GEOLOGIC MAP OF THE SPIRIT LAKE WEST QUADRANGLE, SKAMANIA AND COWLITZ COUNTIES, WASHINGTON

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INTRODUCTION

The Spirit Lake West quadrangle is located on the western slope of the Cascade Range in southern Washington about 15 km north of Mount St. Helens. Bedrock consists of Oligocene volcanic and volcaniclastic rocks and Oligocene to early Miocene shallow-level plutonic rocks forming the core of the Tertiary Cascade volcanic arc. Surficial deposits include drift representing at least two episodes of alpine glaciation as well as eruptive products of Mount St. Helens volcano (Mullineaux and Crandell, 1981; Mullineaux, 1986; Crandell, 1987).

Repeated glacial advances during the Pleistocene sculpted the area into a terrain of considerable relief, but bedrock exposures are generally restricted to outcrops in high-gradient streams due to the extensive and heavily vegetated surficial cover. Nearly all of the quadrangle is within the area of devastation resulting from the May 18, 1980, eruption of Mount St. Helens (Lipman and Mullineaux, 1981). A laterally directed pyroclastic blast-surge leveled old-growth forest in this area and buried the countryside under a stratigraphically complex blanket, as thick as 1 m, of ash, lapilli, and blocks (Hoblitt and others, 1981; Moore and Sisson, 1981; Waitt, 1981; Fisher and others, 1987). Subsequent erosion and salvage logging of the denuded slopes, however, has stripped much of this cover as well as older surficial materials. Surficial deposits were entirely removed from slopes above Spirit Lake and along the North Fork Toutle River and South Coldwater Creek by passage of the rockslide-debris avalanche on the morning of May 18 (Voight and others, 1981; Fisher and others, 1987). As a result, exposures of Tertiary bedrock in the Spirit Lake West quadrangle and adjoining areas (Evarts and Ashley, 1993a) are unsurpassed in the western Cascade Range. This area thus provides an exceptional opportunity to examine stratigraphic and structural details of the Tertiary volcanic arc.

ACKNOWLEDGMENTS

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SUMMARY OF GEOLOGY

The strata exposed in the Spirit Lake West quadrangle are part of a thick section of middle Tertiary subaerial volcanic rocks that underlies the Mount St. Helens area (Evarts and others, 1987). This section strikes approximately north-south and dips eastward at low to moderate angles, forming the gentle western limb of a major syncline whose axis lies about 15 km to the east in the French Butte quadrangle (Walsh and others, 1987; Swanson, 1989). The strata are lithologically heterogeneous and stratigraphically complex. Distinctive marker units are absent, and although unconformities have been recognized, their regional significance is unknown; therefore, construction of a formal stratigraphic framework was not attempted, and only lithologic and local informal units are shown on this map. Isotopic age determinations are the most useful data for regional correlations. The age data from this and adjacent areas (table 1; Evarts and others, in press) indicate that the volcanic rocks in the quadrangle erupted between about 36 and 27 Ma. Magmatic activity manifested as the epizonal Spirit Lake pluton continued until about 20 Ma. A $^{40}Ar/^{39}Ar$ laser-fusion age for a dike cutting the pluton suggests very minor activity as young as about 9 Ma (table 1).

Many rocks of the quadrangle appear to represent near-source depositional environments characterized by abundant lava flows, pumiceous pyroclastic rocks, coarse-grained epiclastic deposits, fine-grained subvolcanic intrusions, and zones of hydrothermal alteration (Cas and Wright, 1987; Smith, 1993). Stacks of lava flows such as those exposed near Coldwater Lake, for example, may represent cross sections through the flanks of mafic shield volcanoes. The concentration of andesitic and basaltic dikes, plugs, and hydrothermally altered areas at the western end of Johnston Ridge possibly includes one or more exhumed subvolcanic vent zones that may have fed overlying lava flows. This area of preferentially east-west-trending dikes appears to be the eastern margin of a large early Oligocene basaltic andesite volcano centered on a plutonic complex at Spud Mountain (Evarts and Ashley, 1990). Phaneritic intrusive rocks such as those that make up the sill complex on Windy Ridge (Twr) may well exemplify deeper zones of volcanic plumbing systems, though whether they actually vented to the surface is unknown. Laterally continuous sections such as that extending from The Dome to Spirit Lake, however, were more likely deposited on dispersal aprons low on the flanks of volcanoes or in intervolcanic lowlands.

