GEOLOGIC MAP OF THE COWLITZ FALLS QUADRANGLE, LEWIS AND SKAMANIA COUNTIES, WASHINGTON

By Russell C. Evarts and Roger P. Ashley

INTRODUCTION

The Cowlitz Falls quadrangle is situated on the western slope of the southern Washington Cascade Range approximately 25 km northeast of Mount St. Helens. Bedrock consists of late Oligocene to early Miocene volcanic and volcaniclastic rocks and 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 and abundant tephra erupted from Mount St. Helens during the past 40,000 years (Mullineaux and Crandell, 1981; Mullineaux, 1986). Bedrock exposures are limited due to the extensive and heavily vegetated surficial cover, but stratigraphic sections are commonly well exposed in high-gradient streams such as those on Tumwater and Strawberry Mountains.

ACKNOWLEDGMENTS

Champion International Corporation freely allowed access to its lands in the northern part of the quadrangle. We were ably assisted in the field during the early stages of mapping by Walt Avramenko, Rick Bishop, Mike Covey, Jerry Infeld, Mike Lukk, Scott Petersen, and Carolyn Peterson. Proficient laboratory support was provided by Joe Ash, Mary Caress, Mike Covey, Jerry Infeld, Rick Pietropaoli, Scott Petersen, Carolyn Peterson, and especially Rick Bishop. We are grateful to LedaBeth Gray, Brent D. Turrin, and James G. Smith for providing K-Ar and $^{40}Ar/^{39}Ar$ ages. We have also benefitted from logistical support provided by Bobbie Myers and the staff of the David A. Johnston Cascades Volcano Observatory. We are indebted to Donald A. Swanson, Paul E. Hammond, James G. Smith, William M. Phillips, Michael A. Korosec, Virgil A. Frizzell, Donal R. Mullineaux, William E. Scott, and Dwight R. Crandell for sharing with us many thought-provoking discussions of Cascade Range geology, and to Don Swanson and Dave Sherrod for exceptionally careful and valuable critical reviews of the manuscript.

SUMMARY OF GEOLOGY

The strata exposed in the Cowlitz Falls 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 western limb of a broad regional syncline whose axis lies about 5 km east of the quadrangle in the Greenhorn Buttes quadrangle (Walsh and others, 1987; Swanson, 1989). The strata are lithologically heterogeneous and stratigraphically complex. Distinctive marker units are absent, and regionally important unconformities have not been recognized in this or adjacent quadrangles; therefore, construction of a formal stratigraphic framework was not attempted, and only lithologic or local informal units are shown on this map. The most valuable data for regional correlation are the isotopic age determinations (table 1). The age data from this and adjacent areas (Evarts and Ashley, 1993a, b; Swanson, 1989) show that most of the volcanic rocks in the Cowlitz Falls quadrangle are between 25 and 23 million years old.

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 intrusions, and zones of hydrothermal alteration (Cas and Wright, 1987; Smith, 1993). Huffaker Mountain and Glenoma Peak, for example, consist of sequences, apparently greater than 2 km thick, of mafic flows, flow-breccia, minor agglomerate (volcanic-bomb) beds, and fine- to medium-grained mafic dikes that probably formed the flanks of large basaltic cones or shields. Stacks of porphyritic andesite that underlie the summits of Tumwater and Strawberry Mountains may have formed parts of andesitic cones similar to the Miocene Tieton volcano southeast of Mount Rainier described by Swanson (1966), and scattered dacitic dikes and small domes were probably emplaced into the sides of stratovolcanoes in the same manner as those exposed on the slopes of Mount St. Helens (Hopson, 1971). A small cylindrical plug (unit Tibc) on the ridgecrest north of the summit of Strawberry Mountain is composed of distinctive, virtually aphyric black andesite identical to flows that crop out in Benham Creek a short distance to the east, and almost certainly occupies the vent that fed these flows. Sequences of laterally continuous strata, such as that which makes up much of Tumwater Mountain, were probably deposited as dispersal aprons on the lower flanks of stratovolcanoes or in lowlands between active volcanic edifices.

A more problematic volcanic structure is an inferred caldera underlying an area in Quartz Creek immediately northeast of the (informally named) Spirit Lake pluton (fig. 1). Exposures in this area consist of a thick pile of pyroclastic debris, much of which is pyritic and highly altered to quartz-sericite or propylitic mineral assemblages. Lithic volcanic clasts in these rocks are as large as several meters across, and the matrix is composed of pumice lapilli and ash. Outcrops of lithic-poor rocks display pronounced eutaxitic structure that dips toward Quartz Creek on both sides of the canyon. Dacitic intrusions occur throughout the section but are often difficult to distinguish from tuff owing to intense alteration. No discrete caldera-margin faults have been identified, perhaps because of the poor exposure, alteration, and obliteration by younger intrusions; alternatively, the structure may be downsag caldera of the type described by Walker (1984).

