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CHEMISTRY OF THERMAL WATERS AND MINERALOGY OF THE NEW DEPOSITS AT MOUNT ST. HELENS--A PRELIMINARY REPORT

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by

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INTRODUCTION

The May 18, 1980 eruption of Mount St. Helens, Washington, filled the upper North Fork of the Toutle River with debris as much as 150 m thick. Deposits from (1) an avalanche consisting of hot and cold rock debris and ice blocks, (2) a hot "lateral blast", (3) pyroclastic flows, and (4) mudflows cover more than 500 km^2 of devastated area to the northwest, north, and northeast of the volcano. Interactions between the hot deposits and shallow ground water produced ephemeral phreatic eruptions and thermal ponds and streams. In early June we collected water and sediment samples from about 20 sites in the devastated zone to study the initial alteration of the new deposits, and the effects of the eruption on water chemistry. We were also interested in the levels of certain trace elements in thermal waters, and whether these mineralized waters were reaching the North Fork Toutle River in appreciable quantities.

In the following sections we discuss collection and analysis procedures, the mineralogy of the new deposits, and the chemistry of the thermal waters. Finally, we compare the chemistry of water from different deposits, and discuss alteration reactions suggested by the water chemistry and the mineralogy of the deposits. A detailed discussion of alteration reactions, based on data presented in this report as well as that collected since June, 1980, will appear elsewhere (Dethier, Pevear, and Frank, in preparation).

METHOD

We collected water, suspended-sediment, and dry sediment samples from 18 sites to the north and west of Mount St. Helens (Figure 1) on June 7 and 8, 20 days after the catastrophic eruption of May 18. In addition, we collected sediment samples from four other locations, including several steam vents, and T. Casadevall (U.S. Geological Survey) provided us with four water samples collected on June 5. To aid in comparative studies, we also analyzed the mineralogy and texture of some 70 air-fall tephra samples collected from the slopes of the volcano to as far as North Platte, Nebraska from late March through early August. Appendix 1 gives a detailed description of water and sediment-sample locations, and Appendix 2 shows the location of the air-fall tephra collection sites.

Sediment samples were air-dried and the <2-μm fraction was separated by centrifugation. Oriented <2-μm samples and bulk, randomly oriented samples were treated by standard methods (Jackson, 1974), and analyzed by x-ray diffraction techniques on a General Electric XRD-5 diffractometer, and by scanning electron microscope (SEM) methods using an AMR-1200 equipped with an energy-dispersive beam analyzer (EDAX). Selected samples were treated with DMSO to check for kaolinite (Abdel-Kader, Jackson, and Lee, 1978). Grain mounts and thin sections were examined by standard petrographic techniques.

Water temperature, pH, and specific conductance were measured in the field, and on return to the laboratory, where about one liter of each sample was filtered through a 0.45-μm cellulose filter. Filtered and unfiltered samples were submitted to the Central Laboratory by the Tacoma District Office of the U.S. Geological Survey and were analyzed by standard methods (Skougstad et al, 1978) for about 75 constituents.

DATA

Mineralogy   Table 1 lists the major, minor, and trace minerals present in selected deposits at Mount St. Helens, and in air-fall tephra collected at some distance from the mountain. Mineralogy of the <2-μm fraction of samples collected June 7 and 8 is listed in Appendix 3. Plagioclase (andesine), glass, and ferromagnesian minerals dominate the >2-μm fraction of most of the samples, while trioctahedral smectite accompanies these minerals in the <2-μm fraction of all samples. Hypersthene and hornblende are the principal ferromagnesian minerals, while minor clinopyroxene has been reported by some authors (see Fruchter et al, 1980; Korosec, Rigby, and Stoffel, 1980) and minor amounts of mica, probably biotite, are present in some samples. Titaniferous magnetite, often intergrown with apatite, is the major opaque mineral described in all samples we collected, and constitutes at least 5 percent, by weight, of some air-fall tephra (Korosec, Rigby, and Stoffel, 1980). Cristobalite and tridymite occur in most samples but account for less than 5 percent of the <2-μm fraction. Oxidized iron minerals, hematite and possibly goethite, occur in large altered blocks in the debris-avalanche deposit, and are probably present as trace constituents in other deposits. Zeolites (phillipsite and chabazite) have also been identified in both the coarse and fine fraction of the avalanche deposit, and are probably derived from older portions of the cone which were incorporated by the avalanche. Finally, chlorite and smectite/chlorite intergrade occur in trace to minor amounts in many samples.

Gypsum and sulfur were noted coating rocks at the mouth of a fumarole (SHW-CW) which exceeded 150°C on June 7. Gypsum was identified as a surface coating at several places in the pyroclastic flows, and at steam vents in the pyroclastic flows and the debris avalanche deposit. None of these minerals were present as suspended sediment in any of the thermal waters we sampled.

Water chemistry   Appendix 4 lists complete chemical analyses for 18 water samples collected in early June from Spirit Lake thermal ponds, and streams in the devastated area northwest of Mount St. Helens, two samples collected from the Spirit Lake outlet and the North Fork Toutle River before May 18, and includes partial analyses of four samples collected at lakes in the blast area on June 5. The range in concentration of the major and minor constituents in these samples is listed in Tables 2 and 3, respectively. Sodium and calcium were the dominant dissolved cations in all samples, while the anions sulfate and chloride predominated in most samples, and bicarbonate, as calculated from alkalinity, was the major anion in 2 samples. Specific conductance was highly correlated ($r^2>0.9$) with the concentration of each of the major ions, with the smallest scatter present in plots of specific conductance and chloride (see Figure 2).

The pH of most samples was near neutral, and while field pH measured at Spirit Lake (Samples SHW 8-13) averaged about 6.0, laboratory values were almost one-half pH unit higher. The reasons for this discrepancy are not known, but field and laboratory values for near-neutral waters were generally within 0.2 pH units of each other. Concentrations of dissolved silica displayed the smallest range of any measured constituents.

Analyses were performed for about 25 substances which are usually considered to be "trace" or "minor" constituents in water. Only 10 of these were found at detectable levels in most samples in either dissolved or suspended form. Manganese, iron, boron, and strontium were present at concentrations exceeding 500 μg/L in many samples, and manganese was the major dissolved "trace" metal in all samples. Manganese concentration exceeded the 50 μg/L drinking water standard recommended by the Environmental Protection Agency (1976) in 20 out of 24 samples, while iron exceeded standards in 7 samples. "High" levels of dissolved lead were reported for SHW 11 and 13, but these samples reported lower "total" lead levels, so the dissolved values may be incorrect. Arsenic, boron, and lithium were detected in most samples, but at much lower levels than those reported for thermal waters at Mount Hood (Wollenberg et al, 1979), Mount Baker (Frank, in press), the Long Valley Caldera (Sorey et al, 1978), and at Yellowstone National Park (Stauffer, Jenne, and Ball, 1980). However, with the exception of two springs at Mount Hood, dissolved manganese levels measured in the thermal waters at Mount St. Helens are much higher than those reported in these other studies.

DISCUSSION

<u>Mineralogy</u> Eruptive products from Mount St. Helens consist of a magmatic component (glass, plagioclase, hypersthene, hornblende, and magnetite) and a lithic component which includes, in addition to the minerals just noted, smectite, chlorite, interlayered chlorite/smectite, mica, cristobalite, tridymite, and quartz. The minerals unique to the lithic component are present in the early (March 27-May 17) phreatic tephra and in the old, altered rock of the debris avalanche, but are

absent from the new pumice flows and, with the exception of cristobalite, from the dome that formed in the crater in June. The lithic fragments were probably abraded from the vent by escaping volatiles during eruptive events. Because of high-velocity grain impacts, appreciable abrasion must occur during eruptions, as minerals such as plagioclase are present even in the <0.2-μm size fraction.

