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Preliminary Geologic Map of the Elk Mountain quadrangle, Cowlitz County, Washington

by

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INTRODUCTION

The Elk Mountain 7.5-minute quadrangle is on the western slope of the Cascade Range of southern Washington, centered about 20 km west of the summit of Mount St. Helens (fig. 1). Bedrock consists of diverse volcanic and volcaniclastic rocks of late Eocene and early Oligocene age. These rocks are overlain by extensive Pleistocene glacial deposits and mantled by tephra erupted from Mount St. Helens during latest Pleistocene and Holocene time. The South Fork Toutle River valley contains deposits of volcaniclastic debris also derived from the volcano.

Natural bedrock exposures are limited owing to the dense vegetation of temperate coniferous rain forest and the thick surficial cover. However, outcrops are common along the many streams in the area. In addition, an extensive network of private logging roads constructed during the past two decades provides excellent access as well as many roadcut exposures, allowing the stratigraphy of the quadrangle to be pieced together in reasonable detail.

This is one of a series of maps at a scale of 1:24,000 that cover the region near Mount St. Helens (Evarts and Ashley, 1990a, b; 1991; in press a, b, c, d; Swanson, 1989, 1991), published in a program designed to produce a detailed geologic transect across the Cascade Range of southern Washington. The mapping is intended to acquire the basic information necessary to elucidate the petrologic and structural evolution of the Cascade volcanic arc and its mineral deposits. The strata in this and the adjacent quadrangles to the east, southeast, and south (Evarts and Ashley, 1990a, b; 1991) are older than those in mapped areas north and northeast of Mount St. Helens (fig. 1; Evarts and Ashley, in press a, b, c, d), and include some of the oldest known products of the Cascades volcanic arc (Phillips and others, 1989).

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DGER, and our USGS colleagues Donald A. Swanson, William E. Scott, and James G. Smith.

SUMMARY OF GEOLOGY

Surficial Deposits

Surficial deposits unconformably overlying Tertiary bedrock include middle and late Pleistocene glacial deposits and latest Pleistocene and Holocene eruptive products of Mount St. Helens volcano. Debris from the volcano makes up much of the valley fill along the South Fork Toutle River, and (unmapped) tephra (chiefly the C and J sets of Mullineaux, 1986) erupted from Mount St. Helens during the last 50,000 years forms a thin but widespread cover in the northern and eastern parts of the Elk Mountain quadrangle.

The area of the quadrangle was little impacted by the May 18, 1980 eruption of Mount St. Helens. During the early stages of that event, a large lahar was generated from pyroclastic surges on the west flank of the volcano. This lahar flowed down the South Fork Toutle River, partially burying older laharic and glacial deposits (Scott, 1988).

Glacial deposits

Drift in the Elk Mountain quadrangle is correlated with similar deposits near Mount Rainier that represent the last two or three major advances of alpine glaciers in the Cascade Range (Crandell and Miller, 1974). The youngest glacial deposits occupy the floors of deep U-shaped valleys in the North Fork Kalama River and Trouble Creek drainages, the bench above the east canyon wall of Trouble Creek, and the area below a cirque occupied by Coweeman Lake on the north side of Elk Mountain. These deposits exhibit well-preserved glacial morphology and contain clasts with weathering rinds much less than 1 mm thick; they are correlated with the Evans Creek Drift deposited during the Fraser glaciation, the last major glacial advance in the Washington Cascade Range (Crandell, 1987). The pair of weakly weathered moraines in the upper Coweeman River provide evidence for two glacial advances during Evans Creek time, possibly corresponding to those recorded by terrace deposits in the Cowlitz River described by Dethier (1988).

Glaciers in the Elk Creek quadrangle during Evans Creek time were mostly restricted to the larger valleys that headed on the steep northern slopes of peaks higher than about 4,000 ft. Earlier in the Pleistocene, however, ice cover in this area was much more extensive, as indicated by widespread older deposits that are correlated with the Hayden Creek Drift on the basis of similar weathering characteristics (Crandell and Miller, 1974). They veneer areas of low relief in the northern two-thirds of the quadrangle and are present sporadically along the lower valley walls of the South Fork Toutle River. Dissected but recognizable moraines of Hayden Creek age are found in several areas. The terminus of a Hayden Creek-age glacier in the South Fork Toutle River is marked by a moraine at the mouth of Whitten Creek (Crandell, 1987). Outwash deposits with similar weathering characteristics crop out along the south bank of the river a few hundred meters to the east. A small glacier extended northward down Bear Creek during Hayden Creek time, but terminated about 3 km upstream from the South Fork Toutle River. Its terminus is marked by a subdued morainal deposit overlain by lacustrine beds presumably deposited in a meltwater lake impounded behind the moraine.

Roadcuts north of the South Fork Toutle River and west of Harrington Creek reveal till and glaciofluvial deposits much more deeply weathered than those of Hayden Creek age. These deposits are probably correlative with the Wingate Hill Drift, although they could be older. The Wingate Hill Drift mantles the lower western slopes of the Cascade Range west of Mount Rainier (Crandell and Miller, 1974; Dethier, 1988) and may be as old as middle Pleistocene (Colman and Pierce, 1981). The exceptionally deep weathering of bedrock in the northwestern part of the Elk Mountain quadrangle is consistent with a long span of time since glacial ice last covered this area.

Deposits of Mount St. Helens volcano

Lahars generated on the slopes of Mount St. Helens have moved down the South Fork Toutle River valley repeatedly during the volcano's 40,000-year history (Crandell, 1987). The deposits of these lahars, and of alluvium composed of reworked laharic debris, are preserved in terrace remnants on both sides of the river in the Elk Mountain quadrangle. The terraces have been studied intensively by Scott (1988), who showed that most of the major eruptive periods of Mount St. Helens (Crandell, 1987) are represented in these deposits. Individual terraces are typically composite features that contain deposits of several eruptive periods; therefore it was not feasible to divide the terrace deposits by eruptive period on this map as was done in the adjacent Goat Mountain quadrangle (Evarts and Ashley, 1990b).

Paleogene Bedrock

The Tertiary section of the Elk Mountain quadrangle consists of a unit of distinctive porphyritic and lesser aphyric flows of tholeiitic basalt (the basalt of Kalama River) conformably underlain and overlain by diverse volcanic and volcaniclastic rocks broadly similar to those exposed elsewhere in the Mount St. Helens area (Evarts and others, 1987; Evarts and Ashley, 1990a, b; 1991; in press a, b, c, d). These rocks strike generally northwesterly and dip to the northeast, forming the northeast flank of the Lakeview Peak anticline (Phillips, 1987), a broad, gently southeast-plunging structure the crest of which crosses the southwesternmost part of the quadrangle near Butler Butte.

The only radiometric age available from the Elk Mountain quadrangle is a whole-rock K-Ar determination of 36.3±2.2 Ma by Phillips and others (1986) for a glassy basaltic andesite flow exposed in a quarry about 1 km west of Big Bull. Although K-Ar ages determined for such glassy (but hydrated) Tertiary rocks in the Cascade Range are commonly unreliable, this result is consistent with regional stratigraphic relations and dates from nearby areas (Phillips and others, 1986; Evarts and Ashley, 1990a), which indicate that strata of the quadrangle range from late Eocene to early Oligocene.

Basalt of Kalama River

A sequence of petrographically and chemically distinctive tholeiitic basalt, informally named the basalt of Kalama River, underlies much of the southwestern part of the Elk Mountain quadrangle as well as large areas south and southeast of the quadrangle (Evarts and Ashley, 1990a; 1991). It varies in thickness from about 400 m in the northwestern part of this quadrangle to more than 1,000 m along the Kalama River in the Lakeview Peak quadrangle to the south. The unit has not been dated directly, but in the Cougar quadrangle it underlies volcaniclastic strata that yielded a K-Ar age of about 36 Ma (latest Eocene; Evarts and Ashley, 1990a).

The basalt of Kalama River contrasts sharply with subjacent and superjacent rocks in consisting solely of basalt flows and generally lacking interbedded volcaniclastic beds. Black, strikingly plagioclase-phyric amygduloidal basalt constitutes approximately 75 percent of the unit. The remainder is composed of virtually aphyric, but chemically similar, basalt. Individual flows are typically sheetlike bodies 4 to 8 m thick; many can be traced as low cliffs for distances exceeding 1 km with little variation in thickness. Typical flows exhibit massive, blocky-jointed interiors that grade upward into highly vesiculated and commonly flow-brecciated tops. A few cliff-forming, relatively coarse-grained basalts near the base of the unit exhibit well developed columnar jointing and lack flow-breccia zones; these are probably sills.

Beds of massive, indurated, brick-red hematitic siltstone, less than 1 m thick, are present between many flows. This siltstone appears to be a combination of fine-grained eolian sediment and lateritic soil that developed *in situ* on flow surfaces; no pumice, shards, or any other detritus indicative of active intermediate to silicic volcanism have been found in these beds. Palagonitic hyaloclastite and pillow breccia are present in the lowermost part of the unit west and northwest of Elk Mountain. Columnar-jointed flows with hackly-fractured entablature zones also crop out in this area. The earliest lavas of this unit, therefore, flowed into a fluvial or shallow subaqueous environment, but voluminous outpourings of basalt rapidly built up a broad subaerial shield volcano. The eruptive source of the basalt flows is unknown, as petrographically equivalent dikes have not been located; however, the increasing thickness of basalt from north to south suggests that the vents lie buried beneath younger Tertiary strata to the south.

Both upper and lower contacts of the basalt of Kalama River are relatively abrupt but appear to be conformable. As mapped, the lower few tens of meters of the unit include minor interbedded tuffaceous mudstone and siltstone. The upper contact is generally quite sharp. However, one isolated basalt flow of Kalama River type, shown as Tb_2, crops out on the north wall of the South Fork Toutle River valley about 70 m above the upper contact as mapped.

The basalt of Kalama River is petrographically and chemically unlike other known Tertiary volcanic rocks in the southern Washington Cascade Range. It consists of olivine-normative, low-potassium, high-alumina tholeiites (table 1; figs. 2, 3, 4, and 5) that closely resemble some oceanic basalts in their major and traceelement geochemistry (Evarts, 1991). The abundant porphyritic flows contain conspicuous phenocrysts and glomerocrysts of blocky, weakly zoned plagioclase as large as 1 cm across accompanied by smaller phenocrysts of olivine. Augite phenocrysts are uncommon, and their modal abundance rarely exceeds 2 percent. Groundmass textures are dominantly diktytaxitic-intergranular to subophitic. The abundant vesicles are invariably filled with secondary minerals, chiefly calcic zeolites and smectites. Preferential weathering of the feldspar phenocrysts and amygdules gives the basalts a characteristic pockmarked appearance on weathered surfaces. Aphyric lavas tend to be less vesicular and possess a finer-grained intergranular groundmass; many of them exhibit a pronounced flow-foliation.

Other Tertiary volcanic and volcaniclastic rocks

The stratigraphic sections above and below the basalt of Kalama River contain diverse rock types that are for the most part typical of those found throughout the southern Washington Cascade Range. They consist largely of andesitic to dacitic pyroclastic and volcanogenic sedimentary rocks interstratified with lava flows that range in composition from subalkaline basalt to dacite. Most flows in this quadrangle are basaltic andesite and andesite (between 52 and 63 percent SiO_2) according to the I.U.G.S. classification shown in figure 2, similar to most other analyzed Tertiary volcanic rocks of the region (Evarts and Ashley, 1990a, b; in press a, b, c, d; Swanson, 1989, 1991). Most plot as calc-alkaline on the classification diagrams of Irvine and Baragar (1971) and Miyashiro (1974) as shown in figures 3 and 4, respectively, and have K_2O contents similar to those of Quaternary volcanic rocks southern Washington (fig. 5). Dacite and rhyolite, which are common components of overlying Oligocene and Miocene strata to the east and northeast, are rare in the Elk Mountain quadrangle.

Rocks beneath the basalt of Kalama River. Almost 1 km of strata is exposed below the basalt of Kalama River in the westernmost part of the Elk Mountain quadrangle. They consist chiefly of interbedded ash-flow tuff, volcaniclastic sandstone and siltstone, porphyritic basalt and basaltic andesite, and several aphyric andesite flows. This section also contains two other notable rock types, ferrobasalt (unit Tfb) and quartzose sandstone (unit Tqs).