Chemical analyses (table 2) reveal that the quadrangle contains a diverse group of volcanic rocks ranging from basalt through dacite (I.U.G.S. nomenclature of Le Bas and Streckeisen, 1991; see fig. 1). Mafic to silicic andesite (between 52 and 63 weight percent SiO_2) is the most common rock type. Thick piles of relatively uniform basalt (less than 52 weight percent SiO_2) flows dominate the section north of the Cispus River, but elsewhere basalt is comparatively rare. Dacite and rhyolite (greater than 63 weight percent SiO_2) are more abundant than the small number of analyses in table 2 implies, but few silicic rocks are fresh enough for chemical analysis. More than half of the samples are classified as calc-alkaline on the AFM plot (fig. 2) of Irvine and Baragar (1971) whereas most are tholeiitic according to the FeO*/MgO versus. 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 indicate that it has been tilted to the east along with its host rocks, so folding of the Tertiary section must be younger than 21 Ma, the crystallization age of the pluton (table 1). The age of folding is otherwise poorly constrained, and folding may have taken place over an extended period (Evarts and others, 1987).

Faults and shear zones are uncommon. Those that have been observed are subvertical and typically exhibit offsets of only a few meters. Generally, the rocks on both sides of faults are identical and the sense of offset cannot be determined. Most faults are flanked by zones of hydrothermally altered rocks and a few are occupied by Tertiary dikes. Some of the faults are therefore relatively old and probably represent local small-scale adjustments to movements of magma within Tertiary volcanic centers rather than responses to regional tectonic stresses.

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 south and west of the Cowlitz Falls quadrangle (Evarts and Ashley, 1993b, c); only the northeastern quarter of the intrusion is shown on this map. Along most of the margin of the pluton contacts with country rock are sharp and steep and they truncate volcanic stratigraphy at high angles. However, the eastern contact, on the west flank of Strawberry Mountain, cuts across the gently east-dipping volcanic and sedimentary host rocks at low to moderate angles (cross section *B-B'*) and is interpreted as the roof of the intrusion. The overall configuration of the body at the present level of exposure is that of an eastward-tilted flat-roofed cylinder (Evarts and others, 1987).

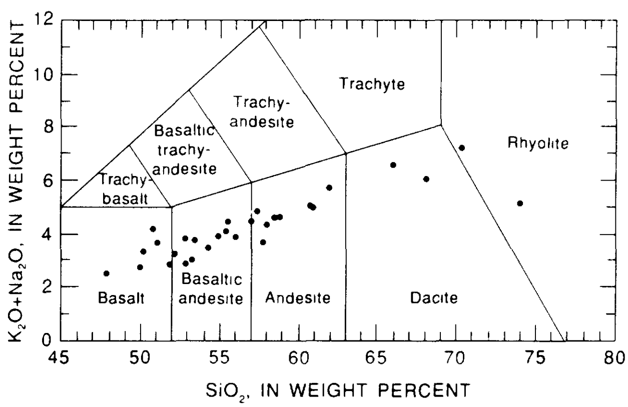

Figure 1.--Na_2O+K_2O versus SiO_2 (recalculated volatile-free) for volcanic and hypabyssal intrusive rocks from Cowlitz Falls quadrangle showing classification according to I.U.G.S. (Le Bas and Streckeisen, 1991).

