QUANTITATIVE ASSESSMENT OF THERMAL FEATURES OF THE SOUTHWEST PORTION OF YELLOWSTONE PARK

William T. Parry
David S. Chapman
John R. Bowman
Richard G. Allis
The University of Utah

Objectives

The objectives of this project are to obtain chemical, thermal, and hydrological data for thermal features in the southwest portion of Yellowstone National Park, and to make assessments of the heat, mass, and chemical budgets for the region. With a better understanding of the hydrothermal regime we intend to delineate key thermal features which should be monitored on a periodic basis to detect inadvertent geothermal development impact.

Assessment of Water Chemistry

Quantitative assessment of the thermal features of the southwest portion of Yellowstone Park requires measurement of the chemical composition of thermal fluids and an estimate of the geological processes leading to the observed compositions. Processes which should be evaluated include equilibration of the fluid with minerals, steam separation, mixing of thermal fluids with cold water, and irreversible mass transfer among minerals and fluid.

Water samples were collected from the following thermal areas: Upper Boundary Creek, Middle Boundary Creek, Lower Boundary Creek, Silver Scarf, Bechler Ford, Mountain Ash, Three Rivers, and Summit Lake. Collection procedures followed the method of Presser and Barnes (1974). The samples have been analyzed using the methods outlined in Brown et al. (1970) and American Public Health Association (1971) and analytical results are shown in Table 1. Quartz saturation temperatures and Na-K-Ca temperatures are also shown in Table 1.

Results

Silica contents of water samples are shown in Figure 1 with saturation curves for amorphous silica and quartz. All of the waters are supersaturated with quartz and some are near amorphous silica saturation at their measured temperatures. The springs all issue from volcanic rocks rich in glass, but the flow path may have included other lithologies:

Table 1. Chemical compositions of spring water from Southwestern Yellowstone Park Springs in mg/1.

	UBCTA #"S"	UBCTA #57	UBCTA Cold Spr	MBCTA #27	MBCTA #44	MBCTA #45	SILVER S #1	SILVER S #A	SILVER S #65
Collection Date	8/20/81	8/18/81	8/18/81	8/19/81	8/19/81	8/19/81	8/20/81	8/21/81	8/20/81
T °C	64	42.5	13.8	80.5	61	62.5	69	85	88
Field pH	6.4	5.4	5.0	6.3	6.2	6.3	6.6	6.8	6.7
Lab pH	6.92	5.81	6.89	7.46	7.46	7.74	7.31	7.65	7.57
SiO_2	123	89	32	181	161	159	173	230	225
Ca	4.0	7.4	5.3	5.5	5.1	3.0	3.9	3.4	4.1
Mg	.19	.94	.54	.24	.43	.23	.18	.12	.04
Na	112	20	6	156	143	149	155	175	185
K	5.5	8.0	2.1	5.6	4.8	4.4	8.0	8.6	9.4
HCO_3	147	67	22	268	241	232	237	268	277
SO_4	7	5	1	10	9	12	9	6	10
F	14	5.1	2.9	13.5	17	17	16	21	20
C1	77	1	1	71,73	64,63	73	88	95	94
NA-K-Ca	151	87	49	139	136	135	159	160	161
Qtz Steam	143	127	86	163	157	156	160	176	175
Qtz Cond	148	130	82	172	165	164	169	189	187

Table 1. (cont.)

	SILVER S #138	SILVER S #155	LBCTA #B	LBCTA #23	LBCTA #47	BECHLERF #3	MBCTA #48	MATA #6	MATA #11	MATA #49
Collection Date	8/19/81	8/19/81	8/27/81	8/27/81	8/26/81	9/6/81	8/19/81	9/10/81	9/10/81	9/11/81
$T^{o}C$	86	89	54	56.6	57	55.3	81.5	41.6	40.9	36
Field pH	6.5	6.5	6.4	6.4	6.8	7.1	6.5	6.4	6.6	6.4
Lab pH	7.52	7.54	7.80	7.05	7.04	7.92	7.56	6.70	6.78	6.81
SiO_2	217	211	129	127	112	182	197	110	107	110
Ca	3.7	3.1	4.0	4.0	4.4	23	3.5	4.7	5.0	5.2
Mg	.10	.11	.44	.34	.49	4.7	.14	.11	.16	.20
Na	178	165	84	88	87	377	165	106	101	97
K	8.1	7.1	4.6	4.5	5.5	36	6.2	7.5	7.1	8.5
HCO_3	281	259	147	143	152	656	259	201	196	196
SO_4	10	10	7	6	4	15	7	6	7	12
F	20	21	9.6	8.4	11	7.6	18	9.3	8.9	10
C1	92	90	38	41	38	259/265	87	39	37	28
Na-K-Ca	156	153	152	149	159	192	146	167	165	176
Qtz Steam	173	171	145	144	138	163	167	137	136	137
Qtz Cond	185	183	151	150	143	173	178	142	140	142

Table 1. (cont.)

