U.S. DEPARTMENT OF THE INTERIOR

U. S. GEOLOGICAL SURVEY

Preliminary Geologic Map of the Cougar quadrangle, Cowlitz and Clark Counties, Washington

by

Russell C. Evarts[1] and Roger P. Ashley[1]

Open-File Report 90-631

Prepared in cooperation with the Washington Department of Natural Resources, Division of Geology and Earth Resources

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1990

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INTRODUCTION

The Cougar 7.5-minute quadrangle is on the western slope of the Cascade Range of southern Washington, centered about 15 km south-southwest of the summit of Mount St. Helens (fig. 1). Bedrock consists of diverse volcanic and volcaniclastic rocks of late Eocene to middle Oligocene age cut by numerous shallow-level intrusive bodies ranging from basalt to granite. These rocks are overlain by extensive late Pleistocene glacial deposits and mantled by tephra erupted from Mount St. Helens during latest Pleistocene to Holocene time. The Lewis and Kalama River valleys contain thick deposits of alluvium and volcanic rocks, also derived from the volcano.

Natural bedrock exposures are limited owing to the dense vegetation of temperate coniferous rain forest as well as to the thick surficial cover. However, outcrops are common along the many small 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 in 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, 1990; in press a, b, c, d; Swanson, 1989), and is a contribution to 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 north and west (Evarts and Ashley, 1990; unpub. mapping, 1990) are older than those in areas north and northeast of Mount St. Helens (fig. 1), and include some of the oldest known magmatic products of the Cascade arc (Phillips and others, 1989).

Acknowledgments

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SUMMARY OF GEOLOGY

Surficial Deposits

Surficial deposits unconformably overlying Tertiary bedrock include middle Pleistocene olivine basalt, late Pleistocene glacial deposits and latest Pleistocene and Holocene eruptive products of Mount St. Helens volcano. Clastic debris from the volcano makes up most of the valley fill along the Lewis and Kalama Rivers. In addition, tephra (chiefly the C and J sets of Mullineaux, 1986) erupted from Mount St. Helens during the last 50,000 years mantles much of the northern half of the quadrangle; these widespread deposits have not been mapped but locally form a layer more than a meter thick on low-dipping surfaces adjacent to the Kalama River.

Basalt of Speelyai Creek

The basalt of Speelyai Creek was erupted about 800 ka (table 1) from a vent marked by exposures of agglutinate and oxidized scoria about 2.6 km west of Merrill Lake. Intense glaciation has strongly modified the original edifice but scattered remnants of basalt suggest that a flow or flows from this vent moved southward down an ancestral Speelyai Creek to the Lewis River. Additional flows moved north-northeastward toward Merrill Lake and westward into a major tributary of the Kalama River, thence northward into the Kalama valley itself west of Kalama Falls. Chemically the Quaternary basalt differs most clearly from the underlying Tertiary basalt in its much higher K_2O and MgO contents (table 2; fig. 5).

Glacial deposits

Drift in the Cougar quadrangle is correlated with similar deposits near Mount Rainier that represent the last two major advances of alpine glaciers in the Cascade Range (Crandell and Miller, 1974). The older and much more widely distributed deposits include the Amboy drift of Mundorff (1984) which is probably correlative with the Hayden Creek Drift (Crandell and Miller, 1974) on the basis of similar weathering characteristics. They cover much of the gently sloping upland surfaces along the Kalama River and west of the community of Cougar. Roadcuts in these areas reveal that this till is overlain by biotite-bearing tephra erupted early in the history of Mount St. Helens, approximately 40 ka (Crandell (1987).

The younger glacial deposits contain clasts lacking weathering rinds, indicating that they are correlative with the Evans Creek Drift deposited during the Fraser glaciation, the last major glacial advance in the Washington Cascade Range (Crandell, 1987). They are largely restricted to east of Cinnamon Peak, where they rest on striated surfaces developed on the andesite of Cinnamon Peak.

Deposits of Mount St. Helens volcano

The Lewis and Kalama River valleys have filled repeatedly by fragmental eruptive products of Mount St. Helens. The streams deeply trenched their fill between depositional events, producing a series of terraces that are especially well developed along the Lewis River. These deposits have been studied extensively by Hyde (1975), Crandell (1987), and Major and Scott (1988) and the distribution of units shown on this map is based heavily on their descriptions supplemented by our own observations.

Crandell divided the 40,000- to 50,000-year history of Mount St. Helens volcano into four eruptive stages (fig 2). Deposits representing the last three of these stages are exposed in the Cougar quadrangle. Most deposits in the Lewis River valley are assigned to the Cougar and Swift Creek eruptive stages. Deposits of the older Ape Canyon stage are exposed along the valley bottom 1.5 km upstream (east) from this quadrangle and downstream along the shore of Lake Merwin (Major and Scott, 1988); they presumably underlie the younger deposits in the area of this map. Deposits in the Kalama River valley are generally younger than those along the Lewis River, and belong mostly to the Spirit Lake eruptive stage of Crandell (1987).

Lewis River Valley

The Cougar- and Swift Creek-age deposits that crop out along Yale Lake consist chiefly of fine-grained distal laharic deposits and alluvium derived from pyroclastic-flow and other volcanic deposits. Pyroclastic-flow deposits are an important component of the Cougar-age fill that forms high terraces near the east end of Yale Lake; Hyde (1975) reported radiocarbon ages of 20,350±500 and 18,560±550 years from these deposits along the Lewis River upstream from Yale Lake. The deposits at the mouth of (diverted) Speelyai Creek constitute the eastern end of a thick fill of Cougar-age deposits which occupy a former course of the Lewis River (Crandell, 1987). A radiocarbon age of 22,720±1400 years was obtained for this fill by Major and Scott (1988) from a locality about 2 km WSW of the Cougar quadrangle. Deposits forming a slightly lower set of terraces along Yale Lake, including that on which the community of Cougar sits, are of Swift Creek age according to Crandell (1987). These beds have not been dated directly, but they are overlain by tephra set S, which is approximately 13,000 radiocarbon years old (Hyde, 1975; Crandell, 1987).

Flowage deposits younger than pre-S Swift-Creek age are exposed along the Lewis River upstream and downstream from Yale Lake, and probably form the low terraces now beneath the surface of the reservoir. The youngest significant product of Mount St. Helens activity in the Lewis River valley is the Cave Basalt (Greeley and Hyde, 1972), a pahoehoe flow famed for its abundant lava tubes (caves) as long as 3.4 km. It was erupted from the southwest flank of the volcano about 1700 years ago, near the end of the Castle Creek eruptive period of the Spirit Lake eruptive stage (Crandell, 1987). The flow covered a broad area of Cougar-age deposits east of the Cougar quadrangle and split into three lobes, one of which terminated in Cougar Creek. The other lobes spilled down into the Lewis River, coalesced, and flowed westward as far as the mouth of Christmass Canyon.

Kalama River valley

At about the same time that the Cave Basalt was extruded, a similar basalt flow moved down the Kalama River, reaching a point about 0.7 km southwest of Kalama Falls, where the river spills over the eroded edge of the flow. This flow formed Merrill Lake by damming a short tributary of the Kalama River, although a smaller lake may have existed prior to this time due to blockage of the tributary by volcaniclastic deposits that underlie the basalt. These older deposits are exposed sporadically along the Kalama River downstream from Kalama Falls (Crandell, 1987; Evarts and Ashley, 1990; unpub. mapping, 1990). Their age is poorly known although laharic deposits of Castle Creek and Pine Creek(?) age and older crop out downstream (Crandell, 1987). The paucity of these older deposits indicates that the Kalama valley received a much smaller volume of Mount St. Helens debris than did the Lewis valley during the early history of the volcano.

For most of its length the basalt of Kalama Falls is covered by younger Kalama-age pyroclastic flows, laharic deposits, and alluvium (Hyde, 1970, 1975; Crandell, 1987; Evarts and Ashley, 1990), which may be why no lava tubes have been discovered in it. In the Cougar quadrangle these latter are primarily alluvial and minor laharic deposits derived from pyroclastic flows exposed upvalley about 3 km to the north. Radiocarbon ages on these pyroclastic flows in the Goat Mountain quadrangle to the north show that they were deposited during the early part of the Kalama eruptive period between 1480 and 1640 A.D. (Crandell, 1987).

Tertiary Bedrock

Tertiary bedrock in the Cougar quadrangle consists of porphyritic and minor aphyric basalt flows overlain by a diverse group of intermediate to silicic volcanic and volcaniclastic rocks. These strata are exposed on the eastern limb of the Lakeview Peak anticline (Phillips, 1987a, b), the crest of which crosses the southwestern part of the quadrangle west of Speelyai Creek. The few available radiometric age determinations from the area suggest an age range of about 38(?) to 31 Ma for these rocks.

Basalt of Kalama River

The basalt of Kalama River is the lowest stratigraphic unit exposed in the Cougar quadrangle. It underlies most of the western half of the quadrangle as well as a large area to the west and northwest (R.C. Evarts and R.P. Ashley, unpub. mapping, 1990). It has not yet been dated directly, but it underlies rocks older than 36 Ma (table 1). In most locations, the contact of the basalt of Kalama River with overlying andesites and volcaniclastic rocks is sharp and conformable. West of Yale Lake, however, a few flows petrographically and chemically identical to the basalt of Kalama River are interbedded with volcaniclastic strata above the contact as mapped. The base of the basalt of Kalama River is not exposed in the Cougar quadrangle.