Chemical analyses (table 2) demonstrate that low-potassium subalkaline basalt (less than 52 weight percent SiO_2) and basaltic andesite (between 52 and 57 weight percent SiO_2) dominate the section (fig. 1). Dacite and rhyolite (greater than 63 weight percent SiO_2), although abundant among stratigraphically higher rocks to the east (Evarts and Ashley, 1993a), are rare in the Spirit Lake West quadrangle. More than half of the samples are

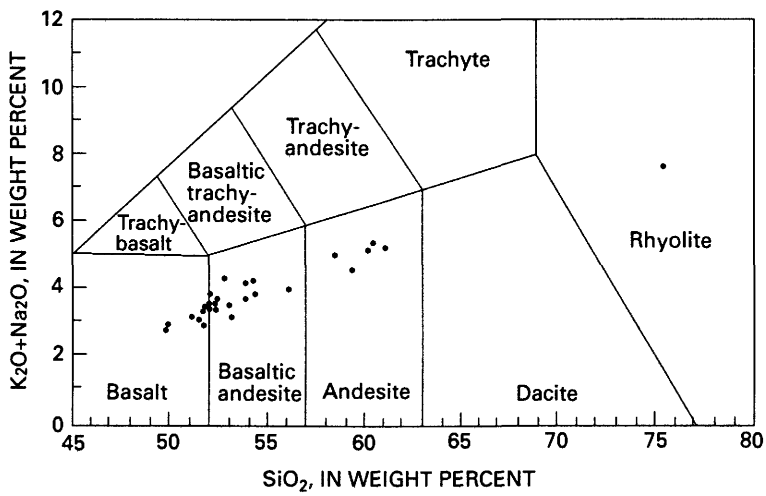

Figure 1. Na_2O+K_2O versus SiO_2 (recalculated volatile-free) for volcanic and hypabyssal intrusive rocks from Spirit Lake West quadrangle showing classification according to International Union of Geological Sciences (LeBas and Streckeisen, 1991).

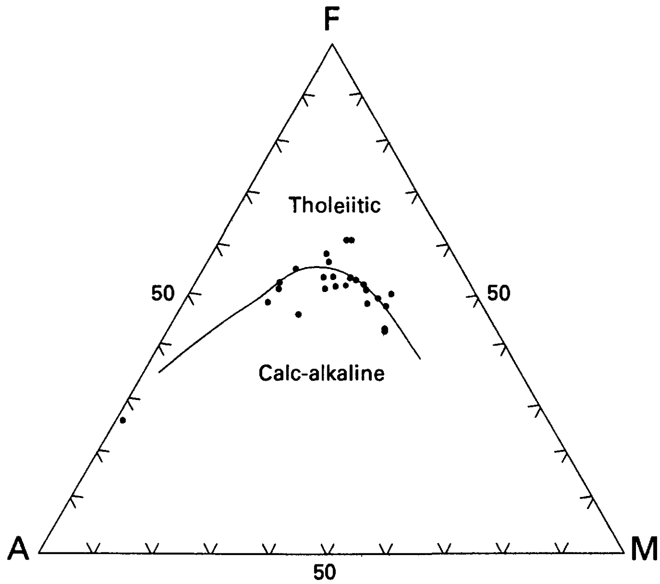

Figure 2. AFM diagram for volcanic and hypabyssal intrusive rocks from Spirit Lake West quadrangle (A, Na_2O+K_2O; F, $FeO+Fe_2O_3+MnO$; M, MgO). Line separating tholeiitic and calc-alkaline rocks from Irvine and Baragar (1971).

