U.S. DEPARTMENT OF THE INTERIOR

U. S. GEOLOGICAL SURVEY

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

by

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

Open-File Report 90-632

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

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards or with the North American Stratigraphic Code. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

[1]Menlo Park, California

1990

U.S. DEPARTMENT OF THE INTERIOR OPEN-FILE REPORT 90-632

U. S. GEOLOGICAL SURVEY

PRELIMINARY GEOLOGIC MAP OF THE GOAT MOUNTAIN QUADRANGLE, COWLITZ COUNTY, WASHINGTON

By

Russell C. Evarts and Roger P. Ashley

INTRODUCTION

The Goat Mountain 7.5-minute quadrangle is on the western slope of the Cascade Range of southern Washington, centered about 10 km west of the summit of Mount St. Helens (fig. 1). Bedrock consists of diverse volcanic and volcaniclastic rocks of Oligocene and possibly late Eocene age cut by numerous shallow-level intrusive bodies ranging in composition from basalt to quartz monzodiorite. 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 Kalama and South Fork Toutle 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 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, 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 south and southwest (Evarts and Ashley, 1990) 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).

Acknowledgments

Our mapping program in the Cascade Range has been supported by the Washington Department of Natural Resources, Division of Geology and Earth Resources. Permission by Weyerhaueser Paper Co. to work on their timberlands and use their road networks was essential to undertaking the work presented here. The enthusiasm and knowledge of William M. Phillips of the Division of Geology and Earth Resources, who spent several days in the field with us, was welcome and enlightening. Discussions of the geology of southwest Washington with Paul Hammond of Portland State University, Donald A. Swanson and William E. Scott of the Cascades Volcano Observatory, and our Menlo Park USGS colleague James G. Smith helped place our mapping in a regional perspective.

SUMMARY OF GEOLOGY

Surficial Deposits

Surficial deposits unconformably overlying Tertiary bedrock include late Pleistocene glacial deposits and latest Pleistocene and Holocene eruptive products of Mount St. Helens volcano. Debris from the volcano makes up most of the valley fill along the Kalama and South Fork Toutle Rivers, and 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 Goat Mountain quadrangle. The widespread tephra, which was not mapped, is locally as much as 3 m thick on the gently sloping surfaces adjacent to the Kalama River valley.

The May 18, 1980 eruption of Mount St. Helens significantly impacted parts of the Goat Mountain quadrangle. The laterally directed blast extended into the northern part of the quadrangle, leaving a blanket of blast pyroclastic-surge deposits less than 0.5 m thick (Hoblitt and others, 1981; Moore and Sisson, 1981; Waitt, 1981; Fisher and others, 1987) and associated ponded blast pyroclastic-flow deposits (Hoblitt and others, 1981; Fisher and others, 1987) on most of the terrain north of the South Fork Toutle River. Deposits of the May 18 debris avalanche (Voight and others, 1981; Glicken, 1986) are present in Castle Creek in the extreme northeast part of the quadrangle. A large lahar was generated from pyroclastic surges on the west flank of the volcano within minutes of the initial blast. This lahar flowed down the South Fork Toutle River, burying older laharic and pyroclastic-flow deposits (Scott, 1988). Smaller lahars left lahar-runout deposits near Blue Lake and McBride Lake.

Glacial deposits

Drift in the Goat Mountain 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 are probably correlative with the extensive Hayden Creek Drift (Crandell and Miller, 1974) on the basis of similar weathering characteristics (Crandell, 1987); they veneer many of the gently sloping upland surfaces north of the Kalama River. Surficial deposits shown as the Hayden Creek Drift on slopes in the Kalama River valley locally include as much as several meters of tan, weathered, fine-grained tephra and probable ash-cloud deposits generated by pre-1980 eruptions of Mount St. Helens.

The younger glacial deposits exhibit well-preserved glacial morphology and 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). Locally, as in roadcuts near McBride Lake and 2 km west of Sheep Canyon, till overlies early eruptive products of Mount St. Helens (Hyde, 1975; Crandell, 1987). Unlike the older drift, the Evans Creek Drift is generally restricted to the bottoms of glaciated valleys such as the tributaries of Fossil Creek and north-flowing tributaries of the South Fork Toutle River. Glacial morphology is particularly well developed on the west side of Trouble Creek, where small medial moraines were formed between the trunk glacier and subsidiary glaciers that occupied several short, cirque-headed, hanging-valley tributaries. The Trouble Creek glacier may have merged with the South Fork Toutle River glacier that headed on Mount St. Helens, although outcrops of older till downstream suggest that the South Fork glacier probably did not extend as far as Whitten Creek, 9 km west of the Goat Mountain quadrangle, during Fraser time.

Deposits of Mount St. Helens volcano

The South Fork Toutle and Kalama River valleys have been 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 in the South Fork Toutle drainage.

The record left by these terraces and associated deposits have been studied intensively by Hyde (1975), Crandell (1987), 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 all four stages are exposed in the Goat Mountain quadrangle, but those of the earliest (Ape Canyon) stage are restricted to tephra and minor unmapped flowage deposits in the South Fork Toutle River. Most of the deposits exposed in the Kalama River valley in this quadrangle belong to the Kalama eruptive period of the Spirit Lake eruptive stage of Crandell (1987), although isolated remnants of older deposits crop out locally and presumably underlie the younger fill. The series of terraces in the South Fork Toutle River are made up largely of deposits of the Cougar and Swift Creek eruptive stages.

Kalama River valley

The valley fill downstream from McBride Lake consists of early Kalama-age (c. A.D. 1480-1640) dacitic pyroclastic-flow deposits and, downstream from Kalama dome, of alluvium and minor laharic deposits derived from them (Crandell, 1987). These fragmental deposits are at least 60 m thick where trenched by the river south of Goat Mountain. Near Kalama dome, the river has cut entirely through these unconsolidated materials to reveal the underlying basalt of Kalama Falls (Evarts and Ashley, 1990), a lava flow of Castle Creek age that was probably extruded at about the same time as the Cave Basalt on the south side of the volcano (Greeley and Hyde, 1972). The Cave Basalt is about 1700 radiocarbon years old (Crandell, 1987). North of McBride Lake the early Kalama deposits are overlain by dark andesitic pyroclastic-flow deposits of middle Kalama age and light-gray dacitic flowage deposits of late Kalama age. The late Kalama-age deposits consist of debris generated during emplacement of the dacite dome that formed the pre-1980 summit of Mount St. Helens (Crandell, 1987); tree-ring dating of similar deposits in the South Fork Toutle River by Yamaguchi and Hoblitt (1986) have bracketed their age to the interval A.D. 1647-1688.

Pre-Kalama-age deposits are exposed near McBride Lake and north of Kalama dome. Deposits of Cougar age that underlie Fraser-age till near McBride Lake have been described by Hyde (1975) and Crandell (1987). They consist of lahar and pyroclastic-flow deposits as well as a poorly-sorted fragmental deposit that has been interpreted by Mullineaux and Crandell (1981), Newhall (1982), and Crandell (1987) as a debris-avalanche deposit similar to the one formed in the North Fork Toutle River on May 18, 1980. A block-lava flow of silicic andesite (Greeley and Hyde, 1972) terminates at

Kalama Springs north of McBride Lake. Its age is uncertain but it appears to occupy a canyon incised into the Cougar-age deposits. To the east in the Mount St. Helens quadrangle, the andesite is overlain by the basalt of Kalama Falls (which moved downvalley along the north margin of the andesite and was subsequently buried by Kalama-age pyroclastic flow deposits).

The age of the Mount St. Helens deposits mapped near Kalama dome is not known, and they may well represent more than one eruptive stage. They appear to be remnants of a thick valley fill that was largely eroded away by the Kalama River prior to eruption of the basalt of Kalama Falls, and thus are presumably pre-Castle Creek in age. Laharic deposits of Pine Creek(?) age and older are known to crop out downstream (Crandell, 1987). The paucity of these older deposits suggests that the Kalama valley received a much smaller volume of Mount St. Helens debris than did the South Fork Toutle valley during the early history of the volcano.