Smectite is the dominant mineral in the <2-μm size fraction of all 1980 deposits. The smectite appears to be trioctahedral on the basis of the 060 reflection at 1.54 Å and the absence of a peak near 5 Å on the heat-treated (collapsed) samples. Cavities in altered old rocks from the debris avalanche are filled with zeolites and smectite which appear to have crystallized from interstitial solutions. The dissolved components of these solutions may have been derived from ferromagnesian minerals, glass, and plagioclase. The smectite in the 1980 deposits is probably derived from this type of material, although some fraction may have formed by hydrothermal alteration during the present eruptive cycle. However, it is unlikely that the smectite survived heating to near-magmatic temperatures, since it is unstable at temperatures greater than about 450°C.

Chlorite is rarely present in the air-fall tephra and pyroclastic flows, and is only slightly more common in the rock of the debris avalanche and blast deposit. It could have formed by hydrothermal alteration of biotite or by alteration of the trioctehedral smectite. The presence of interlayered chlorite/smectite (smectite with hydroxy interlayers) in most samples and its relative abundance in some tephra heated by fumarolic activity suggests that the transformation series trioctahedral smectite → mixed-layer chlorite/smectite → chlorite is present at Mount St. Helens.

Silica polymorphs are abundant in the altered rock of the debris avalanche, and in the lithic tephra. They are absent from the new pumice, but a fragment of the June dome contained abundant cristobalite, but little or no glass. Cristobalite in rocks of the dome probably formed by high-temperature devitrification of the matrix glass. Silica polymorphs in the altered rock of the debris avalanche may have an origin similar to that of the dome or may have formed at lower temperature by hydrothermal processes. However, silica vein-fillings are apparently absent, and the predominance of smectite, suggest that low-temperature conditions at slightly basic pH were most common in the cone of Mount St. Helens before the May 18 eruption. Minerals characteristic of hydrothermal acid-sulfate alteration (Frank, in press), like vein- or vesicle-filling kaolinite, cristobalite, or opal, are conspicuously absent.

<u>Water chemistry</u> The data listed in Appendices 3 and 4 provide a basis for comparison of water chemistry before and after the eruption at the same site, and the comparison of water composition from Spirit Lake to waters in the pyroclastic flows and in the debris-avalanche deposit.

In Figure 3 we compare the chemistry of a water sample collected on March 28 at the outlet of Spirit Lake to SHW-10, collected from Spirit Lake on June 8. Dissolved aluminum and silica were enriched by about 500 percent over late March levels, the major cations and bicarbonate were enriched by 10 to 50X, and concentrations of SO_4, Cl, As, B, Fe, Li, Mn, and other trace metals (not plotted) were more than 50 times the pre-eruption values. Arsenic, boron, chloride, lithium, and sulfate are thought to have become enriched on particle surfaces during the eruption (see, for instance, Fruchter et al, 1980), and were easily leached when the deposits came in contact with water. High levels of major cations suggest accelerated weathering processes, probably due to the attack of slightly acidic waters on the glass, plagioclase, and pyroxene abundant in the new deposits; reaction rates were probably aided by the high surface area of material in contact with the warm weathering solutions. Low concentrations of silica and aluminum suggest that they are relatively immobile in the weathering reactions. The enrichment of manganese and iron may be related to mobilization and complexation of these metals by organic compounds, rapid oxidation and weathering of magnetite and the ferromagnesian minerals, or other factors.

Many of the patterns shown in Figure 3 are also apparent in a comparison of Spirit Lake and pyroclastic-flow waters to a thermal pond in the debris avalanche, and to a sample from the North Fork Toutle River (see Figures 4 and 5). Concentrations of major ions in Spirit Lake exceeded those measured in waters draining pyroclastic flows, and concentrations in the North Fork Toutle River were generally lower than those measured upstream. In early June, apparently only small amounts of the mineralized upstream waters were reaching the North Fork Toutle River; the water in the North Fork at that time was derived mainly from the blast zone south of the North Fork valley. In all cases the major ions were sodium, calcium, sulfate, and chloride, but major amounts of bicarbonate were present in some samples. Trace metals were highly enriched in Spirit Lake water and, for most elements, in the thermal ponds in the debris-avalanche deposit. Very high levels of iron and manganese were determined in Spirit Lake water, but in the debris avalanche, manganese levels were high and iron levels low, suggesting the precipitation of an iron-rich phase. T. Casadevall (written communication, 1980) observed that while iron and manganese concentrations in Spirit Lake were similar in late May, by mid-July iron levels had decreased by about 30X, while Mn levels remained nearly constant. Precipitation mechanisms may be similar in both cases, but additional studies are required to establish specific reactions. Relatively high manganese levels were present in each of the water types, but with the exception of dissolved iron, trace-metal levels in the North Fork Toutle River were lower than those closer to Mount St. Helens.

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TABLE 1

Mineralogic composition of deposits erupted from Mount St. Helens in 1980

	Vitric pyroclastic flows[1] and vitric air-fall tephra	Lithic air-fall tephra	Debris-avalanche and blast deposits[2]
>2-μM	glass plagioclase hypersthene hornblende magnetite	minor glass plagioclase hypersthene hornblende magnetite	minor glass plagioclase hypersthene hornblende magnetite gypsum[3] sulfur[3] thenardite[3]
<2-μM	---	smectite mixed layer chl./smect. tridymite cristobalite[4] quartz plagioclase mica	smectite chlorite mixed layer chl./smect. cristobalite tridymite quartz chabazite phillipsite hematite unidentified, poorly crystallized, iron-rich phase

1/ Unless individual pumiceous shards are carefully sampled and cleaned, "lithic" contaminants like smectite and cristobalite are present in all 1980 deposits.

2/ Contains abundant, charred organic matter at many locations.

3/ Present as a condensate or encrusting precipitate.

4/ Present in the June dome as well.

Table 2

Concentration range for dissolved major ions
in surface water at Mount St. Helens in early June, 1980

Ion	Range (N=22) MG/L
Ca	1.6-229
Mg	0.4-51
Na	1.3-270
K	0.3-31
SO_4	2.2-730
Cl	2.0-340
HCO_3[1]	0-171
F	0.0-0.7
SiO_2	6.7-46
pH	6.1-7.5

1/ calculated from alkalinity

Table 3

Concentration range for dissolved trace elements in surface water at Mount St. Helens in early June, 1980

Constituent	Range (N=22) μG/L	Drinking Water Standard[1] μG/L
Al	0-250	----
As	1-12	50
Ba	4-100	1000
B	0-870	----
Fe	40-3600	300 (7)
Pb	0-110(?)	50
Li	4-160	----
Mn	17-5400	50 (20)
Ni	0-10	----
Sr	10-1000	----
Sb, Be, Cd, Cr, Co, Cu, Hg, Mo, Se, Ag, V, Zn	Detected in <5 samples, at concentrations from 1-15 μg/L	----

1/ U.S. Environmental Protection Agency (1976); the number of samples exceeding the drinking water standard is shown in parentheses.