The unit contrasts sharply with younger Tertiary rocks in the Mount St. Helens area in that it consists solely of basalt flows and lacks interbedded volcaniclastic beds. The dominant rock type is black, strikingly plagioclase-phyric, amygduloidal basalt that constitutes approximately 80 percent of the unit. The remainder of the unit is composed of essentially aphyric basalt. Individual flows are typically several meters thick and many can be traced as clifflines for distances exceeding 1 km with little variation in thickness. The flows typically consist of massive, blocky-jointed interiors encased in highly vesiculated flow-breccia at their tops and bottoms. Beds of brick-red hematitic siltstone, less than 1 m thick, are present between some flows. This material appears to be a combination of fine-grained eolian sediment and lateritic soil developed *in situ* on flow surfaces; no pumice, shards, or other detritus indicative of contemporaneous intermediate to silicic volcanism were observed. Taken together, these characteristics suggest rapid subaerial extrusion of fluid basalt flows that formed large sheets inundating a topographically subdued terrain. The source for the basalt flows is unknown, as petrographically equivalent dikes have not yet been located in this or adjacent quadrangles.

These basalts are petrographically and chemically unusual compared to other known Tertiary mafic volcanic rocks in the southern Washington Cascade Range, being composed almost exclusively of rather uniform low-potassium, high-alumina tholeiites (table 2; figs. 3, 4, 5, and 6). Phenocrysts and glomerocrysts of plagioclase (chiefly bytownite) over 1 cm long are characteristic of the porphyritic flows, most of which also contain olivine phenocrysts. Augite is typically restricted to the groundmass; only a few flows contain as much as 1 percent augite phenocrysts. Groundmass textures are dominantly diktytaxitic-intergranular to subophitic. The abundant vesicles are invariably filled with secondary minerals, especially zeolites. Aphyric lavas tend to be less vesicular with a finer-grained intergranular groundmass; many of these exhibit a pronounced flow-foliation.

Other volcanic and volcaniclastic rocks

The strata overlying the basalt of Kalama River are diverse in character, consisting largely of volcaniclastic sedimentary and andesitic to dacitic pyroclastic rocks interstratified with lava flows of variable composition. The well-bedded character of much of the strata and scarcity of very coarse tuff-breccia suggest that most of these rocks were deposited low on the flanks of volcanoes or in distal intervent environments between major volcanic edifices. (Cas and Wright, 1987; Smith, in press).

The stratigraphic sequence east of Yale Lake differs in several important respects from the correlative sequence to the north. Lava flows are more abundant east of the lake, and include distinctive flows of basalt and minor basaltic andesite that contain augite megacrysts as much as 1 cm across. At the top of the section is the tuff of Ole Creek, a unit of pumiceous ash-flow tuffs and minor volcaniclastic sedimentary rocks. The basal bed of the tuff of Ole Creek is a porphyritic ash-flow tuff containing quartz phenocrysts (rare in this part of the Cascade Range) that has yielded a plagioclase K-Ar age of 31 Ma (table 1).

North of Yale Lake, the sequence is composed chiefly of volcaniclastic sedimentary rocks overlain by a unit of porphyritic andesite flows. Pumiceous tuff beds are common near the top of the volcaniclastic section in upper Dry Creek; none of them appear to contain quartz phenocrysts. Interbedded lava flows are scarce, and none were found to contain augite megacrysts.

The uppermost clastic unit north of the lake is the volcanic breccia of Lost Creek, a heterogeneous section of dark, very poorly sorted, coarse-grained breccia and conglomerate accompanied by minor well bedded sedimentary rocks, pumiceous lapilli tuff and mafic lava flows. The breccias typically form massive beds, as much as 100 m thick, that lack discernible internal structures. The clasts, locally as large as 4 m across, are mostly porphyritic basalt and basaltic andesite similar in appearance to the rare intercalated lava flows; the matrix consists of lithic and crystal fragments derived from similar rocks. Clast-matrix contacts in many outcrops are obscure, in part because of intense zeolitization. Some of these breccias are probably thoroughly autobrecciated lava flows but most are believed to be deposits of lahars derived from a nearby but unexposed mafic volcano.

The stratigraphic section north of Yale Lake is capped by the andesite of Cinnamon Peak, a stack of two-pyroxene andesite to mafic dacite flows that contains little interbedded clastic debris except for minor andesite-cobble conglomerate. The flows were deposited on an irregular erosion surface developed on the volcanic breccia of Lost Creek. They were erupted about 32 Ma based on an $^{40}Ar/^{39}Ar$ determination on plagioclase (Table 1).

Lava flows interbedded with the volcaniclastic strata that overlie the basalt of Kalama River in the Cougar quadrangle are mostly basaltic andesite according to the IUGS classification (between 52 and 57 percent) shown in Figure 3, and are closely resemble Oligocene to early Miocene basaltic andesites in the Spirit Lake area to the northeast (Evarts and Ashley, in press a, b, c, d,). . Andesites and dacites (greater than 57 percent SiO_2) are found only in the andesite of Cinnamon Peak and as dikes in the eastern half of the quadrangle. (Most of the dikes are too altered for meaningful chemical analysis). The analyses straddle the tholeiitic versus calc-alkaline boundary on the classification diagrams of Irvine and Baragar (1971) and Miyashiro (1974) as shown in Figures 4 and 5, respectively, and tend to be lower in K_2O than Quaternary volcanic rocks of equivalent SiO_2 contents in southern Washington (fig. 6).

Intrusive rocks

Small intrusions are common in the dominantly volcaniclastic section above the basalt of Kalama River. The most prominant in this quadrangle is the Cougar Creek stock east of Cougar. The stock is associated with a swarm of dikes that extends up to 3 km from its margin; these dikes tend to be oriented radially to the stock, although north to north-northwest strikes predominate. The stock is composite, consisting of many separate intrusions of fine- to medium-grained rocks that range from basaltic andesite to rhyolite; the dominant composition is andesitic. Deuteric alteration is typical and commonly pervasive. Some of the andesitic intrusions in the stock and many of the surrounding dikes contain brown hornblende megacrysts, and are probably closely related to the hornblende-bearing porphyry bodies exposed south of the stock. One of the augite megacryst-bearing basalt flows east of Yale Lake also contains hornblende megacrysts, suggesting that some of the flows in that area may have been erupted from a vent located above the Cougar Creek stock; none of the rocks associated with the stock contain augite megacrysts, however.

The intrusions west and south of Merrill Lake are mainly sill-like bodies of medium-grained two-pyroxene diorite and fine-grained hypersthene quartz diorite. Pyroxene in these rocks is unaltered but plagioclase is typically zeolitized, giving them a distinctive salt-and-pepper appearance in outcrop.

Structure

Strata in the Cougar quadrangle strike generally northerly and dip moderately (20-30°) to the east, forming the eastern limb of the broad Lakeview Peak anticline (Phillips, 1987a), a north-northwest-striking, southeast-plunging structure whose axis traverses the southwestern corner of the quadrangle. Along the axis of the anticline west of Yale Lake, the strata swing sharply around from north-south to east-west trends. According to Phillips (1987b) the Lakeview Peak anticline extends about 8 km to the southeast, where it is truncated against the Chelatchie Prairie fault zone.

A number of comparatively minor faults have been mapped within the quadrangle. Their orientations are diverse, but the longest traceable structures are east-west to west-northwest-striking high-angle faults in the southern half of the quadrangle. Typically, these faults are marked by zones of brecciated and bleached, hydrothermally altered rock. Slickensides are rare, however, so the direction of movement for most of the faults is unknown.

Displacement of strata in a few localities indicates vertical offsets of as much as 25 m, but the amount and sense of horizontal movement is indeterminate.

Metamorphism and hydrothermal alteration

The Tertiary rocks of the Cougar 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. Interestingly, however, the oldest rocks in the quadrangle, the basalt of Kalama River, display less intense metamorphism than do overlying rocks; in most samples from this unit zeolites and clay minerals fill vesicles and interstitial voids but do not replace primary plagioclase, and fresh olivine is common. The contrast in extent of recrystallization is particularly striking with the stratigraphically higher late Oligocene and early Miocene rocks to the northeast (Evarts and Ashley, in press a, b, c, d). The reasons for this apparent discrepancy apparently relate in part to the virtual absence of intrusive bodies cutting the basalt of Kalama River compared to their widespread occurrence in strata to the east. The relative freshness of the basalt of Kalama River suggests that it was not as deeply buried as the great thickness of younger volcanic rocks lying to the east might imply.

Evidence for metasomatic hydrothermal alteration is uncommon in the Cougar quadrangle except within and adjacent to the Cougar Creek stock, where sporadic areas of pyrite-bearing propylitic and argillic alteration are present. Elsewhere, intense alteration is limited to narrow zones of argillized rock along faults. These altered zones are composed entirely of kaolinitic or vermiculitic clay minerals with or without minor limonite; no relict sulfides have been detected in any of these zones.

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______in press b, Geologic map of the Vanson Peak quadrangle, Lewis, Cowlitz, and Skamania Counties, Washington: U.S. Geological Survey Geologic Quadrangle Map GQ-1680, scale 1:24,000.