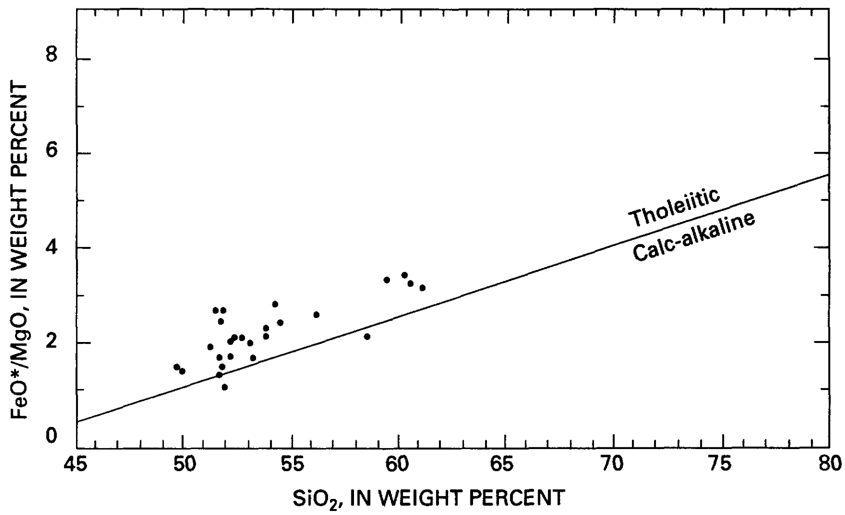

Figure 3. FeO*/MgO versus SiO_2 (recalculated volatile-free) for volcanic hypabyssal intrusive rocks from Spirit Lake West quadrangle showing classification into tholeiitic and calc-alkaline rocks according to Miyashiro (1974). FeO*, total Fe and FeO.

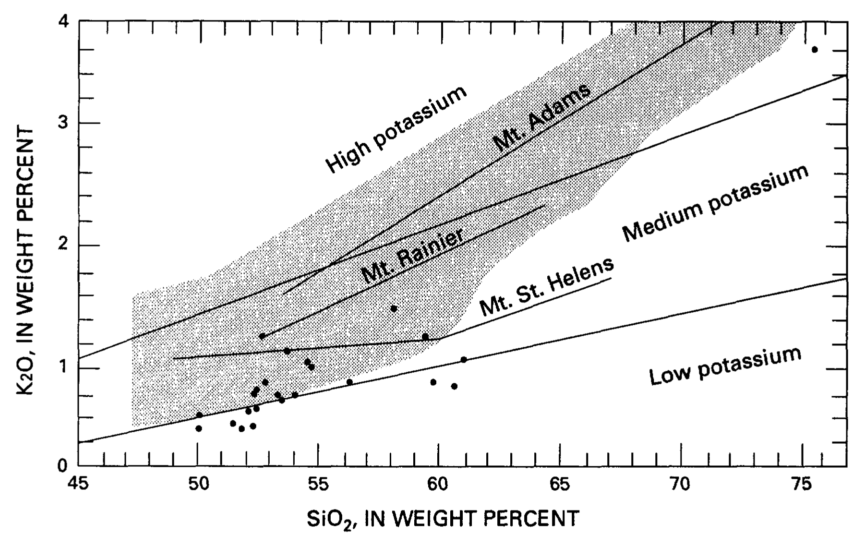

Figure 4. K_2O versus SiO_2 (recalculated volatile-free) for volcanic and hypabyssal intrusive rocks from Spirit Lake West quadrangle [dots}. Low-, medium-, and high-potassium fields from Gill (1981, p. 6). Shaded area encompasses compositions of Quaternary volcanic rocks, exclusive of major stratovolcanoes, of southern Washington Cascade Range from Hammond and Korosec (1938). Trendlines shown for Quaternary stratovolcanoes Mount Ranier, Mount St. Helens, and Mount Adams based on data in Condie and Swenson (1973), Hildreth and Fierstein (1985), and Smith and Leeman (1987).

classified as calc-alkaline on the AFM plot (fig. 2) of Irvine and Baragar (1971) whereas most are tholeiitic according to the FeO*/MgO vs. SiO_2 plot (fig. 3) of Miyashiro (1974). The Tertiary rocks tend to be lower in K_2O than Quaternary volcanic rocks of equivalent SiO_2 contents in southern Washington (fig. 4).

A general westward coarsening of textures in the Spirit Lake pluton (informal name) suggests that it has been tilted to the east along with its host rocks, so folding of the Tertiary section must postdate 21 Ma, the crystallization age of the pluton (table 1). The age of folding is otherwise poorly constrained, and deformation may have taken place over an extended period (Evarts and others, 1987).

Faults and shear zones are common in the Johnston Ridge-South Coldwater Creek area but scarce elsewhere. All are subvertical, and apparent offsets typically are minor, only rarely exceeding 10 m. Generally, rocks on both sides of faults are the same, and the sense of offset cannot be determined, but local slickensides record both strike-slip and dip-slip movements. Most faults are flanked by white to orange zones of hydrothermally altered rock, and some faults are occupied or crossed by Tertiary dikes. Therefore, many faults are probably relatively old and represent local small-scale adjustments to movements of magma within Tertiary volcanic centers. Although fault orientations vary considerably, north to north-northeast trends are most common, possibly reflecting the influence of regional tectonic forces (Evarts and others, 1987).