Massive and exceptionally fresh tholeiitic ferrobasalt forms the lowest stratigraphic unit in the quadrangle. Well developed columnar jointing and a scarcity of flow breccia in the unit suggest that it is composed mainly of sills rather than flows. The ferrobasalt shares many of the petrographic and chemical characteristics of the basalt of Kalama River but possesses higher contents of iron (total Fe as FeO $\geq$13 wt. percent) and titanium (TiO_2 $\geq$2.4 wt. percent). It is thought to have been derived by extensive differentiation, along a pronounced tholeiitic trend, from magma similar to the basalt of Kalama River. A ferrobasalt dike cuts the basalt of Kalama River in the adjacent Lakeview Peak quadrangle, suggesting that it is younger. Presumably because of its comparatively high density, ferrobasalt magma failed to reach the surface and was instead emplaced as intrusions in the shallow subsurface.

The other unusual (for this area) rock type found below the basalt of Kalama River is muscovite-bearing arkosic sandstone that was derived from a source outside the Cascade arc composed largely of felsic plutonic and metamorphic rocks. Lithofacies characteristics, including the presence of coal seams several centimeters thick, indicate deposition in a fluvial environment. Although the quartzose sandstones are interbedded with quartz-free volcaniclastic rocks, beds that exhibit a mixed volcanic and granitic provenance are absent. This suggests that the quartzose and volcanogenic sands were eroded from entirely different source terrains and delivered to the site of deposition via independent river systems. Quartz-rich feldspathic sedimentary rocks underlie volcanic rocks of the Cascade arc in many places on the flanks of the range, but have not been previously reported from the Mount St. Helens region. Compositionally similar and presumably correlative nearshore deposits of the late Eocene Cowlitz Formation are interbedded with typical Cascade volcaniclastic rocks 25 to 30 km west of the Elk Mountain quadrangle (Roberts, 1958; Phillips, 1987)

Rocks above the basalt of Kalama River: Overlying the basalt of Kalama River are lenticular and sheetlike lava flows of basalt, basaltic andesite, andesite, and minor dacite intercalated with well-bedded volcaniclastic siltstone, sandstone, breccia, and conglomerate, tuff, and pumiceous and lithic lapilli tuff. In the northern part of the quadrangle, a series of distinctive olivine-phyric flows (unit Toba) rests directly on the basalt of Kalama River. These flows are characterized by conspicuous olivine phenocrysts pseudomorphed by red to orange smectite+limonite; in most flows, olivine is the sole phenocryst. Despite their similar appearances, the flows display a range in composition from basalt to andesite. The more felsic compositions reflect contamination of basalt by material of granitic composition, as evidenced by the ubiquitous presence of quartz±feldspar and (or) hornblende xenocrysts. As much as 400 m of these olivine-phyric flows is exposed north of the South Fork Toutle River, but the unit thins rapidly to the south and is absent from the southern half of the quadrangle. In the Lakeview Peak quadrangle to the south, identical olivine-phyric flows (the basaltic andesite of Indian George Creek) occupy a similar stratigraphic position on the southwest flank of the Lakeview Peak anticline (Evarts and Ashley, 1991).

Another prominent component of the Tertiary section above the basalt of Kalama River is the stack of porphyritic two-pyroxene andesite flows that are well exposed in the steep glaciated canyon walls of Trouble Creek. This series of flows can be traced continuously northward as far as the North Fork Toutle River (unit Ta_2), about 14 km north of the Elk Mountain quadrangle (Roberts, 1958; Phillips, 1987). It thins to the southeast and pinches out in the Fossil Creek drainage of the Goat Mountain quadrangle (Evarts and Ashley, 1990b). Phillips and others (1986) obtained a whole-rock K-Ar age of 33.9±1.7 Ma for an andesite of this unit from Signal Peak in the adjoining Toutle Mountain quadrangle to the northwest.

The hornblende dacite that crops out near the north edge of the quadrangle west of Harrington Creek is also noteworthy, because hornblende-phyric extrusive rocks are extremely rare among the Tertiary rocks of the southern Washington Cascade Range, nearly all of which contain pyroxene instead (Evarts and others, 1987). Relatively water-rich magmas capable of stabilizing amphibole did not begin to erupt in abundance until middle Miocene time (Swanson and Evarts, 1992).

Intrusive Rocks

Intrusive rocks are uncommon in the Elk Mountain quadrangle. They are clustered in three areas: the Coweeman River valley, the vicinity of Big Bull, and the northeasternmost part of the quadrangle north of the South Fork Toutle River. Most are thin volcanic-textured dikes and sills; larger phaneritic intrusions crop out only in the Coweeman River area, where relatively coarse-grained bodies of gabbro, quartz diorite, and granodiorite intrude the section below the basalt of Kalama River.

The gabbro (unit Tgb) forms a thin sill intruding ferrobasalt. It is a strikingly porphyritic rock that contains abundant aligned, tabular, highly twinned plagioclase phenocrysts more than 1 cm long. Its chemistry and unique petrography indicate that it is unrelated to any other rock unit in the quadrangle.

Exposed in the bed of the Coweeman River at the west edge of the quadrangle is the eastern contact of a body of medium-grained pyroxene granodiorite. The intrusion extends into the unmapped area to the west, and its size and configuration are unknown. However, the relatively coarse-grained, hypidiomorphic-granular texture of the granodiorite and the widespread presence of altered, locally pyritic, host rock in the vicinity indicate that the intrusion may be fairly large. A possibly related rock, fine-grained porphyritic pyroxene quartz diorite, forms a thick northwest-striking dike north of the Coweeman River. Both rocks display intense deuteric alteration of primary minerals to albite, chlorite, calcite, and other secondary phases.

Volcanic-textured dikes and sills are relatively scarce in this quadrangle compared to adjacent areas to the east (Evarts and Ashley, 1990a, b). They are mostly restricted to the eastern third of the quadrangle, where they exhibit a pronounced preferential strike to the northeast. Dikes of basaltic andesite and andesite north of the South Fork Toutle River appear to mark the western fringe of a large radial dike swarm centered on the 31-Ma intrusive complex at Spud Mountain, about 5 km east-northeast of this quadrangle (Evarts and Ashley, 1990b). Another concentration of similar dikes and sills crops out near Big Bull, but is probably too distant from the Spud Mountain complex to be related to it.

Structure

The axis of the Lakeview Peak anticline, one of several broad, southeast-plunging, major folds in southwestern Washington (Phillips, 1987; Walsh and others, 1987), trends across the southwesternmost part of the Elk Mountain quadrangle. Consequently, most strata in the quadrangle strike northwest and dip moderately (20-25°) to the northeast. Dips flatten slightly to the north as the trough of the Napavine syncline is approached.

Numerous faults have been mapped in the southern half of the quadrangle, although none appear to be major regional features. Most of the faults are marked by zones of brecciated and bleached, hydrothermally altered rock, and several of the fault traces shown are inferred solely from the presence of semi-continuous outcrops of such altered rock. Northeasterly strikes predominate, with an important subsidiary northwest orientation; all appear to have relatively steep dips. Slickensides are rare, so the direction of movement for most of the faults is unknown. Displacement of stratigraphy in a few localities indicates that vertical components of offset are as much as 30 m, but the amount and sense of horizontal movement cannot be determined in most places.

The ages of faulting and folding are unknown. Faults oriented parallel to nearby dikes, such as those near the headwaters of Trouble Creek and in the northeastern part of quadrangle, presumably formed at the same time as the dikes and are thus probably Tertiary, but none of the dikes have been dated directly, so a more precise estimate is not possible. There is no evidence to suggest that any faults have been active recently. If the Lakeview Peak anticline was formed at the same time as folds elsewhere in the southern Washington Cascades, it is probably Miocene because relations northeast of the quadrangle suggest that most folding occurred between about 20 and 12 Ma (Evarts and others, 1987; Swanson, 1989; Swanson and Evarts, 1992).

Metamorphism and hydrothermal alteration

The Tertiary rocks of the Elk Mountain quadrangle have been subjected to zeolite-facies regional metamorphism, the general character of which is similar to that described from other areas in the southern Washington Cascade Range (Fiske and others, 1963; Wise, 1970; Evarts and others, 1987). This metamorphism reflects burial beneath overlying strata in the relatively high-heat-flow environment of an active volcanic arc. Neither the grade of metamorphism nor the extent of recrystallization increase noticeably with stratigraphic depth within the quadrangle. The very low grade of metamorphism suggests that the rocks of the quadrangle were never buried as deeply as the more-than-7-km aggregate thickness of younger volcanic rocks to the east might imply.

Metasomatic hydrothermal alteration was observed at several localities within the Elk Mountain quadrangle, most commonly as narrow argillized zones along faults. These altered fault zones are composed entirely of amorphous to poorly crystalline kaolinitic clay minerals with or without minor quartz or limonite. In addition, larger and more diffuse zones of sporadic to pervasive alteration not obviously associated with faulting are present in the vicinty of Harrington Creek, in the valley of Bear Creek west of Little Cow, and in the northern part of the Coweeman River drainage. The Coweeman River occurrences are clearly related to the quartz diorite and granodiorite intrusions; in addition to clay minerals, these zones contain significant amounts of pyrite and carbonates. The cause of alteration at the other two localities is enigmatic, as no intrusive bodies are exposed nearby. They may have been produced by hydrothermal fluids moving laterally away from fault zones along permeable volcaniclastic beds.

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______in press c, Geologic map of the Spirit Lake West quadrangle, Cowlitz and Skamania Counties, Washington: U.S. Geological Survey Geologic Quadrangle Map GQ-1681, scale 1:24,000.

______in press d , 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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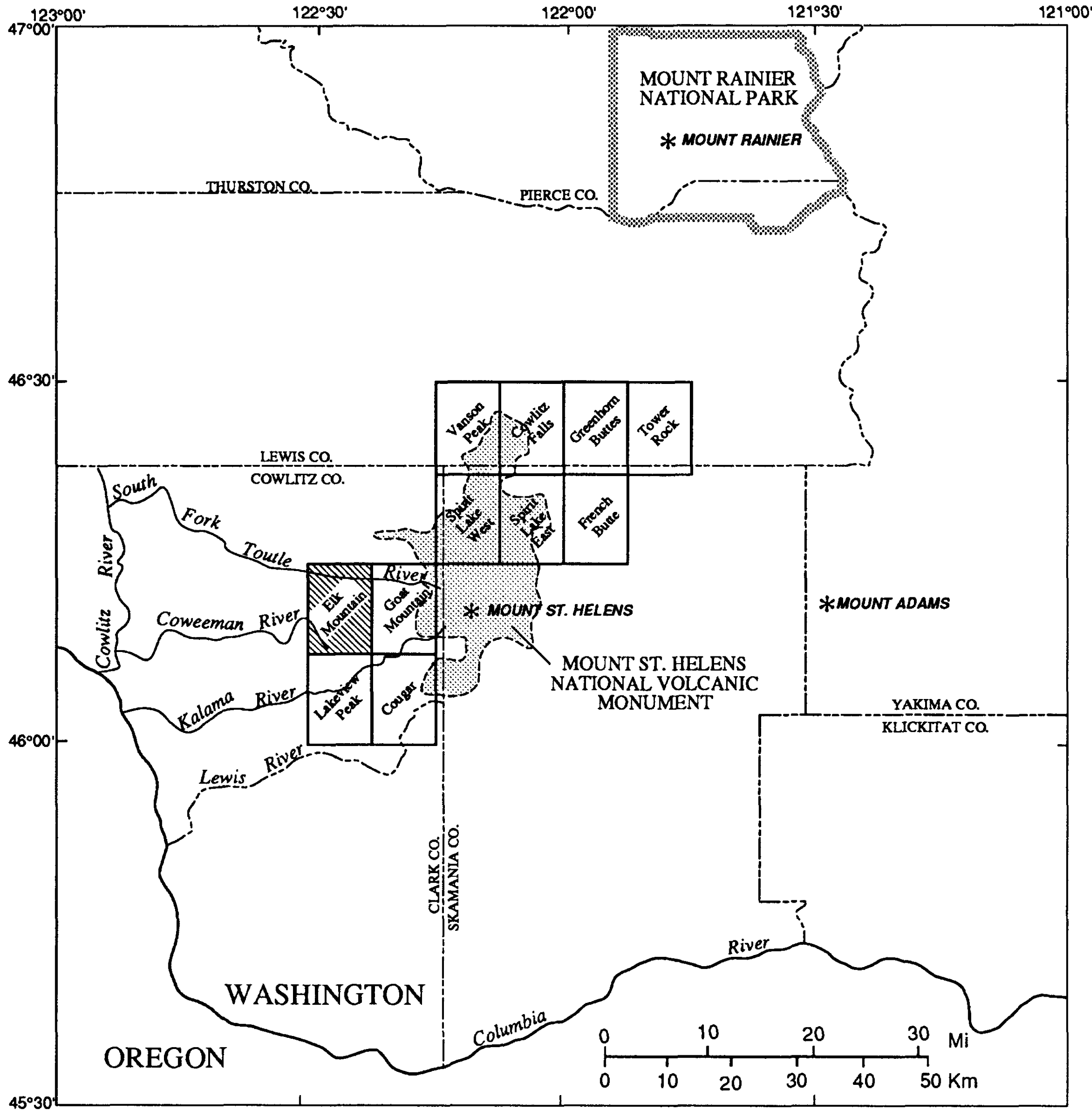


Figure 1.--Index map of southern Wasington showing location of Elk Mountain quadrangle and other 7-1/2 minute quadrangles recently mapped by the USGS.