______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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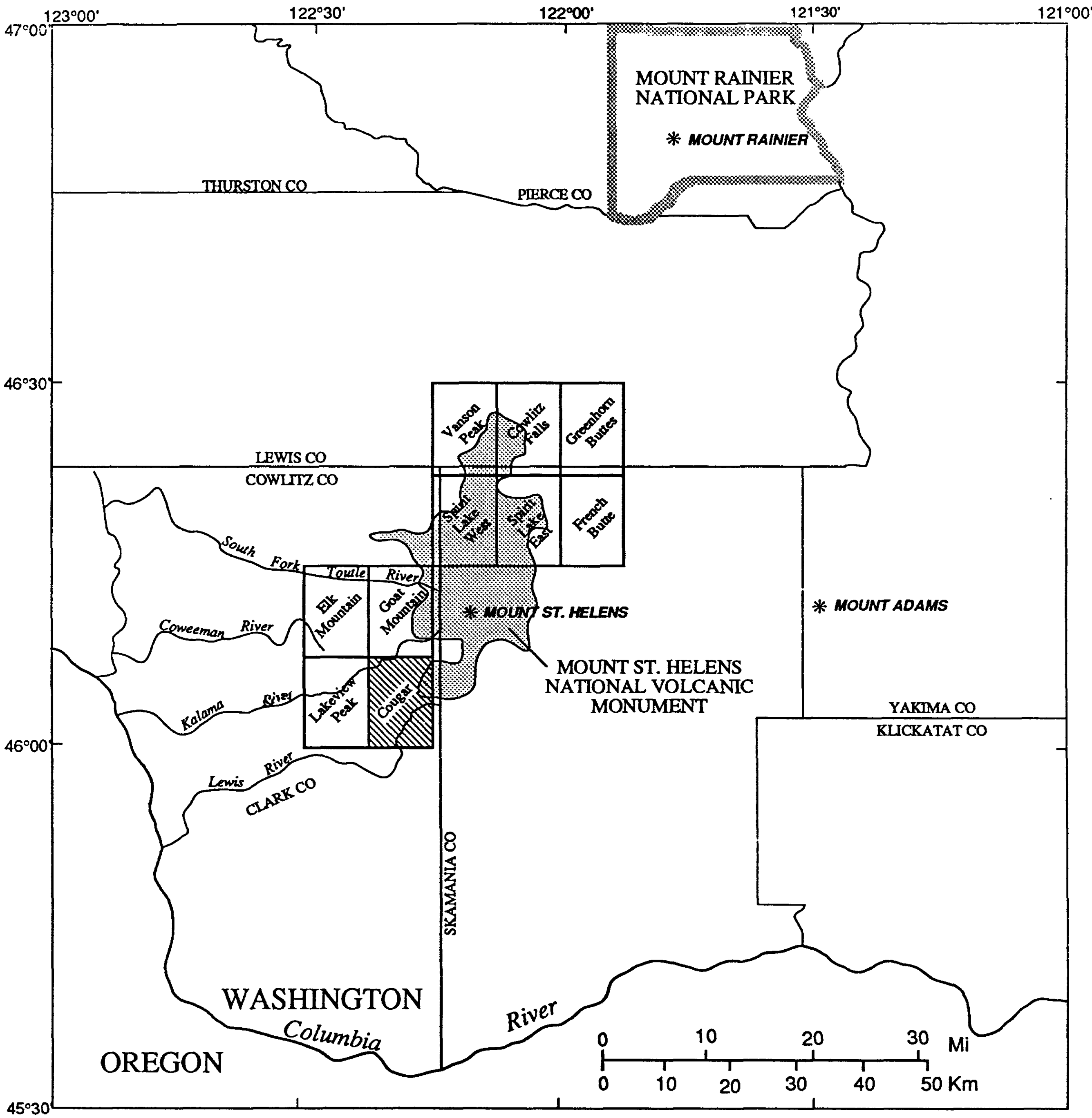


Figure 1.--Index map of southern Wasington showing location of Cougar quadrangle and other 7-1/2 minute quadrangles in which geologic mapping has been or is currently being conducted by the USGS.

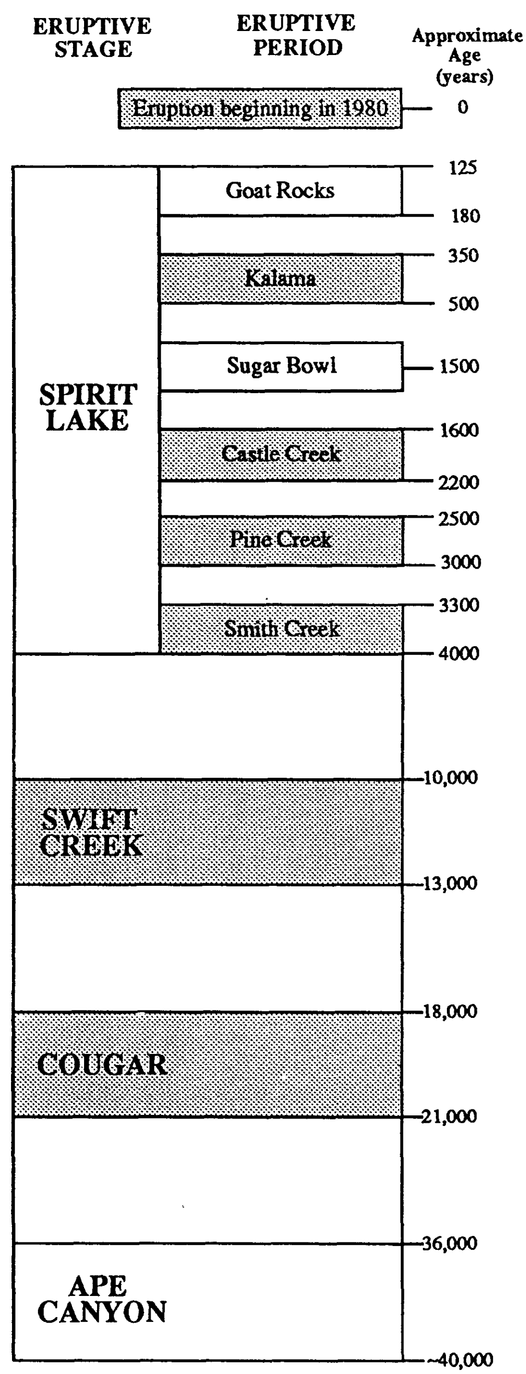


Figure 2.--Diagram showing eruptive stages and eruptive periods of Mount St. Helens volcano (Crandell, 1987). Deposits (exclusive of tephra) of all stages and periods except for Goat Rocks, Sugar Bowl, and Ape Canyon are present in the Cougar quadrangle.

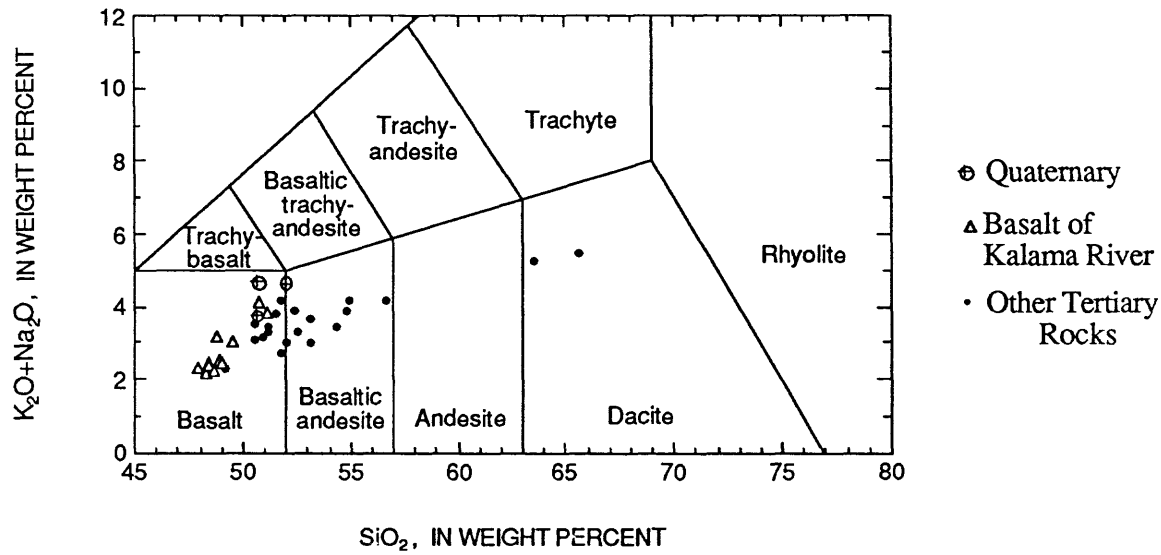


Figure 3.--Na_2O+K_2O versus SiO_2 (recalculated volatile-free) for Quaternary and Tertiary volcanic and hypabyssal intrusive rocks from Cougar quadrangle showing classification according to I.U.G.S. (Le Bas and others, 1986).

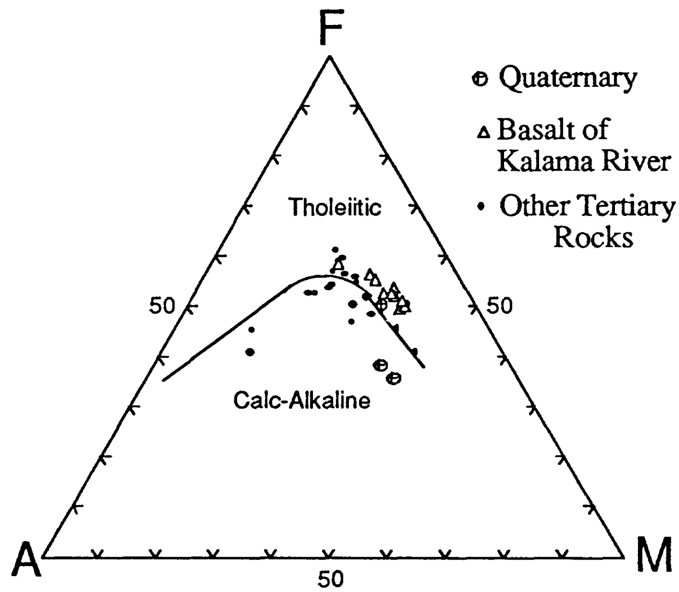


Figure 4.--AFM diagram for volcanic and hypabyssal intrusive rocks from Cougar quadrangle. A, Na_2O+K_2O; F, $FeO+Fe_2O_3+MnO$; M, MgO. Line separating tholeiitic and calc-alkaline rocks from Irvine and Baragar (1971).

