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Chemical Data from Thermal and Nonthermal Springs in Mount St. Helens National Monument, Washington

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INTRODUCTION

Since the spectacular eruption of Mount St. Helens on May 18, 1980, numerous thermal springs have been discovered in Mount St. Helens National Monument. These springs are concentrated essentially into two areas: those in the crater area along Loowit and Step Creeks and those along the North Fork Toutle River issuing from the May 18, 1980, pyroclastic flow (figure 1.). Other thermal springs have been reported elsewhere throughout Mount St. Helens National Monument (Shevenell, 1990), but the above thermal-spring areas appear to be important ones because they have large discharges and temperatures >50 °C (except for "Step Creek hot springs").

Thermal springs along Loowit Creek on the north side of Mount St. Helens (figure 1.) were first observed during the summer of 1983. The first water samples reported here were collected in the Fall of 1983. Initially these thermal springs were informally designated "Lower Travertine," "Avalanche" and "Upper Step." Later, thermal springs having lower measured temperatures and lower discharges were found west of "Loowit Hot Springs" along Step Creek.

In order to avoid confusion between "Loowit Hot Springs" and "Step Creek Hot Springs", field investigators decided to change the informal area names of the "Loowit Hot Springs" at an informal gathering held at the Cascades Volcano Observatory on May 5, 1989. "Lower Travertine" springs was changed to "Lower Loowit" springs; "Avalanche" springs to "Middle Loowit" springs; and "Step" springs to "Upper Loowit" springs. The thermal springs on Step Creek would be informally called "Step Creek hot springs." All thermal-spring locations in this report use the new designations. Earlier abstracts (Thompson and others, 1985 and Thompson and others, 1988) used the old names.

The thermal springs along the North Fork Toutle River are located in an area informally called the "pumice pond" and near the confluence of Step Creek with the North Fork Toutle River. Springs in these areas will be referred to here as "Pumice Pond hot springs" and "Confluence hot springs", respectively. From reconnaissance work, the "Pumice Pond hot springs" appear to be areally larger than the "Confluence hot springs." However, little is known about the thermal springs in the vicinity of the Step Creek confluence with the North Fork Toutle River.

FIELD COLLECTION AND ANALYSES

Spring waters were collected using methods similar to those described in Thompson (1985). In brief, water samples were collected in a 1 liter polyethylene bottle attached to a 2 m long metallic pole, having an adjustable clamp at one end. The bottle was attached to the clamp and was filled and emptied numerous times to rinse it thoroughly. Next, a one-piece plastic 1.2 liter filter and reservoir was also thoroughly rinsed by passing about 0.6 L of water through the filter using a tire pump. The reservoir was then refilled. A 500 mL filtered sample was collected into a polyethylene bottle for anion analysis. A 250 mL filtered sample was collected into a pre-cleaned, acid-rinsed polyethylene bottle and acidified with double-distilled hydrochloric acid. A silica sample was collected by transferring 10 mL of thermal water into a 60 or 125 mL polyethylene bottle containing 50 or 100 mL of distilled water, respectively. Samples for deuterium and oxygen-18 analysis were collected in a 60 or 125 mL flint glass bottle. Samples for carbon-13 analysis were collected in a 250 mL or larger flint glass bottle to which 10 mL of saturated $SrCl_2$ in concentrated NH_4OH was added.

Temperature measurements of the thermal springs were obtained with a maximum-reading, total immersion, conventional mercury-in-glass thermometer. Temperature measurements of cold springs were made with a total immersion, conventional mercury-in-glass thermometer. Determinations of pH were made using a combination, gel-filled pH electrode and portable pH meter having a liquid crystal display. Field measurements of dissolved H_2S and NH_3 were determined using a Baush and Lomb (B&L) minispec 20 spectrophotometer and B&L spectrokits for methods based on American Public Health Association (1975) procedures 418B and 428C, respectively. Dissolved Al samples were collected into screw-topped, 10 mL glass test tubes after chelation with 8-hydroquinoline and extracted into methylisobutyl ketone, following the procedure of Afifi (1982).

LABORATORY METHODS OF ANALYSIS

Sodium was determined by either atomic absorption spectroscopy (AAS) or atomic emission spectroscopy (AES) in an air acetylene flame at 589.0 nm with added K^+ ion (0.1 % by volume (v/v)).

Potassium was determined by either AAS or AES in an air acetylene flame at 766.5 nm with added Na^+ ion (0.1 % v/v).

Lithium was determined by either AES or AAS in an air acetylene flame at 670.8 nm with added K^+ ion (0.1 % v/v)

Cesium and ***rubidium*** were determined by AES in an air acetylene flame at 852.1 nm and 780.0 nm, respectively, using high-purity K+ ion (0.1% v/v).

Calcium and ***magnesium*** were determined simultaneously by AAS in an air acetylene flame at 422.7 nm and 285.2 nm, respectively, with added La^{+3} ion (1 % v/v).