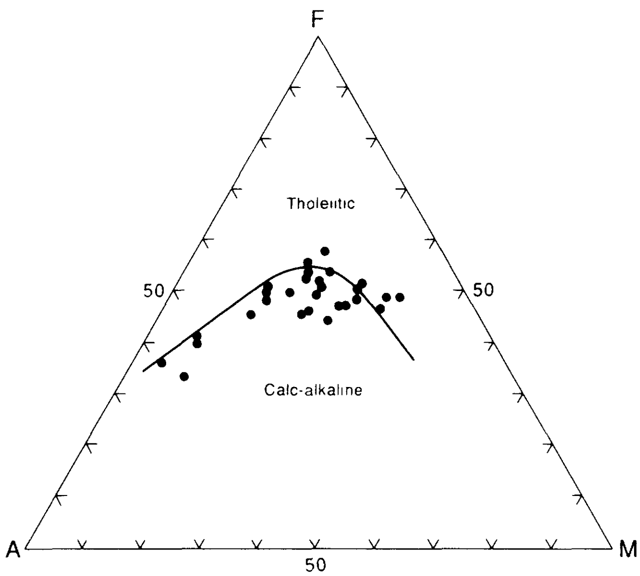

Figure 2.--AFM diagram for volcanic and hypabyssal intrusive rocks from Cowlitz falls quadrangle (A, Na_2O+K_2O; F, $FeO+Fe_2O_3+MnO$; M, MgO). Line separating tholeiitic and calc-alkaline rocks from Irvine and Baragar (1971).

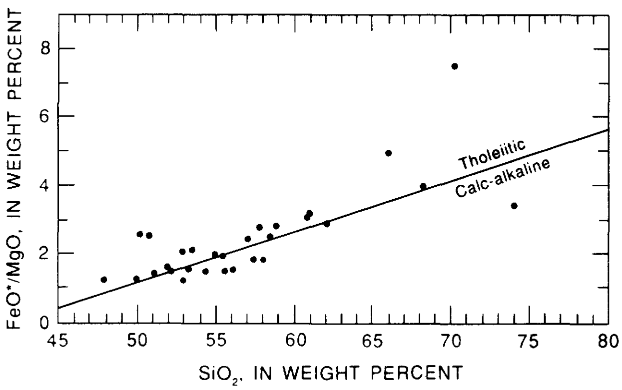

Figure 3.--FeO*/MgO versus SiO_2 (recalculated volatile-free) for volcanic and hypabyssal intrusive rocks from Cowlitz Falls quadrangle showing classification into tholeiitic and calc-alkaline rocks according to Miyashiro (1974). FeO*, total Fe as FeO.

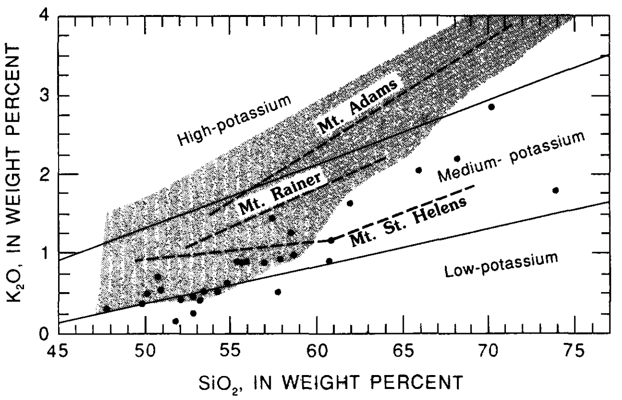

Figure 4.--K_2O versus SiO_2 (recalculated volatile-free) for volcanic and hypabyssal intrusive rocks from Cowlitz Falls quadrangle (dots). Low-, medium-, and high-potassium fields from Gill (1981, p. 6). Shaded area encompasses compositions of Quaternary volcanic rocks, exclusive of major stratovolcanoes, of southern Washington Cascade Range from Hammond and Korosec (1983). Trendlines shown for Quaternary stratovolcanoes Mount Rainier, Mount St. Helens, and Mount Adams based on data in Condie and Swenson (1973), Hildreth and Fierstein (1985), and Smith and Leeman (1987).

The pluton consists of three phases, all of which have yielded radiometric ages between 20 and 23 Ma. The quartz diorite phase (Tsqd), exposed in Goat Creek and on both sides of the ridge extending south from Tumwater Mountain, is a dike and sill complex consisting of numerous altered porphyritic dikes separated by screens of black hornfels; contacts of this phase with country rock are more irregular than those of the other two phases (cross sections *A-A'* and *C-C'*). Field relations suggest that this is the oldest part of the pluton. This inference is supported by a 23.2-Ma K-Ar age for hydrothermal alteration which overprints the quartz diorite phase but not the main or granite phases. The coarser grained and more massive main phase (Tsm), which is texturally and modally variable but has an average composition of granodiorite, constitutes the bulk of the pluton. The granite phase (Tsgr) is slightly younger than the main phase and crops out chiefly near the top of the intrusion east of Quartz Creek.