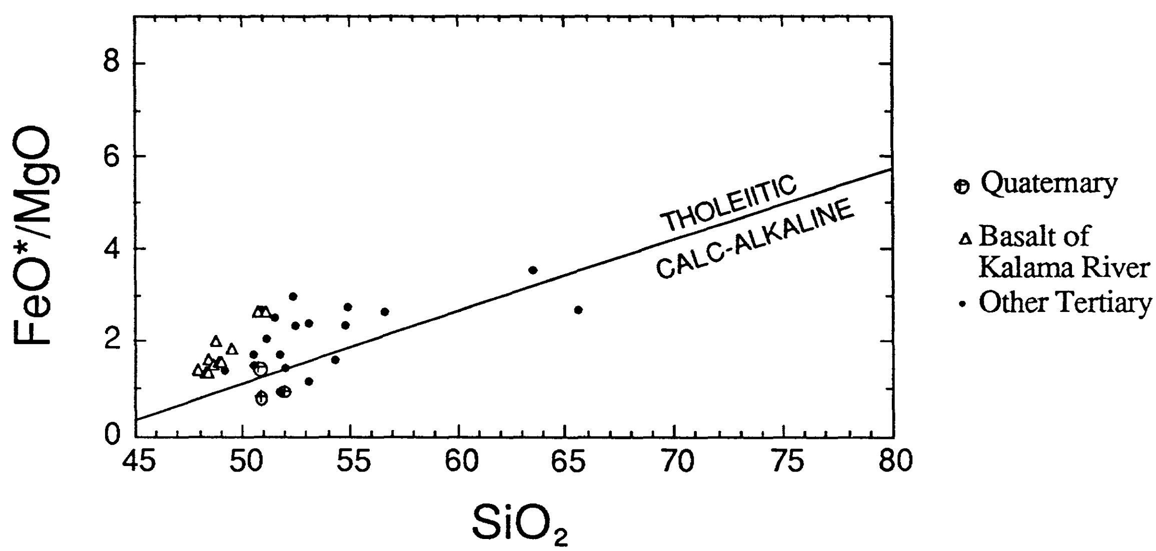


Figure 5--FeO*/MgO versus SiO_2 (recalculated volatile-free) for volcanic and hypabyssal intrusive rocks from Cougar quadrangle showing classification into tholeiitic and calc-alkaline rocks according to Miyashiro (1974). FeO*, total Fe as FeO.

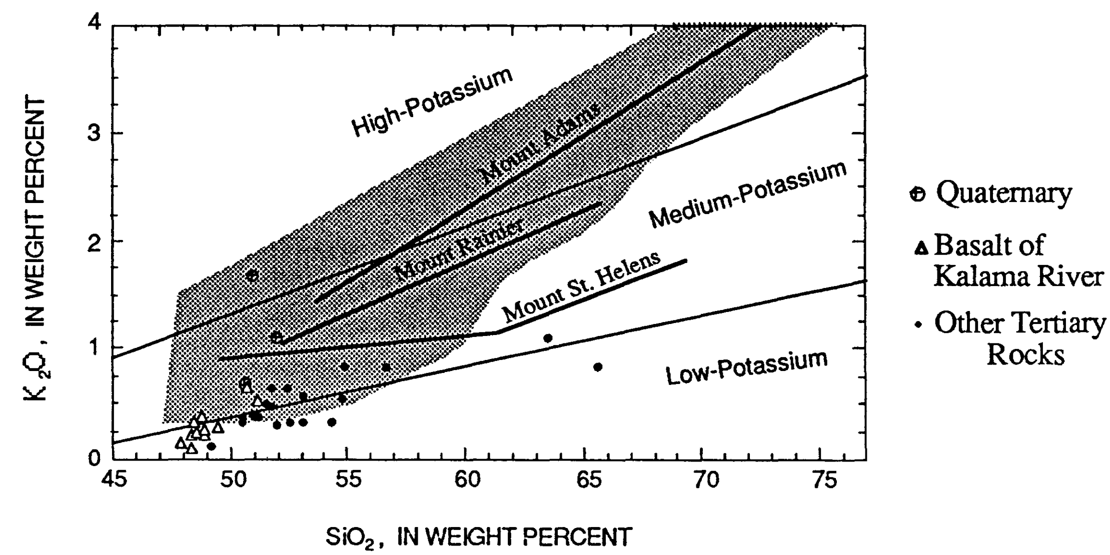


Figure 6.--K_2O versus SiO_2 (recalculated volatile-free) for volcanic and hypabyssal intrusive rocks from Cougar quadrangle. Low-, medium-, and high-potassium fields from Gill (1981, p. 6). Shaded area encompasses compositions of Quaternary volcanic rocks, exclusive of major stratovolcanoes, of southern 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.--Samples dated by fission-track (FT) and potassium-argon (K-Ar) methods

Map No.	Field sample No.	Location		Map unit	Rock type	Material dated	Method	Age (Ma)	Source
		Latitude	Longitude						
1	84CG-A02K	46°05'03"	122°18'20"	Tvs	Crystal-vitric tuff	Plagioclase	K-Ar	35.9±1.1	J. G. Smith, written commun., 1989
2	86CG-V103	46°01'24"	122°16'14"	Ttoq	Quartz-phyric ash-flow tuff	Plagioclase Zircon	K-Ar FT	31.1±0.6 32.5±4.0	J. G. Smith, written commun., 1989 R.C.Evarts, unpublished data
3	86CG-V123A	46°04'54"	122°21'07"	Qbs	Olivine basalt	Whole-rock	K-Ar	0.779±0.032	L. G. Pickthom, written commun., 1989

Table 2.--*Chemical analyses of volcanic and hypabyssal intrusive rocks, Cougar quadrangle*

[Oxides in weight percent. Rock type assigned in accordance with I.U.G.S. scheme of Streckeisen (1976) for plutonic rocks and I.U.G.S. system of Le Bas and others (1986) 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.	**86CG-V124B**	**87CG-V148B**	**87CG-V178**	**86CG-V125A**	**87CG-V128**	**87CG-A48**	**87CG-V179**	**87CG-A59**	**86CG-V122**
Latitude	46°05'49"	46°03'11"	46°03'28"	46°04'47"	46°06'39"	46°03'34"	46°03'44"	46°02'38"	46°05'32"
Longitude	122°21'54"	122°22'19"	122°19'29"	122°22'11"	122°22'24"	122°21'15"	122°21'17"	122°21'58"	122°21'41"
Map unit	Tbk	Tbk	Tdb	Tbk	Tbk	Tbk	Tbk	Tbk	Tbk
Rock type	Basalt	Basalt	Diabase	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt
SiO_2	46.40	46.60	47.00	47.00	47.10	47.10	47.20	47.30	47.80
TiO_2	1.39	1.26	1.34	1.95	1.48	1.31	1.42	1.82	1.63
Al_2O_3	17.30	17.90	16.20	15.90	17.20	19.10	17.20	14.60	16.40
Fe_2O_3	4.12	4.31	5.55	7.01	2.70	2.24	3.05	3.32	3.11
FeO	6.02	5.22	4.64	5.76	7.30	6.88	6.89	8.18	7.74
MnO	0.17	0.14	0.10	0.20	0.17	0.15	0.16	0.21	0.18
MgO	6.69	6.56	6.88	5.78	6.28	5.31	6.92	6.84	6.51
CaO	12.50	12.40	11.60	9.60	12.50	12.80	12.30	11.90	11.80
Na_2O	2.12	2.05	2.11	2.75	2.01	2.03	2.21	2.29	2.23
K_2O	0.17	0.12	0.11	0.40	0.25	0.36	0.24	0.22	0.27
P_2O_5	0.14	0.13	0.16	0.22	0.15	0.14	0.16	0.18	0.17
H_2O^+	1.64	1.76	1.74	1.97	2.21	2.43	1.72	1.98	1.61
H_2O^-	1.61	1.76	2.73	1.73	0.92	0.78	0.86	1.34	1.15
CO_2	0.03	<0.01	0.10	<0.01	0.04	<0.01	0.02	<0.01	0.03
Total	100.30	100.21	100.26	100.27	100.31	100.63	100.35	100.18	100.63

Table 2.--*Chemical analyses of volcanic and hypabyssal intrusive rocks, Cougar quadrangle,* continued

Map No.	10	11	12	13	14	15	16	17	18
Field sample No.	**87CG-A55**	**86CG-V127**	**87CG-V172**	**88CG-A115**	**87CG-V183**	**87CG-A58**	**87CG-V189**	**87CG-V175**	**88CG-V351**
Latitude	46°02'58"	46°04'25"	46°02'55"	46°02'48"	46°02'12"	46°02'16"	46°00'11"	46°03'48"	46°06'33"
Longitude	122°21'01"	122°20'13"	122°18'51"	122°22'00"	122°19'15"	122°21'42"	122°17'14"	122°19'20"	122°21'24"
Map unit	Tbk	Tb	Tb	Tbk	Tb	Tbk	Tab	Tb	Qsck
Rock type	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt
SiO_2	48.10	49.50	49.60	49.80	50.20	50.20	50.40	50.50	50.50
TiO_2	2.11	1.45	1.62	2.19	1.54	2.18	0.74	1.55	1.48
Al_2O_3	14.10	15.60	15.40	15.20	15.80	15.20	16.60	16.10	17.20
Fe_2O_3	4.86	4.37	5.26	6.35	7.38	5.19	3.58	6.23	-- -- --
FeO	7.51	5.97	5.71	6.98	3.98	7.76	4.41	4.93	9.90
MnO	0.26	0.16	0.20	0.23	0.15	0.24	0.13	0.18	0.16
MgO	6.17	6.50	6.08	4.67	5.16	4.65	7.98	5.00	6.69
CaO	11.00	11.30	10.70	8.62	10.50	8.93	10.80	10.70	9.89
Na_2O	2.74	2.72	3.11	3.44	3.03	3.28	2.23	2.94	3.23
K_2O	0.31	0.33	0.37	0.66	0.37	0.55	0.47	0.37	0.55
P_2O_5	0.25	0.19	0.24	0.27	0.21	0.28	0.13	0.22	0.20
H_2O^+	1.05	1.22	0.84	0.59	0.96	0.75	0.89	0.64	0.09
H_2O^-	1.79	1.47	1.25	1.21	1.01	1.38	1.63	1.00	0.06
CO_2	0.01	0.02	<0.01	0.02	0.06	0.05	<0.01	<0.01	0.13
Total	100.26	100.80	100.38	100.23	100.35	100.64	99.99	100.36	100.08