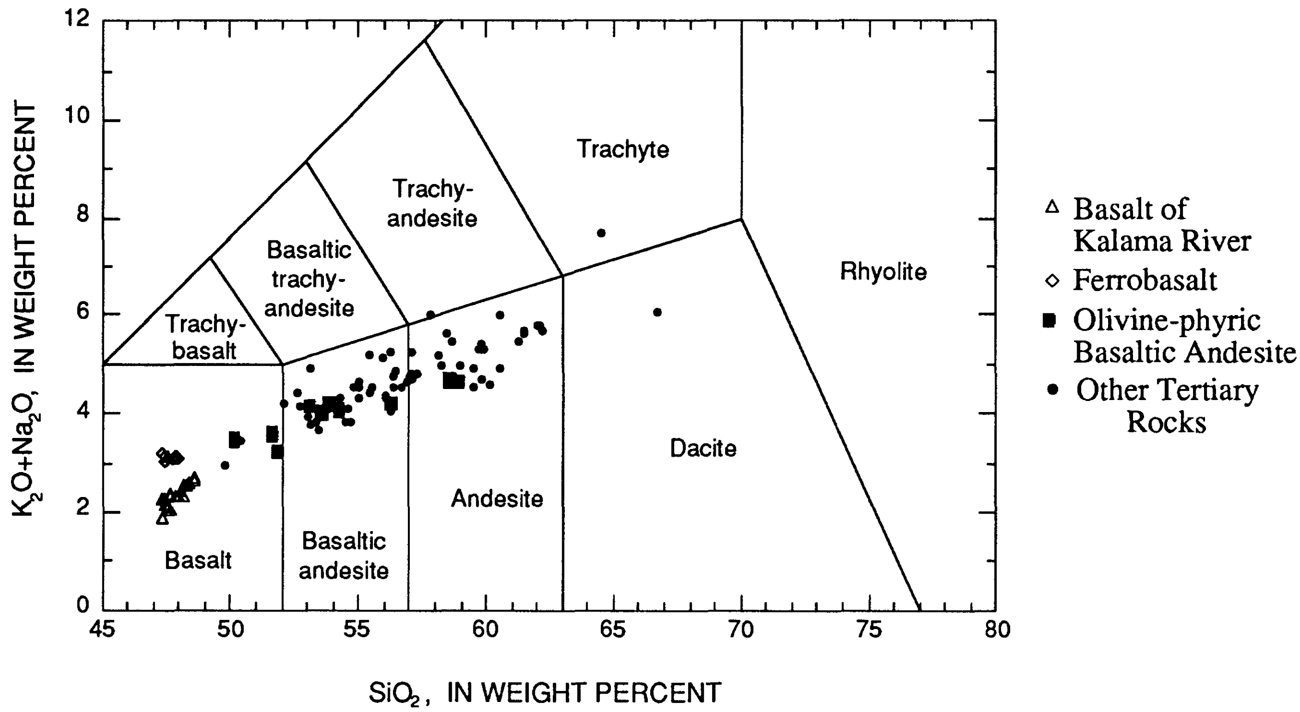


Figure 2.--K_2O+Na_2O versus SiO_2 (recalculated volatile-free) for volcanic and plutonic rocks from Elk Mountain quadrangle showing classification according to I.U.G.S. (Le Bas and Streckeisen, 1991).

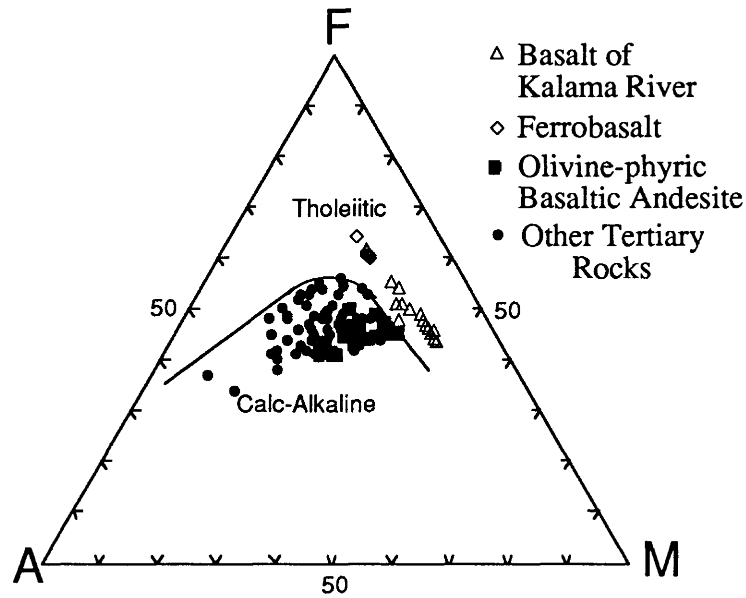


Figure 3.--AFM diagram for volcanic and plutonic rocks from Elk Mountain quadrangle. A, K_2O+Na_2O; F, $FeO+Fe_2O_3+MnO$; M, MgO. Line separating tholeiitic and calc-alkaline fields from Irvine and Baragar (1971).

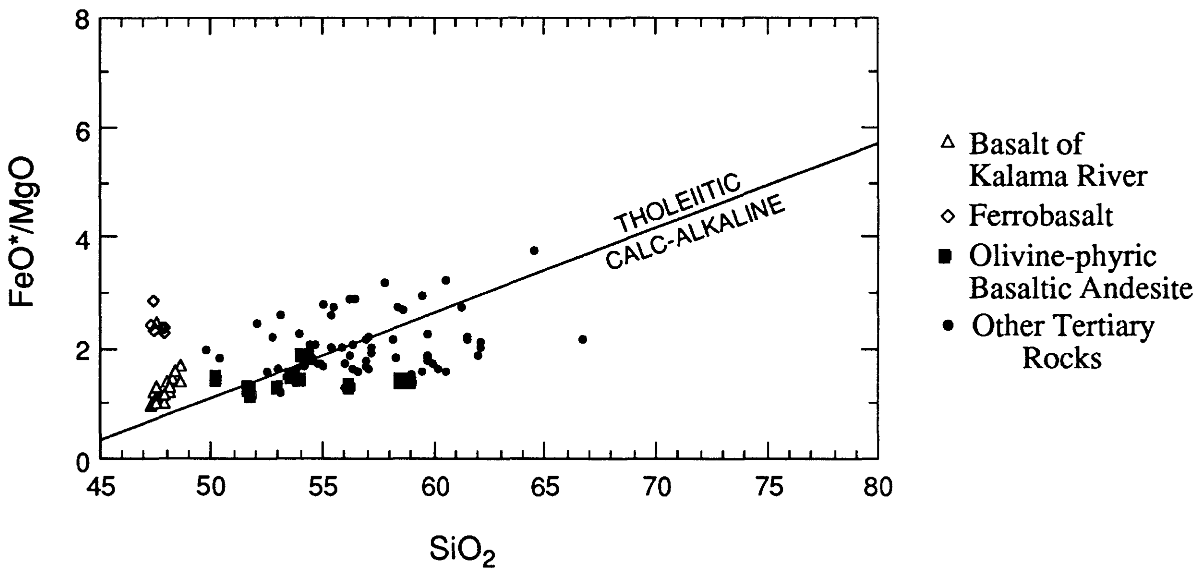


Figure 4.--FeO*/MgO versus SiO_2 (recalculated volatile-free) for volcanic and plutonic rocks from Elk Mountain quadrangle showing classification into tholeiitic and calc-alkaline rocks according to Miyashiro (1974). FeO*, total Fe as FeO.

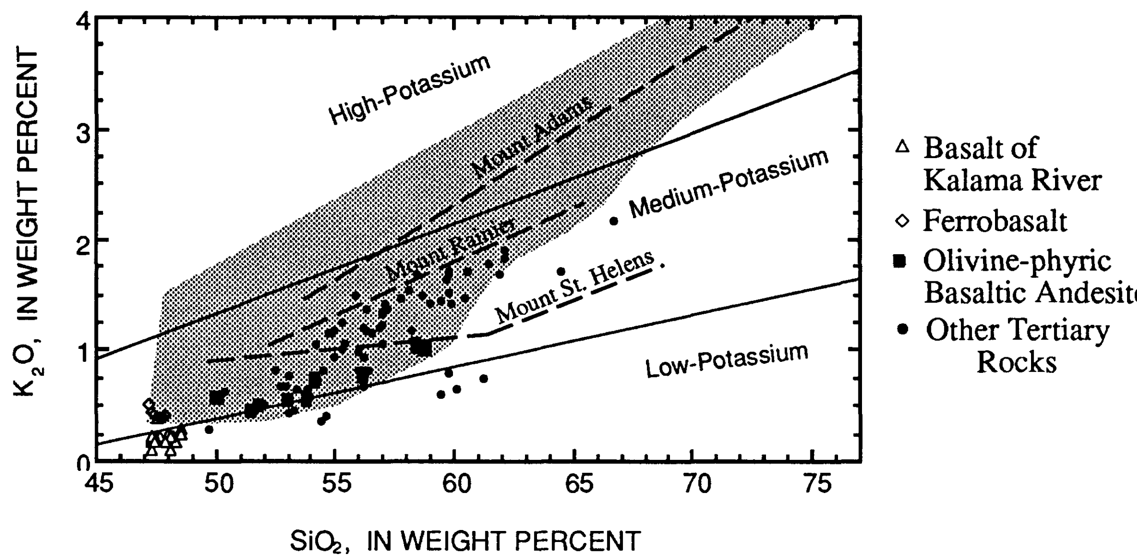


Figure 5.--K_2O versus SiO_2 (recalculated volatile-free) for volcanic and plutonic rocks from Elk Mountain quadrangle. Low-, medium-, and high-potassium fields from Gill (1981, p. 6). Shaded area encompasses compositions of Quaternary volcanic rocks, exclusive of major stratovolcanoes, of southern Washington 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).

Table 1.--*Chemical analyses of volcanic and plutonic rocks, Elk Mountain quadrangle*

[Oxides in weight percent. Rock type assigned in accordance with I.U.G.S. system (Le Bas and Streckeisen, 1991) applied to analyses recalculated volatile-free for volcanic rocks. X-ray fluorescence analyses by methods described in 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, K. Lewis, and S. Pribble.]