The pluton may have reached to within 1 km of the surface. This inference is based on the roughly 2 million years that separates deposition of the youngest host rocks (~23 Ma) and crystallization of the intrusion (~21 Ma), combined with a typical volcanic accumulation rate for the southern Washington Cascades during middle Tertiary time of approximately 300 to 400 m/m.y. (Smith, in press; Evarts and others, in press). Widespread micrographic textures in rocks of the upper (eastern) part of the pluton further suggest that it may have vented to the surface and fed volcanoes, the products of which may be preserved in younger strata exposed east of this quadrangle.

Smaller phaneritic intrusions ranging from diorite to granite are found in a north-northeast-trending zone north of the Spirit Lake pluton. None have been dated by isotopic techniques. However, a similar granodiorite body in the Spirit Lake East quadrangle to the south gave a K-Ar hornblende age of 24.3 ±1.3 Ma (Evarts and others, 1987), and all of the smaller intrusions within the contact aureole of the Spirit Lake pluton were metamorphosed by it. Therefore, most of these satellitic bodies are inferred to be older than the pluton. Some rocks of the (informally named) Quartz Creek stock are texturally identical to those of the quartz diorite and main phases of the Spirit Lake pluton, and these may be coeval.

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 typically 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 mineralogic reconstitution, primary macroscopic textures are commonly well preserved and permit identification of protoliths. 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. Hornfels is locally found at greater distances from the pluton, commonly but not everywhere associated with small phaneritic intrusive bodies (see sketch map). The widespread distribution of recrystallized rock implies that the proportion of plutonic rock increases substantially at shallow depths beneath the present erosion surface.

HYDROTHERMAL ALTERATION AND MINERALIZATION

The effects of hydrothermal alteration and mineralization directly related to volcanism or to later plutonic activity appear throughout the Cowlitz Falls quadrangle. The most widespread type of alteration in the volcanic and sedimentary rocks consists of small patches (less than 1 km^2) that contain erratically distributed bleached limonitic rocks. Most of these areas are present along faults, shear zones, and dikes, or are spatially associated with silicic volcanic rocks. In detail, alteration was controlled by fractures and permeable clastic beds, and patches of rock remain unaffected. Primary minerals in the altered rocks 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 penecontemporaneous with Tertiary volcanism.

The large altered area centered on Quartz Creek locally includes pyrite-bearing propylitic and phyllic as well as clay-carbonate assemblages. This alteration is largely restricted to rocks within and adjacent to the postulated caldera described above and probably is genetically related to it. However, the presence of abundant intrusive rock and associated pyritic hornfels in the area suggests that sulfide may have been remobilized and (or) added during contact metamorphism. The presence of minor sulfide in veinlets scattered throughout the Spirit Lake pluton and other granitic intrusions in the quadrangle indicates that at least some mineralization is directly related to younger, deep-seated plutonic activity rather than to local, high-level, volcanic hydrothermal systems.

Pervasive silicification and argillic to advanced argillic alteration are found in several locations near the center of the quadrangle, including a large area immediately north of Red Spring Creek. The altered rocks range in appearance from dense and massive to brecciated to porous; most are white or pale gray, but orange to brown limonite is common along fractures. They have been intensely leached by acidic solutions that destroyed most primary textures and produced assemblages of fine-grained quartz, pyrophyllite or sericite, limonite, rutile, and minor local andalusite, alunite, diaspore, and (or) topaz(?). Pyrite is generally absent from these rocks but its former presence is indicated by bright-red limonite that forms surficial crusts and cements modern gravels in streams draining these zones. The iron in this limonite was probably liberated by oxidation of abundant sulfides in the shallow subsurface. The intense alteration obscures the protolith, but vague porphyritic and clastic textures in some samples suggest volcanic, volcaniclastic, and quartz diorite (Tsqd) precursors. A K-Ar age of 23.2±0.6 Ma was determined on alunite collected 1 km north of Red Spring Creek.

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Table 1. *Summary of fission-track (FT) and isotopic age determinations, Cowlitz Falls quadrangle*

[From Evarts and others, in press]