Iron and ***manganese*** were determined simultaneously by AAS in an air acetylene flame at 248.3 nm and 275.5 nm, respectively, with added K^{+} ion (0.1 % v/v).

Boron, strontium and ***barium*** were determined by AES in a direct current plasma at 249.7 nm, 421.5 nm and 455.4 nm, respectively.

Arsenic was determined by AES in a direct current plasma at 193.7 nm.

Bicarbonate was determined by automated pH titration using standardized sulfuric acid to an endpoint near pH 4.2. The pH at the start of the titration was reported as the laboratory pH.

Bromide was determined by ion chromatography on a Dionex model 16 ion chromatograph using an AS-3 separator column.

Chloride was determined by automated potentiometric titration to an endpoint near 310 mV with standardized $AgNO_3$.

Fluoride was determined by ion specific electrode using a 1:1 mixture of trans-1,2 diaminocyclohexane-N,N,N',N'-tetraacetic acid monohydrate (CDTA) in an acetate buffer at pH 5.5 with 1 M NaCl (Fishman and Friedman, 1985).

Silica was determined by spectrophotometry using reduced molybdenum blue at 640 nm (Shapiro and Brannock, 1956).

Sulfate was determined by turbidity produced from $BaCl_2$ in acidic NaCl (Fishman and Friedman, 1985).

Conductivity was determined using a Prestotek DP-38 until 1988 when a Whatman CDM 300 conductivity meter having automatic temperature compensation of 2 percent/°C was used.

Deuterium was determined following the technique of Biegelson and others (1952).

Oxygen-18 was determined following the technique of Epstein and Mayeda (1953).

Carbon-13 was determined following the procedure described by Huebner (1981).

Oxygen-18 on sulfate was determined following the technique of Nehring and others (1977).

For those elements determined using atomic spectroscopy, typical relative standard deviations (RSD) for the individual determinations are <2.0 percent for Na, K and Li, range from 2 - 4 percent for Ca and Mg, and range from 5 - 10 percent for B, Sr and Ba. The precisions for Ca, K, Mg, Li and Na in the data set are 7, 9, 6, 12 and 5 %, respectively (Fishman and Friedman, 1985). From standardization titrations, the RSDs for the individual HCO_3 and Cl determinations are ≈1.0 percent, the precision of the data for both is about 4 % (Fishman and Friedman, 1985). The individual measurement RSD for the spectrophotometric silica procedure is estimated to be <2 % based on multiple readings of the same standards and 7 % for the data set (Fishman and Friedman, 1985). RSD for the individual F determinations are about 10 % and are estimated to be about 41 % for the data set.

DATA

Table 1 contains the latitude and longitude of water samples and figure 1 shows the approximate locations of springs from which water samples were collected and analyzed by the U.S. Geological Survey. The results of the analyses are presented in table 2. Table 3 contains the temperatures calculated by chemical geothermometry of the springs in table 2.

Preliminary interpretation of the data has been reported by Thompson and others (1985) and Thompson, White and Maley (1988). These published interpretations were based on chemical data from springs that had not yet attained a steady or constant composition. The interpretations may change after further analysis or when the thermal spring water achieves a relatively constant composition. We are continuing our efforts to understand these important new features.