Map No.	1	2	3	4	5	6	7	8	9
Field sample No.	**90CG-V727**	**90CG-V728**	**89CG-V473**	**89CG-V544**	**90CG-V686**	**89CG-V478**	**90CG-V622**	**89CG-V527**	**90CG-A249**
Latitude	46°08'57"	46°09'17"	46°07'45"	46°08'42"	46°12'05"	46°07'36"	46°09'54"	46°08'55"	46°08'52"
Longitude	122°27'27"	122°27'30"	122°27'59"	122°26'02"	122°26'58"	122°28'23"	122°27'39"	122°25'31"	122°27'05"
Map unit	Tbk	Tbk	Tbk	Tbk	Tbk	Tbk	Tbk	Tbk	Tbk
Rock type	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt
SiO_2	46.3	46.4	46.4	46.4	46.5	46.6	46.6	46.7	46.7
TiO_2	0.86	1.2	1.10	0.91	1.19	1.19	1.16	1.43	1.13
Al_2O_3	20.7	17.70	17.1	21.4	16.2	16.8	17.0	16.1	18.3
Fe_2O_3	1.36	3.15	1.83	2.21	2.71	1.73	1.87	3.76	3.18
FeO	5.80	6.50	7.36	4.98	7.20	7.81	7.50	6.70	5.90
MnO	0.11	0.15	0.15	0.11	0.17	0.16	0.15	0.17	0.14
MgO	7.14	7.86	9.45	5.39	9.48	9.23	8.92	8.61	7.93
CaO	13.6	12.6	12.2	13.9	11.8	12.4	12.6	12.1	12.7
Na_2O	1.72	1.90	2.05	1.96	2.10	1.99	1.93	2.09	1.86
K_2O	0.12	0.21	0.18	0.18	0.20	0.22	0.18	0.20	0.22
P_2O_5	0.09	0.13	0.12	0.10	0.11	0.13	0.12	0.14	0.11
H_2O^+	2.00	1.60	1.67	1.80	2.00	1.70	1.80	0.69	1.40
H_2O^-	0.79	0.83	0.86	0.88	0.82	0.74	0.75	1.45	0.63
CO_2	0.01	0.01	<0.01	0.02	0.01	<0.01	0.02	<0.01	0.01
Total	100.60	100.28	100.47	100.24	100.49	100.70	100.60	100.14	100.21

Table 1.--*Chemical analyses of volcanic and plutonic rocks, Elk Mountain quadrangle, continued*

Map No.	10	11	12	13	14	15	16	17	18
Field sample No.	**90CG-V725**	**90CG-V735**	**89CG-V554**	**90CG-V598**	**90CG-V624C**	**88CG-V441A**	**90CG-V608**	**89CG-V559B**	**90CG-V691B**
Latitude	46°09'36"	46°10'36"	46°07'44"	46°10'49"	46°09'16"	46°07'51"	46°11'55"	46°08'56"	46°09'49"
Longitude	122°29'47"	122°29'46"	122°25'32"	122°27'19"	122°28'06"	122°25'13"	122°28'11"	122°26'50"	122°29'43"
Map unit	Tfb	Tfb	Tbk	Tbk	Tbk	Tbk	Tbk	Tbk	Tfb
Rock type	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt
SiO_2	46.8	46.9	46.9	46.9	46.9	47.0	47.1	47.2	47.3
TiO_2	3.02	2.44	1.34	1.39	2.70	1.09	1.34	1.20	2.49
Al_2O_3	14.1	15.6	16.5	17.2	14.7	18.0	16.1	16.4	15.4
Fe_2O_3	4.10	3.73	3.50	2.60	4.39	2.21	3.66	3.26	3.47
FeO	11.0	9.70	7.12	7.30	10.1	6.80	6.70	6.61	10.2
MnO	0.25	0.21	0.16	0.16	0.23	0.15	0.17	0.16	0.22
MgO	5.11	5.68	7.86	6.85	5.66	8.33	8.77	9.26	5.62
CaO	10.9	11.2	11.3	12.7	10.5	12.8	12.0	12.0	11.0
Na_2O	2.67	2.60	2.25	2.14	2.69	1.80	2.12	2.15	2.65
K_2O	0.44	0.42	0.22	0.24	0.39	0.24	0.17	0.17	0.40
P_2O_5	0.34	0.28	0.14	0.14	0.30	0.11	0.14	0.12	0.29
H_2O^+	1.30	0.94	1.64	1.60	0.80	1.71	1.40	0.94	0.71
H_2O^-	1.00	0.88	1.10	0.70	1.20	0.30	0.78	0.64	0.39
CO_2	0.01	0.02	0.02	0.01	0.01	0.05	0.02	<0.01	<0.01
Total	101.04	100.60	100.05	99.93	100.57	100.59	100.47	100.11	100.14

Table 1.--*Chemical analyses of volcanic and plutonic rocks, Elk Mountain quadrangle, continued*

Map No.	19	20	21	22	23	24	25	26	27
Field sample No.	**90CG-V738**	**89CG-V562**	**90CG-V726**	**90CG-A251**	**90CG-V669**	**89CG-V557**	**90CG-V639**	**90CG-V654D**	**90CG-V693**
Latitude	46°09'39"	46°07'48"	46°09'47"	46°09'34"	46°08'31"	46°08'07"	46°12'56"	46°09'28"	46°09'50"
Longitude	122°28'54"	122°27'49"	122°29'41"	122°26'45"	122°27'45"	122°27'31"	122°29'26"	122°28'56"	122°29'29"
Map unit	Tfb	Tbk	Tfb	Tbk	Tbk	Tbk	Tbk	Tfb	Tfb
Rock type	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt
SiO_2	47.3	47.4	47.4	47.4	47.4	47.5	47.5	47.6	47.6
TiO_2	2.49	1.34	2.49	1.50	1.36	1.73	1.60	2.43	2.53
Al_2O_3	15.5	18.1	15.6	16.2	16.1	15.0	15.5	15.5	15.5
Fe_2O_3	4.19	2.25	4.49	5.05	3.45	3.01	4.42	3.51	2.92
FeO	9.20	7.16	10.1	5.90	6.80	8.46	7.10	9.90	10.7
MnO	0.20	0.15	0.22	0.17	0.16	0.19	0.20	0.21	0.23
MgO	5.43	6.24	5.81	7.37	8.10	6.54	6.96	5.72	5.62
CaO	11.1	12.9	10.6	11.2	12.6	12.4	12.1	11.1	11.0
Na_2O	2.64	2.28	2.67	2.32	2.16	2.37	2.35	2.65	2.72
K_2O	0.40	0.22	0.52	0.24	0.10	0.29	0.19	0.42	0.39
P_2O_5	0.28	0.14	0.29	0.14	0.14	0.17	0.15	0.28	0.29
H_2O^+	0.96	1.51	0.74	1.60	1.00	1.68	1.30	0.57	0.61
H_2O^-	0.66	0.76	0.60	1.60	1.40	0.78	0.93	0.53	0.49
CO_2	0.01	<0.01	0.01	0.02	0.01	<0.01	<0.01	0.01	<0.01
Total	100.36	100.45	101.54	100.71	100.78	100.12	100.30	100.43	100.60

Table 1.--*Chemical analyses of volcanic and plutonic rocks, Elk Mountain quadrangle, continued*

Map No.	28	29	30	31	32	33	34	35	36
Field sample No.	**90CG-V723D**	**90CG-V773B**	**90CG-V692B**	**89CG-V566C**	**90CG-V743**	**87CG-V193**	**90CG-V672**	**89CG-V543A**	**90CG-V671**
Latitude	46°09'17"	46°14'18"	46°09'54"	46°09'22"	46°10'24"	46°09'17"	46°11'50"	46°09'17"	46°12'08"
Longitude	122°29'48"	122°25'47"	122°29'38"	122°25'09"	122°25'46"	122°22'43"	122°26'15"	122°24'10"	122°26'18"
Map unit	Tb_1	Toba	Tgb	Tb_2	Tb_2	Tba_2	Tb_2	Tb_2	Toba
Rock type	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt
SiO_2	48.4	49.0	49.1	49.2	50.0	50.2	50.2	50.6	50.3
TiO_2	1.54	1.37	1.91	1.56	2.11	1.04	2.45	1.94	1.19
Al_2O_3	18.9	17.0	16.2	17.4	15.6	16.0	14.9	16.0	16.6
Fe_2O_3	4.57	6.04	5.21	6.06	5.76	3.54	6.08	5.25	4.12
FeO	4.60	3.60	5.40	4.00	5.40	5.65	6.60	6.17	4.90
MnO	0.19	0.20	0.19	0.14	0.17	0.17	0.21	0.18	0.14
MgO	4.47	6.18	5.50	5.34	4.61	7.98	4.52	4.50	7.20
CaO	11.4	10.6	10.2	9.99	9.28	9.55	8.67	9.09	9.22
Na_2O	2.58	2.80	2.74	3.12	3.42	2.62	3.64	3.65	3.03
K_2O	0.29	0.58	0.60	0.55	0.62	0.17	0.57	0.59	0.46
P_2O_5	0.26	0.26	0.34	0.29	0.34	0.17	0.59	0.29	0.23
H_2O^+	0.61	0.57	1.20	0.91	0.66	0.93	0.60	0.69	1.30
H_2O^-	1.90	1.70	1.80	1.54	2.30	2.20	1.30	1.45	1.60
CO_2	0.02	0.03	0.06	0.01	0.02	0.02	<0.01	<0.01	0.01
Total	99.73	99.93	100.45	100.11	100.29	100.24	100.33	100.40	100.30

Table 1.--*Chemical analyses of volcanic and plutonic rocks, Elk Mountain quadrangle, continued*

Map No.	37	38	39	40	41	42	43	44	45
Field sample No.	**90CG-V676**	**89CG-V573B**	**88CG-V398B**	**89CG-V565B**	**89CG-V575**	**89CG-V578**	**89CG-V543B**	**87CG-V191**	**89CG-V569A**
Latitude	46°14'38"	46°10'21"	46°13'42"	46°09'32"	46°10'42"	46°11'11"	46°09'14"	46°08'02"	46°09'53"
Longitude	122°28'43"	122°26'09"	122°26'06"	122°24'59"	122°26'12"	122°24'58"	122°24'20"	122°22'56"	122°25'22"
Map unit	Toba	Tba_2	Toba	Tb_2	Tba_2	Tiba	Tba_2	Tba_2	Tba_2
Rock type	Basalt	Basaltic andesite	Basalt	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite
SiO_2	50.3	50.9	51.2	51.3	51.5	51.6	51.7	52.1	52.2
TiO_2	1.52	1.38	1.35	1.90	1.39	1.28	1.20	1.89	2.27
Al_2O_3	16.3	16.9	15.2	15.7	15.9	17.1	16.3	15.5	15.7
Fe_2O_3	4.13	5.11	4.32	4.31	2.64	3.57	3.76	5.62	4.28
FeO	5.10	3.59	5.30	7.11	6.26	5.11	4.72	5.30	6.41
MnO	0.16	0.32	0.16	0.18	0.17	0.20	0.13	0.15	0.17
MgO	6.79	5.24	8.08	4.44	5.80	5.14	6.76	4.69	3.99
CaO	9.40	8.73	9.79	9.11	8.80	9.24	8.81	9.01	8.01
Na_2O	3.05	3.48	2.74	3.66	3.26	3.17	3.27	3.46	4.11
K_2O	0.46	0.79	0.49	0.50	0.43	0.65	0.43	0.66	0.75
P_2O_5	0.24	0.38	0.23	0.24	0.34	0.28	0.21	0.36	0.41
H_2O^+	1.00	0.94	0.67	0.61	0.79	1.07	0.78	0.40	0.40
H_2O^-	1.90	2.06	0.83	0.98	0.96	1.73	1.91	0.88	1.12
CO_2	0.01	0.01	0.01	<0.01	1.94	0.36	0.01	<0.01	<0.01
Total	100.36	99.83	100.37	100.04	100.18	100.50	99.99	100.02	99.82

Table 1.--*Chemical analyses of volcanic and plutonic rocks, Elk Mountain quadrangle, continued*

Map No.	46	47	48	49	50	51	52	53	54
Field sample No.	**90CG-V748B**	**90CG-V688**	**90CG-V755**	**90CG-V718**	**90CG-V750**	**89CG-V583**	**90CG-V690**	**89CG-V572**	**90CG-A243B**
Latitude	46°14'01"	46°14'26"	46°14'17"	46°13'34"	46°14'06"	46°11'49"	46°08'47"	46°10'18"	46°11'20"
Longitude	122°27'45"	122°29'44"	122°23'02"	122°27'33"	122°28'53"	122°24'15"	122°29'39"	122°25'00"	122°23'36"
Map unit	Toba	Toba	Tba_2	Toba	Toba	Tba_2	Tba_1	Tba_2	Ta_2
Rock type	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite
SiO_2	52.2	52.4	52.5	52.9	52.9	53.1	53.1	53.2	53.3
TiO_2	1.18	1.49	1.12	1.23	1.67	1.42	1.34	1.60	1.36
Al_2O_3	16.9	16.2	17.3	17.2	16.3	17.1	16.4	16.4	17.2
Fe_2O_3	4.34	4.24	5.45	3.96	4.23	3.18	4.32	3.71	4.24
FeO	4.20	4.80	3.30	4.30	5.20	5.18	4.00	6.12	4.20
MnO	0.13	0.13	0.14	0.32	0.14	0.14	0.14	0.15	0.15
MgO	6.40	5.65	5.24	5.43	4.95	4.96	4.53	4.22	4.75
CaO	8.63	8.60	9.37	8.48	7.89	9.16	8.28	8.60	8.55
Na_2O	3.56	3.34	2.94	3.60	3.23	3.38	3.05	3.62	3.22
K_2O	0.55	0.62	0.64	0.56	0.72	0.65	1.12	0.58	1.03
P_2O_5	0.19	0.36	0.18	0.20	0.32	0.23	0.32	0.32	0.23
H_2O^+	0.31	0.80	0.87	0.59	0.69	0.82	1.00	0.67	0.70
H_2O^-	1.70	1.30	1.50	1.40	2.10	0.72	2.20	0.86	1.10
CO_2	0.02	0.03	0.01	0.02	0.02	<0.01	0.14	0.02	<0.01
Total	100.31	99.96	100.56	100.19	100.36	100.04	99.94	100.07	100.03