Map No.	Field sample No.	Location		Map unit	Rock type	Material dated	Method	Age (Ma) (±1-s error)	Comments
		Latitude	Longitude						
1	S78-C1-R36	46°26'55"	122°06'20"	Tt	Pumice lapilli tuff	Plagioclase	$^{40}Ar/^{39}Ar$	23.5±0.6	Laser incremental heating age
2	S77-C2-N144	46°25'32"	122°05'40"	Ttm	Basaltic andesite	Plagioclase	$^{40}Ar/^{39}Ar$	23.7±0.6	Laser-fusion age
						Plagioclase	$^{40}Ar/^{39}Ar$	28.6±8	Laser incremental heating age
3	S82-D1-E106	46°28'31"	122°00'05"	Thm	Basalt	Plagioclase	K-Ar	23.3±1.2	----------
						Plagioclase	K-Ar	23.2±0.7	----------
								23.3±0.6	Weighted mean age
4	S77-D3-R12	46°23'14"	122°02'17"	Ta	Pyroxene andesite	Plagioclase	K-Ar	22.6±0.6	Possibly reset by Spirit Lake pluton, minimum age
5	S77-C3-J18	46°23'05"	122°04'16"	Tsm	Grano-diorite	Zircon	FT	20.9±2.2	----------
6	S76-C3-N98	46°24'33"	122°03'32"	Tsgr	Granite	Zircon	FT	22.6±2.0	----------
7	S77-C3-J49	46°23'35"	122°05'24"	Tsqd	Silicified quartz diorite	Alunite	K-Ar	23.5±0.6	Area of ad-vanced argillic alteration near Red Spring
						Alunite	K-Ar	22.9±0.6	Creek; alteration age
						Alunite	K-Ar	22.9±0.6	Weighted mean age

Table 2. *Chemical analyses and modes of volcanic and hypabyssal intrusive rocks, Cowlitz Falls quadrangle*

[Oxides in weight percent. For modal analyses, secondary minerals counted as primary mineral replaced; tr: trace; px: pyroxene. Rock type names assigned in accordance with I.U.G.S. system (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, J. Baker, A.J. Bartel, D. Fey, D. Siems, K. Stewart, J.E. Taggart, and J.S. Wahlberg; 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 No.	0E38	1E05	1E17B	0E68	7E04	2E106	0E13B	7N26	0E19B
Latitude	46°28'16"	46°28'00"	46°28'42"	46°29'42"	46°25'45"	46°28'30"	46°28'00"	46°28'23"	46°27'46"
Longitude	122°00'57"	122°01'28"	122°02'59"	122°05'35"	122°01'15"	122°00'05"	122°06'40"	122°03'35"	122°05'57"
Map unit	Thm	Thm	Tgb	Tgc	Thm	Thm	Tgc	Thm	Tgc
Rock type	Basalt	Basalt	Gabbro	Basalt	Basalt	Basalt	Basaltic andesite	Basaltic andesite	Basaltic andesite