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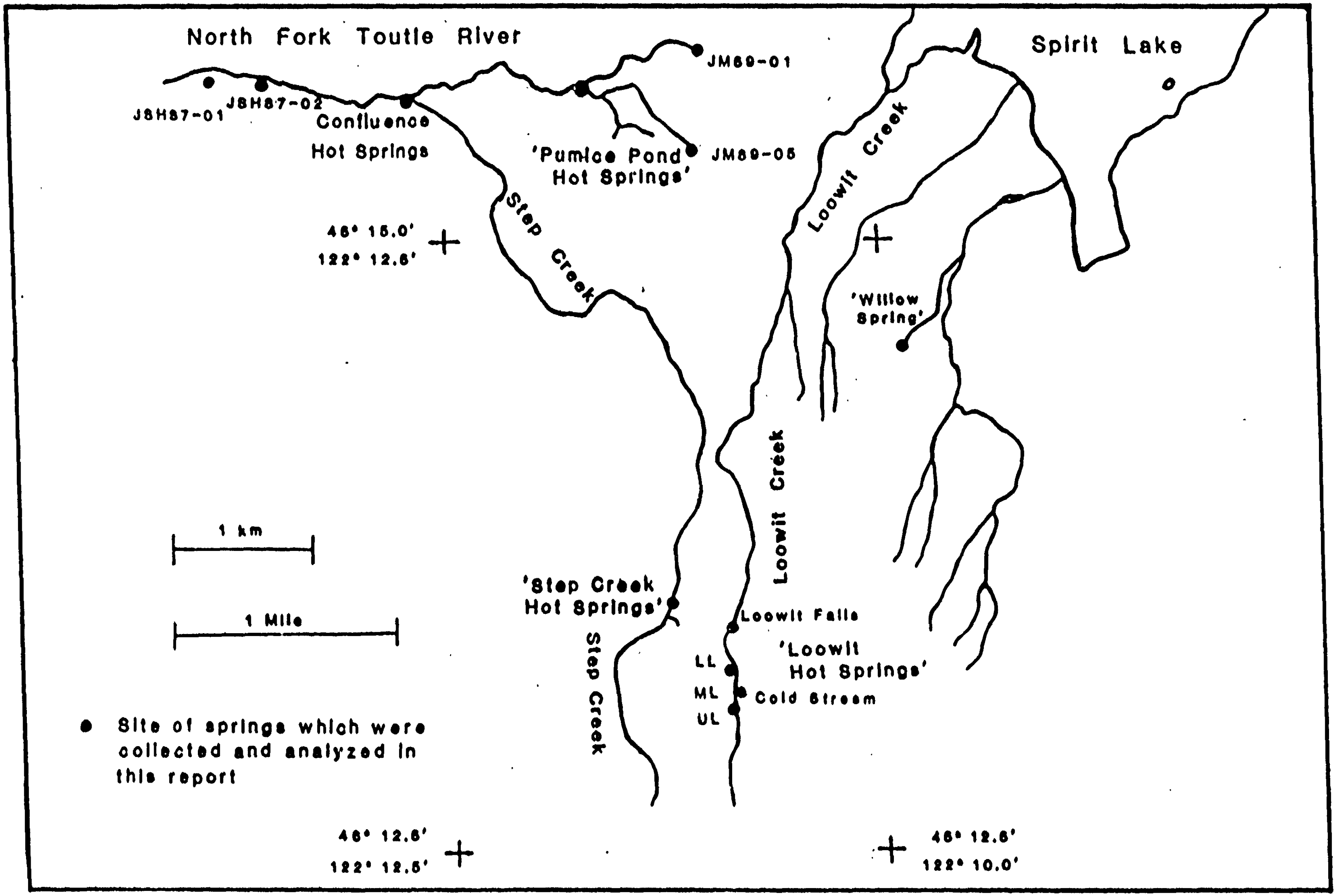

Figure 1. Location map of water samples in the Mount St. Helens National Monument; LL, Lower Loowit; ML, Middle Loowit; UL, Upper Loowit. Sample JM89-01 is the source of the North Fork Toutle River. Sample JM89-05 is the eastern end of the "Pumice Pond hot springs". Sample JSH87-01 appeared to be the western end of the North Fork Toutle River hot springs in 1987.

Table 1. Locations, collectors and dates of water samples.

Number	Field Number Reference	Latitude	Longitude	Collector	Date
Loowit Hot Springs, Lower Springs					
1	TC-83-02	46° 13.2'	122° 10.9'	TC	8 Nov 83
2	TC-84-03	46° 13.2'	122° 10.9'	TC	19 Jan 84
3	TC-84-06	46° 13.2'	122° 10.9'	TC	1 Jun 84
4	JSH-84-01	46° 13.2'	122° 10.9'	JMT	10 Aug 84
5	JSH-85-04	46° 13.2'	122° 10.9'	JMT	12 Aug 85
6	JSH-87-08	46° 13.2'	122° 10.9'	JMT	26 Aug 87
7	JSH-88-07	46° 13.2'	122° 10.9'	JMT	13 Sep 88
8	JSH-89-03	46° 13.2'	122° 10.9'	JMT	7 May 89
9	Loowit	46° 13.2'	122° 10.9'	MI	6 Sep 89
Loowit Hot Springs, Middle Springs					
10	JSH-84-02	46° 13.1'	122° 10.9'	JMT	10 Aug 84
11	JSH-85-03	46° 13.1'	122° 10.9'	JMT	12 Aug 85
12	JSH-87-07	46° 13.1'	122° 10.9'	JMT	26 Aug 87
13	JSH-88-04	46° 13.1'	122° 10.9'	JMT	15 Sep 88
Loowit Hot Springs, Upper Springs					
14	TC-83-01	46° 13.1'	122° 10.9'	TC	23 Oct 83
15	TC-84-04	46° 13.1'	122° 10.9'	TC	19 Jan 84
16	TC-84-05	46° 13.1'	122° 10.9'	TC	6 Mar 84
17	TC-84-07	46° 13.1'	122° 10.9'	TC	1 Jun 84
18	JSH-84-04	46° 13.1'	122° 10.9'	JMT	10 Aug 84
19	JSH-85-01	46° 13.1'	122° 10.9'	JMT	12 Aug 85
20	JSH-87-05	46° 13.1'	122° 10.9'	JMT	26 Aug 87
21	JSH-88-06	46° 13.1'	122° 10.9'	JMT	13 Sep 88
22	JSH-89-01	46° 13.1'	122° 10.9'	JMT	7 May 89
Loowit Hot Springs, cold stream at Loowit Middle Springs					
23	JSH-84-03	46° 13.1'	122° 10.9'	JMT	10 Aug 84
24	JSH-85-02	46° 13.1'	122° 10.9'	JMT	12 Aug 85
25	JSH-87-06	46° 13.1'	122° 10.9'	JMT	26 Aug 87
26	JSH-88-05	46° 13.1'	122° 10.9'	JMT	13 Sep 88
27	JSH-89-02	46° 13.1'	122° 10.9'	JMT	7 May 89
Loowit Creek at Brink of Loowit Falls					
28	JSH-89-04	46° 13.4'	122° 10.9'	JMT	7 May 89
29	JM-89-06	46° 13.4'	122° 10.9'	JM	14 Sep 89
Step Creek Below Hot Springs					
30	JM-89-07	46° 13.1'	122° 11.2'	JM	14 Sep 89