South Fork Toutle River valley

A stack of Cougar-age dacitic pumiceous and lithic pyroclastic-flow deposits about 200 m thick, overlain by an Evans Creek-age lateral moraine, is banked against the south wall of the South Fork Toutle River valley west of Sheep Canyon. These deposits are a remnant of a thick fill that was largely eroded away before or during the Fraser glaciation (Crandell, 1987). Upstream, erosional remnants of a subsequent fill deposited during the Swift Creek eruptive stage form both walls of the river valley near Sheep Canyon; correlative deposits occupy the north-flowing tributary of the South Fork Toutle River directly north of Goat Mountain and form low terraces along the main river below the mouth of the tributary (Crandell, 1987; Scott, 1989).

Exposed deposits of the Spirit Lake eruptive stage are rare in the South Fork Toutle River within the quadrangle. Deposits of the Pine Creek eruptive period are exposed downstream in the adjacent Elk Mountain quadrangle (Scott, 1989) and may be present in some of the terraces mapped as deposits of Swift Creek age in this quadrangle. These terraces are locally veneered by thin laharic deposits of Kalama age (Scott, 1989), and Crandell (1987) and Yamaguchi and Hoblitt (1986) report a Kalama-age pyroclastic flow deposit that contains summit-dome debris crops out low on the north valley wall. Laharic deposits of the Kalama eruptive period probably underlie much of the valley floor that was buried by the May 18, 1980 lahar.

Pliocene(?)-Quaternary Dacites

Fresh dacites significantly younger than the Tertiary rocks that underlie most of the Goat Mountain quadrangle are found in three localities. The most prominent of these is Goat Mountain itself, a large plug-dome of very coarsely porphyritic hornblende-biotite dacite containing plagioclase, quartz, and biotite phenocrysts as large as 1 cm across. Petrographically identical dacite forms the elongate hill northeast of Blue Lake. Biotite and hornblende from a sample collected on the western flank of Goat Mountain (Engels and others, 1976) are discordant (hornblende: 3.2±0.3 Ma, biotite: 1.1±0.06 and 0.8±0.06 Ma) but indicate a late Pliocene to mid-Pleistocene age of emplacement. It is not known for certain if the Goat Mountain magma reached the surface to form a dome because its original morphology has been thoroughly modified by extensive late Pleistocene glaciation. The dacite is relatively soft, however, so differential erosion compared to the Tertiary host rocks seems unable to account for its topographic prominence.

A smaller, postglacial dacite dome crops out along the Kalama River southwest of Goat Mountain. It has not been dated but consists of hypersthene-hornblende dacite petrographically similar to dacites erupted during the Swift Creek eruptive stage of Mount St. Helens, suggesting that it may be less than about 13,000 years old.

Paleogene Bedrock

Tertiary strata in the Goat Mountain quadrangle consist of volcanic and volcaniclastic rocks broadly similar to those exposed elsewhere in the Mount St. Helens area (Evarts and others, 1987; Evarts and Ashley, 1990; in press a, b, c, d) and typical of subaerial volcanic arc terranes (Cas and Wright, 1987). Although the Tertiary rocks in this quadrangle have not yet been adequately dated, regional stratigraphic relationships and age determinations from nearby areas suggest they are mostly of early Oligocene age.

South of the Kalama River, in the lower Fossil Creek drainage, and in the area between Goat Mountain and Sheep Canyon, bedrock is composed chiefly of volcaniclastic sedimentary rocks with minor interbedded lava flows. Pumiceous tuff beds make up a substantial proportion of these strata; abundant lithic fragments in some of these beds probably reflect some postdepositional reworking and mixing of the ash and pumice with epiclastic debris. The uppermost unit south of the Kalama River is the andesite of Cinnamon Peak, a sequence of porphyritic two-pyroxene andesite to mafic dacite flows that underlies larger areas in adjacent quadrangles. A $^{40}Ar/^{39}Ar$ age on plagioclase of 32.1±1.0 Ma (L. G. Pickthorn, written commun., 1988) has been determined for a rock taken from sample location 68.

The andesite of Cinnamon Peak was deposited on an irregular erosion surface developed on 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.

In the upper Fossil Creek drainage, the dominantly clastic section is overlain by a thick sequence of mafic lava flows and coarse-grained breccia and conglomerate (lithologically similar to the coarse clastic rocks of the volcanic breccia of Lost Creek) that extends north to the quadrangle boundary. South of the South Fork Toutle River, the flows and clastic rocks (which include probable fluvial conglomerates containing well-rounded cobbles and boulders) form a relatively well-stratified section that dips at low angles to the south-southeast; similar interbedded flows and breccia in the Castle Lake basin dip to the east. In the area between the river and the lake, breccia (with mostly angular to subangular clasts) predominates and lava flows are scarce; in Disappointment Creek, the section consisting almost entirely of breccia exceeds 400 m thick. Mafic to intermediate fine-grained dikes are abundant in this same area. Although many of the dikes are highly irregular, especially where they intrude breccia, they tend to vary consistently in strike from northwest in the east half of the quadrangle to northeast in the west half, forming a crude swarm radially disposed about the multiphase phaneritic intrusions near Spud Mountain. These relationships suggest that the rocks in the northern part of the quadrangle are part of a large Oligocene volcano centered on the Spud Mountain intrusive complex, with the better stratified, conglomerate-bearing sections south of the South Fork Toutle River representing the lower flanks of the edifice (Williams and McBirney, 1979; Cas and Wright, 1987). Virtually identical rocks crop out in the Spirit Lake West quadrangle immediately to the northeast (Evarts and Ashley, in press c); these may have been deposited on the eastern flank of this same volcano.

The lava flows of the inferred ancient volcano are basaltic andesite and minor basalt according to the IUGS chemical classification shown in Figure 3 (mostly between 51 and 57 percent SiO_2). Andesites and dacites (greater than 57 percent SiO_2) are restricted to some of the dikes (most of which are too altered for meaningful chemical analysis).

The base of the volcano is marked by a bed of ash-flow tuff which can be traced from Fossil Creek northward along the western edge of the quadrangle and across the South Fork Toutle River. The rocks beneath the tuff, well-exposed in the cliffs above Trouble Creek, consist of porphyritic pyroxene andesite and lesser basaltic andesite and dacite flows interbedded with volcaniclastic rocks. These andesitic rocks are part of a gently east-dipping section that extends as far as 5 km to the west (Phillips, 1987; R.C. Evarts, unpub. mapping)

The Paleogene rocks of the Goat Mountain quadrangle 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

Dikes and sills of fine- to medium-grained phaneritic intrusive rocks are widely scattered throughout the Goat Mountain quadrangle. Nearly all of these are pyroxene diorites which are probably the intrusive equivalents of chemically similar basaltic andesite lava flows. Medium- to coarse-grained, more silicic rocks are found only in a thick sill south of the Kalama River and in a group of irregular intrusions near Spud Mountain. The sill consists of uniform quartz monzodiorite and was apparently emplaced in a single event.

In contrast, the intrusive complex of Spud Mountain includes texturally variable diorites, quartz diorites, and quartz monzodiorites that clearly represent multiple intrusive episodes. Contact relations and recrystallization of earlier intrusions by later ones reveals a consistent mafic-to-felsic compositional trend with time. Pyroxenes, commonly uralitized or chloritized, are the primary mafic silicate phases in all of the intrusions; magmatic hornblende and biotite are restricted to groundmass phases in the more felsic bodies.

None of the intrusions have been dated radiometrically. However, an unusual hornfels breccia adjacent to the quartz monzonite body east of Spud Mountain contains coarse-grained metamorphic titanite for which a fission-track age of 31.0 ±1.0 Ma was determined (R.C. Evarts, unpub. data). This age is considered to approximate the time of emplacement and crystallization of the Spud Mountain complex.

Structure

Strata in the Goat Mountain quadrangle and adjacent areas generally strike north to northwest and dip moderately (20-30°) to the east or northeast. They comprise the lower part of a continuous several-kilometer-thick sequence of Oligocene and Miocene volcanic rocks which extends to the east and northeast (Evarts and Ashley, in press a, b, c, d). The overlying rocks include substantial proportions of andesite and dacite and are on average more silicic than the rocks in this quadrangle. Moderate deviations from the overall trend, such as the gentle southeasterly dip of the interbedded flows and breccia north of Goat Mountain, probably reflect primary dip variations on the slopes of the large mafic volcano centered on Spud Mountain.