Texture	porphyritic/ intergranular	porphyritic/ intergranular	coarse/ intergranular	porphyritic/ subophitic	porphyritic/ intergranular	seriate/ intergranular	porphyritic/ intergranular	seriate/ intergranular	porphyritic/ intergranular
Method	XRF	RR	RR	RR	XRF	RR	RR	RR	XRF
SiO_2	47.1	48.3	48.5	49.4	50.4	51.0	51.0	51.4	51.6
TiO_2	1.3	1.3	1.4	1.4	1.14	1.0	0.99	0.97	0.98
Al_2O_3	17.6	18.5	16.7	20.5	17.9	18.8	16.4	18.2	17.2
Fe_2O_3	3.84	4.7	3.3	4.2	3.32	4.0	3.1	3.7	2.88
FeO	6.97	4.6	6.6	5.5	5.54	5.3	5.2	5.0	5.64
MnO	0.18	0.14	0.18	0.16	0.15	0.17	0.15	0.16	0.14
MgO	8.36	3.5	7.3	3.6	5.27	6.1	6.5	5.5	5.19
CaO	10.6	9.8	10.3	10.2	10.5	9.7	10.3	10.3	10.2
Na_2O	2.18	3.3	2.3	2.8	2.67	3.1	2.5	2.8	2.56
K_2O	0.34	0.68	0.37	0.50	0.17	0.56	0.26	0.42	0.39
P_2O_5	0.11	0.32	0.17	0.15	0.15	0.32	0.17	0.15	0.13
H_2O^+	0.70	0.62	0.40	0.36	0.96	0.58	0.30	0.50	1.17
H_2O^-	1.25	0.65	1.5	0.94	1.49	0.52	1.9	1.2	0.64
CO_2	0.05	3.8	0.72	0.04	0.54	0.02	0.76	0.15	0.72
Total	100.58	100.21	99.74	99.75	100.20	101.17	99.53	100.45	99.44
Analyses recalculated volatile-free and normalized to 100 percent									
SiO_2	47.78	50.77	49.94	50.20	51.85	50.97	52.81	52.13	53.25
TiO_2	1.32	1.37	1.44	1.42	1.17	1.00	1.03	0.98	1.01
Al_2O_3	17.85	19.45	17.20	20.83	18.41	18.79	16.98	18.46	17.75
Fe_2O_3	3.90	4.94	3.40	4.27	3.42	4.00	3.21	3.75	2.97
FeO	7.07	4.83	6.80	5.59	5.70	5.30	5.38	5.07	5.82
MnO	0.18	0.15	0.19	0.16	0.15	0.17	0.16	0.16	0.14
MgO	8.48	3.68	7.52	3.66	5.42	6.10	6.73	5.58	5.36
CaO	10.75	10.30	10.61	10.36	10.80	9.70	10.67	10.45	10.53
Na_2O	2.21	3.47	2.37	2.85	2.75	3.10	2.59	2.84	2.64
K_2O	0.34	0.71	0.38	0.51	0.17	0.56	0.27	0.43	0.40
P_2O_5	0.11	0.34	0.18	0.15	0.15	0.32	0.18	0.15	0.13
Modes									
Plagioclase	33.6	25.1	59.9	39.8	34.1	47.4	16.9	18.2	8.2
Clinopyroxene	0.5	1.3	15.2	---	tr	1.8	3.1	---	1.1
Orthopyroxene	---	---	11.8	---	---	0.4	---	---	---
Olivine	13.1	3.3	6.1	1.7	2.8	0.2	5.8	2.0	0.5
Fe-Ti oxide	0.3	tr	2.3	---	---	0.4	---	---	---
Hornblende	---	---	---	---	---	---	---	---	---
Quartz	---	---	---	---	---	---	---	---	---
K-feldspar	---	---	---	---	---	---	---	---	---
Groundmass	52.5	70.3	4.7	58.5	63.1	49.8	74.2	79.8	90.2
Number of points counted	741	767	836	689	539	812	776	814	747