Table 2.--*Chemical analyses of volcanic and hypabyssal intrusive rocks, Cougar quadrangle,* continued

Map No.	19	20	21	22	23	24	25	26	27
Field sample No.	**86CG-V106**	**86CG-V100A**	**88CG-V355A**	**86CG-V123A**	**86CG-V105**	**87CG-A79**	**88CG-A94**	**87CG-V185**	**82CG-V13B**
Latitude	46°00'04"	46°02'17"	46°04'09"	46°04'54"	46°00'08"	46°00'55"	46°00'51"	46°01'22"	46°06'17"
Longitude	122°15'34"	122°15'28"	122°17'44"	122°21'07"	122°15'51"	122°22'15"	122°21'48"	122°20'30"	122°18'09"
Map unit	Tcpp	Tab	Thp	Qbs	Tiba	Tb	Tb	Qbs	Tiba
Rock type	Basalt	Basalt	Diorite	Basalt	Basalt	Basalt	Basalt	Basalt	Basaltic andesite
SiO_2	50.60	50.70	50.70	50.70	51.80	50.90	51.40	51.60	51.90
TiO_2	1.41	1.72	1.32	1.15	1.89	1.36	0.93	1.49	1.12
Al_2O_3	19.70	17.90	17.60	15.20	15.30	15.70	16.50	16.50	15.70
Fe_2O_3	3.52	5.52	4.07	4.09	4.93	5.93	4.36	3.53	2.94
FeO	6.47	5.57	6.15	4.39	7.99	4.66	4.99	4.77	6.14
MnO	0.16	0.22	0.14	0.14	0.22	0.19	0.16	0.13	0.15
MgO	3.56	4.13	4.19	9.78	4.14	5.70	6.08	8.19	7.28
CaO	10.70	8.63	8.87	9.01	8.69	9.65	11.40	8.04	9.44
Na_2O	2.76	3.26	2.86	3.09	3.18	3.47	2.71	3.53	2.67
K_2O	0.41	0.49	0.33	1.67	0.65	0.63	0.30	1.10	0.32
P_2O_5	0.14	0.41	0.31	0.34	0.19	0.19	0.12	0.41	0.15
H_2O^+	0.69	0.83	1.59	0.32	0.80	1.18	0.60	0.55	0.92
H_2O^-	0.61	1.02	1.44	0.27	0.42	0.83	0.92	0.36	0.63
CO_2	<0.01	0.06	0.62	0.06	<0.01	0.03	0.01	0.05	0.06
Total	100.73	100.46	100.19	100.21	100.20	100.42	100.48	100.25	99.42

Table 2.--*Chemical analyses of volcanic and hypabyssal intrusive rocks, Cougar quadrangle*, continued

Map No.	28	29	30	31	32	33	34
Field sample No.	**82CG-A04**	**88CG-V263A**	**88CG-V352**	**86CG-V117C**	**82CG-V20**	**84CG-V58A**	**88CG-V262C**
Latitude	46°05'38"	46°06'08"	46°00'56"	46°05'16"	46°03'46"		46°06'00"
Longitude	122°17'29"	122°16'27"	122°117'11"	122°20'04"	122°17'17"		122°16'46"
Map unit	Tba	Tba	Tdi	Tdi	Tcc	Tcp	Tid
Rock type	Basaltic Andesite	Andesite	Diorite	Diorite	Quartz Diorite	Dacite	Dacite
SiO_2	52.10	53.20	53.20	53.70	55.70	61.00	63.50
TiO_2	1.56	0.98	1.27	1.31	1.18	1.01	0.72
Al_2O_3	17.80	18.50	18.30	17.60	17.20	15.70	14.90
Fe_2O_3	3.38	3.34	4.95	3.17	5.35	2.36	2.10
FeO	5.96	4.18	3.58	6.33	3.66	3.72	3.26
MnO	0.16	0.12	0.10	0.17	0.18	0.14	0.11
MgO	3.74	4.46	2.93	3.89	3.23	1.64	1.93
CaO	9.58	9.73	8.32	7.82	7.44	5.16	4.82
Na_2O	3.07	3.05	3.26	3.28	3.32	4.03	4.54
K_2O	0.56	0.34	0.81	0.54	0.83	1.06	0.81
P_2O_5	0.22	0.16	0.22	0.31	0.23	0.34	0.14
H_2O^+	1.11	0.87	0.86	1.35	1.33	2.27	2.47
H_2O^-	0.97	0.88	2.24	0.98	0.93	1.51	0.56
CO_2	0.03	0.02	0.01	0.16	0.03	0.12	0.13
Total	100.24	99.83	100.05	100.61	100.61	100.06	99.99

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

af **Artificial fill**--Levee of power canal along north side of Lewis River east of Cougar

Qrt **River terrace deposits (Holocene)**--Unconsolidated fine- to coarse-grained alluvium forming low terraces near northeast end of Yale Lake; terraces extend downstream beneath lake surface. At Beaver Bay Park, terrace gravels rest on distal end of Cave Basalt flow (Tscc), but submerged terraces may include older deposits

Ql **Lake deposits (Holocene)**--Silt, fine-grained sand, and tephra underlying marshy areas along shore of Merrill Lake. Lake formed when basalt of Kalama Falls (Qsck) and underlying clastic debris from Mount St. Helens (Hyde, 1970) dammed short tributary of Kalama River

Qrs **Rockslide deposits (Holocene)**--Unvegetated accumulation of large, angular, lichen-covered blocks of Tertiary basalt (Tib) at the base of scarps on the flanks of Cooney Peak in southeastern corner of quadrangle

Qt **Talus (Holocene and Pleistocene)**--Unsorted accumulations of loose, angular blocks of rock forming steep unvegetated slopes beneath cliffs; talus in Christmass Canyon east of Beaver Bay Park composed of basalt blocks broken from margin of Cave Basalt (Qscc) flow as underlying unconsolidated deposits (Qsc) were eroded away

Qa **Alluvium (Holocene and Pleistocene)**--Unconsolidated, poorly to moderately sorted deposits of silt, sand, and gravel in valleys of active streams. Locally includes colluvium and talus; also locally includes minor drift, especially in small basins above about 2,900 ft northeast of Cinnamon Peak

Qc **Colluvium (Holocene and Pleistocene)**--Unconsolidated, unsorted deposits consisting of angular fragments of locally-derived bedrock; along east shore of Yale Lake at south edge of quadrangle

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. Most slides head at theatre-shaped scars and exhibit subhorizontal tops, bulbous toes, and hummocky surfaces. Most common in areas underlain by clay-rich zeolitic volcaniclastic rocks (Tvs)

Deposits of Mount St. Helens volcano (Holocene and Pleistocene)--Divided into:

Deposits of the Spirit Lake eruptive stage--Divided into:

Qsk **Deposits of the Kalama eruptive period**--Unconsolidated fragmental deposits discontinuously overlying the basalt of Kalama Falls (Qsck) in the Kalama River valley. In this quadrangle, consist chiefly of alluvium derived from reworking of pyroclastic-flow deposits exposed upvalley but also include minor interbedded laharic deposits; thickness variable, about 16 m of alluvium is exposed in gravel pit just west of mouth of Dry Creek (Crandell, 1987). Conflicting radiocarbon ages have been obtained from the pyroclastic-flow deposits in the adjacent Goat Mountain quadrangle, but Crandell (1987) indicates that deposition probably occurred during the early part of the Kalama eruptive period, after A.D. 1480 and before A.D. 1640

Deposits of the Castle Creek eruptive period--Divided into:

Qscc **Cave Basalt**--Flow of light-gray to black, porphyritic, vesicular, pahoehoe basalt; distal end of flow exposed along north side of Lewis River (Greeley and Hyde, 1972); flow is about 11 km long and was extruded from a vent on the southwest flank of the volcano. Flow backed up against southern bank of Cougar Creek cut into Cougar-age flowage deposits (Qscg) that have since been partially eroded away; basalt lobes poured through two gaps in the Cougar Creek-Lewis River drainage divide (one immediately east of Christmass Canyon and the second about 300 m east of quadrangle) and down into the Lewis River valley, terminating near the mouth of Christmass Canyon. Typical basalt sample contains phenocrysts of plagioclase (10-20 percent; 1 to 3 mm long) and olivine (5 percent; 0.5 to 1 mm across) and spherical vesicles (up to 20 percent; as large as 8 cm) in an intergranular to intersertal groundmass. Sparsely forested flow surface is flat to hummocky, with abundant tilted slabs, pressure-ridges, tumuli, and lava tubes (caves); collapsed tumuli form craters up to 50 m in diameter; lava tube segments as long as 3,400 m are known (Greeley and Hyde, 1972). Charcoal from roots at base of tree molds beneath flow at two localities in adjacent Mount Mitchell quadrangle yielded radiocarbon ages of 1,870 and 1,925 years before present (b.p.) (Greeley and Hyde, 1972), but stratigraphic relations indicate that it must be younger than tephra layer Bu which is about 1,700 radiocarbon years old (Crandell, 1987, p. 54); eruption thus occurred near the end of the Castle Creek eruptive period (approximately 2,200 to 1,600 years b.p., Crandell, 1987)