Table 1.--*Chemical analyses of volcanic and plutonic rocks, Elk Mountain quadrangle, continued*

Map No.	55	56	57	58	59	60	61	62	63
Field sample No.	**90CG-V595B**	**90CG-V694**	**90CG-V683A**	**90CG-V631**	**90CG-V684D**	**90CG-V747**	**90CG-V665B**	**90CG-V689**	**90CG-V628**
Latitude	46°09'35"	46°09'20"	46°07'57"	46°07'56"	46°08'33"	46°10'28"	46°11'17"	46°08'07"	46°08'56"
Longitude	122°22'38"	122°29'03"	122°29'26"	122°29'48"	122°29'36"	122°25'20"	122°29'29"	122°29'39"	122°29'05"
Map unit	Tba_2	Tba_1	Tba_1	Tba_1	Tba_1	Tiba	Tba_1	Tba_1	Tba_1
Rock type	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite
SiO_2	53.3	53.3	53.3	53.4	53.5	53.8	53.9	54.6	54.8
TiO_2	1.41	1.29	1.19	1.19	1.35	2.30	1.36	1.46	1.47
Al_2O_3	17.0	16.4	18.2	18.2	16.6	14.6	16.9	16.5	17.1
Fe_2O_3	4.65	3.35	3.41	3.43	3.66	3.38	3.73	3.45	3.56
FeO	3.90	4.80	4.60	4.50	4.70	7.20	4.70	4.20	4.20
MnO	0.17	0.13	0.21	0.14	0.14	0.16	0.18	0.12	0.11
MgO	4.50	4.73	3.76	3.69	4.67	3.69	4.00	3.86	3.69
CaO	8.62	8.13	9.29	9.06	8.35	7.46	7.89	8.31	7.69
Na_2O	3.18	3.28	3.37	3.33	3.28	3.64	3.32	3.49	3.59
K_2O	0.81	1.14	0.36	0.40	1.13	0.91	0.98	0.66	1.47
P_2O_5	0.16	0.30	0.20	0.20	0.31	0.68	0.31	0.36	0.34
H_2O^+	1.00	0.90	1.10	0.80	1.00	1.30	1.30	1.70	1.10
H_2O^-	1.10	1.20	1.30	1.40	1.30	1.20	1.60	1.30	1.40
CO_2	0.04	0.02	0.04	0.01	0.13	0.01	0.03	0.01	0.01
Total	99.84	98.97	100.33	99.75	100.12	100.33	100.20	100.02	100.53

Table 1.--*Chemical analyses of volcanic and plutonic rocks, Elk Mountain quadrangle, continued*

Map No.	64	65	66	67	68	69	70	71	72
Field sample No.	**89CG-V584B**	**90CG-V776**	**90CG-A259**	**89CG-V584A**	**90CG-A232**	**90CG-V680**	**89CG-V584C**	**90CG-A208**	**90CG-V642**
Latitude	46°11'05"	46°09'45"	46°10'34"	46°11'08"	46°14'38"	46°11'12"	46°11'05"	46°12'43"	46°13'08"
Longitude	122°24'16"	122°23'11"	122°23'23"	122°24'16"	122°25'50"	122°25'46"	122°24'22"	122°23'34"	122°27'03"
Map unit	Tba_2	Tba_2	Tba_2	Tba_2	Tba_2	Tba_2	Tiba	Tma	Toba
Rock type	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite
SiO_2	54.9	54.9	54.9	55.1	55.1	55.2	55.4	55.4	55.4
TiO_2	1.70	1.05	1.73	0.95	1.07	1.86	1.95	0.70	0.95
Al_2O_3	16.6	15.7	17.1	19.0	17.4	15.8	15.0	17.1	16.7
Fe_2O_3	4.57	3.58	5.14	3.24	3.91	5.19	3.24	2.98	4.08
FeO	4.67	4.40	3.80	3.31	3.50	4.60	6.72	3.80	3.50
MnO	0.16	0.14	0.15	0.12	0.11	0.15	0.16	0.11	0.14
MgO	3.37	5.95	3.08	3.61	4.33	3.20	3.34	5.08	5.38
CaO	7.74	7.80	8.21	8.54	7.43	6.53	7.21	9.14	8.08
Na_2O	3.88	3.27	3.47	3.50	3.32	4.21	3.99	2.77	3.32
K_2O	1.24	0.97	1.04	0.81	1.34	0.92	0.79	1.19	0.78
P_2O_5	0.25	0.17	0.25	0.17	0.23	0.41	0.30	0.15	0.16
H_2O^+	0.39	0.66	0.79	0.34	0.70	0.80	1.27	0.86	0.66
H_2O^-	0.60	1.70	0.91	1.16	1.20	1.10	0.55	0.94	0.84
CO_2	<0.01	0.06	<0.01	<0.01	0.02	0.01	<0.01	0.01	0.01
Total	100.07	100.35	100.57	99.85	99.66	99.98	99.92	100.23	100.00

Table 1.--*Chemical analyses of volcanic and plutonic rocks, Elk Mountain quadrangle, continued*

Map No.	73	74	75	76	77	78	79	80	81
Field sample No.	**90CG-A253B**	**90CG-A230**	**90CG-A210B**	**88CG-V419B**	**90CG-A244**	**89CG-V508**	**90CG-V706**	**90CG-V591**	**88CG-V420**
Latitude	46°11'21"	46°14'38"	46°12'25"	46°10'17"	46°11'21"	46°08'34"	46°14'58"	46°12'32"	46°10'36"
Longitude	122°22'46"	122°22'59"	122°22'55"	122°23'39"	122°23'40"	122°24'20"	122°27'24"	122°23'52"	122°24'20"
Map unit	Ta_2	Ta_2	Ta_2	Ta_2	Ta_2	Ta_2	Ta_2	Ta_2	Ta_2
Rock type	Basaltic andesite	Andesite	Basaltic andesite	Andesite	Andesite	Andesite	Andesite	Basaltic andesite	Andesite
SiO_2	55.6	55.7	55.8	55.9	55.9	56.0	56.0	56.1	56.3
TiO_2	1.29	1.32	1.15	1.41	1.32	1.49	1.09	1.14	1.18
Al_2O_3	16.8	15.9	16.0	16.4	15.9	17.2	17.2	16.1	16.0
Fe_2O_3	4.10	3.92	3.90	4.18	4.19	3.29	4.11	4.33	4.42
FeO	4.30	4.40	4.20	4.03	4.20	4.20	3.20	3.70	3.80
MnO	0.15	0.12	0.15	0.14	0.14	0.13	0.11	0.13	0.12
MgO	3.88	4.14	4.93	3.61	3.99	3.26	4.20	4.53	4.40
CaO	7.85	7.09	7.69	7.46	6.99	7.09	7.24	7.67	7.59
Na_2O	3.32	3.19	3.30	3.36	3.33	4.13	3.39	3.41	3.47
K_2O	1.15	1.38	1.14	1.30	1.35	1.03	1.33	1.19	1.22
P_2O_5	0.25	0.29	0.25	0.29	0.29	0.31	0.24	0.25	0.25
H_2O^+	0.70	0.80	0.74	0.74	0.60	0.60	0.59	0.76	0.37
H_2O^-	0.90	1.20	0.96	1.07	1.20	1.05	1.10	0.74	0.99
CO_2	0.01	<0.01	0.02	0.11	0.02	0.02	<0.01	0.01	0.07
Total	100.30	99.45	100.23	100.00	99.42	99.80	99.80	100.06	100.18

Table 1.--*Chemical analyses of volcanic and plutonic rocks, Elk Mountain quadrangle, continued*

Map No.	82	83	84	84	86	87	88	89	90
Field sample No.	**88CG-V422**	**90CG-V745**	**89CG-V581A**	**90CG-V760**	**90CG-V656**	**90CG-V696**	**87CG-V195**	**90CG-A221A**	**90CG-V707**
Latitude	46°10'49"	46°10'20"	46°12'23"	46°14'08"	46°08'08"	46°09'19"	46°09'58"	46°11'57"	46°14'14"
Longitude	122°23'42"	122°25'31"	122°24'02"	122°27'26"	122°30'00"	122°24'48"	122°22'49"	122°22'52"	122°28'06"
Map unit	Tia	Ta_2	Ta_2	Toba	Ta_1	Ta_2	Ta_2	Tma	Toba
Rock type	Andesite	Andesite	Andesite	Andesite	Andesite	Andesite	Andesite	Andesite	Andesite
SiO_2	56.7	56.9	57.2	57.2	57.2	57.3	57.6	57.8	58.0
TiO_2	1.45	1.83	1.38	0.99	1.78	1.12	1.49	0.72	0.98
Al_2O_3	15.5	15.5	15.7	16.4	15.7	16.9	16.3	16.3	16.3
Fe_2O_3	2.78	4.80	3.68	3.31	4.16	3.61	5.02	3.08	3.04
FeO	4.88	4.20	4.42	3.40	4.30	3.40	2.88	3.30	3.70
MnO	0.15	0.18	0.14	0.14	0.13	0.13	0.12	0.15	0.11
MgO	2.54	2.67	3.55	4.51	2.91	3.70	2.76	3.81	4.64
CaO	6.64	5.87	6.84	7.13	5.65	7.05	6.31	7.00	7.05
Na_2O	3.76	4.45	3.60	3.52	3.87	3.73	3.87	3.34	3.56
K_2O	0.58	1.44	1.52	1.02	1.65	1.17	1.47	1.41	1.01
P_2O_5	0.29	0.61	0.31	0.18	0.48	0.22	0.31	0.17	0.18
H_2O^+	2.64	0.24	0.60	0.82	0.90	0.60	0.60	1.00	0.63
H_2O^-	1.86	1.30	0.83	1.50	1.30	1.00	1.03	1.50	1.10
CO_2	0.06	0.01	<0.01	0.03	0.01	<0.01	<0.01	<0.01	0.01
Total	99.83	100.00	99.77	100.15	100.04	99.93	99.76	99.58	100.31

Table 1.--*Chemical analyses of volcanic and plutonic rocks, Elk Mountain quadrangle, continued*

Map No.	91	92	93	94	95	96	97	98	99
Field sample No.	**88CG-V397**	**88CG-V292A**	**90CG-V756**	**90CG-V733**	**88CG-V427**	**89CG-V586**	**89CG-V577A**	**90CG-A198**	**90CG-A205**
Latitude	46°13'30"	46°10'08"	46°14'07"	46°10'17"	46°13'16"	46°11'07"	46°11'52"	46°13'06"	46°12'41"
Longitude	122°23'41"	122°24'03"	122°23'07"	122°29'21"	122°23'34"	122°24'52"	122°25'02"	122°24'58"	122°24'52"
Map unit	Ta_2	Tia	Ta_2	Tia	Ta_2	Ta_2	Ta_2	Ta_2	Ta_2
Rock type	Andesite	Andesite	Andesite	Andesite	Andesite	Andesite	Andesite	Andesite	Andesite
SiO_2	58.0	58.4	58.5	58.6	58.6	58.9	58.9	58.9	59.0
TiO_2	1.04	1.11	1.10	1.63	1.09	1.09	0.94	0.95	1.09
Al_2O_3	16.1	16.2	16.0	15.0	16.2	16.7	16.7	16.3	16.1
Fe_2O_3	3.19	1.95	3.47	2.12	3.21	3.34	2.40	2.30	3.66
FeO	3.60	4.80	3.40	5.50	3.57	3.43	3.75	4.10	3.20
MnO	0.10	0.11	0.10	0.14	0.11	0.09	0.12	0.11	0.11
MgO	4.28	3.49	3.57	2.30	3.53	2.87	3.40	3.84	3.66
CaO	6.88	6.80	6.39	5.17	6.47	6.69	6.70	6.65	6.31
Na_2O	3.47	3.83	3.54	4.14	3.57	3.70	3.77	3.87	3.64
K_2O	1.40	0.77	1.65	1.66	1.61	1.49	1.41	0.64	1.70
P_2O_5	0.19	0.21	0.10	0.46	0.20	0.21	0.20	0.20	0.21
H_2O^+	0.88	1.21	0.75	2.10	1.63	0.49	0.33	1.70	0.61
H_2O^-	0.91	0.45	1.10	0.52	0.16	0.74	0.44	0.58	0.89
CO_2	0.10	0.07	0.02	0.02	0.12	0.01	0.05	<0.01	0.02
Total	100.14	99.40	99.69	99.36	100.07	99.75	99.11	100.14	100.20