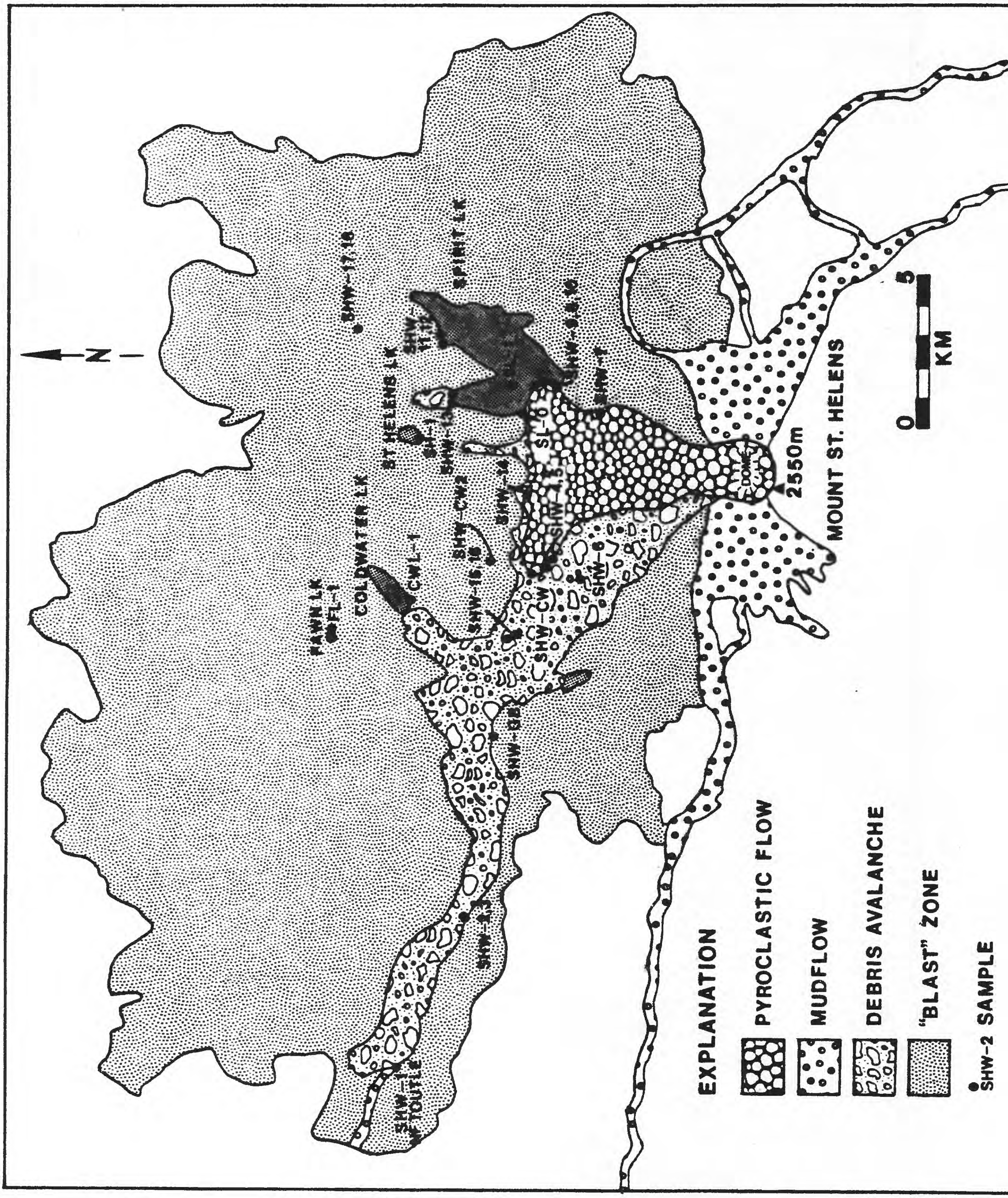


Figure 1.--Deposits erupted from Mount St. Helens on 18 May 1980(modified from Rosenfeld, 1980) and June sample sites.

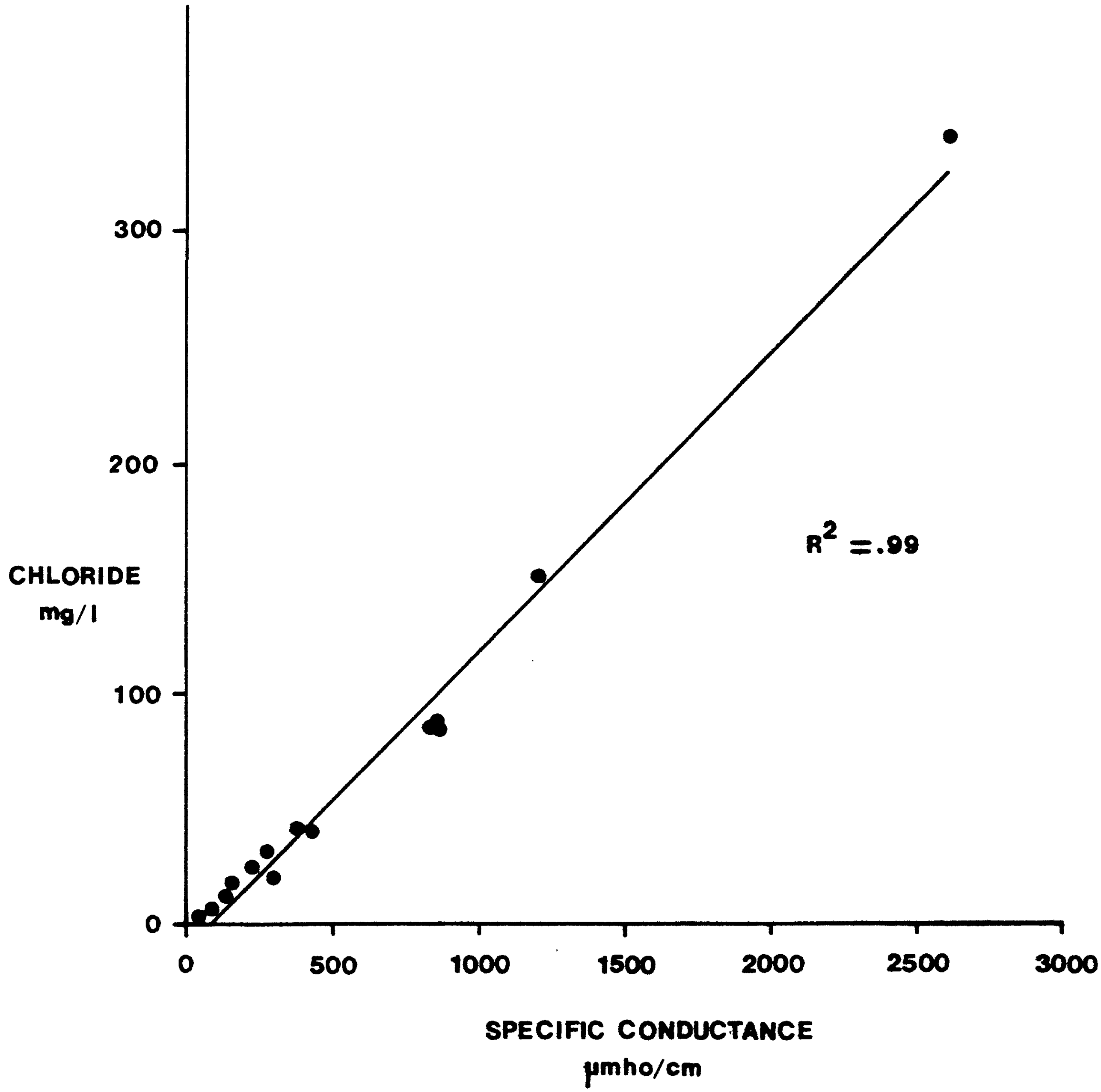


Figure 2.--Plot of chloride vs specific conductance for 20 samples of surface water from Mount St. Helens, Washington.