Qsck **Basalt of Kalama Falls**--Black to dark-gray basalt flow in the Kalama River valley. Similar to Cave Basalt (although lacking known lava tubes) and probably extruded during the same eruption; chemical analysis (table 2, no. 18). is virtually identical to that of Cave Basalt reported by Greeley and Hyde (1972). According to Hyde (1970), geophysical data suggest that the basalt extends beneath the northern half of Merrill Lake. Drill cores (Hyde, 1970) indicate that the unit consists of several flow units and is about 40 m thick near the mouth of Dry Creek and 18 m thick near the north shore of Merrill Lake; about 14 m of basalt crop out at Kalama Falls, where the base is not exposed. Extensively overlain north of Merrill Lake by unconsolidated deposits of the Kalama eruptive period (Qsk) and underlain by as much as 65 m of older Mount St. Helens laharic deposits (Qspc) (Hyde, 1970)

Qspc **Pre-Castle Creek deposits in Kalama valley, undivided**--Unconsolidated laharic and alluvial deposits along margins of basalt of Kalama Falls (Qsck) and in low terrace remnant downstream from falls. Basalt flowed down valley incised into these deposits. Virtually all clasts are dacites like those erupted during the early history of the volcano, and clasts of typical Castle Creek-age andesite and basalt are absent, suggesting these deposits are predominantly older than the Castle Creek eruptive period. Correlative deposits exposed downvalley from this quadrangle include products of the Castle Creek and Pine Creek eruptive periods of the Spirit Lake eruptive stage and possibly deposits as old as the Swift Creek eruptive stage of Crandell (1987)

Qssw **Deposits of the Swift Creek eruptive stage**--Unconsolidated deposits forming scattered terrace remnants along Lewis River and Yale Lake at elevations below about 650 ft. Equivalent to the younger part of the Swift Creek assemblage of Hyde (1975), which was deposited during the Swift Creek eruptive period (Crandell, 1987); these terraces are older than Mount St. Helens tephra set S which is approximately 13,000 radiocarbon years old (Hyde, 1975; Crandell, 1987). Composed of lahar and lahar-runout deposits and fine- to coarse-grained alluvium that filled valley cut into similar deposits of Cougar age (Qscg); the laharic deposits are poorly-sorted and relatively fine-grained, containing angular to subangular clasts of older Mount St. Helens pumiceous and lithic dacite which rarely exceed 10 cm; alluvial deposits are composed chiefly of Mount St. Helens lithologies reworked from contemporaneous flowage deposits (Hyde, 1975; Crandell, 1987; Major and Scott, 1988)

Qscg **Deposits of the Cougar eruptive stage**--Unconsolidated to slightly indurated fragmental deposits forming higher terraces along both sides of Lewis River and Yale Lake. Equivalent to the older part of the Swift Creek assemblage of Hyde (1975), which was deposited during the Cougar eruptive period between approximately 22 and 18 ka (Crandell, 1987; Major and Scott, 1988). Deposits between about 650 and 1,050 ft elevation north of Lewis River in and near Christmass Canyon and between 600 and 750 ft elevation south of the river include pumiceous and lithic pyroclastic flow deposits, lahar deposits, and alluvium which make up the southwestern margin of a broad thick fan of Cougar-age centered on Swift Creek 4 km to the east in the Mount Mitchell quadrangle (Hyde, 1975); some of these deposits contain boulders of old Mount St. Helens dacite and andesite as large as 2 m and pumice as large as 1 m. Terrace remnants north of Cougar and along Yale Lake in southern part of quadrangle are underlain by alluvium and minor relatively fine-grained lahar and lahar-runout deposits lithologically similar to those of Swift Creek age (Hyde, 1975; Major and Scott, 1988)

Evans Creek Drift (Pleistocene)--Divided into:

Qet **Till deposits**--Unsorted, unstratified diamicton near Cinnamon Peak (Hyde, 1975) composed of angular to rounded clasts of volcanic rock as large as 1 m in a compact matrix of sand, silt, and clay; locally includes glaciofluvial sand and gravel deposits, postglacial colluvium, and areas of modern alluvium too small to map separately. Till is oxidized to depths up to 1 m and contains volcanic clasts which lack discernible weathering rinds, features which characterize the Evans Creek Drift (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 moraine near 2,400 ft bisected by Dry Creek

Hayden Creek Drift (Pleistocene)--Divided into:

Qht **Till deposits**--Unsorted, unstratified diamicton composed of angular to rounded clasts up to boulder size in compact matrix of sand, silt, and clay; locally includes glaciofluvial sand and gravel deposits, postglacial colluvium, probable loess, and areas of modern alluvium too small to map separately. Forms discontinuous blanket on areas of low relief throughout quadrangle but shown only where thick and extensive enough to obscure bedrock. Overlain by biotite-bearing tephra of set C of Mullineaux (1986) erupted from Mount St. Helens during the Ape Canyon eruptive stage approximately 40 ka. Till is typically intensely weathered to depth of 1 m, oxidized to depth of 1 to 2 m or more, and contains clasts of volcanic rock in the upper part of the weathering profile that exhibit weathering rinds 1 to 2 mm thick. In Lewis River valley, coextensive downstream with Amboy Drift of Mundorff (1984). Correlated with the Hayden Creek Drift of the Mount Rainier region, which possesses similar weathering characteristics (Crandell and Miller, 1974; Colman and Pierce, 1981), but areas mapped as Hayden Creek till deposits may locally include some older till. Age of the Hayden Creek Drift is controversial; 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**--Deeply weathered deposits lithologically similar to those mapped as Hayden Creek till (Qht) forming small lateral moraines near mouth of Dry Creek. Considered by Hyde (1975) and Crandell (1987) to be of Fraser (Evans Creek) age but deposits are lithologically identical to drift exposed in roadcut on north side of Dry Creek which is overlain by tephra set C, so must be older

Qho **Outwash deposits**--Deposits of compact, crudely stratified, clast-supported gravel forming terrace remnants along Kalama River. Consist of well-rounded cobbles and boulders of Tertiary volcanic and volcaniclastic rocks in a sandy matrix; locally includes clasts of coarsely porphyritic biotite-hornblende dacite identical to that which makes up Goat Mountain, but lacks clasts of typical Mount St. Helens lithologies

Qoa **Older alluvium**--Unconsolidated, poorly to moderately sorted deposits of silt, sand, and gravel in abandoned stream valley northwest of Kalama Falls. Deposited by stream flowing along north margin of Kalama River glacier during Hayden Creek time

Qbs **Basalt of Speelyai Creek (Pleistocene)**--Light- to medium-gray seriate olivine basalt underlying area west of Merrill Lake and southern part of ridge east of lower Speelyai Creek. Consists of 5-10 percent olivine phenocrysts 1 mm across, accompanied in some samples by microphenocrysts of plagioclase and augite, in an intergranular groundmass of plagioclase, pyroxene, and Fe-Ti oxide. Agglutinate and oxidized agglomerate exposed on Peak 3370 west of Merrill Lake probably demark the vent for the flows. Outcrop to the south near Yale Lake appears to be erosional remnant of flow that moved down ancestral valley of Speelyai Creek. Overlain by and occurs as clasts in Hayden Creek drift. A whole-rock K-Ar age of 779±32 ka was obtained from a sample collected about 50 m east of Peak 3370 (table 1)

BEDROCK

Intrusive rocks

Tcpp **Cooney Peak plug (Oligocene?)**--Plug forming sharp peak in southeastern corner of quadrangle. West flank consists of sparsely-phyric basaltic andesite intrusion containing plagioclase phenocrysts (5 percent; 0.5-1 mm long, a few as long as 3 mm) and microphenocrysts of altered olivine (<1 percent; <0.5 mm across, partially resorbed with rims of fine-grained vermicular magnetite and pyroxene), augite (<1 percent; 0.3 to 0.5 mm across), and magnetite (< 1 percent; <0.1 mm across) in an intergranular groundmass of plagioclase, pyroxene, Fe-Ti oxide and interstitial fresh glass. East flank underlain by columnar-jointed, steeply east-dipping dike of porphyritic basalt containing phenocrysts of plagioclase (33 percent; 1-3 mm long, a few as long as 7 mm) and olivine (< 0.5 percent; 1 to 2 mm across) in an intergranular groundmass of plagioclase, pyroxene, Fe-Ti oxide, and interstitial glass; olivine and some glass altered to yellow-orange smectite

Tia **Intrusive andesite (Oligocene)**--Dikes and sills of porphyritic to seriate pyroxene andesite and rare aphyric andesite, mainly in eastern half of quadrangle. Typically composed of plagioclase (20-30 percent; 1 to 5 mm), augite (0-3 percent; 0.5 to 6 mm), hypersthene (0-3 percent; 0.5 to 2 mm), and Fe-Ti oxide (<1 percent; 0.1 to 1 mm) phenocrysts in an intergranular, intersertal, or pilotaxitic groundmass of plagioclase, pyroxene, Fe-Ti oxide, quartz and altered glass. Generally highly altered, particularly near Cougar Creek stock (Tcc), to assemblages of albite, smectite, chlorite, carbonate, titanite, and zeolites such as laumontite, heulandite, stilbite, epistilbite, and gismondine. Compositionally and texturally gradational to diorite (Tdi) and hornblende-bearing porphyry (Thp)