Table 1. Locations, collectors and dates of water samples (continued).

Number	Field Number	Reference	Latitude	Longitude	Collector	Date
Springs near confluence of Step Creek with North Fork Toutle						
31	JSH-87-01		46° 15.7'	122° 13.7'	JMT	25 Aug 87
32	JSH-87-02		46° 15.7'	122° 13.6'	JMT	25 Aug 87
33	JSH-87-03		46° 15.7'	122° 12.9'	JMT	25-Aug 87
34	JSH-87-04		46° 15.7'	122° 12.8'	JMT	25 Aug 87
Pumice Pond Hot Springs						
35	JSH-85-05	upstream	46° 15.7'	122° 11.7'	JMT	13 Aug 85
36	JSH-85-06	nr confluence	46° 15.7'	122° 11.8'	JMT	13 Aug 85
37	JSH-88-01	upstream	46° 15.7'	122° 11.8'	JMT	13 Sep 88
38	JSH-88-02	on drainage	46° 15.7'	122° 11.8'	JMT	13 Sep 88
39	JM-89-02	downstream	46° 15.7'	122° 11.8'	JM	12 Sep 89
40	JM-89-03	PP drainage	46° 15.7'	122° 11.8'	JM	12 Sep 89
41	JM-89-04	upstream PP	46° 15.7'	122° 11.8'	JM	13 Sep 89
42	JM-89-05	ES PP	46° 15.4'	122° 11.1'	JM	13 Sep 89
Headwaters N. F. Toutle (cold Spring)						
43	JM-89-01	cold spg	46° 15.7'	122° 11.1'	JM	12 Sep 89
Willow Spring (cold spring on old Corps of Engineers road)						
44	JSH-88-03		46° 14.5'	122° 9.8'	JMT	13 Sep 88
45	JM-89-08		46° 14.5'	122° 9.8'	JM	14 Sep 89

Collectors: TC, Tom Casadevall; MI, Mark Iven, JM, Jack Meeks; JMT, Mike Thompson, U.S. Geological Survey.

Table 2. Chemical analyses of springs in the Mount St. Helens National Monument (analyst, J. M. Thompson, chemistry; L. D. White, δD, $\delta^{18}O$ and $\delta^{13}C$; C. J. Janik, $\delta^{18}O$ SO_4).