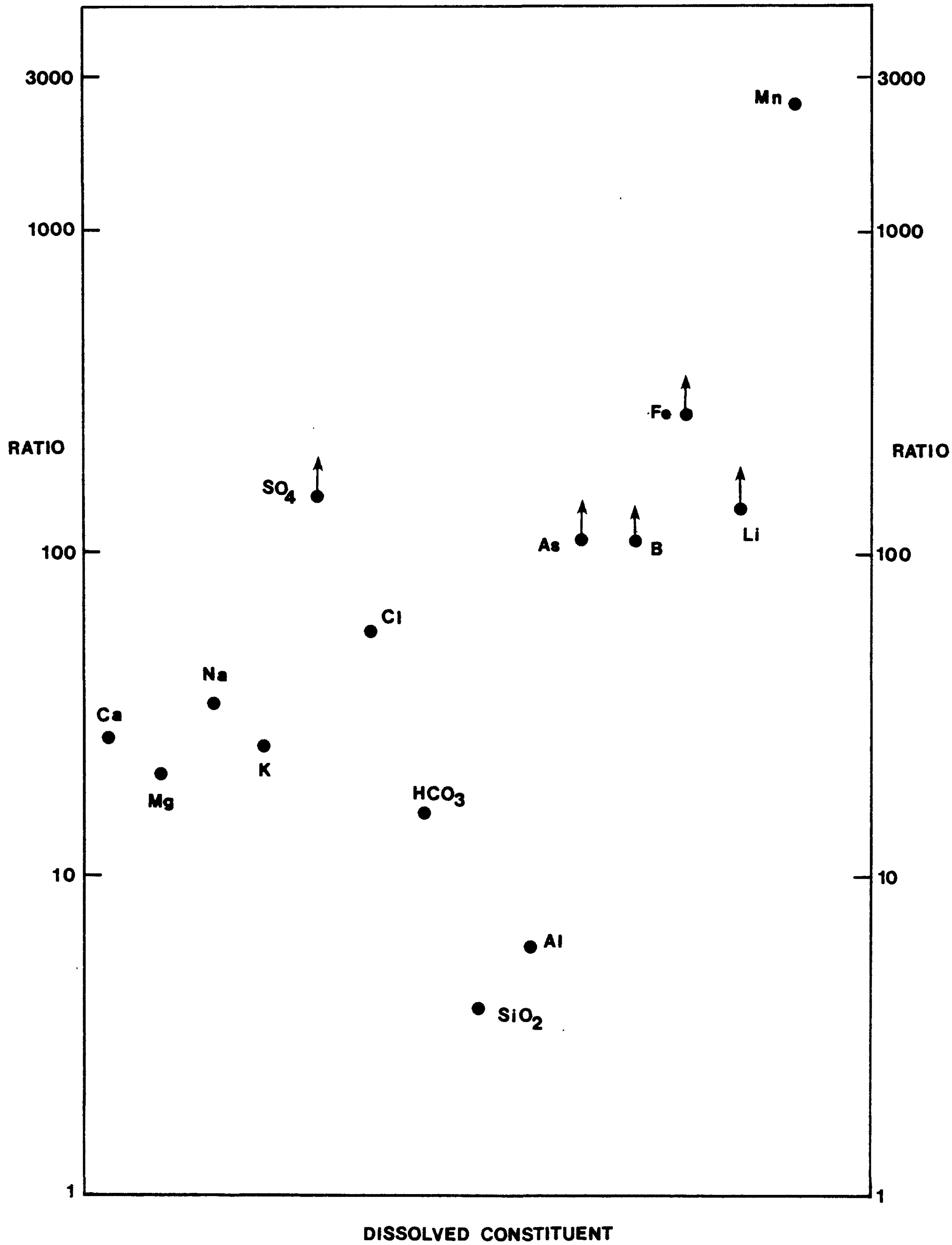


Figure 3.--Ratio of ((Spirit Lake concentration, early June(SHW-10))/((Spirit Lake concentration, late March(SL-0)) for selected major and minor constituents. Points with arrows indicate minimum values obtained by dividing the SHW-10 value by the detection limit for the element.

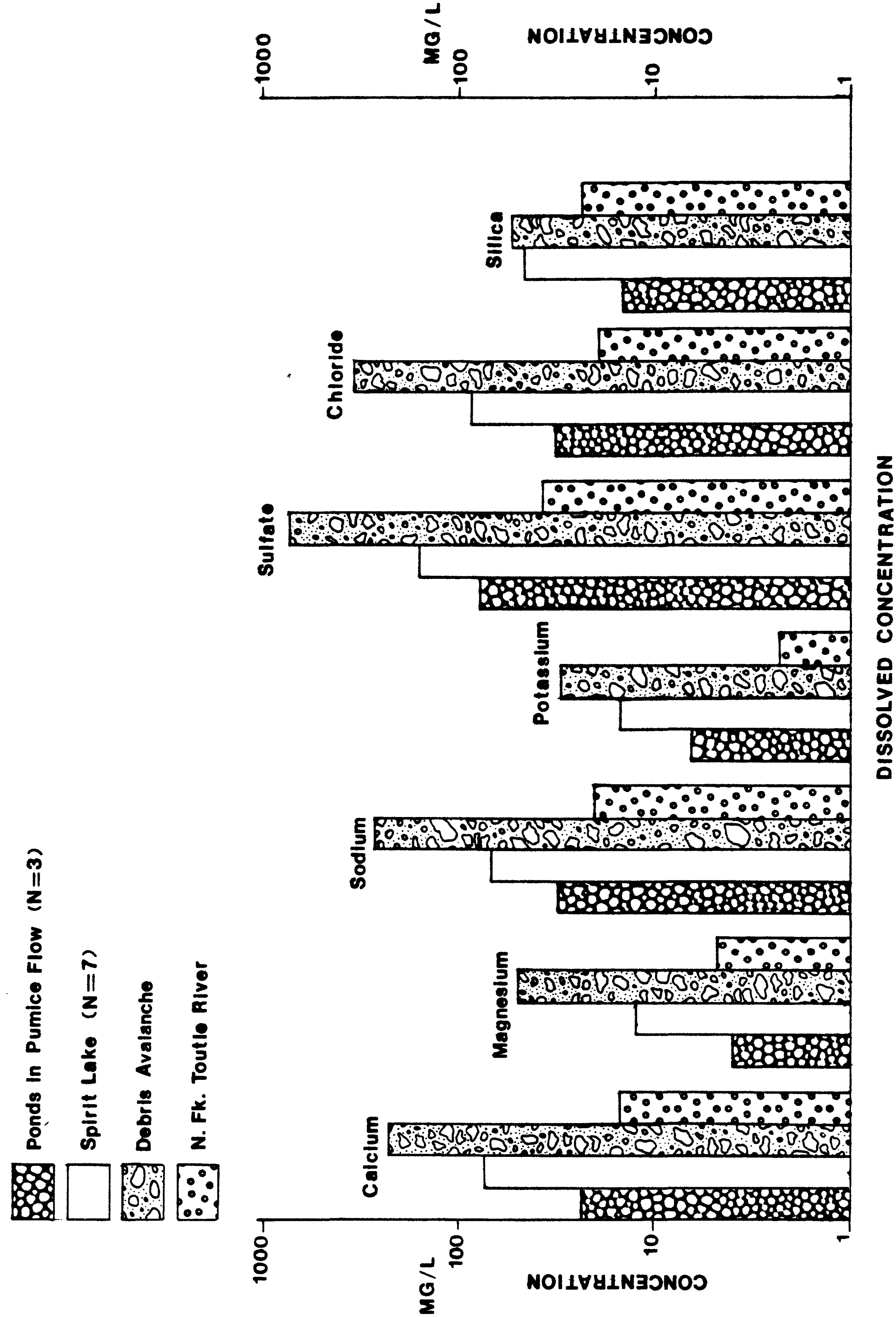


Figure 4.--Comparison of major-ion concentration in waters from pumice flows, Spirit Lake, the debris-avalanche deposit, and the N. Fk. Toutle River in early June 1980.

