01	<.01	1	50	180	
3N-4E-21	---	---	---	---	38.0	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
3N-10E-10AB1S	7-16-81	1	255	9.8	33.0	---	---	---	---	---	---	---	---	6	56	98	---	---	---	---	---	---	---	---	---	---	---
33ACD1S	7-16-81	200	226	9.5	53.0	4	0	1.5	<.1	46	95	10	1.1	27	38	85	16	2.9	2.9	72	193	.16	<.01	1	10	40	
3N-12E-70CD1S	7-15-81	10	258	9.1	50.0	9	0	3.5	.1	53	92	7.6	.9	71	12	78	24	8.4	5.8	45	188	.20	.01	1	70	110	
3N-13E-70CD1S	7-15-81	45	343	9.1	62.0	6	0	2.5	<.1	75	95	13	1.9	90	19	105	27	12	13	70	264	.02	<.01	4	110	190	
3N-14E-19DBB1S	7-14-81	8	344	9.6	41.0	5	0	1.8	<.1	78	97	16	1.8	37	34	97	32	7.3	15	59	246	.07	<.01	2	50	200	
28CDB1S	7-14-81	466	337	9.4	87.0	4	0	1.5	<.1	69	96	16	1.9	33	40	94	35	5.3	13	95	277	.17	<.01	3	50	190	
30AAAL1S	7-14-81	10	362	9.4	61.0	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
2N-10E-5ACAL1S	8-4-81	75	243	9.5	59.0	---	---	---	---	---	---	---	---	33	38	90	---	---	---	---	---	---	---	---	---	---	---
5ADAL1S	8-4-81	50	243	9.5	60.0	3	0	1.3	.9	54	96	13	1.3	35	38	92	17	3.6	4.1	76	213	<.01	.15	0	20	61	
2N-10E-19ADAL1S	---	---	---	---	56.0	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
1N-10E-5	---	---	---	---	73.0	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

¹Flow rate is for entire spring complex.
²Water temperature is highest temperature at spring vents or temperature of sampled vent.
³Total alkalinity distributed as carbonate and bicarbonate at the spring temperature and pH.
⁴An unknown part of the reported sulfate concentrations may be the result of oxidation of sulfide to sulfate prior to analysis.
⁵Analyses from Lewin and Young (1980).
⁶Reported.

Chemical and Isotopic Geothermometers

Reservoir temperatures in the Boise 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 and others, 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 reservoir; (3) chemical equilibrium is established at depth between the hot water and the specific reservoir matrix; (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 ($\text{H}_4\text{SiO}_4 + \text{H}_3\text{SiO}_4^-$) consists mostly of H_4SiO_4 , and, under these conditions, 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 ($\text{H}_4\text{SiO}_4 + \text{H}_3\text{SiO}_4^-$) therefore must 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 pH, and silica-reservoir temperatures were estimated assuming equilibrium with both quartz and chalcedony (table 2). The pH of water in the thermal reservoir would be slightly lower than the pH measured at the spring, and calculation of reservoir pH might increase the H_3SiO_4^- -corrected quartz temperature by 5° or 10°C (R. H. Mariner, U.S. Geological Survey, written commun., 1980). Calculation of reservoir 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 sampled thermal waters 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.

Table 2.--Estimated reservoir temperatures and free energy of formation for selected thermal springs