No regionally significant faults have been mapped in the Goat Mountain quadrangle. Minor faults and dikes north of the South Fork Toutle River form a crude radial pattern centered on the intrusions near Spud Mountain. Most are subvertical. In most places, lithologies on both sides of the faults are similar, and the sense of offset cannot be determined, but local slickensides record both strike-slip and dip-slip movements. Visible offsets rarely exceed 5 m. Many of these faults are flanked by white to orange zones of hydrothermally altered rock, and some are occupied or crossed by Tertiary dikes. Therefore, most of the mapped faults probably formed early and represent local small-scale adjustments to movements of magma within the Tertiary volcanic center.

The only exception to this relatively simple structural picture is a zone of severely disrupted Tertiary bedrock that surrounds Goat Mountain and apparently reflects forcible emplacement of the plug-dome of viscous dacite. There, young faults marked by unaltered but pervasively brecciated rock bound several rotated blocks. Tertiary strata within the blocks deviate greatly from the regional trend and tend to dip away from Goat Mountain; those directly west of the mountain are near-vertical and locally overturned. Rocks within the blocks closest to the plug-dome commonly exhibit a steep, widely-spaced but throughgoing fracture cleavage, and may be broken by additional unexposed faults. Other related faults undoubtedly exist beneath the Quaternary fill of the Kalama River south and east of Goat Mountain. Faults emanating from the northern flank of Goat Mountain do not extend north of the South Fork Toutle River. They probably terminate against an unexposed east-striking fault that is inferred from contrasts in the lithology and orientation of strata on opposite sides of the river valley in this area. The inference of a buried fault is supported by the presence of an outcrop of shattered Tertiary volcanic rocks in the valley bottom 0.5 km east of the quadrangle (R.P. Ashley and R.C. Evarts, unpub. mapping); the projection of this fault passes beneath the crater of Mount St. Helens.

Metamorphism and hydrothermal alteration

The Tertiary rocks of the Goat 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. In addition, rocks adjacent to the larger intrusive bodies have been recrystallized to epidote- and (or) amphibole-bearing hornfels. Contact-metamorphism is particularly common near the northern boundary of the quadrangle, suggesting that the relatively small isolated intrusions near Spud Mountain are cupolas above a larger composite pluton not far below the present erosion surface.

Metasomatic hydrothermal alteration in the Goat Mountain quadrangle is limited to minor local pyritic hornfels near Spud Mountain and to narrow argillized zones along faults. These altered fault zones are composed entirely of kaolinitic clay minerals with or without minor limonite; no relict sulfides have been detected in any of them.

REFERENCES

Barnosky, C.W., 1984, Late Pleistocene and early Holocene environmental history of southwestern Washington State, U.S.A.: Canadian Journal of Earth Sciences, v. 21, p. 619-629.

Cas, R.A.F., and Wright, J.V., 1987, Volcanic successions: modern and ancient: London, Allen and Unwin, 528 p.

Colman, S.M., and Pierce, K.L., 1981, Weathering rinds on andesitic and basaltic stones as a Quaternary age indicator, western United States: U.S. Geological Survey Professional Paper 1210, 56 p.

Condie, K.C., and Swenson, D.H., 1973, Compositional variation in three Cascade stratovolcanoes: Jefferson, Rainier, and Shasta: Bulletin Volcanologique, v. 37, p. 205-230.

Crandell, D.R., 1987, Deposits of pre-1980 pyroclastic flows and lahars from Mount St. Helens, Washington: U.S. Geological Survey Professional Paper 1444, 91 p.

Crandell, D.R., and Miller, R.D., 1974, Quaternary stratigraphy and extent of glaciation in the Mount Rainier region, Washington: U.S. Geological Survey Professional Paper 847, 59 p.

Dethier, D.P., 1988, The soil chronosequence along the Cowlitz River, Washington: U.S. Geological Survey Bulletin 1590-F, p. F1-F47.

Engels, J.C., Tabor, R.W., Miller, F.K., and Obradovich, J.D., 1976, Summary of K-Ar, Rb-Sr, U-Pb, Pb-α, and fission-track ages of rocks from Washington prior to 1975 (exclusive of Columbia Plateau basalts): U.S. Geological Survey Miscellaneous Field Studies Map MF-710, scale 1:1,000,000.

Evarts, R.C., and Ashley, R.P., 1990, Preliminary geologic map of the Cougar quadrangle, Cowlitz and Clark Counties, Washington: U.S. Geological Survey Open-File Report 90-631, scale 1:24,000

______in press a, Geologic map of the Spirit Lake East quadrangle, Skamania County, Washington: U.S. Geological Survey Geologic Quadrangle Map GQ-1679, scale 1:24,000.

______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.

Evarts, R.C., Ashley, R.P., and Smith, J.G., 1987, Geology of the Mount St. Helens area: record of discontinuous volcanic and plutonic activity in the the Cascade arc of southern Washington: Journal of Geophysical Research, v. 92, p. 10,155-10,169.

Fisher, R.V., Glicken, H.X., and Hoblitt, R.P., 1987, May 18, 1980, Mount St. Helens deposits in South Coldwater Creek, Washington: Journal of Geophysical Research, v. 92, p. 10,267-10,283.

Fiske, R.S., Hopson, C.A., and Waters, A.C., 1963, Geology of Mount Rainier National Park, Washington: U.S. Geological Survey Professional Paper 444, 93 p.

Gill, J.B., 1981, Orogenic andesites and plate tectonics: New York, Springer-Verlag, 390 p.

Glicken, H.X., 1986, Rockslide-debris avalanche of May 18, 1980, Mount St. Helens volcano, Washington: Santa Barbara, University of California, Ph.D. dissertation, 303 p.

Glicken, Harry, Meyer, William, and Sabol, Martha, 1989, Geology and ground-water hydrology of Spirit Lake blockage, Mount St. Helens, Washington, with implications for lake retention: U.S. Geological Survey Bulletin 1789, 33 p.

Greeley, Ronald, and Hyde, J.H., 1972, Lava tubes of the Cave Basalt: Geological Society of America Bulletin, v. 83, p. 2397-2418.

Hammond, P.E., and Korosec, M.A., 1983, Geochemical analyses, age dates, and flow-volume estimates for Quaternary volcanic rocks, southern Cascade Mountains, Washington: Washington Division of Geology and Earth Resources Open-File Report 83-13, 36 p.

Hildreth, W., and Fierstein, J., 1985, Mount Adams: eruptive history of an andesite-dacite stratovolcano at the focus of a fundamentally basaltic volcanic field, *in* Guffanti, M., and Muffler, L.J.P., eds., Proceedings of the Workshop on geothermal resources of the Cascade Range, May 22-23, 1985, Menlo Park, Calif.: U.S. Geological Survey Open-File Report 85-521, p. 44-50.

Hoblitt, R.P., Miller, C.D., and Vallance, J.W., 1981, Origin and stratigraphy of the deposit produced by the May 18 directed blast, *in* Lipman, P.W., and Mullineaux, D.R., eds., The 1980 eruptions of Mount St. Helens, Washington: U.S. Geological Survey Professional Paper 1250, p. 401-419.

Hyde, J.H., 1970, Geologic setting of Merrill Lake and evaluation of volcanic hazards in the Kalama River Valley near Mount St. Helens, Washington: U.S. Geological Survey Open-File Report, 17 p.

____, 1975, Upper Pleistocene pyroclastic-flow deposits and lahars south of Mount St. Helens volcano, Washington: U.S. Geological Survey Bulletin 1383-B, 20 p.

Irvine, T.N., and Baragar, W.R.A., 1971, A guide to the chemical classification of the common igneous rocks: Canadian Journal of Earth Sciences, v. 8, p. 523-548.

Jackson, L.L., Brown, F.W., and Neil, S.T., 1987, Major and minor elements requiring individual determination, classical whole rock analysis, and rapid rock analysis, *in* Baedecker, P.A., ed., Methods for geochemical analysis: U.S. Geological Survey Bulletin 1770, p. G1-G23.

Janda, R.J., Scott, K.M, Nolan, K.M., and Martinson, H.A., 1981, Lahar movement, effects, and deposits, *in* Lipman, P.W., and Mullineaux, D.R., eds., The 1980 eruptions of Mount St. Helens, Washington: U.S. Geological Survey Professional Paper 1250, p. 461-478.

Le Bas, M.J., Le Maitre, R.W., Streckeisen, A., and Zanettin, B., 1986, A chemical classification of volcanic rocks based on the total alkali-silica diagram: Journal of Petrology, v. 27, p. 745-750.