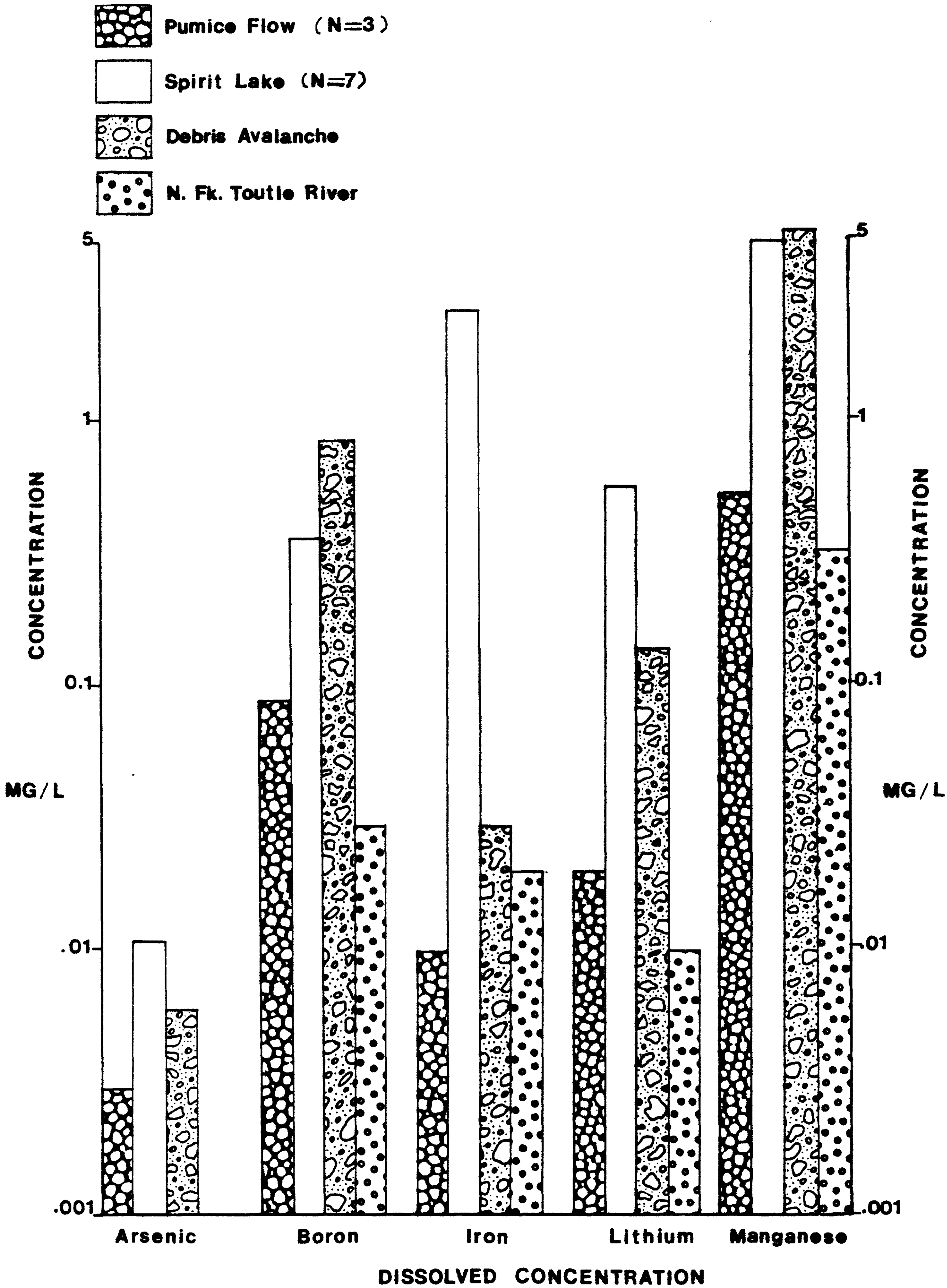


Figure 5.--Comparison of trace-element concentrations in waters from pumice flows, Spirit Lake, the debris-avalanche deposit, and the N.Fk. Toutle River in early June 1980.

APPENDIX 1

Water and sediment-sample locations, Mount St. Helens area, Washington

Sample	Location	Associated Deposits	Latitude	Longitude	Time	Date	Suspended Sediment g/L	Field Measurements: Temperature °C	Field Measurements: pH	Field Measurements: Specific Conductance μmho/cm
SHW-1	N. Fork Toutle River	Debris Avalanche/ Mudflow	46°18'30"	122°26'15"	1115	6/7/80	1.50	12.0	7.1	205
SHW-2	Thermal Pond	Debris Avalanche	46°16'45"	122°20'00"	1145	6/7/80	0.13	22.0	7.1	2500
SHW-3	N. Fork Toutle River	Debris Avalanche	46°16'45"	122°20'00"	1150	6/7/80	0.05	12.5	6.9	135
SHW-4	Thermal Pond	Pyroclastic Flow	46°15'30"	122°13'15"	1730	6/7/80	0.26	24.0	6.9	380
SHW-5	Thermal Pond	Pyroclastic Flow	46°15'30"	122°13'15"	1735	6/7/80	0.65	21.0	7.3	380
SHW-6	Thermal Pond	Blast	46°14'30"	122°14'00"	1800	6/7/80	0.46	20.0	6.4	1180
SHW-7	Tributary to St. Arm of Spirit Lake	Pyroclastic Flow	46°14'15"	122°09'45"	1840	6/7/80	0.05	7.5	6.6	125
SHW-8	Spirit Lake SE Arm	Pyroclastic Flow/Organic Material	46°15'30"	122°09'15"	1230	6/8/80	0.15	25.5	6.0	825
SHW-9	Spirit Lake SE Arm	Pyroclastic Flow/Organic Material	46°15'15"	122°09'00"	1300	6/8/80	1.70	26.0	6.0	825
SHW-10	Spirit Lake SE Arm	Pyroclastic Flow/Organic Material	46°15'30"	122°09'15"	1320	6/8/80	0.52	26.0	6.0	830
SHW-11	Spirit Lake NE Arm	Blast/ Organic Material	46°17'15"	122°08'00"	1400	6/8/80	0.04	27.0	6.0	840
SHW-12	Spirit Lake NE Arm	Blast/ Organic Material	46°17'15"	122°07'45"	1420	6/8/80	0.15	26.5	6.0	845
SHW-13	Spirit Lake NW Arm	Debris Avalanche/ Blast/ Organic Material	46°17'15"	122°09'30"	1600	6/8/80	0.90	26.5	5.9	825
SHW-14	Thermal Pond	Pyroclastic Flow	46°15'45"	122°10'45"	1700	6/8/80	14.00	24.0	7.1	280
SHW-15	Thermal Pond	Debris Avalanche	46°15'45"	122°14'30"	1745	6/8/80	0.16	23.5	6.9	380
SHW-16	Thermal Pond	Debris Avalanche	46°15'45"	122°14'30"	1830	6/8/80	0.67	23.0	6.7	210
SHW-17	Stream on Mt. Margaret	Blast	46°19'00"	122°08'12"	1630	5/31/80	1.20	1.5	5.7	21
SHW-18	Stream on Mt. Margaret	Blast	46°19'00"	122°08'12"	1700	5/31/80	3.40	0.5	5.5	260