Spring No.	Water temperature at the surface	Estimated reservoir temperatures, in °C, on the basis of geothermometers						Free energy of formation ¹						Reference No. (fig. 2)		
		Silica quartz- conductive		Silica quartz- conductive H ₂ SiO ₄ corrected		Sodium-potassium-calcium		Silica-chalcedony		Silica-chalcedony H ₂ SiO ₄ corrected		Aragonite Calcite Chalcedony Quartz				
		109	117	72	75	68	76	80	88	40	43	0	0		0	0.5
6N-5E-33ABC1S	40.5	109	117	72	75	68	80	88	40	43	0	0	0	0	0.5	1
33ADC1S	42.0	108	118	70	73	63	79	90	38	27	.2	.1	.1	.5	2	
6N-10E-30CDA1S	64.0	116	129	64	73	65	87	101	32	41	.1	.2	.5	0	3	
6N-11E-30ADB1S	50.5	109	128	60	74	50	80	100	28	43	.1	.2	.3	.2	4	
35DAD1S	60.0	121	113	57	67	84	93	84	24	36	-.2	-.2	-.6	-.1	5	
35DDB1S	53.0	124	117	93	75	85	96	85	62	43	-.2	-.1	.1	.6	6	
5N-7E-24BDD1S	76.0	137	118	82	73	91	110	78	50	27	-.1	0	-.4	.1	7	
34CCB1S	60.0	114	129	64	73	52	85	78	32	41	.4	.5	-.4	.1	8	
34DBA1S	55.0	118	128	64	74	61	90	67	32	43	-.1	0	-.3	.2	9	
5N-8E-10DCA1S	51.0	123	113	82	67	77	95	64	51	36	0	.1	0	.5	10	
5N-9E-5AAD1S	56.0	117	117	75	75	76	88	76	43	43	-.1	0	-.2	.3	11	
7BAB1S	65.0	118	118	59	59	78	90	78	27	27	-.1	0	-.6	-.1	12	
4N-6E-24BCB1S	67.0	129	129	73	73	78	101	78	41	41	-.1	0	-.4	.1	13	
4N-7E-8CBB1S	61.0	128	128	74	74	67	100	67	43	43	.3	.4	-.3	.2	14	
4N-11E-34DBB1S	53.0	113	113	67	67	64	84	64	36	36	.1	.2	-.3	.3	15	
4N-14E-29DCD1S	64.5	119	119	72	72	70	90	70	40	40	.5	.6	-.3	.1	16	
3N-10E-33ACD1S	53.0	120	120	73	73	74	91	74	41	41	0	.1	-.2	.3	17	
3N-12E-7DCD1S	50.0	97	97	75	75	53	67	53	43	43	.3	.4	-.1	.4	18	
3N-13E-7DCD1S	62.0	118	118	87	87	86	90	86	58	58	.4	.5	0	.4	19	
3N-14E-19DDB1S	41.0	110	110	66	66	66	80	66	34	34	.1	.1	-.1	.4	20	
28CAD1S	87.0	134	134	76	76	98	107	98	44	44	.2	.3	-.6	-.2	21	
2N-10E-5ADA1S	60.0	122	122	71	71	85	94	85	39	39	0	.1	-.3	.2	22	

¹ Values are departure from theoretical equilibrium in kilocalories; (+) values indicate supersaturation, (-) values indicate unsaturation. Calculations from computer program SOLMNEQ (Kharaka and Barnes, 1973).