The most seismically active area in Washington, the St. Helens seismic zone (SHZ) of Weaver and Smith (1983), trends north-northwest through the western part of the quadrangle (see sketch map). The greatest concentration of earthquakes in this zone occurs about 16 km beneath the Elk Lake area north of Coldwater Creek (Grant and others, 1984). Many mapped faults in this zone approximate the north-south, vertical orientation of fault planes inferred from earthquake focal mechanisms to be responsible for the SHZ (Weaver and others, 1987), but none show evidence of recent movement.

SPIRIT LAKE PLUTON

The Spirit Lake pluton is one of several large, epizonal, multiphase, granitic intrusions of Miocene age in the Washington Cascade Range (Fiske and others, 1963; Tabor and Crowder, 1969; Hammond, 1979; Evarts and others, 1987). The pluton underlies an area of about 120 km^2, most of which lies outside the Spirit Lake West quadrangle to the north and east; only the southwestern quarter of the intrusion is shown on this map. Contacts with country rock are sharp and steep, truncating volcanic stratigraphy at high angles. The granitic rocks exposed in this quadrangle are generally coarser grained and more uniform in texture than those in outcrops to the east. This relationship suggests that the body has been tilted to the east along with its host rocks, so that outcrops in this quadrangle represent the deepest exposed levels in the intrusion.

The pluton consists of three phases that have yielded radiometric ages between 20 and 23 Ma. Contacts between phases range from sharp to gradational and are commonly obscured by intense deuteric alteration. Virtually all of the pluton in this quadrangle belongs to the main phase (**Tsm**), a texturally and compositionally heterogeneous unit of predominantly granodiorite. Field relations and K-Ar ages indicate that the quartz-diorite phase (**Tsqd**), which crops out chiefly in the Vanson Peak and Cowlitz Falls quadrangles to the north and northeast (Evarts and Ashley, 1993b, c), is older, and the granite phase (**Tsgr**), which was emplaced chiefly near the top of the intrusion in the Spirit Lake East and Cowlitz Falls quadrangles to the east and northeast (Evarts and Ashley, 1993a, b), is slightly younger than the main phase.

Small phaneritic intrusions of dioritic to granodioritic composition are widely scattered throughout the quadrangle. Similar rocks are more abundant to the east in the Spirit Lake East quadrangle (Evarts and Ashley, 1993a). Only the sill complex of Windy Ridge (24.3 ±1.3 Ma) has been dated by isotopic techniques. However, because intrusions within the contact metamorphic aureole of the Spirit Lake pluton are recrystallized, all of these satellitic bodies are inferred to be older than the pluton.

METAMORPHISM

Tertiary volcanic and intrusive rocks throughout the southern Washington Cascade Range have been overprinted by zeolite-facies burial metamorphism (Fiske and others, 1963; Wise, 1970; Hammond, 1980). Volcanic glass is nearly everywhere replaced by iron-bearing smectites that give the rocks their characteristic green colors. Olivine phenocrysts are generally replaced by clots of limonite+smectite, microcrystalline quartz, and (or) carbonate. Orthopyroxene is commonly converted to smectite+titanite, but clinopyroxene remains fresh. Recrystallization of plagioclase is more variable both in extent and mineralogy; partial replacement by albite, calcite, laumontite, stilbite, and various clay minerals is widespread.

A contact metamorphic aureole extends as far as 4 km beyond the Spirit Lake pluton. Despite thorough mineralogical reconstitution, primary macroscopic textures are typically well preserved and permit protoliths to be determined. The aureole can readily be subdivided in the field into an inner zone of black, flinty, aphanitic amphibole-bearing hornfels and an outer zone of green epidote-bearing hornfels (see sketch map).

HYDROTHERMAL ALTERATION AND MINERALIZATION

The effects of hydrothermal alteration and mineralization directly related to volcanism or to later plutonic activity are present throughout the Spirit Lake West quadrangle. The most conspicuous type of alteration in the volcanic and sedimentary rocks consists of small areas (less than 1 km^2) that contain erratically distributed bleached limonitic rocks. Most of these altered areas are closely associated with faults, shear zones, and dike swarms; in detail, the alteration was controlled by fractures and permeable clastic beds, and some unaltered rock remains within the areas of hydrothermal alteration shown on this map. Primary igneous minerals in the altered rocks. Primary minerals in these irregular patches have been totally replaced by carbonate+clay assemblages composed of some combination of kaolinite, montmorillonite, illite, calcite, siderite, dolomite, ankerite, quartz, and limonite. The distribution and mineralogy of these intensely altered areas suggest that they are products of low-temperature, shallow-level, acidic geothermal systems pene-contemporaneous with Tertiary volcanism.