Table 2. *Chemical analyses and modes of volcanic and hypabyssal intrusive rocks, Cowlitz Falls quadrangle—Continued*

Map No.	10	11	12	13	14	15	16	17	18
Field sample No.	7N19	9I41A	7N45	8W13	7N162	7N144	5E53	3E17	0E62
Latitude	46°28'31"	46°26'04"	46°28'42"	46°26'50"	46°25'44"	46°25'32"	46°26'34"	46°27'49"	46°26'59"
Longitude	122°01'28"	122°06'21"	122°01'21"	122°07'04"	122°05'08"	122°05'40"	122°05'20"	122°05'03"	122°03'14"
Map unit	Tgb	Ttm	Tgb	Ta	Ttm	Ttm	Ta	Ta	Tqqd
Rock type	Gabbro	Basaltic andesite	Gabbro	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Andesite	Quartz diorite
Texture	porphyritic/ intergranular	seriate/ intergranular	coarse/ intergranular	porphyritic/ subophitic	porphyritic/ intergranular	seriate/ intergranular	porphyritic/ intergranular	seriate/ intergranular	porphyritic/ intergranular
Method	RR	RR	RR	RR	RR	RR	XRF	XRF	RR
SiO_2	52.1	52.9	53.4	53.7	54.3	54.5	54.5	55.6	56.1
TiO_2	1.4	0.81	1.1	1.2	0.83	0.93	1.11	1.55	0.94
Al_2O_3	17.7	17.4	19.4	17.8	16.5	16.4	17.5	15.7	16.8
Fe_2O_3	3.3	2.9	2.7	3.3	3.3	3.5	4.28	3.67	3.4
FeO	6.5	5.0	5.6	5.2	4.6	4.6	3.94	5.57	3.9
MnO	0.16	0.16	0.14	0.15	0.14	0.17	0.16	0.17	0.13
MgO	4.5	5.0	3.8	4.0	5.0	4.9	3.94	3.55	3.8
CaO	8.9	9.6	9.8	8.5	8.4	8.3	8.69	7.10	7.3
Na_2O	3.3	2.9	3.2	3.2	3.5	2.9	3.18	3.46	3.3
K_2O	0.45	0.52	0.52	0.61	0.88	0.88	0.89	0.88	0.90
P_2O_5	0.23	0.30	0.17	0.20	0.25	0.27	0.17	0.28	0.18
H_2O+	0.50	0.94	0.28	0.90	0.80	1.3	0.88	1.01	1.7
H_2O^-	1.1	0.77	0.72	1.0	1.1	0.97	0.90	0.87	0.57
CO_2	0.19	0.66	0.06	0.07	0.18	0.42	0.40	0.10	0.64
Total	100.33	99.86	100.89	99.83	99.78	100.04	100.54	99.51	99.66
Analyses recalculated volatile-free and normalized to 100 percent									
SiO_2	52.87	54.26	53.49	54.87	55.58	55.98	55.41	57.01	57.98
TiO_2	1.42	0.83	1.10	1.23	0.85	0.96	1.13	1.59	0.97
Al_2O_3	17.96	17.85	19.43	18.19	16.89	16.85	17.79	16.10	17.36
Fe_2O_3	3.35	2.97	2.70	3.37	3.38	3.60	4.35	3.76	3.51
FeO	6.60	5.13	5.61	5.31	4.71	4.73	4.01	5.71	4.03
MnO	0.16	0.16	0.14	0.15	0.14	0.17	0.16	0.17	0.13
MgO	4.57	5.13	3.81	4.09	5.12	5.03	4.01	3.64	3.93
CaO	9.03	9.85	9.82	8.69	8.60	8.53	8.83	7.28	7.55
Na_2O	3.35	2.97	3.21	3.27	3.58	2.98	3.23	3.55	3.41
K_2O	0.46	0.53	0.52	0.62	0.90	0.90	0.90	0.90	0.93
P_2O_5	0.23	0.31	0.17	0.20	0.26	0.28	0.17	0.29	0.19
Modes									
Plagioclase	68.8	32.9	77.6	32.3	25.3	25.6	21.6	3.6	53.7
Clinopyroxene	---	4.0	18.1	2.3	6.5	4.3	6.7	tr	5.0
Orthopyroxene	px 25.8	3.2	---	1.9	6.7	6.6	4.6	0.3	17.1
Olivine	0.5	2.6	2.1	2.2	1.5	1.7	1.1	---	---
Fe-Ti oxide	2.8	tr	1.6	0.4	0.8	0.5	1.6	tr	2.1
Hornblende	---	---	---	---	---	---	---	---	0.5
Quartz	2.1	---	---	---	---	---	---	---	12.3
K-feldspar	---	---	---	---	---	---	---	---	9.3
Groundmass	---	57.3	0.6	60.9	59.2	61.3	64.4	96.1	---
Number of points counted	800	782	634	728	826	815	629	749	579