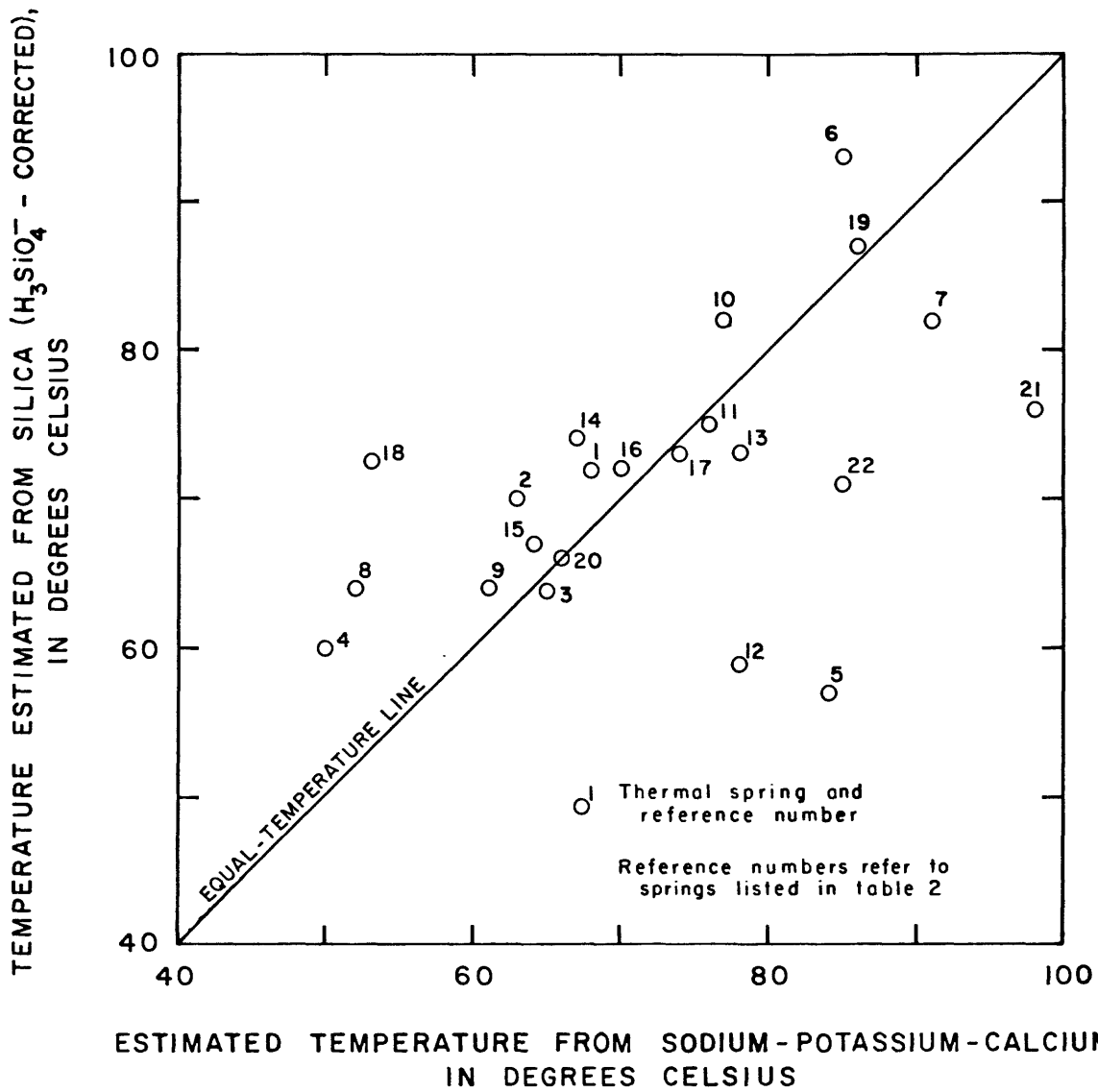


Figure 4.--Comparison of reservoir temperatures estimated by the silica and sodium-potassium-calcium geothermometers.

Reservoir temperatures calculated from water analyses for 22 thermal springs in the Boise River basin are given in table 2, along with mineral equilibrium data. The calculated free energy of formation (table 2) showed that thermal waters generally were unsaturated with chalcedony. Therefore, in applying the $H_3SiO_4^-$ -corrected silica geothermometer for thermal springs, best estimates of reservoir temperatures generally were obtained by assuming that quartz was 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 near the equal-temperature line ($T_{SiO_2} = T_{Na-K-Ca}$; slope = 1) are likely to be unmixed waters or waters that have reequilibrated with the reservoir 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 reservoir 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 result from: (1) Mixing with another type water without sufficient time to equilibrate with the surrounding rock (in mixed waters, silica-estimated temperatures generally are lower 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 owing to loss of carbon dioxide without adjustment of sodium and potassium through reaction with clays, zeolites, or other minerals (Fournier and others, 1979).

Figure 4 is a plot of reservoir temperatures estimated using silica and Na-K-Ca geothermometers for thermal springs in the Boise 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 or are mixed waters that have had time to reequilibrate. Several springs (samples 5, 12, 21, and 22) plot significantly below the equal-temperature line and may indicate a mixed water or water from which calcite and aragonite or silica have precipitated. Table 2 shows that samples 5, 12, and 21 are unsaturated with silica (quartz) and have probably precipitated silica or mixed with shallow, nonthermal ground waters. Table 2 also shows that waters from samples 12, 21, and 22 are supersaturated with calcite or aragonite, which may indicate a possible loss of calcium without an adjustment of the sodium and potassium concentrations. The silica geothermometer probably gives the better estimate of reservoir temperature for sample 22, and the Na-K-Ca geothermometer probably gives the better estimate of reservoir temperature for samples 5, 12, and 21.