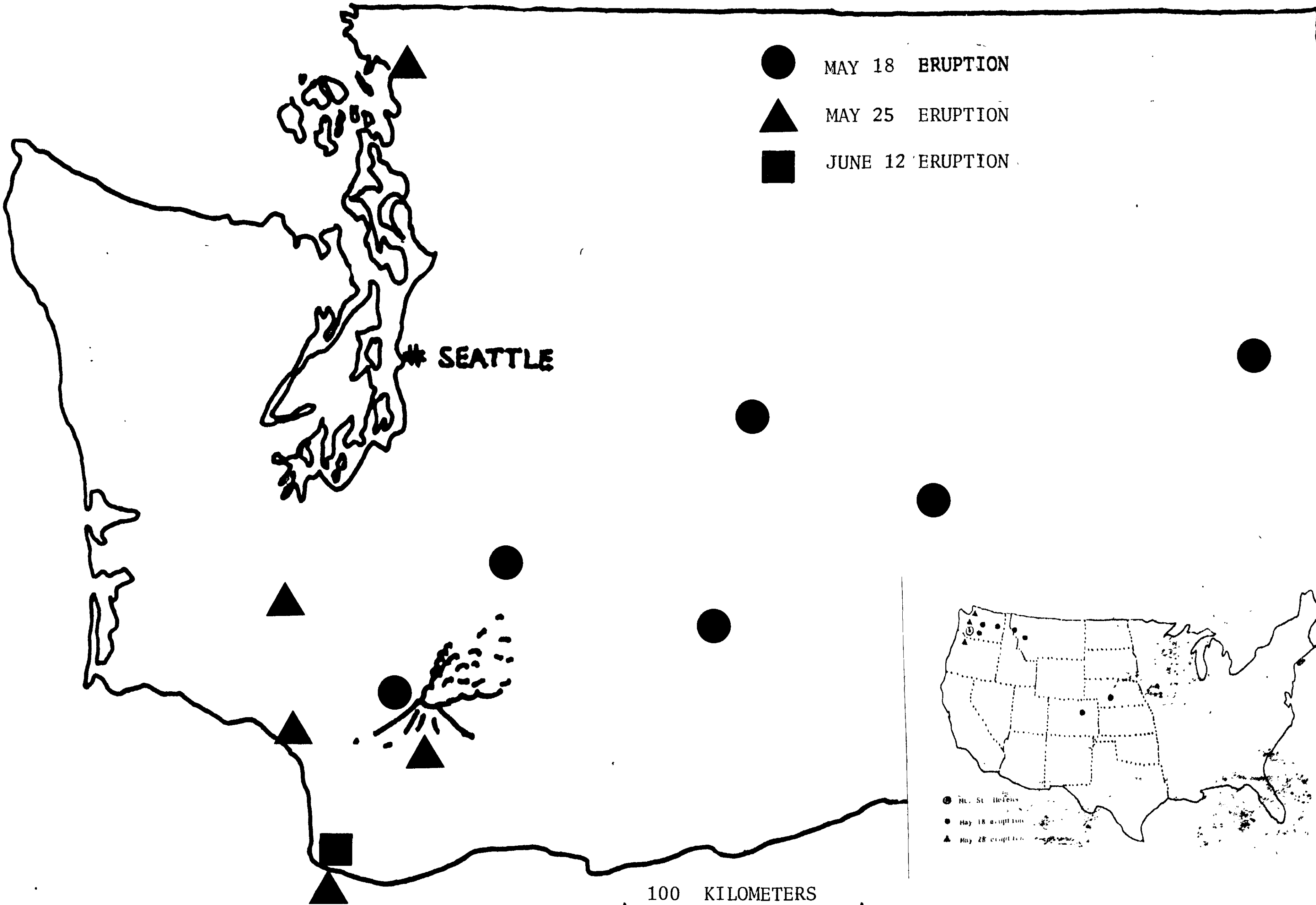
Sample	Location	Associated Deposits	Latitude	Longitude	Time	Date	Suspended Sediment g/L	Field Measurements: Temperature °C	Field Measurements: pH	Field Measurements: Specific Conductance µmho/cm
CWL-1[1]	Coldwater II Lake	Blast/ Debris Avalanche	46°18'15"	122°14'15"	1345	6/5/80	-	10.0	5.9[2]	640
FL-1[1]	Fawn Lake	Blast	46°19'30"	122°15'15"	1400	6/5/80	-	5.0	6.6[2]	640
LSH-1[1]	Lake St. Helens	Blast	46°18'00"	122°10'15"	1425	6/5/80	-	5.0	6.3[2]	155
SL-1[1]	Spirit Lake South Island	Pyroclastic Flow/Debris Avalanche	46°16'00"	122°09'00"	1430	6/5/80	-	28.0	6.2[2]	850
SL-0	Spirit Lake	pre-eruption	46°15'47"	122°09'46"	1600	3/28/80	-	2.6	7.1	30
NF TOUTLE-0	North Fork Toutle R.	pre-eruption	46°16'42"	122°21'18"	1730	3/28/80	-	5.2	7.7	77
SHW-GB	Near Castle Creek	Debris Avalanche	46°16'15"	122°18'00"	1215	6/7/80	-	-	-	-
SHW-CW-1,2	2 km south of Coldwater Ridge	Debris Avalanche	46°15'45"	122°13'15"	1430	6/7/80	-	-	-	-
SHW-CW2-1,2	Coldwater Ridge	Blast	46°16'30"	122°13'15"	1300	6/7/80	-	-	-	-
SHW-SL-1	Spirit Lake SE Arm	Pyroclastic Flow	46°15'30"	122°09'15"	1300	6/8/80	-	-	-	-

1/ Collected by T. Casadevall, U.S. Geological Survey

2/ pH measured in lab after return from field

APPENDIX 2

Location of air-fall tephra collection sites



APPENDIX 3

Mineralogy of samples collected in early June, 1980 near Mount St. Helens

ST. HELENS SAMPLES (<2μm)

Sample #	Plag.	Amph.	Pyrox.	Mica	Crist.	Trid.	Qtz.	Smect.	ML Ch/Sm.	Chlor.	Other
SHW-1-W	M				t?			M	m	t	
SHW-1-YW	m				t?			M	t	t	
SHW-2-W	M				t?			M	t		
SHW-2-D	m				t?			M	m	t	
SHW-4-W	M			t	t?			M	t	m	
SHW-4-D	M			t	t?			M	t		
SHW-5-W	M				t?			M	t	t	
SHW-5-D	M				t			M	t		
SHW-6-W	M				t?			M	t		
SHW-6-D	M				t?			M	t		
SHW-7-W	M			?	m			M	m	t	
SHW-7-D	M				m			M	m		
SHW-8-W	m				t			M	m		
SHW-8-D	m			t	t			M	t		
SHW-9-W	m				t			M	t		
SHW-9-D	m			?	t			M	t		
SHW-10-W	m				t			M	t	t	
SHW-10-D	m			t	t			M	t		
SHW-11-W	m				t			M	t		
SHW-11-D	m				t			M	t		
SHW-12-W	m				t			M	t		
SHW-12-D	m				t			M	t		
SHW-13-W	M			?	m			M	m	t	
SHW-13-D	m			?	t			M	t		
SHW-14-W	m				t			M	t	m	

ST. HELENS SAMPLES (<2μm)

Sample #	Plag.	Amph.	Pyrox.	Mica	Crist.	Trid.	Qtz.	Smect.	ML Ch/Sm.	Chlor.	Other
SHW-14-D	m			t	t	?		M	t		
SHW-15-W	m			t	t			M	t	?	
SHW-15-D	m			t	t			M	t	t	
SHW-16-W	m			t	t			M	m	t	
SHW-16-D	m				t			M		t	
SHW-1-F	M			t?	t?			M	t	t	
SHW-2-F	M							M	m		
SHW-3-F	M				t			M	m		
SHW-4-F	m	t			t			M	t		
SHW-5-F	m				t?			M	t		
SHW-6-F	m			t?	t			M	m		
SHW-7-F			NO SAMPLE								
SHW-8-F			NOT ENOUGH SAMPLE								
SHW-9-F	M				t			M	m		
SHW-10-F	M				t			M	t		
SHW-11-F	M				t			M	t		
SHW-12-F	M				t			M	t		
SHW-13-F	M			t	m			M	m		
SHW-14-F	m				t			M	m		
SHW-15-F	m			t	t			M	t		
SHW-16-F			NOT ENOUGH SAMPLE								

ST. HELENS SAMPLES—<2μm Misc.