Table 1.--*Chemical analyses of volcanic and plutonic rocks, Elk Mountain quadrangle, continued*

Map No.	100	101	102	103	104	105	106	107*	108*
Field sample No.	**90CG-V711B**	**90CG-A226**	**89CG-V483**	**90CG-A203**	**90CG-V705**	**88CG-V428**	**90CG-V713**	**90CG-V724**	**90CG-V704**
Latitude	46°14'24"	46°14'22"	46°14'48"	46°12'50"	46°14'44"	46°13'16"	46°14'06"	46°09'20"	46°15'03"
Longitude	122°25'20"	122°24'39"	122°23'46"	122°24'18"	122°27'19"	122°24'19"	122°24'35"	122°30'04"	122°28'23"
Map unit	Ta_2	Ta_2	Ta_2	Ta_2	Ta_2	Ta_2	Ta_2	Tgd	Thd
Rock type	Andesite	Andesite	Andesite	Andesite	Andesite	Andesite	Andesite	Granodiorite	Hornblende Dacite
SiO_2	59.3	59.5	59.9	60.3	60.4	60.5	61.0	62.9	64.6
TiO_2	0.97	1.04	1.21	1.07	0.90	0.84	0.85	1.04	0.61
Al_2O_3	16.1	16.2	16.2	16.1	16.2	15.9	16.0	15.6	15.2
Fe_2O_3	1.94	3.36	1.22	3.68	4.01	3.19	3.29	2.93	3.68
FeO	4.20	2.80	5.18	2.70	1.70	2.86	2.70	2.70	0.73
MnO	0.10	0.11	0.10	0.12	0.11	0.10	0.11	0.14	0.07
MgO	3.71	2.68	2.30	2.71	2.84	2.71	2.83	1.42	1.86
CaO	6.63	5.36	6.00	5.56	5.43	5.40	5.55	2.87	4.04
Na_2O	3.37	3.78	4.64	3.78	3.99	3.80	3.76	5.83	3.79
K_2O	1.43	1.71	0.72	1.73	1.65	1.85	1.80	1.66	2.10
P_2O_5	0.21	0.21	0.30	0.22	0.22	0.19	0.20	0.36	0.16
H_2O^+	0.87	1.00	0.82	0.50	0.71	1.15	0.66	0.86	0.72
H_2O^-	0.72	1.50	0.72	1.20	1.70	1.09	1.20	0.91	1.90
CO_2	<0.01	0.04	<0.01	0.03	0.01	0.08	0.10	<0.01	0.01
Total	99.55	99.29	99.31	99.70	99.87	99.66	100.05	99.22	99.47

* Sample collected outside of quadrangle.

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

Alluvial and Mass Wastage Deposits

Qa **Alluvium (Holocene and Pleistocene)**—Unconsolidated, poorly to moderately sorted deposits of silt, sand, and gravel in valleys of active streams; includes lacustrine deposits along shore of Coweeman Lake

Qt **Talus (Holocene and Pleistocene)**—Unsorted accumulations of loose, angular blocks of rock forming steep unvegetated to brushy slopes beneath cliffs at head of Trouble Creek and in cirque on north side of Elk Mountain

Qls **Landslide deposits (Holocene and Pleistocene)**—Diamicton of unsorted, angular, mixed bedrock and surficial material transported down-slope *en masse*. Includes more-or-less coherent slumps and internally disrupted rockslide, earthflow, and debris-avalanche deposits. Slides typically head at theatre-shaped scars and exhibit subhorizontal tops, bulbous toes, and hummocky, poorly drained surfaces. Some landslides developed by failure along zeolitized tuffaceous claystone beds of the Tertiary volcaniclastic section (Tvs) that extends from Cedar Creek in southeastern part of quadrangle north-northwestward to South Fork Toutle River

Deposits of Mount St. Helens Volcano

Qsl **Lahar deposits of the 1980 eruption (Holocene)**—Flat-surfaced, unconsolidated deposits, mostly less than 2 m thick, of light-gray to light-brown, unsorted to poorly sorted, generally unstratified and matrix-supported volcanic diamicton in South Fork Toutle River; chiefly the flood-plain facies deposited by peak flow of lahar flood wave generated from a pyroclastic surge within minutes of initial catastrophic eruption of Mount St. Helens on May 18, 1980 (Janda and others, 1981; Scott, 1988). Consists of angular to subangular pebbles, cobbles, and boulders dispersed in a matrix of abundant brown ash; diverse clast composition, including basalt, andesite, and dacite from pre-eruption edifice, local concentrations of pumice and woody debris, and less than 2 percent prismatically jointed particles of juvenile blue-gray microvesicular "blast" dacite (Scott, 1988). Extensively reworked by posteruption fluvial processes

Qsu **Deposits older than 1980, undivided (Holocene and Pleistocene)**—Unconsolidated laharic and derivative alluvial deposits forming low terrace remnants along South Fork Toutle River. Include fluvial and lacustrine silt, sand, and pebble- to boulder-size gravel; pebbly, matrix-supported, probable mudflow deposits; and locally underlying drift. The clast populations in most of these beds consist of porphyritic dacites like those erupted during the early history of the volcano accompanied by variable but minor proportions of Tertiary bedrock; clasts of Mount St. Helens-derived andesite and basalt are generally absent, suggesting that most of these deposits predate the Castle Creek eruptive period, which began about 2,200 years ago (Crandell, 1987). A terrace section about 0.5 km east of the mouth of Bear Creek is described in detail by Scott (1989), who reported radiocarbon ages of 2,630± 185 and 19,700±550 yrs BP from that locality

Glacial Deposits

Evans Creek Drift (Pleistocene)—Divided into:

Qet **Till deposits**—Unsorted, unstratified diamicton composed of angular to rounded clasts of volcanic rock as large as 1 m in a compact matrix of sand, silt, and clay; occupies floors of U-shaped valleys of Trouble Creek, uppermost Coweeman River, and the major northeast-flowing tributary of North Fork Kalama River, and the high bench east of Trouble Creek; locally includes glaciofluvial sand and gravel deposits, postglacial colluvium, probable older drift, and areas of modern alluvium too small to map separately. Till is oxidized to depth of as much as 1 m; volcanic clasts in these deposits typically lack discernible weathering rinds, although rinds less than 1 mm thick are present on clasts of the basalt of Kalama River (Tbk), which weathers more rapidly than other rock types; these weathering characteristics suggest correlation with the Evans Creek Drift of the Mount Rainier region (Crandell and Miller, 1974; Colman and Pierce, 1981), deposited during the Fraser glaciation. Age approximately 17 to 25 ka (Barnosky, 1984; Crandell, 1987)

Qem **Moraine deposits**—Deposits lithologically similar to those mapped as Evans Creek till (Qet) forming small terminal moraines north and northeast of Elk Mountain and lateral moraines near the lip of the high bench along the east side of Trouble Creek. The lower moraine below Coweeman Lake is slightly more weathered than the upper pair, but less so than deposits mapped as Hayden Creek Drift in this quadrangle

Ql **Lake beds (Pleistocene)**—Approximately 2 m of tan to chocolate-brown, finely laminated, semi-lithified mudstone beds exposed in bed of Bear Creek about 3 km from its mouth. Overlies probable Hayden Creek moraine

Hayden Creek Drift (Pleistocene)—Divided into:

Qht **Till deposits**—Unsorted, unstratified diamicton composed of angular to rounded clasts, as large as boulder size, in compact matrix of sand, silt, and clay; locally includes glaciofluvial sand and gravel deposits, postglacial colluvium, probable older and younger drift, possible loess, and areas of modern alluvium too small to map separately. Forms discontinuous blanket in areas of modest relief northeast of Elk Mountain, between Bear Creek and Trouble Creek, and north of South Fork Toutle River; also locally present on lower valley walls and floor of South Fork Toutle River, but largely buried by younger deposits. Locally overlain by biotite-bearing tephra set C of Mullineaux (1986; not mapped) that was erupted from Mount St. Helens during the Ape Canyon eruptive stage approximately 40 ka (Crandell, 1987). Till typically is intensely weathered to depth of 1 m, oxidized to depth of 1 to 2 m, and contains clasts of volcanic rock in the upper part of the weathering profile that exhibit weathering rinds 1 to 2 mm thick. Correlated with the Hayden Creek Drift of the Mount Rainier region, which possesses similar weathering characteristics (Crandell and Miller, 1974; Colman and Pierce, 1981); areas mapped as Hayden Creek till deposits may locally include older till. Age of the Hayden Creek Drift is uncertain; it may be as young as about 60 ka (Crandell and Miller, 1974; Crandell, 1987) or greater than 300 ka (Dethier, 1988); 140 ka is preferred age of Colman and Pierce (1981) based on weathering-rind thicknesses

Qhm **Moraine deposits**—Deposits lithologically similar to those mapped as Hayden Creek till (Qht) that form a terminal moraine along South Fork Toutle River near mouth of Whitten Creek (Crandell, 1987), a probable lateral moraine remnant on south side of South Fork Toutle River 1.5 km east of Bear Creek, a northwest-trending lateral moraine about 1.5 km north of Little Cow, and a pair of lateral moraine remnants on east valley wall of the major southeast-flowing tributary of North

Fork Kalama River. A probable moraine of Hayden Creek age is mapped at elevation of 1,700 ft in Bear Creek, where a subdued, hummocky-surfaced deposit of poorly sorted gravels, overlain by lake beds (unit Ql), is present at point where relatively broad valley narrows downstream into pronounced bedrock gorge

Qho **Outwash deposits**—Stratified and moderately sorted sand and pebble- to boulder-size gravel near mouth of Whitten Creek; well-exposed in south bank of South Fork Toutle River approximately 500 m east of Whitten Creek; approximately 5 m thick; overlain by pre-1980 deposits of Mount St. Helens (unit Qsu). Upper meter or two intensely weathered with abundant clay; oxidation extends as deep as 3 m

Qwd **Wingate Hill Drift** (Pleistocene)—Deeply weathered and oxidized till and glaciofluvial sand and gravel exposed in roadcuts on north side of South Fork Toutle River valley opposite Bear and Whitten Creeks; overlies intensely weathered Tertiary volcaniclastic rocks; locally overlain by tephra set C (Mullineaux, 1986; not mapped) erupted about 40 ka (Crandell, 1987). Clasts of Tertiary volcanic rocks exhibit pronounced weathering rinds ranging from 2 to as much as 10 mm thick, the thickest rinds being developed on basalt stones; such thicknesses indicate that these deposits are significantly older than the Hayden Creek Drift, and are probably correlative with the Wingate Hill Drift which mantles foothills of Cascade Range west of Mount Rainier (Crandell and Miller, 1974). Age probably between 300 and 600 ka (Colman and Pierce, 1981)

BEDROCK

Intrusive rocks

Tia **Intrusive andesite (Oligocene or Eocene)**—Dikes and sills of andesite petrographically similar to andesite flows of unit Ta_2. Most abundant in vicinity of Big Bull and in northeastern part of quadrangle north of South Fork Toutle River. Also includes two thick sills of black, glassy, virtually aphyric andesite in tributary of Coweeman River near west edge of quadrangle

Tiba **Intrusive basaltic andesite (Oligocene)**—Dikes and sills and plugs of basaltic andesite petrographically similar to basaltic andesite flows of unit Tba_2; may locally include basalt. Most are spatially associated with andesite intrusions (unit Tia) in eastern half of quadrangle

Tid **Intrusive dacite (Oligocene)**—North-northwest-striking dike-like body of slabby, dark greenish-gray, light-gray weathering, sparsely? phyric dacite near east edge of quadrangle about 2 km north of Cedar Creek. Contains phenocrysts of plagioclase (5 percent; 0.5-1 mm across), augite (1 to 2 percent; 0.5-1 mm across), and olivine (1 to 2 percent; 0.5-1 mm across; contains chromite inclusions; replaced by quartz+smectite) and microphenocrysts of hypersthene and Fe-Ti oxide in a mottled pilotaxitic groundmass of feldspar, quartz, Fe-Ti-oxide, and clay minerals. Body locally brecciated and veined with quartz and smectite