Tgr **Granite (Oligocene)**--Light-tan, altered, porphyritic rock containing phenocrysts of albitized plagioclase (10-15 percent; 1 to 2 mm long) and completely altered hypersthene(?) (<5 percent; up to 1 mm long) in a fine-grained groundmass of plagioclase, quartz, K-feldspar, smectite after pyroxene, and titanite. Forms small, locally columnar-jointed sills exposed along south shore of Yale Lake east of Cougar

Tdi **Diorite (Oligocene)**--Light- to medium-gray, medium-grained, coarsely porphyritic to seriate to hypidiomorphic granular pyroxene diorite to quartz diorite. Coarser grained varieties contain plagioclase (about 65 percent; 2 to 5 mm long), hypersthene (5-15 percent; 1 to 2 mm long), augite (5-10 percent; 1 mm across), Fe-Ti oxide (1-2 percent; 0.5 mm across), and minor interstitial smectite (replacing mafic minerals and (or) glass), apatite, and in some samples, quartz and hornblende. Forms dikes and large crudely sill-like bodies in volcaniclastic rocks throughout quadrangle; most abundant east of Yale Lake. Commonly partially altered to albite, laumontite, smectite, titanite, stilbite, and calcite. Locally amygduloidal, especially near upper contacts of sills

Tcc **Cougar Creek stock (Oligocene)**--Multiphase stock that crops out in lower stretch of Cougar Creek. Poorly exposed but appears to consist of many small intrusions of fine- to medium-grained, porphyritic to seriate rocks ranging in composition from basaltic andesite to rhyolite. Most common rock-types are plagioclase- and two-pyroxene-phyric andesite, diorite, and quartz diorite petrographically similar to intrusive andesite (Tia) and diorite (Tdi) dikes and sills in nearby country rocks; many intrusions contain sparse scattered megacrysts of brown hornblende and are petrographically similar to hornblende-bearing porphyry (Thp). Hornblende-bearing breccia body of unknown configuration crops out on north valley wall of Cougar Creek. Most of stock moderately to highly altered to assemblages containing albite, quartz, chlorite, carbonate, sericite, titanite, and pyrite; some rocks contact-metamorphosed by younger intrusions to epidote-, amphibole-, and biotite-bearing hornfels

Thp **Hornblende-bearing porphyry (Oligocene)**--Dikes, sills, and plugs of fine-grained porphyritic to seriate andesite to diorite bearing megacrysts of brown hornblende; contain phenocrysts of plagioclase, augite, hypersthene, and Fe-Ti oxide and petrographically resemble intrusive andesite (Tia) and diorite (Tdi) except for presence of hornblende. Megacrysts rarely constitute more than 1 or 2 percent of rock but are conspicuous owing to their large size, commonly exceeding 2 cm and locally as long as 14 cm; mostly subhedral to euhedral, some skeletal. Hornblende invariably rimmed or completely replaced by black dehydration rinds composed of fine-grained aggregates of augite, hypersthene, plagioclase and abundant Fe-Ti oxide. Intrusions more or less radially distributed around periphery of Cougar Creek stock, which contains similar hornblende-bearing phases

Tdc **Dry Creek sill (Oligocene)**--Sill of light-brown to medium-gray, medium-grained, intergranular pyroxene diorite forming cliffline that caps north-striking ridge between Dry Creek and Merrill Lake. Consists of plagioclase (about 65 percent; 1-3 mm long), augite (about 10 percent; 0.5-1 mm across), hypersthene (about 15 percent; 0.5-1 mm long), Fe-Ti oxide(1 percent; 0.5-1 mm across), and traces of interstitial quartz, hornblende and apatite; one sample contains irregular clots of dark-brown smectite surrounded by pyroxene grains that may be altered olivine. Smectite and zeolites including epistilbite, stilbite, and laumontite extensively replace magmatic minerals and fill interstitial voids

Tid **Intrusive dacite (Oligocene)**--Dike of sparsely-phyric, flow-banded, pyroxene dacite cutting andesite and volcaniclastic rocks south of Cinnamon Peak. Contains phenocrysts of plagioclase (7 percent; 1 mm long) and equant microphenocrysts of augite (1-2 percent), hypersthene (1-2 percent), and Fe-Ti oxide (<1 percent) in a glassy pilotaxitic groundmass

Tiba **Intrusive basaltic andesite (Oligocene)**--Rare small intrusions of porphyritic to seriate basaltic andesite. Contain phenocrysts of plagioclase (15-35 percent; 1 to 3 mm long; locally as long as 6 mm), olivine (1-3 percent; 0.5 to 1 mm across; locally as large as 3 mm across), and in most samples augite (0-4 percent; 1 to 3 mm across) in an intergranular groundmass of plagioclase, augite, Fe-Ti oxide, and minor altered interstitial glass. Locally amygdular. Most samples moderately altered to albite, carbonate, smectite, zeolites, and titanite

Thqd **Hypersthene quartz diorite (Oligocene)**--Light-greenish gray to medium-gray, fine- to medium-grained, porphyritic to seriate hypersthene quartz diorite to diorite forming large, multiphase sill-like bodies intruding volcaniclastic rocks west and south of Merrill Lake. Contains phenocrysts of blocky plagioclase (5-10 percent; 1 to 2 mm long), and microphenocrysts of prismatic to acicular hypersthene (10-15 percent; less than 1 mm long), in a groundmass of plagioclase, hypersthene, Fe-Ti oxide, quartz, apatite, and local traces of K-feldspar, biotite; very scarce phenocrysts of brown hornblende observed in one outcrop. Generally highly altered to zeolite-facies assemblages which include laumontite, stilbite, albite, smectite, prehnite, calcite, titanite, and pumpellyite. Amygdules locally abundant, especially adjacent to upper contacts. Coarse-grained (3 to 5 mm grain size) cognate inclusions of norite present in a few samples

Tdb **Diabase (Oligocene)**--Dikes and sills of mottled, medium-grained diabase with well-developed ophitic texture. Most common in volcaniclastic sedimentary rocks west of Dog Creek. Consists of randomly oriented plagioclase laths about 0.5 mm long and smaller olivine and Fe-Ti oxide crystals poikilitically enclosed in subspherical grains of pale brownish augite 1 to 3 mm across; some samples contain 1-2 percent plagioclase phenocrysts as long as 5 mm; greenish-brown smectite totally replaces olivine and fills abundant irregular vesicles

Volcanic and sedimentary rocks

Tto **Tuff of Ole Creek (Oligocene)**--Sequence of pumiceous lapilli-tuff beds underlying high peaks east of Yale Lake in the headwaters of Ole Creek. Light-green to buff, pumice-rich, lithic-poor, sparsely phyric ash-flow tuff and minor interbedded volcaniclastic siltstone and sandstone. Tuff typically contains a few percent of plagioclase and altered pyroxene phenocrysts; carbonized wood fragments common, especially near bases of tuff beds. Locally at base contains:

Ttoq **Quartz-phyric tuff**--The thickest and stratigraphically lowest tuff bed in the tuff of Ole Creek; lithologically similar to the other tuffs but distinguished by the presence of

20.percent quartz phenocrysts as large as 2 mm across. A plagioclase K-Ar age of 31.1±0.6 Ma and zircon fission-track age of 32.5±4.0 Ma were obtained from this unit (table 1)

Tab **Augite-phyric basalt (Oligocene)**--Flows and flow-breccia of porphyritic to seriate basalt east of Yale Lake that contain conspicuous large phenocrysts and clots of shiny black equant augite as large as 1 cm across. Contain phenocrysts of plagioclase (15-30 percent; 1-3 mm long), altered olivine (2-7 percent; 0.5 to 1 mm across, locally to 4 mm across), Fe-Ti oxide (1-2.5 percent; 0.5 to 1 mm across), and scarce hypersthene (<0.5 percent; 1 mm long) in addition to augite (5-10 percent) in an intergranular groundmass of the same minerals. Scattered hornblende megacrysts seen at one locality suggest that the Cougar Creek stock (Tcc) was the source for at least some of these flows

Tcp **Andesite of Cinnamon Peak (Oligocene)**--Sequence of coarsely porphyritic pyroxene andesite flows and very minor interbedded conglomerate underlying area east of Cinnamon Peak. Overlies volcanic breccia and conglomerate along gently east-dipping but locally highly irregular erosion surface. Contains phenocrysts of plagioclase (20-35 percent; 1 to 3 mm long; some as long as 6 mm), augite (2-6 percent; 0.5 to 3 mm across), hypersthene (3-7 percent; 0.5 to 3 mm long), and microphenocrysts of Fe-Ti oxide (1-2 percent; 0.2 to 0.5 mm across) in a felsic pilotaxitic to hyalopilitic groundmass. Some samples contain a trace of chromite-bearing altered olivine xenocrysts; small cognate inclusions of two-pyroxene gabbro common in some flows. Andesites in this unit notably less altered than flows in subjacent strata. A sample from northeast of Cinnamon Peak in the Goat Mountain quadrangle yielded a plagioclase $^{40}Ar/^{39}Ar$ plateau age of 32.0±1.0 Ma (L.G. Pickthorn, written commun., 1988)

Tvbl **Volcanic breccia of Lost Creek (Oligocene)**--Massive, varicolored, very poorly sorted, polymict volcanic breccia and conglomerate exposed in northeast part of quadrangle. As much as 250 m thick in Lost Creek, but exhibits relatively abrupt variations in thickness owing to deposition on an irregular surface and to extensive postdepositional erosion. In most areas directly underlies andesite of Cinnamon Peak (Tcp). Generally green on fresh surfaces but weathers dark reddish to purplish brown. Locally interbedded with minor amounts of finer-grained bedded sedimentary rocks, tuff (Tt), and small lava flows of basaltic andesite (Tba) and andesite (Ta); carbonized woody debris including fragments of logs as long as 1 m present locally. Clasts as large as 4 m across are mostly basalt and basaltic andesite, but matrix/clast contacts in many outcrops obscure owing to intense zeolite-facies metamorphism; augite typically sole remaining primary mineral. Origin of most of unit enigmatic; much of it probably deposited by lahars but some parts appear to consist largely of autobrecciated lava flows