Table 2. *Chemical analyses and modes of volcanic and hypabyssal intrusive rocks, Cowlitz Falls quadrangle—Continued*

Map No.	19	20	21	22	23	24	25	26	27
Field sample No.	87R08B	5E71	8E15	7E23	8W11	3E30A	9E116	8R35	5E72
Latitude	46°26'27"	46°27'00"	46°26'36"	46°26'42"	46°26'51"	46°27'29"	46°26'42"	46°26'31"	46°26'47"
Longitude	122°03'40"	122°07'27"	122°05'34"	122°06'33"	122°06'53"	122°06'51"	122°06'56"	122°07'02"	122°07'25"
Map unit	Tqqd	Ta	Ta	Ta	Ta	Ta	Ta	Td	Td
Rock type	Quartz diorite	Andesite	Andesite	Andesite	Andesite	Andesite	Andesite	Dacite	Dacite
Texture	porphyritic/ hypidiomorphic	aphyric/ pilotaxitic	porphyritic/ hyalopilitic	porphyritic/ pilotaxitic	porphyritic/ hyalopilitic	aphyric/ hyalopilitic	porphyritic/ pilotaxitic	porphyritic/ micropoikilitic	porphyritic/ micropoikilitic
Method	XRF	XRF	RR	XRF	RR	XRF	RR	RR	XRF
SiO_2	56.4	56.6	56.9	57.4	58.9	59.3	60.7	64.1	66.6
TiO_2	1.09	1.29	1.0	1.14	1.5	1.40	1.2	0.83	0.81
Al_2O_3	16.8	15.7	17.7	16.6	15.1	15.2	15.8	14.9	14.4
Fe_2O_3	3.78	3.20	4.3	5.28	2.9	3.95	3.7	5.0	2.93
FeO	3.99	5.72	2.4	2.83	4.8	4.09	3.2	1.0	2.04
MnO	0.14	0.18	0.14	0.13	0.15	0.13	0.12	0.11	0.07
MgO	4.00	3.07	2.2	3.02	2.4	2.38	2.2	1.1	1.13
CaO	7.11	8.39	7.5	6.96	5.9	5.87	5.1	3.4	3.67
Na_2O	3.35	3.13	3.5	3.30	4.0	3.71	4.0	4.4	3.77
K_2O	1.42	0.52	0.95	1.25	0.90	1.15	1.6	2.0	2.15
P_2O_5	0.20	0.19	0.20	0.22	0.35	0.24	0.32	0.27	0.20
H_2O^+	1.72	1.13	0.50	0.51	1.3	0.96	0.70	0.50	1.30
H_2O^-	0.35	0.37	1.6	1.36	0.91	0.90	1.5	1.3	0.31
CO_2	<0.01	0.82	0.65	0.16	0.04	0.79	0.08	0.04	0.07
Total	100.35	100.31	99.54	100.16	99.15	100.07	100.22	98.95	99.45
Analyses recalculated volatile-free and normalized to 100 percent									
SiO_2	57.39	57.76	58.79	58.49	60.78	60.87	61.98	66.01	68.12
TiO_2	1.11	1.32	1.03	1.16	1.55	1.44	1.23	0.85	0.83
Al_2O_3	17.09	16.02	18.29	16.92	15.58	15.60	16.13	15.34	14.73
Fe_2O_3	3.85	3.27	4.44	5.38	2.99	4.05	3.78	5.15	3.00
FeO	4.06	5.84	2.48	2.88	4.95	4.20	3.27	1.03	2.09
MnO	0.14	0.18	0.14	0.13	0.15	0.13	0.12	0.11	0.07
MgO	4.07	3.13	2.27	3.08	2.48	2.44	2.25	1.13	1.16
CaO	7.23	8.56	7.75	7.09	6.09	6.03	5.21	3.50	3.75
Na_2O	3.41	3.19	3.62	3.36	4.13	3.81	4.08	4.53	3.86
K_2O	1.44	0.53	0.98	1.27	0.93	1.18	1.63	2.06	2.20
P_2O_5	0.20	0.19	0.21	0.22	0.36	0.25	0.33	0.28	0.20
Modes									
Plagioclase	26.0	0.6	19.6	23.6	5.1	1.8	12.0	9.4	5.5
Clinopyroxene	3.3	0.5	2.9	4.5	0.7	0.4	---	0.7	0.6
Orthopyroxene	5.4	---	4.5	5.2	0.1	0.4	0.7	0.5	1.0
Olivine	---	0.2	1.0	---	0.1	tr	1.3	---	---
Fe-Ti oxide	0.5	---	0.3	1.2	0.2	0.1	0.8	0.7	0.2
Hornblende	---	---	---	---	---	---	---	---	---
Quartz	---	---	---	---	---	---	---	---	---
K-feldspar	---	---	---	---	---	---	---	---	---
Groundmass	64.8	98.7	71.7	65.5	93.8	97.3	85.2	88.7	92.7
Number of points counted	634	627	626	673	802	813	835	810	631

Table 2. *Chemical analyses and modes of volcanic and hypabyssal intrusive rocks, Cowlitz Falls quadrangle—Continued*

Map No.	28	29
Field sample No.	7N04D	7R49
Latitude	46°27'31"	46°26'52"
Longitude	122°01'38"	122°06'12"
Map unit	Tgr	Tt
Rock type	Granite	Rhyolite tuff
Texture	porphyritic/xenomorphic	porphyritic/vitrophyric
Method	XRF	XRF
SiO_2	68.6	71.3
TiO_2	0.54	0.56
Al_2O_3	13.8	13.3
Fe_2O_3	1.88	1.11
FeO	2.73	2.07
MnO	0.08	0.07
MgO	0.59	0.88
CaO	2.30	1.97
Na_2O	4.20	3.24
K_2O	2.81	1.71
P_2O_5	0.10	0.11
H_2O^+	0.60	2.97
H_2O^-	0.32	0.86
CO_2	0.76	0.01
Total	99.31	100.16
Analyses recalculated volatile-free and normalized to 100 percent		
SiO_2	70.27	74.02
TiO_2	0.55	0.58
Al_2O_3	14.13	13.81
Fe_2O_3	1.93	1.15
FeO	2.80	2.15
MnO	0.08	0.07
MgO	0.60	0.91
CaO	2.36	2.05
Na_2O	4.30	3.36
K_2O	2.88	1.78
P_2O_5	0.10	0.11
Modes		
Plagioclase	8.4	8.4
Clinopyroxene	0.9	1.3
Orthopyroxene	0.2	---
Olivine	---	---
Fe-Ti oxide	0.7	0.5
Hornblende	2.0	---
Quartz	---	---
K-feldspar	---	---
Other	---	---
Groundmass	87.8	89.8
Number of points counted	663	790

*U.S. G.P.O.:1994-301-077:80083