Tgd **Granodiorite (Oligocene or Eocene)**—Light pinkish gray, medium-grained, hypidiomorphic granular pyroxene granodiorite exposed in bed of Coweeman River at west edge of quadrangle; unit cuts bleached, pyritic volcaniclastic sedimentary rocks; presumably a stock but configuration unknown. Consists of euhedral to subhedral plagioclase (60 to 65 percent; 2-5 mm long; highly altered to albite+clay minerals), orthopyroxene (4 to 5 percent; 1 mm across; totally replaced by smectite+prehnite+ titanite), augite (1 percent; 1 mm long), Fe-Ti oxide (2 to 3 percent; ≤ 0.5 mm across), and pale green to brown hornblende (4 to 5 percent; ≤ 0. 5 mm across), and anhedral quartz (about 20 percent; 0.5 mm across), and K-feldspar (5 to 6 percent; < 0.5 mm across; largely albitized), accompanied by traces of apatite, titanite, and allanite. Analyzed sample (#107 in table 1) collected from riverbed about 50 m west of quadrangle

Tgd **Quartz Diorite (Oligocene or Eocene)**—Dark greenish-gray, porphyritic to seriate, pyroxene quartz diorite forming a thick, highly jointed, northwest-striking dike exposed in south-flowing tributary of Coweeman River near west edge of quadrangle. Contains phenocrysts of plagioclase (about 10 percent; as long as 7 mm; intensely altered to albite, calcite, and clay minerals), orthopyroxene (≤3 percent; 1/2 to 1 mm long; replaced by green chlorite and smectite), and augite (<1 percent; <1 mm across; largely altered to calcite) in a murky fine- to medium-grained groundmass of plagioclase, quartz, granophyric intergrowths of quartz+K-feldspar, Fe-Ti oxide, altered pyroxene, trace apatite and hornblende; miarolitic cavities filled with quartz, calcite, smectite

Tgb **Gabbro (Eocene?)**—A sill of black, strikingly plagioclase-phyric, porphyritic gabbro exposed at pronounced bend in the Coweeman River near west boundary of the quadrangle. Contains large, tabular, unaltered plagioclase phenocrysts (25-30 percent; average 5 mm but as long as 12 mm) displaying limited oscillatory zoning, pronounced polysynthetic twinning, and moderate preferred orientation, accompanied by olivine euhedra (about 5 percent; 1 to 3 mm across; largely replaced by pale green to orange-brown smectite ± quartz and calcite; with minute chromite inclusions) and fresh subhedral to anhedral augite (about 1 percent; 1 mm across; with compositional and hourglass zoning) in a medium-grained intergranular to intersertal groundmass of plagioclase, augite, Fe-Ti oxide, and interstitial, dark-brown, devitrified glass; smectite amygdules as large as 10 mm.

Volcanic and sedimentary rocks

Volcaniclastic sedimentary rocks (Oligocene and Eocene)—in this area, divided into:

Tvs_2 **Unit 2**–Volcaniclastic sedimentary rocks stratigraphically above basalt of Kalama River (Tbk). Diverse assemblage of continental volcaniclastic rocks of inferred epiclastic origin. Consists of generally well-bedded, well- to poorly sorted tuffaceous claystone, siltstone, sandstone, conglomerate, and breccia, all composed of volcanic debris. Locally includes thin beds of pumiceous pyroclastic rocks and lava flows too small or poorly exposed to map; coal beds several centimeters thick are present in this unit southeast of Big Bull. Typically light green to olive green or greenish gray but also white, tan, brown, or maroon. Virtually all lithic clasts are volcanic rocks petrographically identical to interbedded mafic to intermediate flows; minor components include pumice, felsite, vitric ash, fine-grained plutonic rocks, crystals of plagioclase, olivine, and pyroxene, and plant remains. Interpreted as predominantly fluvial and lacustrine in origin, deposited in low-lying intervolcano areas. Intense low-grade alteration to zeolites, smectite, kaolinite, carbonate, quartz, leucoxene, and hematite is typical; laumontite and heulandite or clinoptilolite are common cements. Locally consists of:

Tvbc **Volcanic breccia and conglomerate facies**—Massive, varicolored, well-indurated, polymict volcanic breccia and conglomerate; particularly thick sections exposed near southeast corner of quadrangle and along lower walls of Trouble Creek canyon; more abundant in Goat Mountain quadrangle to east (Evarts and Ashley, 1990b). Generally drab brown, green, red, and purplish brown to gray, with color varying from clast to clast. Predominantly poorly sorted, matrix-supported breccias lacking apparent internal structure; contain angular to subrounded fragments of mafic volcanic rocks ranging up to 2 m across in a dark sandy matrix of similar composition; because of similar appearance, distinguishing clasts from matrix in many outcrops is difficult; clastic nature typically more obvious on weathered surfaces. Locally contains lenses of well-bedded sandstone, clast-supported conglomerate, and pumiceous lapilli tuff. The breccia beds were probably deposited by lahars, although some may be thoroughly autobrecciated lava flows; the conglomerates are considered to be fluvial deposits of high-gradient streams

Tvs_1 **Unit 1**–Volcaniclastic sedimentary rocks stratigraphically below basalt of Kalama River. Lithologically similar to those of unit Tvs_2; some beds contain minor to trace amounts of quartz and muscovite flakes like those in unit Tqs

Tuff (Oligocene and Eocene)—In this area, divided into:

Tt_2 **Unit 2**–Tuff stratigraphically above basalt of Kalama River. Beds of andesitic to rhyolitic tuff, pumiceous lapilli-tuff, and pumice-bearing tuff-breccia; inferred to be mostly of pyroclastic (chiefly ash-flow) origin. Unit ncludes all mappable strata that contain abundant pumice lapilli or possess an ash-rich matrix, hence unit contains some slightly to moderately reworked pyroclastic deposits that are relatively lithic rich. Also includes sequences of tuffaceous rocks interbedded with and gradational to pumice-poor epiclastic sedimentary rocks (such as those southeast of Big Bull) in which pumice-bearing beds dominate. Mainly shades of green to brown, but locally white, gray, or purple. Proportion of angular volcanic and fine-grained plutonic lithic fragments highly variable, but commonly exceeds 15 percent. Pumice lapilli mostly flattened in lithic-poor tuff but less so where lithic clasts are abundant; flattening in thin (probable air-fall) tuff beds attributed to compaction during burial rather than to welding. Carbonized woody debris present locally. Phenocrysts and broken crystal fragments rarely constitute more than 15 percent of juvenile material in tuff, and include plagioclase, augite, and Fe-Ti oxide; some tuffs contain hypersthene as well, and traces of hornblende are present in an ash-flow tuff west of Big Bull, but no quartz or biotite was observed. Except in rare densely welded (but hydrated) vitrophyres, original glass completely devitrified to cryptocrystalline quartz and alkali feldspar or replaced by fine-grained smectites or zeolites, most commonly heulandite or clinoptilolite

Tt_1 **Unit 1**–Tuff beds lithologically similar to those of unit Tt_2 but stratigraphically below basalt of Kalama River.

Basalt (Oligocene and Eocene)—In this area, divided into:

Tb_2 **Unit 2**–Basalt flows and flow breccia stratigraphically above basalt of Kalama River. Unit consists of four or five aphyric and porphyritic flows in lower 125 m of section overlying basalt of Kalama River; well-exposed on steep west-facing slope that extends from divide between North Fork Kalama River and Cedar Creek northwestward into upper Bear Creek valley; individual flows can be traced as continuous clifflines for more than 5 km along strike. Porphyritic flows contain plagioclase (as much as 15 percent; 1-2 mm long), olivine (3 to 5 percent; 0.5- 1 mm across; altered to smectite+hematite), and rarely, augite (≤1 mm across) phenocrysts in fine-grained intergranular groundmass of plagioclase, pyroxene, Fe-Ti oxide, and interstitial smectite. Aphyric flows possess intergranular texture and are typically platy owing to pronounced flow alignment of plagioclase crystals. These basalts, and some associated basaltic andesites, are relatively Fe- and Ti-rich tholeiites that resemble some flows in the basalt of Kalama River (Tbk) and ferrobasalt (Tfb) units, but they have higher SiO_2, Na_2O, and K_2O contents.

Tb_1 **Unit 1**–Basalt flows and flow breccia stratigraphically below basalt of Kalama River. Composed of two flows of gray porphyritic basalt that crop out on steep slope above Coweeman River near west edge of quadrangle. Contain phenocrysts of plagioclase (10 to 25 percent; 1-4 mm long) and chromite-bearing olivine (2 to 3 percent; 1-3 mm across; replaced by smectite, quartz, and calcite) with or without augite (≤1 percent; 1-2 mm across) in an intergranular groundmass of plagioclase, pyroxene, Fe-Ti oxide, and interstitial quartz and smectite

Tba **Basaltic andesite (Oligocene and Eocene)**—In this area, divided into:

Tba_2 **Unit 2**–Flows and flow-breccia of grayish-green to dark-gray, porphyritic to aphyric, basaltic andesite stratigraphically above basalt of Kalama River; locally includes minor basalt flows. Porphyritic varieties typically contain phenocrysts of plagioclase (as much as 35 percent; 1 to 4 mm long; locally as long as 7 mm; containing abundant minute inclusions of altered glass), olivine (as much as 5 percent; as large as 3 mm across; commonly partly resorbed and rimmed by fine-grained granular pyroxene±magnetite; contains minute chromite inclusions in some samples; generally pseudomorphed by smectite and (or) quartz or by calcite), and, in most flows, augite (as much as 5 percent; 0.5 to 3 mm across; locally as large as 5 mm across) and Fe-Ti oxide (<1 percent; ≤0.5 mm across) in an intergranular groundmass of the same minerals plus interstitial glass (largely altered to smectite±quartz); phenocrysts or microphenocrysts of hypersthene (0-3 percent; 0.5 to 2 mm long) present in some basaltic andesite flows. Aphyric varieties commonly exhibit pronounced flow foliation and platy parting. Variable alteration, especially pronounced in flow-breccia zones, to zeolite-facies assemblages including albite, laumontite, stilbite, smectites, quartz, prehnite, titanite, hematite, and calcite

Tba_1 **Unit 1**–Flows and flow-breccia of basaltic andesite petrographically similar to porphyritic to seriate flows of unit Tba_2 but stratigraphically below basalt of Kalama River

Ta **Andesite (Oligocene and Eocene)**—In this area, divided into:

Ta_2 **Unit 2**–Flows and flow-breccia of brownish-gray to black, aphyric to densely porphyritic pyroxene andesite stratigraphically above basalt of Kalama River; locally contains rare flows of basaltic andesite. Constitutes a large part of section exposed in steep canyon walls of Trouble Creek and South Fork Toutle River; this andesite-dominated section can be traced northwestward to Signal Peak in the Toutle Mountain quadrangle (Phillips, 1987), where a whole-rock K-Ar age of 33.9±1.7 Ma was obtained from an andesite flow by Phillips and others (1986), and southeastward to Fossil Creek in the Goat Mountain quadrangle (Evarts and Ashley, 1990b), where it pinches out. Most andesite flows are dark gray and porphyritic, containing phenocrysts of plagioclase (15 to 30 percent; 1-4 mm long), augite (2 to 7 percent; 0.5-3 mm across), hypersthene (as much as 9 percent; 0.5-3 mm across), and Fe-Ti oxide (0.5 to 1 percent; ≤1 mm across); less than 1 percent olivine (0.5-1 mm across) present in a few flows; groundmass textures range from intersertal to hyalopilitic. Alteration to clay minerals, quartz, limonite, zeolites generally minor except locally in flow-breccia zones, especially north of South Fork Toutle River

Ta_1 **Unit 1**–Flows and flow-breccia of medium-gray to dark greenish-gray aphyric andesite stratigraphically below basalt of Kalama River. Some flows form prominent cliffines in

Coweeman River valley that can be traced for as much as 4 km. Typical flows have pilotaxitic to trachytic textures and display pronounced flow banding; some contain scarce phenocrysts or microphenocrysts of plagioclase, augite, hypersthene, Fe-Ti oxide; all are moderately to thoroughly altered to albite, quartz, clay minerals, carbonates, goethite

Td **Dacite (Oligocene)**—Flows of slabby, purplish gray, sparsely phyric, pyroxene dacite exposed north of South Fork Toutle River in northeastern part of quadrangle. Contains as much as 10 percent plagioclase phenocrysts and 1 to 2 percent each augite, hypersthene, and Fe-Ti oxide microphenocrysts in hyalopilitic, pilotaxitic, or snowflake-textured groundmass of feldspar, quartz, and Fe-Ti oxide. Most flows highly altered to assemblage of quartz, albite, smectite, hematite, zeolites