In the Spirit Lake pluton and adjacent hornfels, minor pyrite is common as thin fracture coatings and replacements of primary mafic silicate and Fe-Ti oxide minerals. Rare veins within the pluton contain quartz and chalcopyrite as well. Preferential weathering of clay-rich supergene alteration zones adjacent to mineralized joints is responsible for a set of prominent northeast-trending topographic lineaments in the area between Spirit Lake and Green River. Sulfides in many of these occurrences are accompanied by fine-grained black tourmaline.

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——1993b , Geologic map of the Cowlitz Falls quadrangle, Lewis and Skamania Counties, Washington: U.S. Geological Survey Geologic Quadrangle Map GQ-1682, scale 1:24,000.

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Table 1. Summary of fission-track (FT) and isotopic age determinations, Spirit Lake West quadrangle
[Source from Evarts and others (in press) except where noted]

Map No.	Field sample no.	Location		Map unit	Rock type	Material dated	Method	Age (Ma) (±1 σ error)	Comments
		Latitude	Longitude						
1	S81-A5-R48A	46°16'11"	122°13'44"	Tb_1	Basaltic andesite	Plagioclase	K-Ar	27.7±3.7	Low radiogenic Ar; minimum age
				do	----do----	Plagioclase	$^{40}Ar/^{39}Ar$	36.1±1.0	Laser-fusion procedure
				do	-----do-----	Plagioclase	$^{40}Ar/^{39}Ar$	35.2±0.5	Laser-fusion age
2	S80-B5-E43	46°15'05"	122°08'33"	Twr	Quartz diorite	Hornblende	K-Ar	24.3±1.3	Dike related to sill complex of Windy Ridge
3	S79-A4-R128	46°20'56"	122°12'06"	Tsm	Granodiorite	Biotite	K-Ar	21.1±0.6	------------------
				do	-----do-----	Zircon	FT	21.6±0.9	------------------
4	S80-A4-R06	46°19'03"	122°12'03"	do	-----do-----	Biotite	K-Ar	20.8±0.6	------------------
				do	----do----	Zircon	FT	21.9±0.7	------------------
5	S80-A4-R08	46°18'41"	122°12'09"	do	----do----	Biotite	K-Ar	22.1±0.7	------------------
6	SH 119-1	46°19.8'	122°12.2'	do	----do----	Hornblende	K-Ar	21.9±0.3	Published age (Engels and others, 1976) recalraulated using currently accepted physical constants (Steiger and Jäger, 1977)
7	S79-B4-I05B	46°19'45"	122°08'07"	Thp	Hornblende andesite dike	Hornblende	$^{40}Ar/^{39}Ar$	9.7±0.2	Laser incremental heating age

Table 2. Chemical analyses and modes of volcanic and hypabyssal intrusive rocks, Spirit Lake West quadrangle

[Oxides in weight percent. For modal analyses, secondary minerals counted as primary mineral replaced; tr: trace; gl+q: interstitial glass+quartz. Rocks-type names assigned in accordance with I.U.G.S. systems Le Bas and Streckeisen, 1991; applied to recalculated analyses for volcanic rocks). Methods: RR, single-solution rapid rock analysis as described by Shapiro (1975); analysts, J. Gillison, and H. Smith; XRF, X-ray fluorescence analysis using methods described by Taggart and others, (1987); analysts, A.J. Bartel, D. Siems, K. Stewart and J.E. Taggart; FeO, H_2O, and CO_2 determined using methods described by Jackson and others (1987); analysts, N. Elsheimer, L. Espos and S. Neil. Texture: first term describes overall rock texture; second term describes groundmass.]