Lipman, P.W., and Mullineaux, D.R., eds., 1981, The 1980 eruptions of Mount St. Helens, Washington: U.S. Geological Survey Professional Paper 1250, 844 p.
Miyashiro, A., 1974, Volcanic rocks series in island arcs and active continental margins: American Journal of Science, v. 274, p. 321-355.
Moore, J.G., and Sisson, T.W., 1981, Deposits and effects of the May 18 pyroclastic surge, *in* Lipman, P.W., and Mullineaux, D.R., eds., The 1980 eruptions of Mount St. Helens, Washington: U.S. Geological Survey Professional Paper 1250, p. 421-438.
Mullineaux, D.R., 1986, Summary of pre-1980 tephra-fall deposits erupted from Mount St. Helens, Washington state, USA: Bulletin of Volcanology, v. 48, p. 17-26.
Mullineaux, D.R., and Crandell, D.R., 1981, The eruptive history of Mount St. Helens, *in* Lipman, P.W., and Mullineaux, D.R., eds., The 1980 eruptions of Mount St. Helens, Washington: U.S. Geological Survey Professional Paper 1250, p. 3-15.
Newhall, C.G., 1982, a prehistoric debris avalanche from Mount St. Helens [abs.]: Eos, American Geophysical Union Transactions , v. 63, no. 45, p. 1141.
Phillips, W.M., 1987, Geologic map of the Mount St. Helens quadrangle, Washington: Washington Division of Geology and Earth Resources Open-File Report 87-4, scale 1:100,000, with 59-p pamphlet.
Phillips, W.M., Walsh, T.J., and Hagen, R.A., 1989, Eocene transition from oceanic to arc volcanism, southwest Washington, *in* Muffler, L.J.P., Weaver, C.S., and Blackwell, D.D., eds., Proceedings of Workshop XLIV, Geological, geophysical, and tectonic setting of the Cascade Range, 01-04 December, 1988: U.S. Geological Survey Open-File Report 89-178, p. 199-256.
Scott, K.M., 1988, Origins, behavior, and sedimentology of lahars and lahar-runout flows in the Toutle-Cowlitz River system: U.S. Geological Survey Professional Paper 1447-A, 76 p.
______, 1989, Magnitude and frequency of lahars and lahar-runout flows in the Toutle-Cowlitz River system: U.S. Geological Survey Professional Paper 1447-B, 33 p.
Smith, D.R., and Leeman, W.P., 1987, Petrogenesis of Mount St. Helens dacitic magmas: Journal of Geophysical Research, v. 92, p. 10,313-10,334.
Steiger, R.H., and Jäger, E., 1977, Subcommission on geochronology: convention on the use of decay constants in geo- and cosmochronology: Earth and Planetary Science Letters, v., 36, p. 359-362.
Streckeisen, A., 1976, To each plutonic rock its proper name: Earth-Science Reviews, v. 12, p. 1-33.

Swanson, D.A., 1989, Geologic maps of the French Butte and Greenhorn Buttes quadrangles, Washington: U.S. Geological Survey Open-File Report 89-309, scale 1:24,000.
Taggart, J.E., Jr., Lindsay, J.R., Scott, B.A., Vivit, D.V., Bartel, A.J., and Stewart, K.C., 1987, Analysis of geological materials by wavelength-dispersive X-ray fluorescence spectrometry, *in* Baedecker, P.A., ed., Methods for geochemical analysis: U.S. Geological Survey Bulletin 1770, p. E1-E19.
Voight, Barry, Glicken, Harry, Janda, R.J., and Douglass, P.M., 1981, Catastrophic rockslide-avalanche of May 18, *in* Lipman, P.W., and Mullineaux, D.R., eds., The 1980 eruptions of Mount St. Helens, Washington: U.S. Geological Survey Professional Paper 1250, p. 347-377.
Waitt, R.B., Jr., 1981, Devastating pyroclastic density flow and attendant air fall of May 18--Stratigraphy and sedimentology of deposits, *in* Lipman, P.W., and Mullineaux, D.R., eds., The 1980 eruptions of Mount St. Helens, Washington: U.S. Geological Survey Professional Paper 1250, p. 439-458.
Williams, Howel, and McBirney, A. R., 1979, Volcanology: San Francisco, Freeman, Cooper and Co., 397 p.
Wise, W.S., 1970, Cenozoic volcanism in the Cascade Mountains of southern Washington: Washington Division of Mines and Geology Bulletin 60, 45 p.
Yamaguchi, D.K., 1983, New tree-rings dates for recent eruptions of Mount St. Helens: Quaternary Research, v. 20, p. 246-250.
Yamaguchi, D.K, and Hoblitt, R.P., 1986, Tree-ring dating of Mount St. Helens flowage deposits emplaced in the valley of the South Fork Toutle River,Washington, during the past 350 years [abs.], *in* Keller, S.A.C., ed., Mount St. Helens, five years later: Cheney, Wash., Eastern Washington University Press, p. 441.

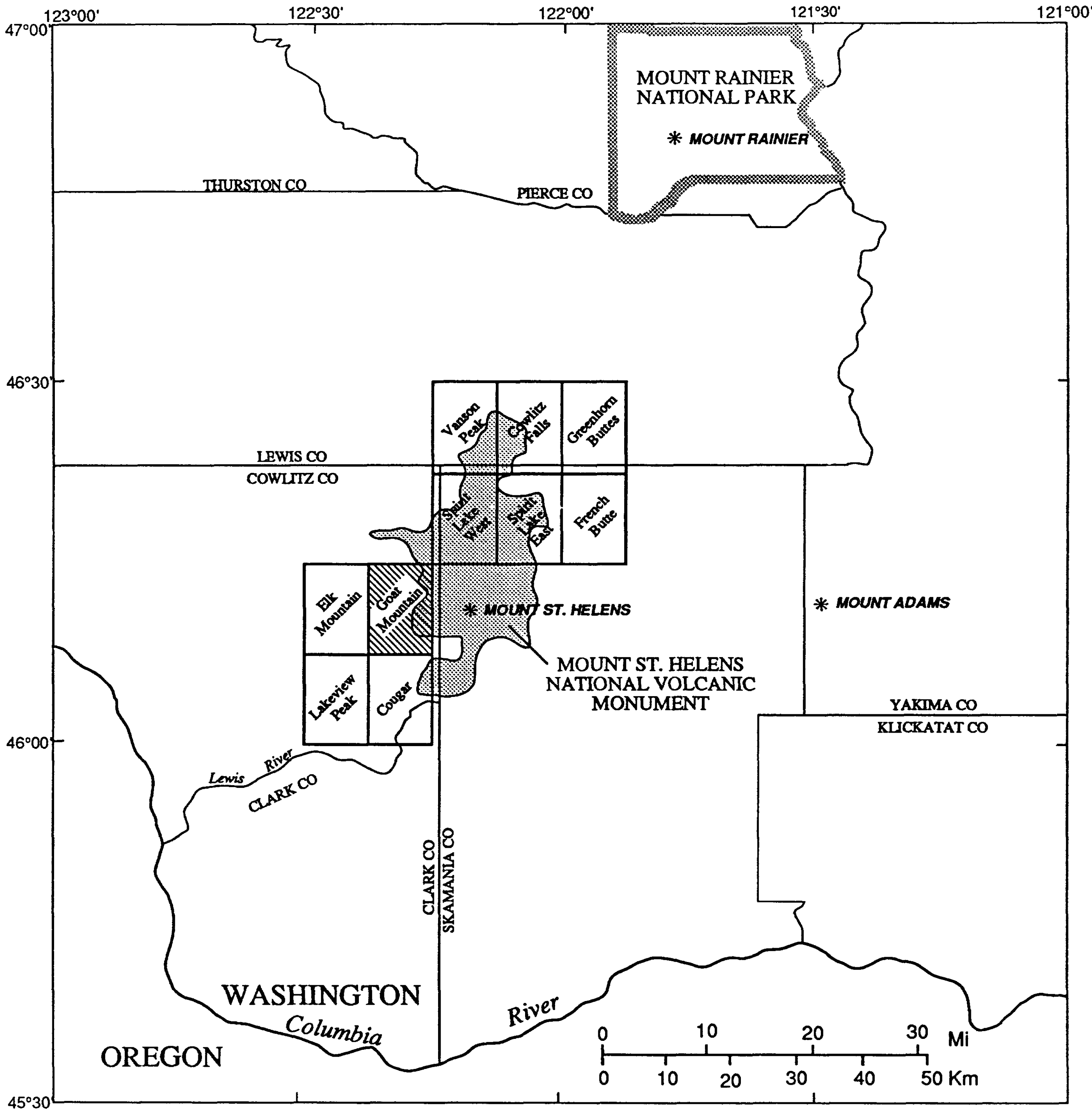


Figure 1.--Index map of southern Wasington showing location of Goat Mountain quadrangle and other 7-1/2 minute quadrangles in which geologic mapping has been or is currently being conducted by the USGS.