Number	Field Number Reference	Date	Temp	F pH	L pH	SiO2	Al	Fe	Mn	As	Ca	Mg	Sr	Ba	Na	K	Li
				°C		<					in mg/L						>
Loowit Hot Springs, Lower Loowit Springs																	
1	TC-83-02	8 Nov 83	nr	na	8.08	177	nc	na	na	na	411	57.6	2.01	na	1470	95.2	2.57
2	TC-84-03	19 Jan 84	nr	na	8.42	170	nc	na	na	na	187	40.4	1.26	na	994	67.5	1.85
3	TC-84-06	1 Jun 84	92	na	7.95	200	nc	na	na	na	233	26.1	1.26	na	1030	71.7	2.20
4	JSH-84-01	10 Aug 84	88	7.02	7.92	209	0.0043	0.26	0.44	2.1	178	14.3	1.04	na	854	63.4	1.20
5	JSH-85-04	12 Aug 85	87	7.33	8.17	180	nc	na	na	0.51	191	15.2	na	na	835	51.8	0.97
6	JSH-87-08	26 Aug 87	76	7.0	7.96	216	nc	0.04	0.95	1.32	295	28.1	1.20	na	866	68.8	1.18
7	JSH-88-07	13 Sep 88	58	na	6.38	181	nc	0.02	0.82	1.15	233	24.8	1.40	na	776	62.7	0.84
8	JSH-89-03	7 May 89	67	6.8	6.6	156	nc	0.01	0.62	0.46	204	17.3	2.0	<.05	649	46.0	0.84
9	Loowit	6 Sep 89	69	na	6.69	147	nc	0.01	0.54	0.31	201	16.6	1.68	<.05	593	48.0	0.88
Loowit Hot Springs, Middle Loowit Springs																	
10	JSH-84-02	10 Aug 84	56	7.79	8.10	199	0.0038	0.27	0.43	1.8	184	10.3	0.93	na	801	67.6	0.94
11	JSH-85-03	12 Aug 85	54	7.52	8.09	153	nc	na	na	0.23	184	13.4	na	na	802	54.0	0.81
12	JSH-87-07	26 Aug 87	71	6.88	7.79	203	nc	0.13	0.49	0.31	147	11.6	0.61	na	789	56.3	1.02
13	JSH-88-04	15 Sep 88	52	7.82	7.38	150	nc	0.02	0.25	0.8	103	8.8	0.51	na	725	53.3	0.80
Loowit Hot Springs, Upper Loowit Springs																	
14	TC-83-01	23 Oct 83	76	6.26	8.44	406	nc	na	na	na	29	2.2	0.17	na	663	49.7	0.64
15	TC-84-04	19 Jan 84	nr	6.36	8.92	185	nc	na	na	na	164	8.4	0.99	na	829	69.0	1.01
16	TC-84-05	6 Mar 84	85	6.54	8.00	138	nc	na	na	na	160	8.2	0.94	na	800	65.9	1.01
17	TC-84-07	1 Jun 84	nr	7.8	8.20	201	nc	0.06	0.51	na	177	1.0	0.9	na	844	68.0	1.10
18	JSH-84-04	10 Aug 84	84	7.42	7.92	187	0.0047	0.24	0.53	2.6	163	8.5	0.84	na	792	67.3	0.97
19	JSH-85-01	12 Aug 85	85	7.0	8.11	166	nc	na	na	<.2	155	9.4	na	na	818	57.7	0.99
20	JSH-87-05	26 Aug 87	72	7.13	7.78	173	nc	0.07	0.23	1.02	89	7.2	0.49	na	654	46.5	0.88
21	JSH-88-06	13 Sep 88	57	7.66	6.33	129	nc	0.08	0.12	0.56	59	5.4	0.45	na	540	38.7	0.40
22	JSH-89-01	7 May 89	74	6.8	7.99	172	nc	0.04	0.32	0.1	130	12	1.05	<.05	805	61.5	1.08
Loowit Hot Springs, cold stream at Loowit Middle Springs																	
23	JSH-84-03	10 Aug 84	2	na	6.71	18.4	nc	na	na	na	2	1.5	na	na	5	0.6	<.01
24	JSH-85-02	12 Aug 85	9	6.2	6.44	31.5	nc	na	na	na	13	2.7	na	na	66	3.6	0.02
25	JSH-87-06	26 Aug 87	5	8.71	6.18	54.7	nc	na	na	na	7	2.6	na	na	33	1.8	0.02
26	JSH-88-05	13 Sep 88	7	8.91	5.56	38.4	nc	0.65	0.05	na	4	1.7	0.1	na	36	1.9	0.03
27	JSH-89-02	7 May 89	1	na	5.88	40.3	nc	na	na	na	7	1.6	0.16	0.07	41	2.6	0.04
Loowit Creek at brink of Loowit Falls																	
28	JSH-89-04	7 May 89	37	6.8	7.58	99.6	nc	<.01	0.01	0.35	71	6.2	0.65	<.05	525	32.5	0.62
29	JM-89-06	14 Sep 89	45	7.2	6.99	129	nc	0.53	0.17	<.2	71	4.9	0.53	<.05	520	34.1	0.63
Step Creek below Hot Springs																	
30	JM-89-07	14 Sep 89	27	8.0	8.05	143	nc	0.02	0.01	<.2	27	15	0.42	<.05	462	22.6	0.68

Table 2. Chemical analyses of springs from Mount St. Helens National Monument (analysts: J. M. Thompson, chemistry; L. D. White, δD, $\delta^{18}O$ and $\delta^{13}C$; C. J. Janik, $\delta^{18}O$ SO_4) (cont.).