Map No.	1	2	3	4	5	6	7	8	9
Field sample Number	9E57	9E37C	2R14	6E18B	88E08	6E18C	7E31	2R37	1R38
Latitude	46°15'47"	46°17'34"	46°16'39"	46°16'11"	46°16'57"	46°16'12"	46°16'29"	46°16'50"	46°15'59"
Longitude	122°08'00"	122°12'55"	122°12'50"	122°11'56"	122°14'42"	122°12'04"	122°12'06"	122°14'57"	122°10'14"
Map unit	Tb_2[1]	Tb_1	Tb_1	Tb_1	Tb_1	Tb_1	Tb_1	Tb_1	Tcp
Rock type	Basalt	Basalt andesite	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt
Method	RR	XRF	XRF	XRF	XRF	XRF	XRF	XRF	XRF
SiO_2	48.6	49.3	49.9	50.5	50.5	50.6	50.9	51.0	51.1
TiO_2	1.0	1.82	2.17	2.11	1.24	1.63	2.22	1.28	1.23
Al_2O_3	19.8	16.4	15.7	15.8	16.5	17.2	15.6	17.4	19.1
Fe_2O_3	3.1	4.55	6.76	5.26	3.19	4.58	3.63	4.26	3.58
FeO	5.2	5.99	5.89	6.34	6.68	5.06	8.62	4.98	5.71
MnO	0.14	0.18	0.22	0.18	0.15	0.20	0.20	0.16	0.16
MgO	5.3	6.97	4.45	4.33	6.98	5.16	4.37	5.89	4.52
CaO	11.4	10.3	8.31	9.70	8.97	9.86	8.83	9.66	10.9
Na_2O	2.4	2.48	2.76	2.62	2.75	2.83	2.89	2.87	2.82
K_2O	0.27	0.36	0.20	0.20	0.51	0.35	0.38	0.54	0.29
P_2O_5	0.16	0.22	0.32	0.39	0.19	0.25	0.34	0.17	0.14
H_2O^+	2.3	1.61	1.86	1.87	0.91	0.99	1.40	0.98	0.79
H_2O^-	0.60	0.73	1.46	0.92	1.69	1.55	0.90	1.25	0.38
CO_2	0.02	0.07	0.05	<0.01	0.03	<0.01	0.02	0.02	0.07
Total	100.29	100.98	100.05	100.22	100.29	100.26	100.30	100.46	100.79
Analyses recalculated volatile-free and normalized to 100 percent									
SiO_2	49.91	50.02	51.61	51.83	51.71	51.78	51.95	51.93	51.33
TiO_2	1.03	1.85	2.24	2.17	1.27	1.67	2.27	1.30	1.24
Al_2O_3	20.33	16.64	16.24	16.22	16.90	17.60	15.92	17.72	19.19
Fe_2O_3	3.18	4.62	6.99	5.40	3.27	4.69	3.70	4.34	3.60
FeO	5.34	6.08	6.09	6.51	6.84	5.18	8.80	5.07	5.74
MnO	0.14	0.18	0.23	0.18	0.15	0.20	0.20	0.16	0.16
MgO	5.44	7.07	4.60	4.44	7.15	5.28	4.46	6.00	4.54
CaO	11.71	10.45	8.60	9.96	9.18	10.09	9.01	9.84	10.95
Na_2O	2.46	2.52	2.85	2.69	2.82	2.90	2.95	2.92	2.83
K_2O	0.28	0.37	0.21	0.21	0.52	0.36	0.39	0.55	0.29
P_2O_5	0.16	0.22	0.33	0.40	0.19	0.26	0.35	0.17	0.14
Modes									
Plagioclase	18.5	0.2	0.5	5.1	18.6	9.9	– – –	5.5	34.2
Clinopyroxene	– – –	– – –	– – –	tr	– – –	2.3	– – –	– – –	– – –
Orthopyroxene	tr	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –
Olivine	0.5	6.2	0.2	0.3	4.0	4.7	– – –	4.6	0.5
Fe-Ti oxide	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –
Hornblende	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –
Quartz	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –
Groundmass	81.0	93.6	99.3	94.6	77.4	83.1	100.0	89.9	65.3
No. of points counted	610	655	587	649	744	658	757	814	548
Texture	porphyritic/ intergranular	seriate/ intergranular	aphyric/ intersertal	porphyritic/ pilotaxitic	seriate/ intergranular	seriate/ intergranular	aphyric/ pilotaxitic	porphyritic/ intergranular	seriate/ intergranular

[1] Sample taken from shore of Spirit Lake prior to 1980 eruption of Mount St Helens; locality now beneath surface of Spirit Lake

Table 2. Chemical analyses and modes of volcanic and hypabyssal intrusive rocks, Spirit Lake West quadrangle--Continued