Tba **Basaltic andesite (Oligocene)**--Widespread flows and flow-breccia of porphyritic to seriate basaltic andesite containing phenocrysts of plagioclase (10-35 percent; 1 to 5 mm long), olivine (as much as 4 percent; 0.5 to 1 mm across; commonly partly resorbed and rimmed by fine-grained granular pyroxene±magnetite; contains minute chromite inclusions in a few samples), augite (as much as 5 percent; 0.5 to 3 mm across), with or without hypersthene (0-2 percent; 0.5 to 1 mm long), and Fe-Ti oxide (<1 percent; <0.5 mm across) in an intergranular groundmass of the same minerals plus interstitial glass (mostly altered to smectite±quartz). Some samples lacking pyroxene may be basalt chemically

Tvs **Volcaniclastic sedimentary rocks (Oligocene)**--Diverse assemblage of continental volcaniclastic rocks of inferred epiclastic origin. Consists of generally well-bedded, well- to moderately well-sorted 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 separately. Typically light green to olive green or greenish gray but also white, tan, or brown. Virtually all lithic clasts are volcanic rocks petrographically identical to interbedded basalt and andesite; minor components include pumice, felsite, plagioclase, olivine, and pyroxene crystals, vitric ash, fine-grained plutonic rocks, and plant remains; coaly beds a few centimeters thick are present locally. Interpreted as predominantly fluvial and lacustrine deposits deposited in low-lying intervolcano areas.

Intense low-grade alteration to zeolites, smectite, carbonate, quartz, leucoxene, and hematite is typical; laumontite and heulandite or clinoptilolite are common cements. Plagioclase separated from thin tuff bed east of Merrill Lake yielded a K-Ar age of 35.9±1.0 Ma (table 1)

Tt **Tuff (Oligocene)**--Beds of andesitic to rhyolitic tuff, pumiceous lapilli-tuff, and pumice-bearing tuff-breccia interbedded with volcaniclastic sedimentary rocks (Tvs); inferred to be mostly of pyroclastic (chiefly ash-flow) origin. Includes all mappable strata that contain abundant pumice lapilli or possess an ash-rich matrix, hence unit contains some slightly to moderately reworked pyroclastic deposits. Also includes sequences of tuffaceous rocks interbedded with and gradational to pumice-poor epiclastic sedimentary rocks in which pumice-bearing beds dominate. Mainly shades of green, but locally white, brown, or purple. Proportion of angular volcanic 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 tuff beds attributed to compaction during burial rather than to welding. Carbonized woody debris present in some tuff. Phenocrysts rarely constitute more than 15 percent of juvenile material in tuff, and include plagioclase, augite, and Fe-Ti oxide but no quartz or biotite; green-brown hornblende found in one tuff bed east of Yale Lake. Original glass completely devitrified to cryptocrystalline quartz and alkali feldspar or replaced by fine-grained smectites or zeolites, most commonly heulandite or clinoptilolite

Ta **Andesite (Oligocene)**--Flows and flow-breccia of aphyric to porphyritic pyroxene andesite chiefly in the east half of quadrangle. Porphyritic varieties contain phenocrysts of plagioclase (as much as 35 percent; 1-3 mm long), augite (0-3 percent; 0.5 to 1 mm across) and (or) hypersthene (0-4 percent; 0.5 to 1 mm long), and microphenocrysts of Fe-Ti oxide (<1 percent; <0.5 mm across) in an intersertal to pilotaxitic groundmass of plagioclase, pyroxene, Fe-Ti oxide, quartz, and altered interstitial glass. Commonly vesicular

Tb **Basalt (Oligocene)**--Flows and flow-breccia of porphyritic to aphyric basalt west of Merrill and Yale Lakes. Petrographically identical to rocks in the basalt of Kalama River

Tbk **Basalt of Kalama River (Eocene)**--Sequence of black, blocky-jointed, strikingly plagioclase-phyric basalt flows and minor slabby virtually aphyric basalt flows in west part of quadrangle; also underlie a large area to the west and northwest. Porphyritic flows make up about 80 percent of unit and consist of 15-35 percent plagioclase phenocrysts and glomerocrysts typically 3 to 10 mm across, and 0-2 percent olivine phenocrysts 1 to 3 mm across in an intergranular to subophitic to ophitic, diktytaxitic groundmass of plagioclase, olivine, augite, and Fe-Ti oxide; some samples contain <1 percent equant augite microphenocrysts. Aphyric to sparsely phyric lavas (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; average 5-8 m thick; tops and bottoms of flows composed of highly vesiculated and zeolitized flow-breccia; vesicles, conspicuous owing to fillings of ubiquitous white zeolites, much less abundant in flow centers but persist throughout. Negligible interbedded volcaniclastic material except for brick-red hematitic siltstone beds less than 1 m thick present locally. Some plagioclase partly replaced by smectite, albite, laumontite, stilbite, calcite; olivine partly to completely replaced by smectite; smectite, prehnite, pumpellyite, analcime, and a variety of calcic zeolites including stilbite, mesolite, thompsonite, levyne, heulandite, and wairakite(?) fill vesicles and numerous interstitial voids; in general, however, basalts of this unit are noticeably fresher than overlying rocks to the east. Thicker and more traceable aphyric lavas shown separately as **Tbka**

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; dotted where concealed; showing direction of plunge

Strike and dip of beds

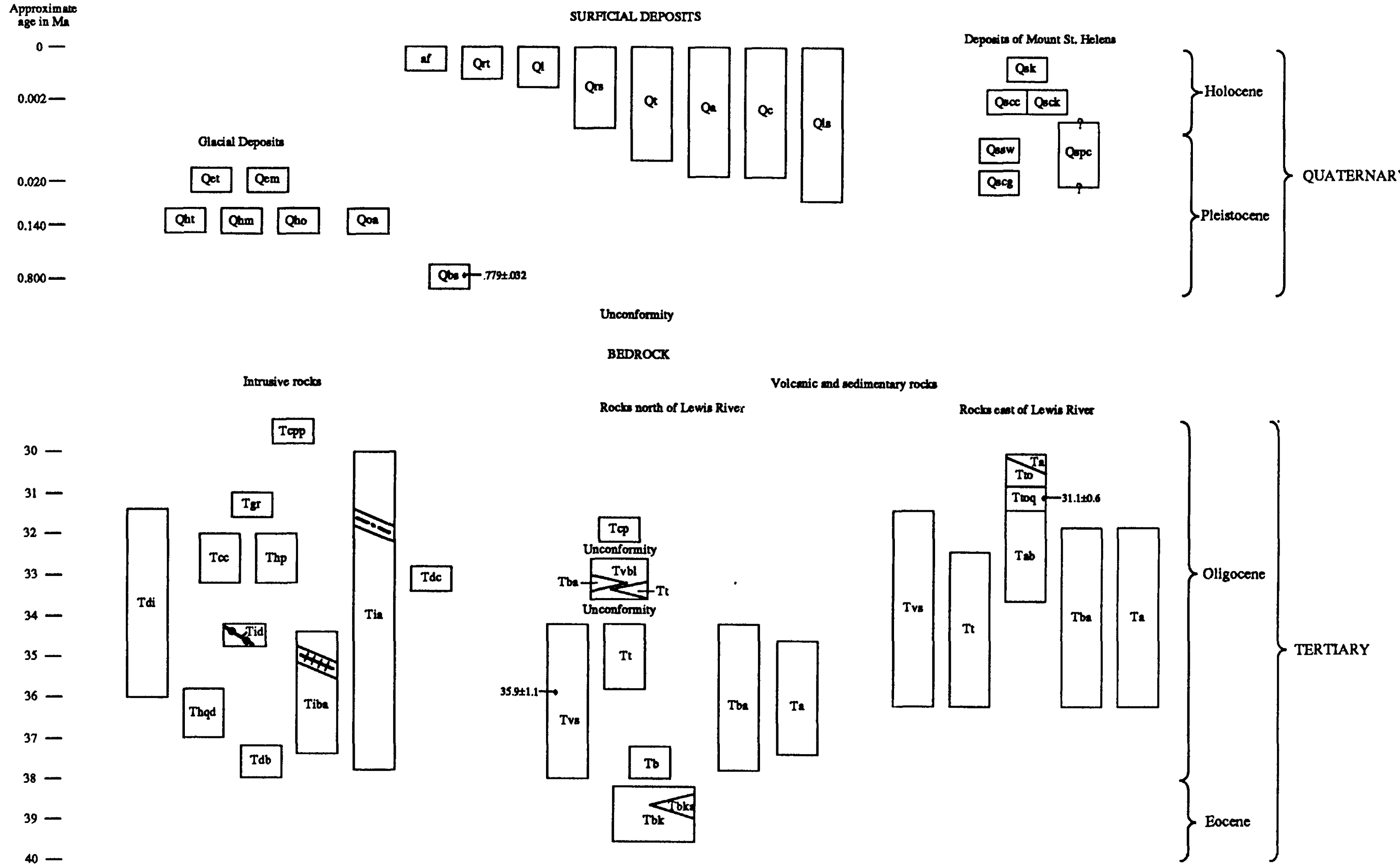
Strike and dip of compaction foliation in pumiceous lapilli tuff

Strike and dip of platy parting in lava flows

Sample locality for age determination--See table 1

Sample locality for chemical analysis--See table 2

CORRELATION OF MAP UNITS[1]



[1] K-Ar and $^{40}Ar/^{39}Ar$ ages shown in Ma are from table 1