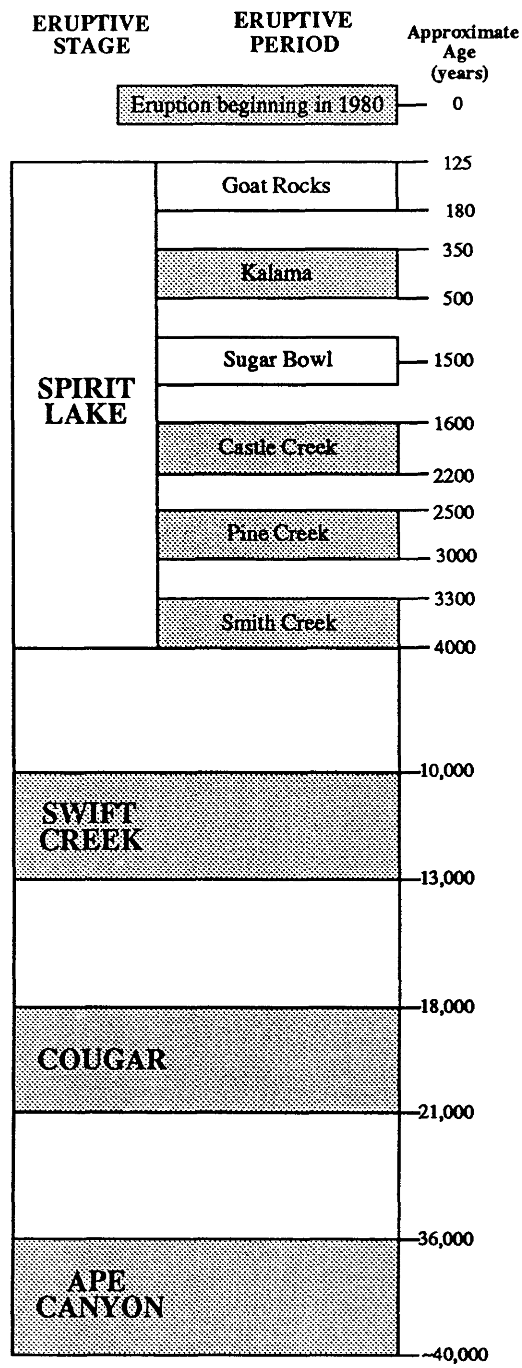


Figure 2.--Diagram showing eruptive stages and eruptive periods of Mount St. Helens volcano (Crandell, 1987). Deposits (exclusive of tephra) of all stages and periods except for Goat Rocks and Sugar Bowl are present in the Goat Mountain quadrangle.

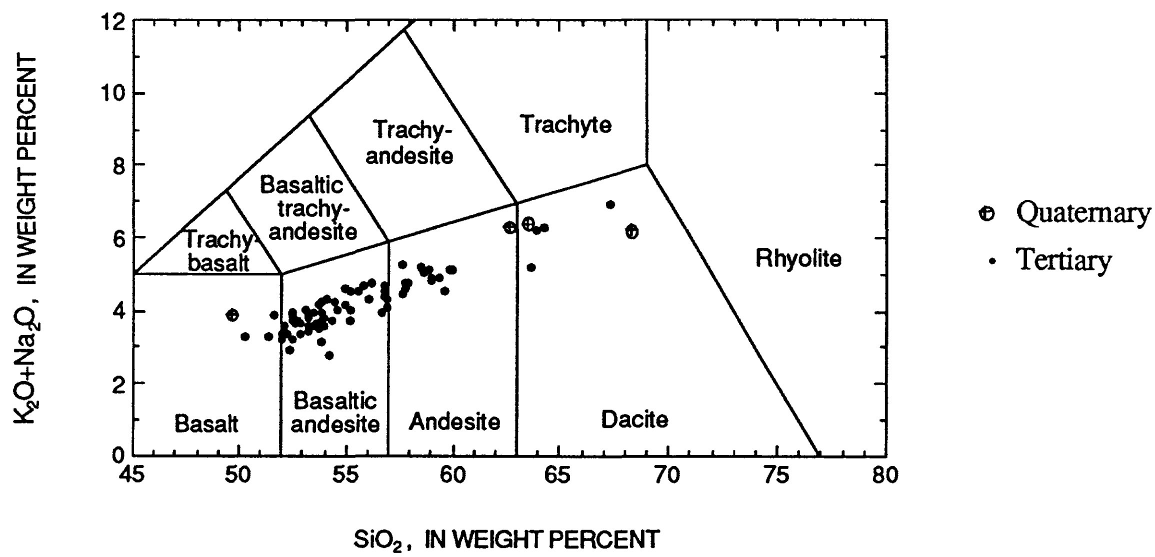


Figure 3.--Na_2O+K_2O versus SiO_2 (recalculated volatile-free) for Quaternary and Tertiary volcanic and hypabyssal intrusive rocks from Goat Mountain quadrangle showing classification according to I.U.G.S. (Le Bas and others, 1986).

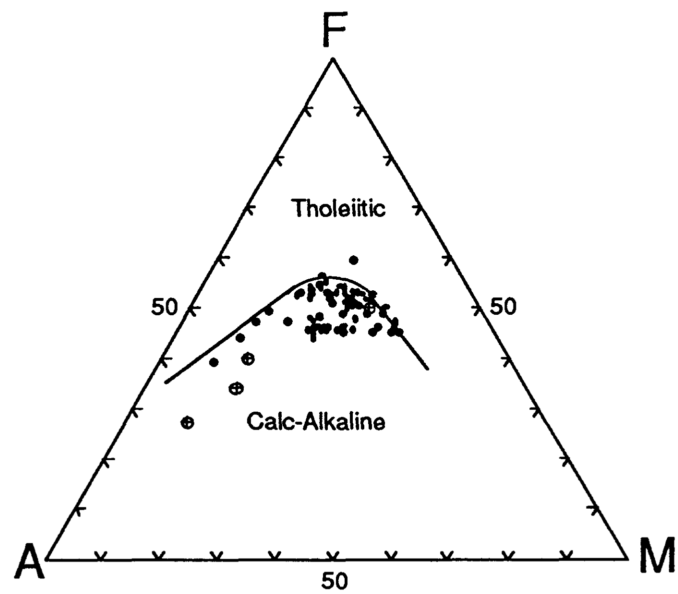


Figure 4.--AFM diagram for Quaternary and Tertiary volcanic and hypabyssal intrusive rocks from Goat Mountain quadrangle. A, Na_2O+K_2O; F, $FeO+Fe_2O_3+MnO$; M, MgO. Line separating tholeiitic and calc-alkaline rocks from Irvine and Baragar (1971).

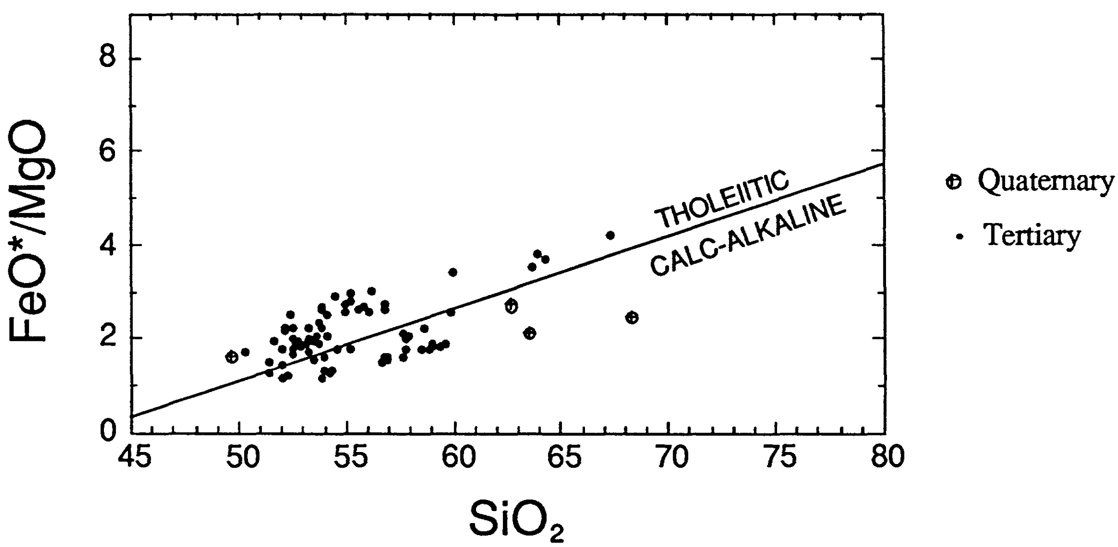


Figure 5--FeO*/MgO versus SiO_2 (recalculated volatile-free) for Quaternary and Tertiary volcanic and hypabyssal intrusive rocks from Goat Mountain quadrangle showing classification into tholeiitic and calc-alkaline rocks according to Miyashiro (1974). FeO*, total Fe as FeO.