Only one spring (sample 18) plots significantly above the equal-temperature line in figure 4. Table 2 shows that this water is supersaturated with aragonite and calcite, which indicates a possible loss of calcium. The calculated free energy of formation for amorphous silica is -0.9 (unsaturated). The cause of the low Na-K-Ca-estimated temperature and high silica-estimated temperature is unknown; however, the silica geothermometer probably gives the better estimate of reservoir temperature.

Estimated reservoir temperatures determined from the silica and Na-K-Ca geothermometer are generally in good agreement for individual springs. Estimated reservoir temperatures for all thermal springs in the Boise River basin are also generally in good agreement and range from 50° to 98°C. Assuming conductive heat loss, a reservoir temperature of 90°C was estimated for sample 21 using the sulfate-water isotope geothermometer described by McKenzie and Truesdell (1977).

Isotopes

Samples of nonthermal and thermal waters from selected springs in the Boise River basin were collected for analysis of tritium, deuterium, and oxygen-18. Concentrations of tritium for three nonthermal springs and three thermal springs are given in table 3. Stable isotopic compositions of 6 nonthermal springs and 14 thermal springs are given in table 4 and are shown in figure 5. Interpretations of the isotopic compositions of these waters concerning age or relation of the various waters are offered only insofar as they apply to the Boise River basin and are considered preliminary.

Tritium

Tritium (^3H) 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 12.4 years, tritium can be used to determine how long a particular water may have been 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 4 to 25 TU (tritium units), according to Nir and others (1966). One TU equals a $^3\text{H}/\text{H}$ ratio of about 10^{-18} , or about 3.2 pico-

Table 3.--Tritium in water from selected springs

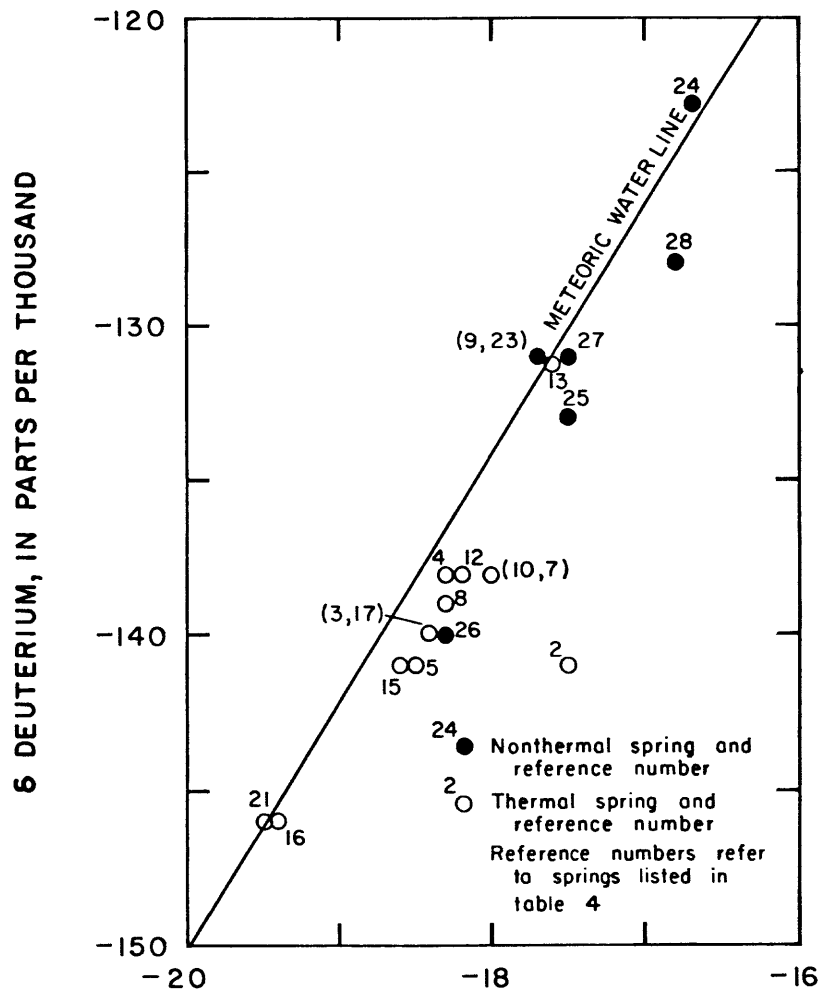
Spring No.	Water temperature at surface (°C)	Tritium (TU)
<u>Nonthermal</u>		
5N-11E- 2DCC1S	7.5	53.6 + 3.4
3N-13E- 2DBA1S	6.0	45.0 + 2.5
2N-10E- 5ADB1S	9.5	24.4 + 3.4
<u>Thermal</u>		
6N- 5E-33ADC1S	42.0	1.0 + 0.4
6N-11E-30ADB1S	50.5	.3 + .4
4N- 6E-24BCB1S	67.0	.6 + .4