Thd **Hornblende dacite (Oligocene)**—Light greenish-gray porphyritic hornblende dacite flow and flow breccia poorly exposed at north edge of quadrangle west of Harrington Creek. Composed of phenocrysts of plagioclase (20-25 percent; 1-5 mm long; partly altered to albite and clay minerals), green to brown hornblende (as much as 4 percent; as large as 3 mm across; variably opacitized), quartz (1 to 3 percent; partially resorbed), augite (<1 percent; 1/2-1 mm across; unaltered), hypersthene (<1 percent; 1/2-1 mm across; totally replaced by smectite), and Fe-Ti oxide (<1 percent; <1/2 mm across) in a felsic cryptocrystalline groundmass; local amygdules of smectite, laumontite. Analyzed sample (#108 in table 1) collected in rock pit 100 m north of quadrangle

Tha **Hornblende andesite (Oligocene)**—Small body of variegated, microvesicular, porphyritic, hornblende-bearing, andesitic flow breccia exposed in roadcut on southwest slope of divide between Cedar Creek and North Fork Kalama River near southeast corner of quadrangle. Consists of plagioclase (10 percent; 1/2-1 mm long), augite (about 3 percent; 1/2-1 mm across), orthopyroxene (2 to 3 percent; 1/2-1 mm across), and equant to prismatic, pale green to orange oxyhornblende (≤3 percent; ≤ 1 mm long, a few as long as 5 mm; with thin rims of very fine-grained granular Fe-oxide) phenocrysts in a groundmass of feldspar, quartz, Fe-Ti oxide, and smectite. Except for augite and hornblende, rock is intensely altered to assemblage of smectite, heulandite, stilbite, and hematite

Tma **Megacrystic andesite (Oligocene)**—Flow or sill of andesite, 15 to 20 m thick, that contains conspicuous megacrysts and glomerocrysts of equant, transparent to yellowish plagioclase in a dark-gray to black groundmass; crops out above volcanic breccia and below sparsely phyric andesite at 2,600 ft elevation on west canyon wall of Trouble Creek and at about 3,000 ft elevation on north-facing slope 1 km to northwest. Contains phenocrysts of fresh plagioclase (10 to 20 percent, as large as 15 mm across; unzoned except for thin rims; relatively sparse twinning), olivine (about 5 percent; 1-2 mm across; altered to pale brown smectite); and fresh augite (4 to 7 percent; as large as 3 mm across; oscillatory zoning), and microphenocrysts of plagioclase, augite, orthopyroxene, Fe-Ti oxide, and apatite in pilotaxitic groundmass of plagioclase, pyroxene, Fe-Ti oxide, and reddish glass; also contains cognate gabbroic xenoliths. Variation in chemistry (analyses 71 and 89, table 1) probably reflects flow sorting of phenocrysts during emplacement

Toba **Olivine-phyric basaltic andesite (Oligocene)**—Sequence of distinctive medium- to dark-gray porphyritic to seriate basaltic andesite, andesite, and minor basalt flows, flow breccia and minor agglomerate in northwestern part of quadrangle that typically contain conspicuous, red to orange, altered olivine as the only or most abundant phenocryst phase; unit as much as 400 m thick where it overlies basalt of Kalama River north of South Fork Toutle River, but thins rapidly to the southeast and is absent from southern half of quadrangle. Olivine phenocrysts (2 to 7 percent) mostly ≤1mm but a few as large as 3 mm, generally thoroughly altered to smectite+hematite±quartz; may contain chromite inclusions and (or) be surrounded by rinds of granular clinopyroxene+magnetite. Some flows contain plagioclase (≤4 percent; average 1 mm) and (or) augite (≤5 percent; ≤1 mm) phenocrysts or microphenocrysts as well; plagioclase is subhedral to anhedral, spongy due to abundant altered glass inclusions, and exhibits reversely zoned rims; augite anhedral to subhedral, displays compositional and sector zoning, and commonly forms multigrain clots. Fine- to medium-grained intergranular groundmass composed of plagioclase, augite, Fe-Ti oxide, and minor interstitial glass altered to smectite. The more silicic flows invariably contain xenocrysts of resorbed quartz surrounded by rinds of fine-grained granular pyroxene; opacitized hornblende and sieved plagioclase xenocrysts accompany quartz in several flows. A unit of essentially identical rocks (basaltic andesite of Indian George Creek of Evarts and Ashley, 1991) occupies an equivalent stratigraphic position on the southwest flank of Lakeview Peak anticline

Tbk **Basalt of Kalama River (Eocene)**—Sequence of black, blocky-jointed, strikingly plagioclase-phyric basalt flows and lesser slabby, virtually aphyric, basalt flows extending from Elk Mountain to South Fork Toutle River. Porphyritic flows make up 70 to 80 percent of unit and consist of 10-35 percent plagioclase phenocrysts and glomerocrysts typically 3 to 10 mm across, and 0-6 percent olivine phenocrysts 1 to 3 mm (rarely 5 mm) across in an intergranular to subophitic to ophitic, diktytaxitic groundmass of plagioclase, olivine, augite, and Fe-Ti oxide. Aphyric to sparsely phyric flows (0-5 percent plagioclase, olivine, ± augite phenocrysts) display intergranular to subophitic textures similar to those of groundmasses of porphyritic flows but commonly show strong flow alignment of plagioclase. Flows range between 3 and 25 m thick; most are 5 to 8 m thick; tops and bottoms of flows composed of highly vesiculated and zeolitized flow breccia; vesicles, rendered conspicuous by fillings of ubiquitous white zeolites, much less abundant in flow centers but persist throughout. Negligible interbedded volcaniclastic material except for scarce, thin-bedded, tuffaceous siltstone (some with trace amounts of quartz and muscovite) near base of unit and local brick-red hematitic siltstone beds less than 0.5 m thick throughout. Minor pillow breccia and palagonitic hyaloclastite present near base of unit north and west of Butler Butte. Probable sills, with well-developed columnar jointing, present near base of unit west of Elk Mountain. Plagioclase phenocrysts in some flows partly replaced by smectites, albite, laumontite, stilbite, and calcite; olivine partly to completely replaced by smectite; smectite, prehnite, pumpellyite, calcite, analcime, and various calcic zeolites including scolecite, stilbite, mesolite, thompsonite, natrolite, levyne, chabazite, gismondine, and heulandite fill vesicles and numerous interstitial voids. Chemically, these basalts are low-potassium tholeiites similar to mid-ocean ridge basalt

Tqs **Quartzose sandstone (Eocene)**—Light-gray to buff, yellowish brown-weathering, friable, thick- to thin-bedded, massive to cross-bedded, fine- to medium-grained, micaceous, locally feldspathic or lithic-rich, quartzose sandstone and siltstone interbedded with minor carbonaceous shale, coal, and volcaniclastic rock. Constitute a tabular, lenticular unit less than 30 m thick within dominantly volcanic section below basalt of Kalama River in upper Coweeman drainage. Sandstone poorly to moderately sorted; framework composed chiefly of angular to subrounded fragments of monocrystalline quartz accompanied by variable amounts of feldspar (mostly altered to kaolinite or smectite), minor but conspicuous muscovite, plant matter, and fragments of deformed polycrystalline quartz and quartz-muscovite schist; traces of zircon and tourmaline present in some beds; interstices occupied by clay minerals, calcite, leucoxene; recognizable volcanic clasts rare to absent. These nonmarine beds probably correlative with compositionally similar nearshore-facies strata of the Cowlitz Formation as mapped by Roberts (1958) and Phillips (1987) along the lower Cowlitz River 25-30 km west of Elk Mountain quadrangle

Tfb **Ferrobasalt (Eocene)**—Dark-gray to black, porphyritic to seriate, massive, coarse-grained basalt exposed in Coweeman River valley at west edge of quadrangle. Typically have phenocrysts of blocky to tabular, weakly zoned plagioclase (8-24 percent; 1 to 5 mm long) and olivine (0-1 percent; ≤1 mm across; partly to completely altered to brown smectite; commonly containing abundant tiny chromite octahedra) in a fine- to medium-grained intergranular to ophitic groundmass of plagioclase, olivine, titaniferous augite, abundant Fe-Ti oxide, and interstitial smectite. Chemical analyses (table 1) show these to be low-potassium tholeiitic ferrobasalt, with ≥13 wt percent FeO* and ≥2.4 wt percent TiO_2; they chemically resemble the most Fe-rich basalts of the basalt of Kalama River (Tbk). The ferrobasalt tends to be coarser-grained and less altered than other Tertiary rocks; this, along with the common presence of columnar jointing and scarcity of flow breccia, suggests that many of the ferrobasalt units are sills rather than flows

Contact--Dashed where approximately located; short-dashed where inferred; dotted where concealed

Fault--Dashed where inferred; dotted where concealed. Ball and bar on downthrown side. Arrows show relative horizontal movement

Crestline of Lakeview Peak Anticline--Approximately located; showing direction of plunge

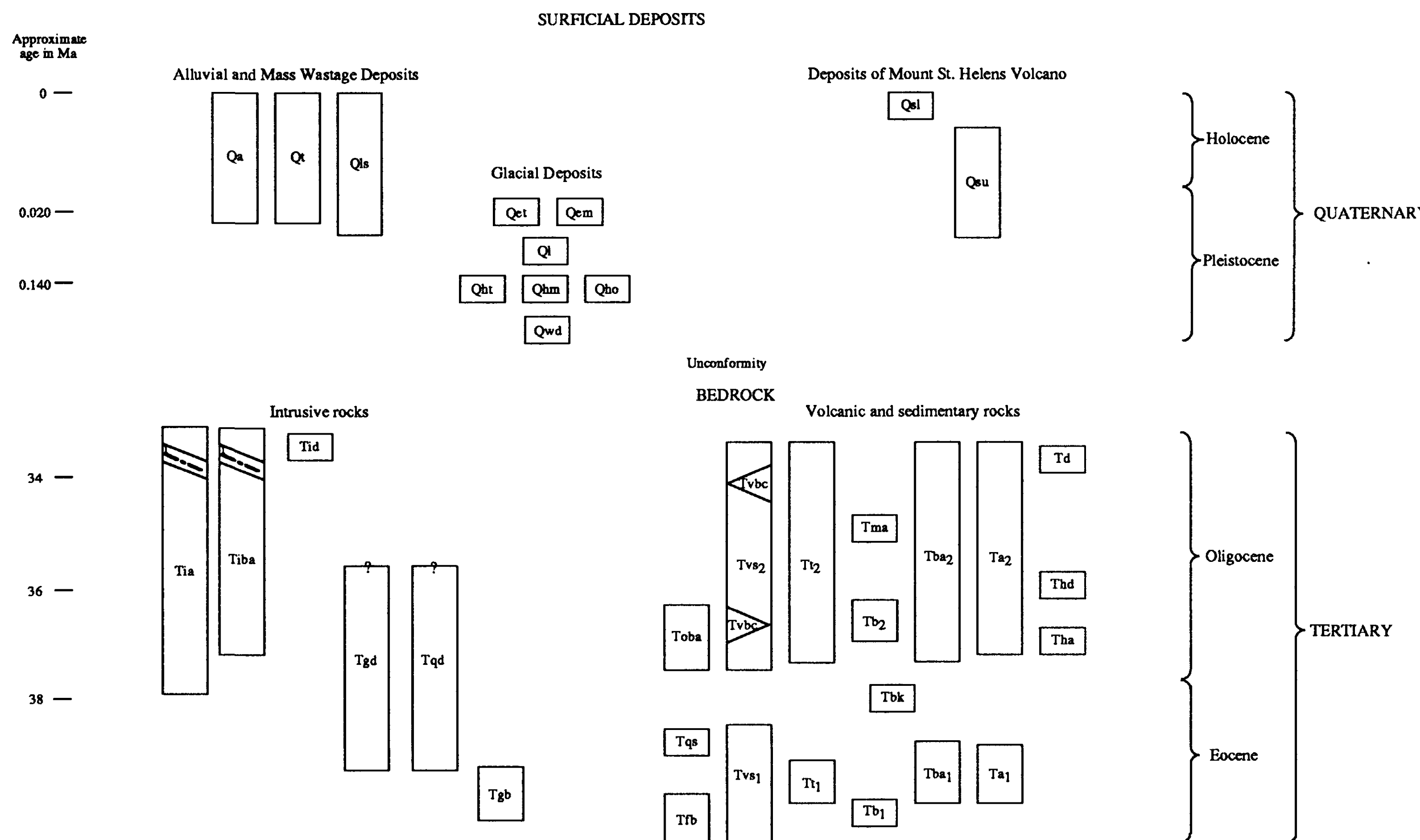
Strike and dip of beds:

Strike and dip of compaction foliation in pumiceous lapilli tuff

Strike and dip of platy parting in lava flows

Sample locality for chemical analysis--See table 1

CORRELATION OF MAP UNITS



[1] Dikes of Tiba and Tia not distinguished on this map.