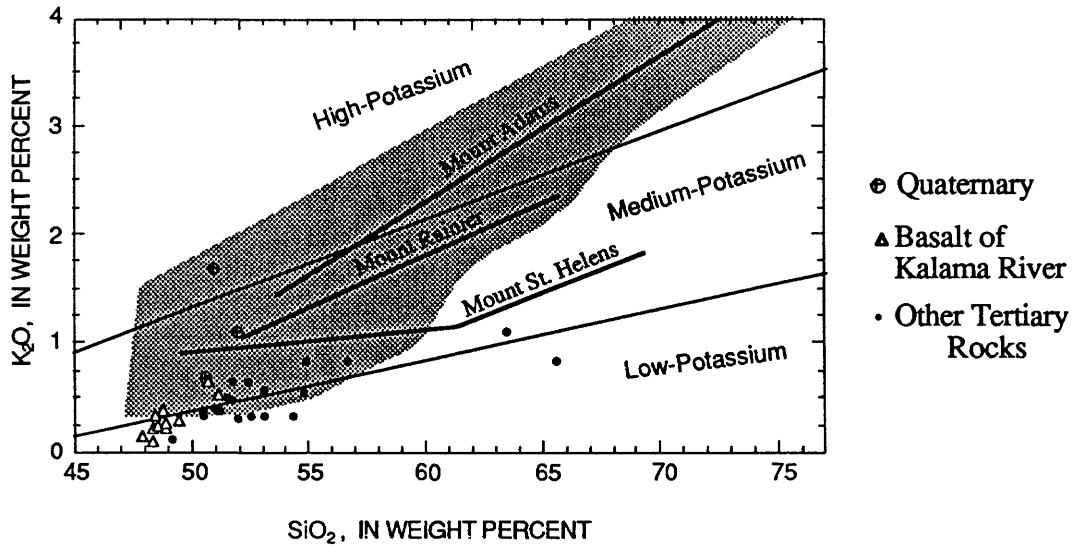


Figure 6.--K_2O versus SiO_2 (recalculated volatile-free) for Quaternary and Tertiary volcanic and hypabyssal intrusive rocks from Goat Mountain quadrangle. Low-, medium-, and high-potassium fields from Gill (1981, p. 6). Shaded area encompasses compositions of Quaternary volcanic rocks, exclusive of 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 hypabyssal intrusive rocks, Goat Mountain 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.	**87CG-V164**	**88CG-A117**	**87CG-V167A**	**88CG-V342A**	**88CG-V362B**	**88CG-V362A**	**88CG-V268C**	**84CG-V67**	**87CG-V166**
Latitude	46°12'02"	46°13'27"	46°12'18"	46°10'31"	46°10'37"	46°10'37"	46°13'40"	46°13'07"	46°11'21"
Longitude	122°19'30"	122°19'31"	122°21'58"	122°19'57"	122°22'18"	122°22'07"	122°21'47"	122°16'27"	122°20'23"
Map unit	Tb	Tiba	Tb	Tba	Tba	Tb	Tdi	Tba	Tba
Rock type	Basalt	Basaltic Andesite	Basalt	Basaltic Andesite	Basaltic Andesite	Basalt	Diorite	Basaltic Andesite	Basaltic Andesite
SiO_2	48.90	49.20	50.50	50.70	50.80	50.80	50.90	50.90	51.00
TiO_2	1.38	1.53	1.20	1.23	1.05	1.46	1.48	1.38	1.07
Al_2O_3	18.00	17.00	16.60	17.10	15.70	16.70	17.00	17.30	16.40
Fe_2O_3	3.88	-- -- --	2.72	-- -- --	-- -- --	-- -- --	-- -- --	4.86	2.82
FeO	6.23	9.63	6.83	8.92	8.67	9.99	9.00	4.81	6.13
MnO	0.15	0.14	0.15	0.15	0.15	0.15	0.14	0.18	0.14
MgO	5.57	3.81	7.33	6.15	7.51	6.70	4.81	5.18	7.09
CaO	9.69	9.73	9.62	9.87	10.40	9.59	9.38	9.71	9.66
Na_2O	2.87	2.65	2.80	2.71	2.51	2.72	2.75	2.80	2.79
K_2O	0.34	0.13	0.48	0.46	0.68	0.56	0.55	0.56	0.50
P_2O_5	0.19	0.27	0.16	0.16	0.22	0.18	0.25	0.19	0.17
H_2O^+	0.90	1.68	0.66	0.71	0.65	0.54	1.22	0.76	0.88
H_2O^-	1.76	2.87	1.13	1.36	1.20	0.70	2.09	1.58	1.36
CO_2	0.11	0.90	0.03	0.03	0.03	<0.01	0.02	0.23	0.06
Total	99.97	99.54	100.21	99.55	99.57	100.09	99.59	100.44	100.07

Table 1.--*Chemical analyses of volcanic and hypabyssal intrusive rocks, Goat Mountain quadrangle,* continued

Map No.	10	11	12	13	14	15	16	17	18
Field sample No.	**87CG-V160B**	**88CG-V326A**	**88CG-V357**	**88CG-V361**	**87CG-V157C**	**84CG-V47B**	**88CG-V304B**	**88CG-V318**	**84CG-V44A**
Latitude	46°11'06"	46°09'50"	46°10'24"	46°11'03"	46°11'44"	46°11'00"	46°11'39"	46°12'30"	46°11'37"
Longitude	122°22'19"	122°20'40"	122°20'41"	122°21'01"	122°21'18"	122°16'22"	122°20'23"	122°20'40"	122°15'53"
Map unit	Tb	Tba	Tba	Tba	Tba	Tiba	Tba	Tba	Tba
Rock type	Basalt	Basaltic Andesite	Basaltic Andesite	Basaltic Andesite	Basaltic Andesite	Basaltic Andesite	Basaltic Andesite	Basaltic Andesite	Basaltic Andesite
SiO_2	51.00	51.10	51.20	51.40	51.60	51.70	51.90	52.00	52.00
TiO_2	1.41	1.45	1.47	1.45	1.20	1.30	1.58	1.56	1.41
Al_2O_3	18.70	19.10	19.00	17.10	18.30	17.80	17.20	17.50	19.20
Fe_2O_3	4.03	-- -- --	-- -- --	-- -- --	3.87	4.47	-- -- --	-- -- --	4.47
FeO	5.56	8.73	8.79	8.98	5.08	4.83	9.72	9.36	4.48
MnO	0.15	0.15	0.14	0.19	0.14	0.15	0.16	0.16	0.15
MgO	4.64	3.92	4.02	4.40	4.73	5.25	5.02	4.70	3.75
CaO	9.25	10.00	9.97	8.99	9.55	9.69	9.21	9.45	9.75
Na_2O	3.32	3.07	3.08	2.94	3.08	2.87	3.06	3.07	3.20
K_2O	0.55	0.49	0.51	0.84	0.60	0.31	0.58	0.61	0.64
P_2O_5	0.21	0.19	0.19	0.25	0.19	0.19	0.20	0.19	0.17
H_2O^+	0.59	0.70	0.53	1.08	0.61	1.06	0.42	0.16	1.41
H_2O^-	1.14	0.99	0.95	1.64	1.36	1.04	1.37	0.76	0.43
CO_2	0.08	<0.01	0.01	<0.01	0.02	0.03	<0.01	0.06	0.10
Total	100.63	99.89	99.86	99.26	100.33	100.69	100.42	99.58	101.16