Sample #	Plag.	Amph.	Pyrox.	Mica	Crist.	Trid.	Qtz.	Smect.	ML Ch/Sm.	Chlor.	Other
SHW-7-Y	m							DIOCT? M	t		HEM.
SHW-7-Z	m				?			M	m		GYP.
SHW-14-DX	m				m			M	t		
SHW-16-DX	m			t	?			M	t		
SHW-7-R-1	t							M			HEM.
SHW-7-R-2	M				?					GLASS	
SHW-1-X-W			amorphous?								
SHW-GB	M				t			M	m		
SHW-CW-1B	M				m	t		M	t		
SHW-CW-1	M				M			m			
SHW-CW-2	m				m		M	m	?		GYP.
SHW-CW2-2	m			t				M	t		
SHW-CW2-1	m				t?			M			
SHW-SL-1	m			t?				M	t		

ST. HELENS SAMPLES—Random Bulk Samples

Sample #	Plag.	Amph.	Pyrox.	Mica	Crist.	Trid.	Qtz.	Smect.	ML Ch/Sm.	Chlor.	Other
SHW-4-W	M				m	m	M				
SHW-7-D	M										
SHW-7-Y	M		t								
SHW-7-R-1	M										HEM.
SHW-7-R-2	M	t	m								
SHW-CW2-2	M	t					M				
SHW-SL-1	M				t			M			
SHW-14-W	M										
SHW-CW-2	M						M				
SHW-CW-1	M				m						
SHW-CW-1B	M				m	t					
SHW-CW-2	m										GYP. SUL.?

M=major; m=minor; t=trace
W=wet sample collected from thermal pond or stream
D=dry sample collected near thermal pond or stream
F=suspended sediment sample collected on 0.45 μm filter paper
Plag.=plagioclase, Amph.=amphibole, Pyrox.=pyroxene, Mica=mica, Crist.=cristobalite, Trid.=tridymite, Qtz.=quartz, Smect.=trioctahedral smectite, ML Ch/Sm.=mixed layer chlorite/smectite, Chlor.=chlorite, HEM.=hematite, GYP.=gypsum SUL.=sulfur

APPENDIX 4

Chemical analyses for water samples collected at Mount St. Helens in early June, 1980

	SHW-1	SHW-2	SHW-3	SHW-4	SHW-5	SHW-6	SHW-7	SHW-8	SHW-9	SHW-10	SHW-11	SHW-12	SHW-13	SHW-14	SHW-15	SHW-16	SHW-17	SHW-18	SL-1	LSH-1	CWL-1	FL-1	SL-0	NF TOUTLE-0
ACIDITY AS H MG/L	0.3	0.7	0.1	0.3	0.2	0.5	0.1	1.6	1.5	1.4	1.5	1.7	1.6	0.2	0.1	0.2	0.1	0.4	----	---	---	---	0.1	0.1
ACIDITY TOT AS $CACO_3$ MG/L	15	35	5	15	10	25	5	79	74	70	74	84	79	10	5	10	5	20	----	---	---	---	5	5
ALK, TOT ($CACO_3$) MG/L	33	140	8	26	25	15	18	120	120	120	130	120	130	21	29	6	0	16	----	---	---	---	8	21
ALUMINUM, DISS μG/L	40	10	20	10	30	30	60	80	40	0	90	90	60	30	70	50	40	100	----	---	---	---	10	20
ALUMINUM, SUSP μG/L	870	240	850	90	880	70	690	520	870	100	10	10	40	880	750	860	390	810	----	---	---	---	190	180
ALUMINUM, TOT μG/L	910	250	870	100	910	100	750	600	910	100	100	100	100	910	820	910	430	910	----	---	---	---	200	200
ARSENIC, DISS μG/L	1	6	1	1	1	4	1	11	12	12	11	11	12	1	9	4	1	1	11	1	3	1	0	1
ARSENIC, SUSP μG/L	9	6	0	1	1	1	0	1	0	0	0	0	0	16	1	7	1	2	----	---	---	---	1	1
ARSENIC, TOT μG/L	10	12	1	2	2	5	1	12	11	12	10	11	11	17	10	11	2	3	----	---	---	---	1	2
BARIUM, SUSP μG/L	90	100	0	0	0	50	0	0	50	50	50	50	50	500	0	0	0	80	----	---	---	---	0	90
BARIUM, TOT μG/L	100	200	0	0	0	100	0	0	100	100	100	100	100	500	0	0	0	100	----	---	---	---	0	100
BARIUM, DISS μG/L	6	100	7	20	20	50	6	50	50	50	50	50	50	10	20	9	4	20	50	8	30	30	10	10
BORON, DISS μG/L	30	870	30	90	90	270	3	480	310	380	410	300	330	30	120	140	0	7	----	---	---	---	0	40
BORON, SUSP μG/L	90	80	10	0	40	170	30	0	0	0	0	20	0	120	70	0	7	80	----	---	---	---	70	70
BORON, TOT μG/L	120	950	40	90	130	440	30	270	300	270	270	320	270	150	190	100	7	90	----	---	---	---	70	110
CALCIUM, DISS MG/L	15	229	11	30	31	71	6.7	73	74	74	75	75	72	22	22	12	1.6	22	73	13	56	63	2.8	5.1
CHLORIDE, DISS MG/L	19	340	17	39	40	150	11	85	86	86	87	87	86	19	40	24	2.0	30	----	---	---	---	1.5	5.9
COBALT, TOT μG/L	21	4	1	4	8	7	2	1	3	3	1	2	3	100	3	9	4	27	----	---	---	---	4	1
COPPER, TOT μG/L	260	25	8	22	40	20	8	8	29	24	9	11	13	880	15	83	13	67	----	---	---	---	9	10
FLUORIDE, DISS MG/L	0.2	0.7	0.2	0.3	0.3	0.7	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.4	0.5	0.0	0.1	----	---	---	---	0.1	0.2
HARDNESS, NON CARB MG/L	24	640	28	66	69	210	1	110	110	110	110	120	100	46	52	36	6	51	----	---	---	---	1	0
HARDNESS, TOT MG/L	57	780	36	92	94	230	19	230	230	230	240	240	230	67	81	42	6	67	230	38	170	180	9	19
IRON, SUSP μG/L	42,000	70	760	6,100	15,000	5,000	290	3,600	12,000	7,900	3,600	8,400	4,400	230,000	1,100	14,000	2,100	4,400	----	---	---	---	60	140
IRON, TOT μG/L	42,000	100	780	6,100	15,000	5,100	290	4,900	14,000	10,000	7,100	12,000	8,000	230,000	1,100	14,000	2,100	4,700	----	---	---	---	70	170
IRON, DISS μG/L	20	31	16	<10	<10	110	<10	1,300	2,100	2,100	3,500	3,600	3,600	<10	<10	<10	22	290	6,200	49	250	10	<10	30
LEAD, SUSP μG/L	20	10	~7	0	5	0	2	6	6	0	0	4	0	19	5	0	8	3	----	---	---	---	19	3
LEAD, TOT μG/L	20	74	7	4	5	4	13	6	6	6	10	4	6	44	5	7	8	15	----	---	---	---	19	3
LEAD, DISS μG/L	0	64	<10	13	0	15	11	0	0	18	26	0	110	25	0	24	0	12	96	30	16	34	0	0
LITHIUM, SUSP μG/L	50	0	~10	10	10	20	6	4	10	4	10	10	0	180	2	10	0	20	----	---	---	---	0	0
LITHIUM, TOT μG/L	60	130	10	30	30	180	20	60	70	60	70	70	60	190	30	30	0	40	----	---	---	---	0	10
LITHIUM, DISS μG/L	11	140	<4	17	18	160	14	56	56	56	59	58	63	12	28	18	<4	16	67	18	55	80	<4	10
MAGNESIUM, DISS MG/L	4.8	51	2.1	4.1	4.1	12	0.54	12	12	12	13	13	12	2.8	6.3	2.8	0.36	3.0	12	1.4	7.7	5.7	0.6	1.6
MANGANESE, SUSP μG/L	670	0	20	130	370	100	7	0	300	300	100	100	0	6,300	30	320	20	650	----	---	---	---	10	10
MANGANESE, TOT μG/L	1,000	5,400	130	750	1,000	2,800	30	4,700	5,200	5,200	5,100	5,100	4,700	6,600	720	740	40	1,100	----	---	---	---	20	20
MANGANESE, DISS μG/L	330	5,400	110	620	630	2,700	23	4,800	4,900	4,900	5,000	5,000	4,800	340	690	420	17	450	4,800	320	1,800	1,100	6	7
MERCURY, SUSP μG/L	0.2	0.1	0	0	0	0	0	0.1	0.1	0	0.1	0	0	0	0	0.1	0	0	----	---	---	---	0.1	0.1
MERCURY, TOT μG/L	0.2	0.1	0	0	0	0	0	0.1	0.1	0	0.1	0	0	0	0	0.1	0	0	----	---	---	---	0.1	0.1
MOLYBDENUM, DISS μG/L	<10	29	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	13	<10	46	19	<10	<10	<10	<10	<10	<10	----	----
NICKEL, DISS μG/L	2	5	0	5	0	10	2	3	0	0	0	0	0	0	0	1	0	9	----	---	---	---	4	3
NICKEL, SUSP μG/L	37	21	7	5	16	8	10	1	8	10	7	9	7	120	6	17	20	80	----	---	---	---	0	6
NICKEL, TOT μG/L	39	26	7	10	16	18	12	4	8	10	7	9	7	120	6	18	20	89	----	---	---	---	1	8