Table 4.--Stable-isotope analyses from selected springs

Spring No.	t°C	δD_{SMOW}	$\delta^{18}O_{SMOW}$	$^1 \Delta^{18}O$	Reference No. (fig. 5)
<u>Nonthermal</u>					
9N- 9E-32BAD1S ²	4.5	-131	-17.7	-0.05	23
7N- 7E-32DAC1S	6.0	-123	-16.7	-.08	24
5N-11E- 2DCC1S	7.5	-133	-17.5	+.38	25
3N-11E- 5ADA1S	10.0	-140	-18.3	+.45	26
3N-13E- 2DBA1S	6.0	-131	-17.5	+.12	27
2N-10E- 5ADB1S	9.5	-128	-16.8	+.45	28
<u>Thermal</u>					
6N- 5E-33ADC1S	42.0	-141	-17.5	+1.38	2
6N-10E-30CDA1S	64.0	-140	-18.4	+.35	3
6N-11E-30ADB1S	50.5	-138	-18.3	+.20	4
35DAD1S	60.0	-141	-18.5	+.38	5
5N- 7E-24BDD1S	76.0	-138	-18.0	+.50	7
34DBA1S	55.0	-131	-17.7	-.08	9
5N- 8E-10DCA1S	51.0	-138	-18.0	+.50	10
5N- 9E- 7BAB1S	65.0	-138	-18.2	+.30	12
4N- 6E-24BCB1S	67.0	-131	-17.6	+.02	13
4N-11E-34DBB1S	53.0	-141	-18.6	+.28	15
4N-14E-29DCD1S	64.5	-146	-19.4	+.10	16
3N-10E-33ACD1S	53.0	-140	-18.4	+.35	17
3N-12E- 7DCD1S	50.0	-139	-18.3	+.32	18
3N-14E-28CAD1S	87.0	-146	-19.5	0	21

¹ Enrichment (+) or depletion (-) of ¹⁸O relative to the meteoric water line.

² Analysis from Lewis and Young (1980).



6 OXYGEN -18, IN PARTS PER THOUSAND

Figure 5.-- Relation between concentrations of deuterium and oxygen-18.

curies per liter. By 1963, northern hemisphere tritium levels had increased several orders of magnitude. Tritium levels in precipitation have since declined, and as of 1980, average about 50 TU.

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 were 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 three 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.

Concentrations of tritium in nonthermal springs ranged from 24.4 ± 3.4 to 53.6 ± 3.4 TU and indicate all are relatively young waters. Concentrations of tritium in sampled thermal springs ranged from 0.3 ± 0.4 to 1.0 ± 0.4 TU. Assuming thermal water moves by piston flow and a pre-bomb tritium level of 10 TU, age of the thermal spring water could be as young as 35-80 years. However, any mixing of considerably older thermal waters void of tritium with even 2 or 3 percent young, nonthermal water would give similar analytical results, so the age of 35-80 years should be considered minimum.