Table 1.--*Chemical analyses of volcanic and hypabyssal intrusive rocks, Goat Mountain quadrangle*, continued

Map No.	19	20	21	22	23	24	25	26	27
Field sample No.	**86CG-V131D**	**88CG-V362C**	**84CG-V75**	**88CG-V358B**	**88CG-V410A**	**88CG-V360A**	**87CG-V168A**	**84CG-V72**	**87CG-V157B**
Latitude	46°08'05"	46°10'37"	46°14'41"	46°10'26"	46°14'53"	46°10'51"	46°12'31"	46°14'01"	46°11'38"
Longitude	122°21'59"	122°22'25"	122°18'11"	122°20'39"	122°18'18"	122°21'23"	122°21'21"	122°15'30"	122°21'11"
Map unit	Tba	Tba	Tqd	Tba	Tqd	Tba	Tba	Tba	Tba
Rock type	Basaltic Andesite	Basaltic Andesite	Quartz Diorite	Basaltic Andesite	Quartz Diorite	Basaltic Andesite	Basaltic Andesite	Basaltic Andesite	Basaltic Andesite
SiO_2	52.10	52.20	52.20	52.30	52.40	52.40	52.50	52.60	52.70
TiO_2	1.70	1.40	1.49	1.17	1.94	1.23	1.29	1.41	1.38
Al_2O_3	17.10	17.90	18.10	18.20	16.90	17.20	19.60	17.60	17.50
Fe_2O_3	-- -- --	-- -- --	4.44	-- -- --	-- -- --	-- -- --	3.06	3.95	4.05
FeO	8.55	8.94	5.37	8.23	9.36	8.58	4.95	5.63	5.11
MnO	0.16	0.15	0.16	0.13	0.16	0.14	0.12	0.15	0.18
MgO	4.10	4.76	4.62	4.78	4.70	5.53	3.45	4.87	4.48
CaO	9.54	9.49	8.79	10.00	9.09	9.25	9.82	8.58	9.18
Na_2O	3.20	3.08	3.32	2.87	2.99	2.94	3.36	3.23	3.18
K_2O	0.40	0.59	0.64	0.56	0.60	0.63	0.39	0.79	0.73
P_2O_5	0.34	0.23	0.30	0.16	0.28	0.22	0.17	0.23	0.22
H_2O^+	1.06	0.34	0.63	0.47	1.06	0.54	0.75	0.60	0.67
H_2O^-	1.35	0.72	0.06	0.85	0.40	1.01	0.82	0.81	0.92
CO_2	0.13	0.12	0.04	<0.01	0.12	<0.01	<0.01	0.04	0.03
Total	99.73	99.92	100.16	99.72	100.00	99.67	100.28	100.49	100.33

Table 1.--*Chemical analyses of volcanic and hypabyssal intrusive rocks, Goat Mountain quadrangle,* continued

Map No.	28	29	30	31	32	33	34	35	36
Field sample No.	**88CG-V324B**	**86CG-V113**	**88CG-V371B**	**88CG-V273A**	**88CG-V296**	**86CG-V87A**	**88CG-V410B**	**88CG-V299A**	**87CG-V157A**
Latitude	46°11'31"	46°09'08"	46°13'43"	46°13'42"	46°12'09"	46°90'22"	46°14'47"	46°11'20"	46°11'27"
Longitude	122°21'42"	122°21'26"	122°20'38"	122°20'03"	122°19'10"	122°19'42"	122°18'19"	122°20'58"	122°21'16"
Map unit	Tba	Tba	Tba	Tba	Tba	Tba	Tqd	Tba	Tba
Rock type	Basaltic Andesite	Basaltic Andesite	Basaltic Andesite	Basaltic Andesite	Basaltic Andesite	Basaltic Andesite	Quartz Diorite	Basaltic Andesite	Basaltic Andesite
SiO_2	52.70	52.80	52.80	52.90	53.00	53.10	53.10	53.20	53.30
TiO_2	1.17	0.96	1.32	1.51	1.19	1.57	1.43	1.17	1.55
Al_2O_3	17.60	16.50	20.40	19.10	16.50	17.60	18.10	18.50	16.50
Fe_2O_3	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --	3.27	-- -- --	-- -- --	4.33
FeO	7.95	7.87	7.14	8.20	8.48	6.02	8.59	8.01	5.74
MnO	0.11	0.13	0.12	0.14	0.13	0.14	0.13	0.14	0.16
MgO	4.93	6.52	2.64	3.10	6.27	3.78	4.13	4.23	4.33
CaO	9.34	9.99	9.74	9.24	8.96	9.01	8.22	10.10	8.64
Na_2O	2.99	2.66	3.14	3.24	2.90	3.35	3.64	2.98	3.38
K_2O	0.73	0.44	0.58	0.66	0.65	0.83	0.61	0.56	0.86
P_2O_5	0.20	0.15	0.19	0.19	0.20	0.21	0.27	0.16	0.25
H_2O^+	0.73	0.61	0.59	0.64	0.51	0.46	0.89	0.34	0.52
H_2O^-	1.16	1.01	0.96	0.70	1.14	0.83	0.54	0.56	0.71
CO_2	<0.01	0.03	0.07	0.07	0.24	0.16	0.13	<0.01	0.11
Total	99.61	99.67	99.69	99.69	100.17	100.33	99.78	99.95	100.38

Table 1.--*Chemical analyses of volcanic and hypabyssal intrusive rocks, Goat Mountain quadrangle,* continued

Map No.	37	38	39	40	41	42	43	44	45
Field sample No.	**88CG-V290**	**87CG-V220B**	**87CG-V197**	**87CG-V162**	**84CG-V49A**	**88CG-V323A**	**84CG-V66A**	**84CG-V51A**	**88CG-V297A**
Latitude	46°09'09"	46°11'40"	46°10'33"	46°12'15"	46°12'16"	46°11'52"	46°13'19"	46°12'05"	46°11'34"
Longitude	122°21'53"	122°16'03"	122°22'25"	122°19'40"	122°16'42"	122°22'08"	122°16'15"	122°15'37"	122°19'13"
Map unit	Tba	Tba	Tba	Tba	Tba	Tba	Tba	Tba	Tba
Rock type	Basaltic Andesite	Basaltic Andesite	Basaltic Andesite	Basaltic Andesite	Basaltic Andesite	Basaltic Andesite	Basaltic Andesite	Basaltic Andesite	Basaltic Andesite
SiO_2	53.40	53.70	53.70	53.80	53.90	54.00	54.00	54.20	54.30
TiO_2	0.99	1.77	1.80	1.51	1.30	1.68	1.16	1.77	1.51
Al_2O_3	16.70	16.50	16.70	18.90	17.30	17.30	17.30	16.70	17.80
Fe_2O_3	-- -- --	4.43	-- -- --	3.28	4.70	-- -- --	4.17	3.95	-- -- --
FeO	7.86	5.92	9.54	5.27	3.94	9.09	4.14	5.90	8.25
MnO	5.91	3.88	3.48	2.79	4.55	3.21	4.39	3.64	3.14
MgO	0.15	0.18	0.19	0.17	0.12	0.16	0.12	0.17	0.12
CaO	9.50	8.35	7.52	8.66	8.82	8.29	8.87	7.99	8.02
Na_2O	2.99	3.54	3.73	3.58	3.08	3.66	3.02	3.42	3.51
K_2O	0.70	0.78	0.79	0.65	0.95	0.34	0.64	0.74	0.96
P_2O_5	0.16	0.26	0.35	0.23	0.16	0.23	0.17	0.22	0.29
H_2O^+	0.47	0.73	0.60	0.56	0.84	0.95	0.99	1.01	0.57
H_2O^-	0.86	0.44	0.94	0.87	1.03	0.60	0.93	0.60	1.18
CO_2	0.04	<0.01	<0.01	<0.01	0.03	<0.01	0.25	0.05	<0.01
Total	99.73	100.48	99.34	100.27	100.72	99.51	100.15	100.36	99.65

Table 1.--*Chemical analyses of volcanic and hypabyssal intrusive rocks, Goat Mountain quadrangle,* continued