Collection Date	TRTA #3 9/4/81	3RTA Phillipa 9/4/81	3RTA #37 9/4/81	3RTA #46 9/5/81	3RTA #98 9/5/81	3RTA #M 9/5/81	SLTA #A 9/19/81
T °C	79.5	53	59.9	51.9	86.4	91.4	85.3
Field pH	7.2	6.9	6.5	6.4	7.0	7.4	5.4
Lab pH	7.41	7.03	7.78	6.95	7.54	8.08	7.01
SiO_2	187	126	144	140	133	161	277
Ca	4.8	4.3	5.4	4.7	5.8	5.2	.46
Mg	.07	.08	.19	.03	.08	.03	.01
Na	337	121	202	115	239	288	51
K	15	9.1	11	11	9.4	11	16
HCO_3	710	254	424	259	509	576	81
SO_4	18	9	10	7	12	31	52
F	18	7.4	12	8.4	12	14	4.2
Cl	87	27	52	24	57	66	4
Na-K-Ca	163	173	163	184	150	152	270
Qtz Steam	165	144	151	149	147	157	187
Qtz Cond	175	150	158	156	153	165	202

fractures armored with hydrothermal quartz for example. The observed silica in water is a function of the thermal history and minerals to which the water has been exposed.

We have attempted to use the dissolution and precipitation kinetics of Rimstidt and Barnes (1980) to model possible thermal histories which will produce the observed silica. The model results are shown in Figure 1. Models shown do not include more conventional models involving steam separation and mixing of hot and cool solutions which are also possible, or even likely, explanations. We are not able at this stage of the investigation to choose among the possible models or combinations but will use other chemical constituents and isotopes to assist in the choice.

Stable Isotope Analysis

Hydrogen and oxygen isotope analyses are currently underway on water samples collected in the southwest portion of Yellowstone Park during August and September, 1981. Collection procedures followed methods recommended by Nehring and Truesdell (1977). Analytical methods for oxygen and hydrogen isotope analysis of water samples follow those of Epstein and Mayeda (1953) and Friedman (1953, respectively. Both hydrogen and oxygen isotope compositions are reported in the "delta" notation relative to SMOW (Craig, 1961).

At this time, all hydrogen-isotope analyses and ten of the twenty-one oxygen-isotope analyses have been completed. These analyses are presented in Table 2. Both hydrogen and oxygen isotope compositions of the waters vary significantly from area to area. The total range of δD values, -117 to -140 is within the range of δD values previously reported for other thermal areas within Yellowstone Park (Truesdell et al., 1977). When all analyses are completed, isotopic and chemical constituents can be compared to assist in interpreting subsurface processes affecting the waters in these thermal areas.