Map No.	10	11	12	13	14	15	16	17	18
Field sample Number	7E43	1R48A	2E67	2R18B	1E79	7E42	2E69	5E08C	9R38
Latitude	46°16'03"	46°16'12"	46°18'40"	46°17'16"	46°17'22"	46°15'53"	46°18'32"	46°19'58"	46°17'07"
Longitude	122°14'22"	122°13'44"	122°14'42"	122°12'47"	122°14'44"	122°11'11"	122°14'13"	122°14'53"	122°10'14"
Map unit	Tb_1	Tb_1	Tb_1	Tb_1	Tb_1	Ta_1	Tdi	Ta_1	Tcp
Rock type	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Diorite	Basaltic andesite	Basaltic andesite
Method	XRF	RR	XRF	XRF	XRF	XRF	XRF	XRF	XRF
SiO_2	51.3	51.5	51.50	51.60	52.10	52.20	52.60	53.10	53.40
TiO_2	1.53	0.95	1.35	1.58	1.38	1.34	1.33	1.58	1.49
Al_2O_3	17.5	15.8	18.80	16.70	18.50	16.50	17.70	16.60	17.50
Fe_2O_3	4.10	3.5	3.04	3.26	4.08	3.60	3.06	4.51	3.58
FeO	5.86	5.6	5.72	6.77	4.89	5.86	6.16	5.49	6.05
MnO	0.19	0.18	0.13	0.16	0.15	0.17	0.16	0.14	0.16
MgO	4.60	7.4	4.01	5.52	3.97	5.25	4.40	4.32	3.88
CaO	9.27	9.9	9.77	9.52	9.12	9.67	9.74	8.42	9.09
Na_2O	3.05	3.2	3.05	2.59	3.08	2.58	2.94	3.11	3.14
K_2O	0.40	0.56	0.59	0.79	1.12	0.51	0.57	0.98	0.53
P_2O_5	0.22	0.28	0.18	0.18	0.15	0.22	0.17	0.31	0.21
H_2O^+	1.02	0.81	0.92	1.14	0.90	1.12	1.04	1.07	0.83
H_2O^-	1.23	0.86	0.49	0.41	1.09	1.16	0.24	0.45	0.25
CO_2	0.07	0.08	0.02	0.01	0.07	0.11	0.32	0.43	0.04
Total	100.34	100.62	99.57	100.23	100.60	100.29	100.43	100.51	100.15
Analyses recalculated volatile-free and normalized to 100 percent									
SiO_2	52.34	52.09	52.48	52.30	52.87	53.32	53.22	53.88	53.92
TiO_2	1.56	0.96	1.38	1.60	1.40	1.37	1.35	1.60	1.50
Al_2O_3	17.85	15.98	19.16	16.93	18.77	16.85	17.91	16.84	17.67
Fe_2O_3	4.18	3.54	3.10	3.30	4.14	3.68	3.10	4.58	3.62
FeO	5.98	5.66	5.83	6.86	4.96	5.99	6.23	5.57	6.11
MnO	0.19	0.18	0.13	0.16	0.15	0.17	0.16	0.14	0.16
MgO	4.69	7.48	4.09	5.59	4.03	5.36	4.45	4.38	3.92
CaO	9.46	10.01	9.96	9.65	9.26	9.88	9.86	8.54	9.18
Na_2O	3.11	3.24	3.11	2.62	3.13	2.64	2.97	3.16	3.17
K_2O	0.41	0.57	0.60	0.80	1.14	0.52	0.58	0.99	0.54
P_2O_5	0.22	0.28	0.18	0.18	0.15	0.22	0.17	0.31	0.21
Modes									
Plagioclase	19.5	15.8	29.7	33.1	27.7	29.2	59.7	23.6	14.7
Clinopyroxene	---	4.7	---	0.5	---	3.3	31.2	0.1	0.2
Orthopyroxene	---	1.2	---	---	---	1.4	---	2.9	---
Olivine	2.0	4.7	1.6	2.0	5.7	2.3	0.2	0.3	0.9
Fe-Ti oxide	---	---	---	---	---	---	2.8	---	---
Hornblende	---	---	---	---	---	---	---	---	---
Quartz	---	---	---	---	---	---	gl+q 6.1	---	---
Groundmass	78.5	73.6	68.7	64.4	66.6	63.8	---	73.1	84.2
No. of points counted	610	770	815	650	665	647	814	660	572
Texture	seriate/ intergranular	seriate/ intergranular	porphyritic/ intergranular	seriate/ intergranular	seriate/ intergranular	seriate/ intergranular	seriate/ intergranular	porphyritic/ intergranular	seriate/ intergranular

Table 2. Chemical analyses and modes of volcanic and hypabyssal intrusive rocks, Spirit Lake West quadrangle--Continued