No.	Rb	Cs	NH_4	HCO_3	SO_4	Cl	F	B	Br	H_2S	Zn	Cu	cond.	δ D	$\delta^{18}O$	$\delta^{13}C$	$\delta^{18}O$ SO4
<						in mg/L						>	µS	°/oo	°/oo	°/oo	°/oo
Loowit Hot Springs, Lower Loowit Springs																	
1	0.52	0.3	na	142	1520	2030	7.6	8	na	na	na	na	na	na	na	nc	nc
2	0.34	0.21	na	208	1440	837	8.3	4.6	na	na	na	na	na	na	na	nc	nc
3	0.29	0.24	na	135	1440	1070	5.8	5.1	na	na	na	na	na	na	na	nc	nc
4	0.53	0.29	2.2	259	1500	379	4.6	3	1.7	0.06	0.03	<.01	4790	-97.4	-12.61	-9.83	5.43
5	na	na	2.2	175	1600	469	4.6	2.5	na	0.03	na	na	6670	-98.8	-12.56	-12.27	nc
6	0.32	0.2	1.2	112	1410	997	3.6	14.7	na	0.06	na	na	na	-87.3	-11.13	-12	nc
7	0.19	0.07	na	119	1100	853	3.1	15.7	na	na	0.01	<.01	na	-84	-10.86	nc	nc
8	0.14	0.11	na	114	1010	690	2.8	13.7	na	na	na	na	na	-92	-11.5	-12.3	nc
9	0.54	0.14	na	119	790	779	2.9	13.2	na	na	na	na	na	na	na	nc	nc
Loowit Hot Springs, Middle Loowit Springs																	
10	0.51	0.26	1.1	167	1500	417	2.7	3.1	1.5	<.01	0.02	<.01	4530	-97.1	-12.21	nc	5.53
11	na	na	2.3	160	1300	664	3.1	5.4	na	0.13	na	na	6540	-95.8	-12	-12.65	nc
12	0.29	0.19	0.7	137	900	909	3.6	15.0	na	0.07	na	na	6980	-89.2	-10.48	-11.1	nc
13	0.15	0.05	na	149	800	822	5.0	17.2	na	na	0.01	<.01	4530	-85	-10.78	-10.06	nc
Loowit Hot Springs, Upper Loowit Springs																	
14	0.05	<.05	na	163	1240	250	7.2	0.9	na	na	na	na	na	na	na	nc	nc
15	0.20	0.07	na	171	1480	358	3.7	1.8	na	na	na	na	na	na	na	nc	nc
16	0.21	0.02	na	145	1840	336	3.9	1.7	na	na	na	na	na	na	na	nc	nc
17	0.29	0.24	na	184	1600	382	3.2	2.8	na	na	na	na	na	na	na	nc	nc
18	0.53	0.91	1.2	201	1530	395	3.8	2.0	1.1	<0.01	0.03	<.01	5250	-98.8	-12.83	-11.92	4.86
19	na	na	1.7	168	1100	776	3.7	8.4	na	0.04	na	na	7560	-96.6	-12.02	-14.18	nc
20	0.25	0.17	0.5	137	781	647	3.9	11.0	na	0.08	na	na	5050	-90.8	-11.74	-11.3	nc
21	0.09	0.04	na	134	550	519	4.0	10.8	na	na	<.01	<.01	4160	-87	-11.57	nc	nc
22	0.22	0.15	na	170	854	972	3.4	17.7	na	na	na	na	na	-86	-10.8	nc	nc
Loowit Hot Springs, cold stream at Middle Loowit Springs																	
23	na	na	na	14	7	7	0.6	0.1	na	na	na	na	130	-98.3	-13.38	nc	nc
24	na	na	na	17	141	21	1.9	0.1	na	na	na	na	960	-101.7	-13.53	nc	nc
25	na	na	na	15	53	9	1.2		na	na	na	na	na	na	na	nc	nc
26	<.01	<.01	na	24	60	8	1.8	0.2	na	na	na	na	260	-94	-13.3	nc	nc
27	na	na	na	78	35	19	0.8	0.2	na	na	na	na	na	-99.5	-14.2	nc	nc
Loowit Creek at brink of Loowit Falls																	
28	0.08	0.07	na	121	410	542	2.4	11.3	na	na	na	na	na	na	na	nc	nc
29	0.14	0.09	na	125	500	518	4.4	10.5	na	na	na	na	na	-89	-11.7	nc	nc
Step Creek below Hot Springs																	
30	0.08	0.07	na	468	200	411	6.0	7.2	na	na	na	na	na	-90	-11.7	nc	nc

Table 2. Chemical analyses of springs in the Mount St. Helens National Monument (analyst, J. M. Thompson, chemistry; L. D. White, δD, $\delta^{18}O$ and $\delta^{13}C$; C. J. Janik, $\delta^{18}O$ SO_4) (cont.).