Assessment of Thermal Discharge

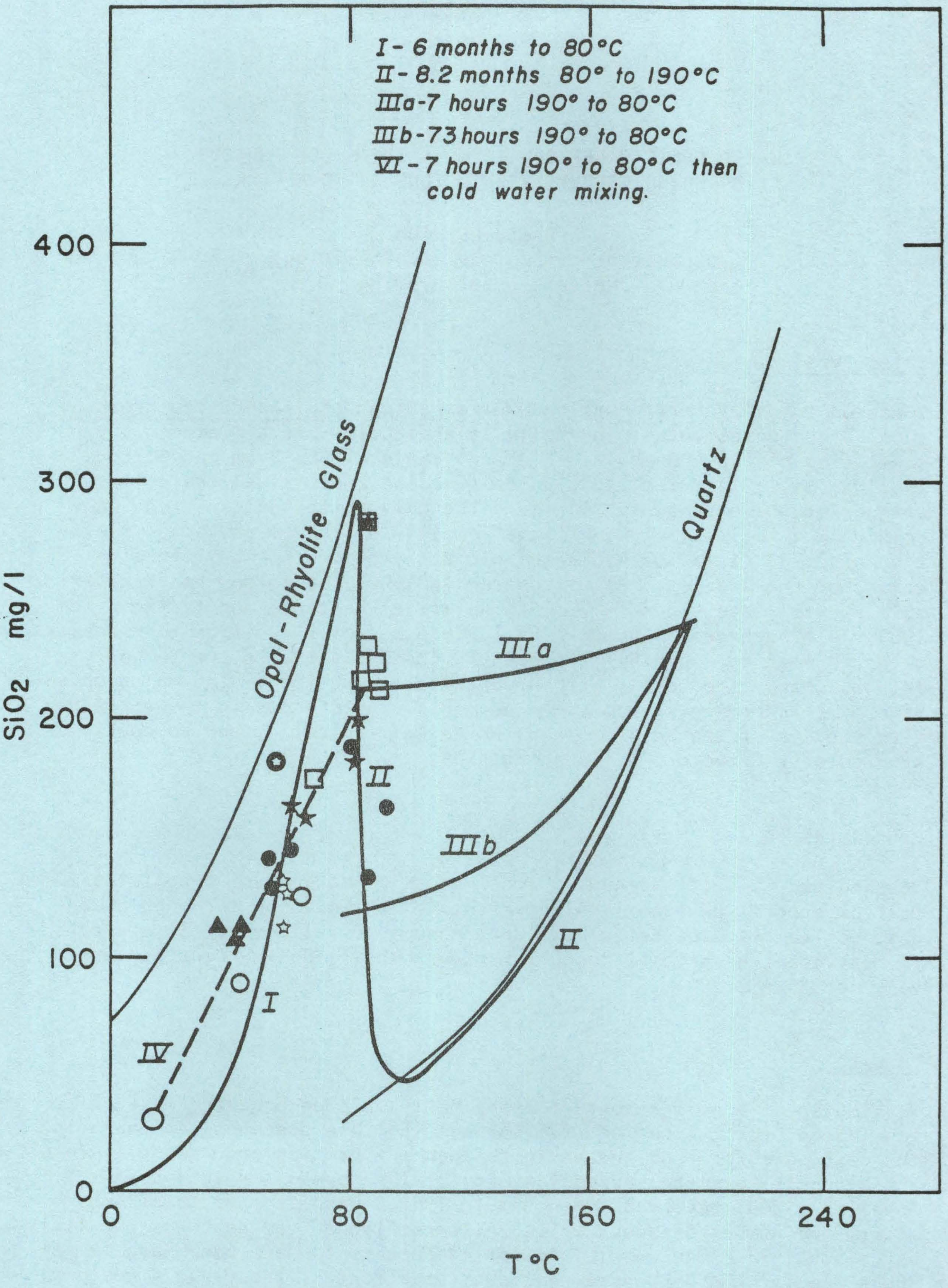
Water discharge and simultaneous temperature and chloride measurements were made at 83 sites in the 8 thermal areas. Temperature measurements were consistent with earlier measurements but flow values varied considerably, indicating annual or seasonal effects that will be important in planning a monitoring program. Thirteen soil temperature profiles yielded a high correlation between shallow temperatures and vegetation type, indicating that aerial photographs can be used to map heat loss in the vapor dominated areas.

Table 2. $\delta^{18}O$ and δD Values of Southwest Yellowstone Waters.

	Sample	$\delta^{18}O$	δD
3RTA[a]	#3	-17.8	-133
	#37	-16.5	-130
	#46	-17.0	-129
	Ferris Fork #M	-17.3	-130
	Phillips Fork	-16.5	-128
MATA	#6		-120
	#11	-17.8	-118
	#49	-18.6	-117
LBCTA	B		-139
	23		-133
	47		-140
MBCTA	27	-16.8	-130
	45		-125
	48	-15.9	-128
UBCTA	Cold Spring		-139
	Swimming Hole		-136
	#57 (North Annex)	-15.6	-129
SLTA	A		-133
Silver Scarf	#65		-122
	#138		-123
Bechler Ford	#3		-124

a Abbreviations are: 3RTA = Three Rivers Thermal Area; MATA = Mountain Ash Thermal Area; LBCTA = Lower Boundary Creek Thermal Area; MBCTA = Middle Boundary Creek Thermal Area; UBCTA = Upper Boundary Creek Thermal Area; SLTA = Summit Lake Thermal Area.

Figure 1. Dissolved silica and temperatures of southwest Yellowstone spring waters with hypothetical reaction paths. Open circles - Upper Boundary Creek, filled circles - Three Rivers, triangles - Mountain Ash, open stars - Lower Boundary Creek, filled stars - Middle Boundary Creek, open squares - Silver Scarf, square/star - Summit Lake, circle/star - Bechler Ford.


I - 6 months to 80°C
II - 8.2 months 80° to 190°C
IIIa - 7 hours 190° to 80°C
IIIb - 73 hours 190° to 80°C
VI - 7 hours 190° to 80°C then cold water mixing.
Opal - Rhyolite Glass
Quartz
IIIa
IIIb
II
I
IV
400
300
200
100
0
0
80
160
240
SiO2 mg/l
T °C