	SHW-1	SHW-2	SHW-3	SHW-4	SHW-5	SHW-6	SHW-7	SHW-8	SHW-9	SHW-10	SHW-11	SHW-12	SHW-13	SHW-14	SHW-15	SHW-16	SHW-17	SHW-18	SL-1	LSH-1	CWL-1	FL-1	SL-0	NF TOUTLE-0
NITR, DISS NO_2+NO_3-N MG/L	0.07	0.00	0.12	0.00	0.00	0.01	0.05	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.02	0.03	0.03	0.00	0.02	0.07	0.02	0.08	0.06	0.04
NITR, DISS NH_4 AS N MG/L	0.01	0.04	0.03	0.01	0.00	0.06	0.04	0.06	0.04	0.04	0.07	0.10	0.03	0.01	0.01	0.01	0.01	0.00	0.03	0.34	0.03	0.59	0.12	0.01
NITR, DISS NH_4+ORG-N MG/L	0.20	0.69	0.19	1.1	0.29	0.89	0.35	0.63	0.53	0.77	0.61	0.83	0.51	0.16	2.7	0.93	0.18	0.21	0.92	0.98	0.79	1.3	0.71	0.51
NITR, DISS ORG AS N MG/L	0.19	0.65	0.16	1.1	0.29	0.83	0.31	0.57	0.49	0.73	0.54	0.73	0.48	0.15	2.7	0.92	0.17	0.21	0.89	0.64	0.76	0.71	0.59	0.50
NITR, DISS AS N MG/L	0.27	0.69	0.31	1.1	0.29	0.90	0.40	0.64	0.54	0.77	0.62	0.83	0.51	0.17	2.7	0.96	0.21	0.21	0.94	1.1	0.81	1.4	0.77	0.55
NITR, DISS NH_4 AS NH_4 MG/L	0.01	0.05	0.04	0.01	0.00	0.08	0.05	0.08	0.05	0.05	0.04	0.13	0.04	0.01	0.01	0.01	0.01	0.00	0.04	0.44	0.04	0.76	0.15	0.01
PH FIELD	7.1	7.1	6.9	6.9	7.3	6.4	6.6	6.0	6.0	6.0	6.0	6.0	5.9	7.1	6.9	6.7	5.7	5.5	6.2	6.3	5.9	6.6	7.1	7.7
PH LAB	7.4	7.5	7.3	7.1	7.2	6.3	7.2	6.4	6.5	6.5	6.5	6.5	6.5	7.0	7.4	6.9	6.3	6.1	----	---	---	---	6.9	7.4
PHOS, DISS(TOT) AS P MG/L	0.01	0.02	0.01	0.01	0.01	0.02	0.06	0.31	0.32	0.32	0.30	0.31	0.30	0.03	0.04	0.02	0.01	0.01	0.88	1.2	1.9	1.3	0.02	0.04
PHOS, TOT(TOT) AS P MG/L	3.9	0.12	0.05	0.18	0.57	0.61	0.06	0.25	0.56	0.40	0.28	0.31	0.31	9.0	0.09	0.58	0.05	3.0	----	---	---	---	0.03	0.04
PHOS, TOT(TOT) -PO_4 MG/L	12	0.37	0.15	0.55	1.7	1.9	0.18	0.77	1.7	1.2	0.86	0.95	0.95	28	0.28	1.8	0.15	9.2	----	---	---	---	0.09	0.12
POTASSIUM, DISS MG/L	2.3	31	1.7	6.9	6.7	24	2.0	15	15	15	15	15	15	4.1	8.4	6.3	0.3	3.4	----	---	---	---	0.6	0.8
POTASSIUM 40, D PCI/L	1.7	23	1.3	5.1	5.0	18	1.5	11	11	11	11	11	11	3.1	6.3	4.7	0.2	2.5	----	---	---	---	0.4	0.6
RESIDUE, DISS 180°C MG/L	145	1890	82	253	258	804	86	607	585	606	613	608	610	178	238	127	19	161	----	---	---	---	33	59
SILICA, DISS MG/L	23	53	8.6	16	14	17	21	46	45	46	46	46	47	12	21	8.8	6.7	6.8	47	7.4	14	12	12	22
SODIUM, DISS MG/L	20	270	9.7	40	40	140	16	67	66	68	71	68	69	23	34	18	1.3	19	70	8.5	45	44	2.0	6.4
SP. CONDUCTANCE, FIELD	205	2500	135	380	380	1180	125	825	825	830	840	845	825	280	380	210	21	260	850	155	640	640	30	77
SP. CONDUCTANCE, LAB	220	2606	142	406	412	1194	126	837	829	828	836	834	824	283	383	215	21	264	----	---	---	---	31	75
STRONTIUM, DISS µG/L	71	1000	47	130	140	330	29	320	320	320	320	320	320	100	120	64	10	100	320	57	250	250	----	----
SULFATE, DISS MG/L	37	730	27	88	94	320	23	150	160	160	170	160	160	76	81	49	2.2	58	----	---	---	---	0	0.5
WATER TEMP (DEG C)	12	22.0	12.5	24.0	21.0	20.0	7.5	25.5	26.0	26.0	27.0	26.5	26.5	24.0	23.5	23.0	1.5	0.5	28.0	5.0	10.0	5.0	2.6	5.2
ZINC, TOT µG/L	90	30	30	50	30	20	120	100	40	30	30	40	20	600	10	90	10	130	----	---	---	---	40	40
ZINC, DISS µG/L	<3	<3	<3	<3	<3	12	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	7	8	44	20	30	10