Number	Field Number	Reference	Date	Temp °C	F pH	L pH	SiO2	Al	Fe	Mn	As	Ca	Mg	Sr	Ba	Na	K	Li
							← in mg/L →											
Springs near confluence of Step Creek with North Fork Toutle River																		
31	JSH-87-01		25 Aug 87	76	7.19	7.81	156	nc	0.16	2.1	0.47	350	50.2	1.67	na	1200	85.2	1.42
32	JSH-87-02		25 Aug 87	53	6.95	6.57	182	nc	0.43	2.4	0.96	466	86.6	2.2	na	983	71.0	1.25
33	JSH-87-03		25 Aug 87	64	6.95	7.73	182	nc	0.43	1.99	na	346	36.3	1.4	na	1000	64.6	1.07
34	JSH-87-04		25 Aug 87	62	7.09	7.71	179	nc	0.62	2.08	0.82	342	35.5	1.3	na	936	60.6	1.00
Pumice Pond (PP) Hot Springs																		
35	JSH-85-05	upstream	13 Aug 85	54	7.28	8.03	129	nc	na	na	0.46	228	17.3	na	na	629	25.0	0.68
36	JSH-85-06	at Toutle	13 Aug 85	96	7.17	7.82	176	nc	na	na	0.8	242	4.2	na	na	988	40.0	0.78
37	JSH-88-01	upstream	11 Sep 88	61	7.87	6.38	188	nc	0.03	0.23	0.84	162	6.4	0.9	na	943	57.0	0.47
38	JSH-88-02	on fork	11 Sep 88	66	7.56	5.99	149	nc	0.27	0.09	0.79	130	2.6	0.58	na	724	27.0	0.56
39	JM-89-02	ds Toutle	12 Sep 89	28	7.0	6.06	86	nc	0.3	0.26	0.34	139	15.1	0.93	<.05	437	20.1	0.36
40	JM-89-03	PP drain.	12 Sep 89	45	7.0	6.51	149	nc	0.04	0.21	<.2	164	15.1	1.5	<.05	750	50.7	0.65
41	JM-89-04	upstr. PP	13 Sep 89	65	7.0	6.28	186	nc	1.02	0.08	<.2	202	4.8	2.01	<.05	1166	51.9	1.15
42	JM-89-05	East PP	13 Sep 89	65	7.0	6.15	208	nc	0.06	0.10	<.2	136	6.2	1.42	<.05	1116	66.4	0.75
Headwaters North Fork Toutle River (cold spring)																		
43	JM-89-01	cold spg	12 Sep 89	10	6.2	5.67	31	nc	na	na	na	63	15.2	0.31	<.05	59	2.6	0.06
Willow Spring (cold spring on old Corps of Engineers road)																		
44	JSH-88-03		11 Sep 88	4	7.88	5.39	21	nc	0.01	0.01	na	23	6.8	0.11	na	31	3.3	0.02
45	JM-89-08		14 Sep 89	5	na	5.06	25	nc	na	na	na	12	4.5	0.01	<.05	31	2.7	0.01

nr, not recorded, na, not analyzed, nc, not collected

TC, Tom Casadevall, MI, Mark Iverson JM, Jack Meeks, JMT, Mike Thompson,

Table 2. Chemical analyses of springs from Mount St. Helens National Monument (analysts: J. M. Thompson, chemistry; L. D. White, δD, $\delta^{18}O$ and $\delta^{13}C$; C. J. Janik, $\delta^{18}O$ SO_4) (cont.).

	Rb	Cs	NH_4	HCO_3	SO_4	Cl	F	B	Br	H_2S	Zn	Cu	cond.	δ D	$\delta^{18}O$	$\delta^{13}C$	$\delta^{18}O$ SO4
	<—						in mg/L					—>	µS	°/oo	°/oo	°/oo	°/oo
Springs near confluence of Step Creek with North Fork Toutle River																	
31	0.40	0.23	1.5	128	1950	1285	2.2	6.2	na	0.05	na	na	11000	-83.7	-11.43	-11.5	nc
32	0.35	0.22	1.5	101	2940	624	2.1	3.7	na	0.06	na	na	8250	-85	-11.42	nc	nc
33	0.32	0.21	1.5	209	1990	824	3.2	3.8	na	0.06	na	na	8470	-86.8	-11.68	-15.4	nc
34	0.31	0.21	1.6	208	1900	690	3.3	3.1	na	na	na	na	7420	-85.8	-11.52	-14.9	nc
Pumice Pond (PP) Hot Springs																	
35	na	na	2.2	189	1300	388	4.3	1.6	na	0.03	na	na	5600	-93.1	-11.9	-14.78	nc
36	na	na	na	246	1700	556	10.6	2.4	na	na	na	na	8850	-89.6	-11.07	-17.62	nc
37	0.19	0.09	na	152	2240	156	6.2	1.5	na	na	0.02	<.01	6200	-79	-10.96	-11.92	nc
38	0.08	0.04	na	89	1200	441	7.6	2.2	na	na	0.01	<.01	3860	-81	-11.51	nc	nc
39	0.05	0.07	na	208	750	345	3.0	1.3	na	na	na	na	na	-85	-11.4	nc	nc
40	0.16	0.13	na	115	1000	792	4.9	2.9	na	na	na	na	na	-86	-11	nc	nc
41	0.20	0.18	na	227	1800	818	4.8	4.0	na	na	na	na	na	-86	-11.3	nc	nc
42	0.26	0.17	na	82	1300	1058	7.3	3.6	na	na	na	na	na	-87	-11	nc	nc
Headwaters of North Fork Toutle River (cold spring)																	
43	na	na	na	98	230	23	1.2	<.1	na	na	na	na	na	-88	-9	nc	nc
Willow Spring (cold spring on old Corps of Engineers road)																	
44	0.01	0.01	na	9	120	10	0.1	<.1	na	na	na	na	430	-91	-12.83	nc	nc
45	na	na	na	15	50	7	0.2	<.1	na	na	na	na	na	-93	-13.1	nc	nc

Table 3. Chemical geothermometer temperatures in °C calculated from data in table 2.