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 D and ^{18}O . 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 nonthermal springs are listed in table 4. Data plotted in figure 5 are expressed in the δ notation:

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

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

It is beyond the scope of this study to discuss the D and ^{18}O relations of waters in the Boise River drainage with those of the Payette and Salmon River drainages. However, several observations can be made. In figure 5, isotopic data are not conclusive insofar as indicating a source area of recharge for the thermal springs. Water from all but one of the nonthermal springs is enriched in D and ^{18}O relative to the thermal waters and does not appear representative of precipitation that recharges any of the thermal springs. Water from spring 26 is similar isotopically to most of the thermal waters sampled and may represent precipitation that recharges at least some of the nearby thermal springs on the South Fork of the Boise River. Owing to a lack of more substantiative data, no suggestion is offered that the vicinity of spring 26 is the recharge area for all the isotopically similar thermal springs in the Boise River drainage.

Some enrichment of ^{18}O relative to the meteoric water line may occur owing to reaction with the more enriched ^{18}O of the confining rock. This "oxygen shift" is apparent in figure 5 for most of the thermal waters. With the exception of spring 2, however, enrichment is less than 0.5 parts per thousand and may not necessarily be associated with high reservoir temperature and reaction with ^{18}O in the rocks. A similar magnitude of enrichment is apparent in several of the cold spring waters and could be caused by partial evaporation of the water prior to recharge.

In figure 5, water from spring 2 is enriched nearly 1.5 parts per thousand relative to SMOW and may indicate a higher reservoir temperature or longer contact time and greater exchange with ^{18}O in the rocks. Owing to the nominal reservoir temperature estimated for the spring (table 2), the most probable reason for the increased ^{18}O is the longer contact with the rocks or a high rock/water ratio in the reservoir.

In figure 5, water from thermal springs 13, 16, and 21 shows little or no enrichment relative to the meteoric water line, although reservoir temperatures estimated for these waters range from about 70° to near 100°C. The lack of any significant ^{18}O shift in these waters may indicate a rather short residence time and contact with the reservoir rock or perhaps flow within a restricted fracture system--a low rock/water ratio in the reservoir.

THERMAL GROUND-WATER DISCHARGE AND ASSOCIATED HEAT FLUX

Annual thermal water discharge in the Boise River basin was estimated for 28 thermal springs. Although most of these springs are unused, several supply water for swimming pools and bathhouses. For purposes of this report, all water discharging from the springs and the heat contained therein is assumed to be consumptively used. Discharge for each spring was estimated or measured during inventory and annual discharge was computed (table 1). Thermal ground-water discharge in the Boise River basin in 1981 totaled at least 4,900 acre-ft and may be higher (measurements or estimates of discharge were not available for several springs).

Heat from the Boise 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 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 (5.0°-7.0°C, depending on spring location).

To estimate the total convective heat flux, the volume of discharge in 1981 for each thermal spring was converted to an instantaneous flow rate and 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. Convective heat flux for inventoried thermal springs from the Boise River basin in 1981 was estimated to be 1.1×10^7 cal/s.

SUMMARY

The Boise River basin drains an area of about 2,680 mi^2 above Lucky Peak Reservoir in south-central Idaho. Topography of the basin is characterized by rugged mountains and narrow river valleys. Granitic rocks of the Idaho batholith of Cretaceous age predominate in the basin.

Water temperatures of thermal springs range from 33° to 87°C. These waters are slightly alkaline--pH values range from 9.1 to 9.8--and are typically a sodium carbonate type. Concentrations of dissolved solids are low (less than 280 mg/L) and are fairly uniform in their chemical composition. Fluoride concentrations range from 2.9 to 15 mg/L.

Estimated reservoir temperatures determined from the silica and Na-K-Ca geothermometers range from 50° to 98°C. Estimated temperatures for most springs are in good agreement and indicate the waters are probably unmixed or have reequilibrated in the system.

Tritium concentrations in sampled thermal waters are near zero and indicate that these waters probably were recharged prior to 1954.

Stable-isotope data are not conclusive insofar as indicating a source area of recharge for the thermal springs. Water from all but one of the nonthermal springs is enriched in D and ¹⁸O relative to the thermal waters and does not appear representative of precipitation that recharges the thermal springs.

Annual (1981) thermal water discharge in the basin is at least 4,900 acre-ft, and the associated convective heat flux is 1.1×10^7 cal/s.

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