Map No.	19	20	21	22	23	24	25	26	27
Field sample Number	7E29	0R22	9R37	4E09	2R35C	1E58	88E07	1E77A	2E90B
Latitude	46°16'46	46°17'42"	46°17'00"	46°15'42"	46°16'36"	46°16'50"	46°16'59"	46°17'14"	46°17'51"
Lonigtude	122°11'21"	122°12'44"	122°10'13"	122°07'53"	122°14'22"	122°10'50"	122°14'30"	122°14'52"	122°07'55"
Map unit	Ta_1	Ta_1	Tcp	Twr	Tia	Ta_1	Tia	Tia	Tid
Rock type	Basaltic andesite	Basaltic andesite	Basaltic andesite	Granodiorite	Andesite	Andesite	Andesite	Andesite	Rhyolite
Method	XRF	RR	XRF	XRF	XRF	RR	XRF	RR	XRF
SiO_2	53.8	54.0	55.8	57.4	57.9	58.8	59.4	59.8	73.8
TiO_2	1.50	1.9	1.62	1.14	1.70	1.6	1.32	1.2	0.23
Al_2O_3	18.0	15.7	15.7	17.1	14.9	15.0	16.4	14.8	12.7
Fe_2O_3	3.18	5.3	3.66	1.52	2.26	3.2	2.42	2.6	1.54
FeO	5.69	6.2	6.61	5.80	6.76	5.5	4.98	5.5	1.38
MnO	0.15	0.2	0.18	0.12	0.16	0.16	0.16	0.15	0.04
MgO	3.42	3.8	3.71	3.26	2.57	2.4	2.17	2.4	0.12
CaO	8.81	7.9	7.68	6.46	6.33	5.5	5.68	5.7	0.68
Na_2O	3.05	3.4	3.27	3.51	3.80	3.8	4.62	4.2	3.94
K_2O	0.76	0.79	0.69	1.39	.065	1.2	0.65	0.92	3.59
P_2O_5	0.24	0.35	0.24	0.20	0.36	0.44	0.31	0.58	<0.05
H_2O^+	1.33	0.60	0.97	1.65	2.00	1.5	1.61	1.8	0.61
H_2O^-	0.53	1.2	0.44	0.36	0.76	0.51	0.55	0.53	0.16
CO_2	0.02	0.04	0.06	0.06	0.04	0.04	0.02	0.02	0.09
Total	100.48	101.38	100.63	99.97	100.18	99.65	100.29	100.20	98.88
Analyses recalculated volatile-free and normalized to 100 percent									
SiO_2	54.56	54.25	56.27	58.63	59.45	60.25	60.54	61.11	75.29
TiO_2	1.52	1.91	1.63	1.16	1.75	1.64	1.35	1.23	0.23
Al_2O_3	18.26	15.77	15.83	17.47	15.30	15.37	16.72	15.13	12.96
Fe_2O_3	3.23	5.32	3.69	1.55	2.32	3.28	2.47	2.66	1.57
FeO	5.77	6.23	6.67	5.92	6.94	5.64	5.08	5.62	1.41
MnO	0.15	0.20	0.18	0.12	0.16	0.16	0.16	0.15	0.04
MgO	3.47	3.82	3.74	3.33	2.64	2.46	2.21	2.45	0.12
CaO	8.94	7.94	7.75	6.60	6.50	5.64	5.79	5.83	0.69
Na_2O	3.09	3.42	3.30	3.59	3.90	3.89	4.71	4.29	4.02
K_2O	0.77	0.79	0.70	1.42	0.67	1.23	0.66	0.94	3.66
P_2O_5	0.24	0.35	0.24	0.20	0.37	0.45	0.32	0.59	0.00
Modes									
Plagioclase	19.0	4.3	0.6	49.3	tr	0.2	3.6	3.7	3.6
Clinopyroxene	0.4	------	------	12.7	tr	0.1	tr	0.8	0.5
Orthopyroxene	------	------	------	4.1	------	tr	tr	0.00	
Olivine	0.7	0.2	------	------	------	------	------	------	------
Fe-Ti oxide	------	------	------	1.1	------	------	tr	0.1	0.3
Hornblende	------	------	------	0.4	------	------	------	------	------
Quartz	------	------	------	------	------	------	------	------	------
Groundmass	79.9	95.5	99.4	32.4	100.0	96.4	99.7	95.3	95.6
No. of points counted	679	512	522	566	700	535	665	732	604
Texture	seriate/ intergranular	micropor-phyritic/ intersertal	aphyric/ intergranular	porphyritic/ microcrys-talline	aphyric/ hyalopilitic	aphyric/ pilotaxitic	porphyritic/ pilotaxitic	porphyritic/ felty	porphyritic/ spherulitic

*U.S. G.P.O.:1994-387-030:45