Number	Qtz[1] Cond.	Qtz[1] ad.	Chal[1]	Amor[1]	Na/K[2] (W&E)	Na/K[2] (F&T)	Na/K[3] (F)	Na/K[4] (A)	Na-K-Ca[2] 1/3	Na-K-Ca[2] 4/3	Na-Li[5,6] (F&M)	Na-Li[5,6] (K&M)	Mg/K[7]	Mg/Li[6]
Loowit Hot Springs, Lower Loowit Springs														
1	172	161	149	50	144	138	182	142	168	150	108	176	101	97
2	169	159	146	47	148	142	185	146	171	153	112	179	97	93
3	180	168	159	57	150	145	187	148	171	149	122	187	104	103
4	183	170	162	60	156	151	192	154	173	149	95	164	109	95
5	173	162	151	51	140	134	179	139	163	137	84	154	103	88
6	185	172	165	62	162	158	198	160	173	137	93	163	102	86
7	173	162	151	51	164	160	199	161	174	139	80	151	101	79
8	164	154	140	42	152	146	189	150	165	126	90	160	98	83
9	160	151	136	38	164	160	199	162	171	127	98	167	100	85
Loowit Hot Springs, Middle Loowit Springs														
10	180	167	168	57	168	164	202	165	179	150	85	155	116	93
11	162	153	154	41	147	141	185	145	167	140	77	148	106	86
12	181	168	169	58	152	147	189	150	172	148	90	160	109	93
13	161	152	153	40	155	150	191	153	175	155	81	152	111	91
Loowit Hot Springs, Upper Loowit Springs														
14	234	211	211	111	157	152	193	155	186	195	74	145	131	103
15	175	163	164	52	167	163	201	164	180	155	87	157	120	97
16	156	148	148	35	166	162	200	163	179	153	88	158	119	98
17	180	168	168	58	nm	nm	nm	nm	nm	110	410	394	155	131
18	175	164	164	53	169	165	203	166	180	153	87	157	119	96
19	168	158	158	46	151	146	188	149	171	148	87	157	113	95
20	170	160	160	48	152	147	189	150	173	152	93	162	110	96
21	152	145	145	31	153	148	190	151	173	153	61	133	109	79
22	170	59	160	48	159	154	194	156	177	157	92	162	111	94
Loowit Hot Springs, cold stream at Loowit Middle Spings														
23	na	na	na	na	na	na	na	na	na	na	na	na	na	na
24	na	na	na	na	na	na	na	na	na	na	na	na	na	na
25	na	na	na	na	na	na	na	na	na	na	na	na	na	na
26	na	na	na	na	na	na	na	na	na	na	na	na	na	na
27	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Loowit Creek at brink of Loowit Falls														
28	137	132	133	17	140	134	179	138	164	139	85	155	102	89
29	152	145	148	31	145	139	183	143	166	141	87	157	107	92
Step Creek below Hot Springs														
30	158	150	150	37	120	113	162	120	158	150	98	167	81	80

Table 3. Chemical geothermometer temperatures in °C calculated from data in table 2 (cont.).

Number	Qtz[1] Cond.	Qtz[1] ad.	Chal[1]	Amor[1]	Na/K[2] (W&E)	Na/K[2] (F&T)	Na/K[3] (F)	Na/K[4] (A)	Na-K-Ca[2] 1/3	Na-K-Ca[2] 4/3	Na-Li[5,6] (F&M)	Na-Li[5,6] (K&M)	Mg/K[7]	Mg/Li[4]
Springs near confluence of Step Creek with North Fork Toutle River														
31	164	154	155	42	152	147	189	150	171	147	85	155	100	83
32	174	162	163	51	153	148	190	151	166	127	89	159	88	73
33	174	162	163	51	143	138	182	142	163	132	80	150	97	80
34	173	162	162	50	144	138	182	142	162	129	80	150	96	79
Pumice Pond (PP) Hot Springs														
35	152	145	145	31	104	96	148	105	136	99	80	151	82	78
36	171	161	161	49	106	98	150	106	143	122	64	136	114	100
37	176	164	165	53	138	131	177	137	165	148	43	116	118	81
38	161	152	152	39	100	91	144	101	140	118	63	135	109	97
39	129	125	126	10	115	108	158	116	141	99	66	138	78	65
40	161	152	152	39	147	142	185	146	167	139	68	140	102	78
41	175	164	164	53	113	105	156	113	152	141	75	146	120	109
42	283	170	170	60	136	130	176	135	169	164	56	129	123	94
Headwaters of North Fork Toutle River														
43	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Willow Spring (cold springs on old Corps of Engineer road)														
44	na	na	na	na	na	na	na	na	na	na	na	na	na	na
45	na	na	na	na	na	na	na	na	na	na	na	na	na	na

[1] Fournier, 1981, Qtz Cond., Quartz conductive; Qtz Ad., Quartz adiabatic; Chal, chalcedony, Amor., amorphous silica,
[2] Truesdell, 1976
[3] Fournier, 1979
[4] Arnorsson and others, 1983
[5] Fouillac and Michard, 1981
[6] Kharaka and Mariner, 1989
[7] Giggenbach and others, 1983,

nm, calculated temperature has no meaning; na, not applicable