Map No.	46	47	48	49	50	51	52	53	54
Field sample No.	**87CG-V222**	**86CG-V97B**	**88CG-V321**	**88CG-V343A**	**88CG-V388**	**88CG-V269**	**88CG-V396C**	**88CG-V387**	**87CG-A84**
Latitude	46°12'07"	46°10'42"	46°14'12"	46°10'50"	46°14'00"	46°13'36"	46°13'06"	46°13'49"	46°13'12"
Longitude	122°15'46"	122°21'46"	122°21'36"	122°20'08"	122°22'10"	122°21'38"	122°21'32"	122°22'03"	122°17'48"
Map unit	Tba	Tba	Tba	Tba	Tba	Tba	Ta	Tba	Tha
Rock type	Basaltic Andesite	Basaltic Andesite	Basaltic Andesite	Basaltic Andesite	Basaltic Andesite	Basaltic Andesite	Basaltic Andesite	Basaltic Andesite	Hornblende Andesite
SiO_2	54.40	54.70	54.70	55.20	55.50	55.60	55.70	55.70	55.70
TiO_2	1.43	1.76	1.79	1.52	1.12	1.02	1.14	1.02	0.91
Al_2O_3	18.50	16.30	16.50	17.70	15.90	17.00	16.00	17.00	17.10
Fe_2O_3	4.42	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --	4.83
FeO	4.10	9.63	9.09	8.12	7.62	7.19	7.74	7.13	2.11
MnO	2.69	3.59	3.48	2.67	4.75	4.72	4.76	4.55	3.19
MgO	0.10	0.17	0.18	0.14	0.15	0.12	0.14	0.12	0.12
CaO	8.26	7.14	7.51	8.01	8.08	8.45	8.08	8.23	7.81
Na_2O	3.65	3.83	3.46	3.64	3.18	3.12	3.23	3.22	3.07
K_2O	0.81	0.78	0.77	1.04	1.06	0.78	1.10	0.85	1.41
P_2O_5	0.20	0.29	0.23	0.31	0.25	0.18	0.25	0.17	0.21
H_2O^+	0.92	0.57	0.87	0.59	0.57	0.49	0.55	0.57	1.47
H_2O^-	0.59	1.16	1.26	0.78	1.07	0.96	1.02	1.04	1.38
CO_2	0.03	<0.01	<0.01	0.09	0.03	0.04	0.15	<0.01	0.70
Total	100.10	99.92	99.84	99.81	99.28	99.67	99.86	99.60	100.01

Table 1.--*Chemical analyses of volcanic and hypabyssal intrusive rocks, Goat Mountain quadrangle*, continued

Map No.	55	56	57	58	59	60	61	62	63
Field sample No.	**88CG-V371A**	**88CG-V363B**	**84CG-V47A**	**84CG-V37A**	**84CG-V76A**	**88CG-V395A**	**86CG-V132**	**87CG-V171A**	**88CG-V320D**
Latitude	46°13'41"	46°09'58"	46°10'51"	46°08"29"	46°14'49"	46°12'56"	46°09'29"	46°12'57"	46°14'11"
Longitude	122°20'38"	122°22'02"	122°16'21"	122°18'17"	122°17'55"	122°21'01"	122°20'36"	122°21'37"	122°21'58"
Map unit	Tba	Ta	Tba	Tqmd	Tqmd	Ta	Ta	Ta	Ta
Rock type	Basaltic Andesite	Andesite	Basaltic Andesite	Quartz Monzodiorite	Quartz Diorite	Andesite	Andesite	Andesite	Andesite
SiO_2	56.20	56.30	56.30	56.60	56.80	56.80	57.40	57.50	57.60
TiO_2	1.77	1.12	1.76	1.52	1.19	1.44	1.38	1.27	1.30
Al_2O_3	16.50	15.80	16.50	15.60	16.00	16.00	15.90	15.40	15.30
Fe_2O_3	-- -- --	-- -- --	3.99	2.63	3.34	-- -- --	-- -- --	3.67	-- -- --
FeO	8.94	7.38	5.29	5.59	4.38	7.80	7.64	4.11	7.47
MnO	3.35	4.52	3.20	3.76	4.15	3.76	3.41	4.07	4.07
MgO	0.19	0.16	0.18	0.13	0.13	0.14	0.14	0.12	0.13
CaO	7.08	7.69	7.17	6.87	7.40	7.22	6.89	6.71	6.85
Na_2O	3.92	3.24	3.68	3.56	3.32	3.35	3.38	3.52	3.20
K_2O	0.75	1.17	0.85	1.64	1.37	1.36	1.55	1.60	1.55
P_2O_5	0.23	0.26	0.25	0.32	0.22	0.30	0.31	0.33	0.33
H_2O^+	0.72	0.50	0.94	1.10	1.15	0.56	0.77	0.52	0.85
H_2O^-	0.24	1.02	0.40	0.88	0.35	0.94	0.92	1.14	1.26
CO_2	0.03	0.02	0.04	0.10	0.22	0.01	<0.01	0.04	<0.01
Total	99.92	99.18	100.55	100.30	100.02	99.68	99.69	100.00	99.91

Table 1.--*Chemical analyses of volcanic and hypabyssal intrusive rocks, Goat Mountain quadrangle,* continued

Map No.	64	65	66	67	68	69	70	71	72
Field sample No.	**87CG-V219**	**88CG-V273B**	**88CG-V276C**	**88CG-V315A**	**84CG-V29**	**88CG-V285A**	**84CG-V70**	**86CG-V135A**	**88CG-V297B**
Latitude	46°09'21"	46°13'39	46°14'16"	46°12'45"	46°07'43"	46°11'50"	46°14'44"	46°11'42"	46°11'31"
Longitude	122°0'02"	122°20'00"	122°19'15"	122°20'57"	122°15'57"	122°18'30"	122°15'39"	122°19'35"	122°19'18"
Map unit	Ta	Tia	Tqmd	Ta	Tcp	Ta	Tid	Td	Td
Rock type	Andesite	Andesite	Quartz Monzodiorite	Andesite	Andesite	Andesite	Dacite	Dacite	Dacite
SiO_2	57.60	57.60	57.70	58.00	58.40	59.00	61.00	62.80	62.90
TiO_2	1.30	1.24	1.17	1.29	1.11	1.30	1.01	1.00	1.10
Al_2O_3	15.50	16.60	15.90	15.30	16.10	17.60	15.60	15.80	15.60
Fe_2O_3	3.15	0.00	0.00	-- -- --	2.26	-- -- --	2.32	2.18	-- -- --
FeO	4.24	6.75	7.05	7.30	4.78	6.72	3.73	4.00	5.97
MnO	3.91	2.61	3.71	3.92	3.56	1.97	1.63	1.55	1.60
MgO	0.13	0.17	0.12	0.13	0.12	0.15	0.14	0.15	0.20
CaO	6.72	6.05	7.12	6.75	7.09	6.42	5.17	4.38	4.09
Na_2O	3.49	3.90	3.27	3.22	3.38	4.09	3.94	5.25	4.51
K_2O	1.57	1.07	1.54	1.57	1.08	0.98	1.07	0.86	1.68
P_2O_5	0.34	0.41	0.25	0.33	0.23	0.27	0.34	0.37	0.39
H_2O^+	0.70	1.26	1.17	0.68	1.68	0.55	2.21	1.11	0.85
H_2O^-	1.26	1.20	0.87	1.16	0.51	0.71	1.48	0.47	0.84
CO_2	<0.01	0.86	0.02	<0.01	0.03	0.02	0.04	0.03	<0.01
Total	99.91	99.72	99.89	99.65	100.33	99.78	99.68	99.95	99.73

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

Map No.	73	74	75	76	77
Field sample No.	**88CG-V320C**	**82CG-A11**	**84CG-V22**	**Basalt of Kalama Falls[1]**	**Andesite of Kalama Spring[1]**
Latitude	46°14'14"	46°08'06"	46°08'49"	46°08'	46°09'
Longitude	122°22'07"	122°19'52"	122°17'05"	122°19'	122°15'
Map unit	Td	Qkd	QPdg	Qsck	Qsak
Rock type	Dacite	Hyp-Hbl Dacite	Hbl-Biot Dacite	Basalt	Andesite
SiO_2	65.50	63.30	67.80	49.59	62.46
TiO_2	0.75	0.71	0.43	1.60	0.92
Al_2O_3	14.20	17.50	16.60	17.47	16.82
Fe_2O_3	-- -- --	2.29	1.74	3.32	1.40
FeO	5.21	2.26	1.13	7.46	4.28
MnO	1.24	2.02	1.09	9.69	5.16
MgO	0.09	0.07	0.05	0.15	0.08
CaO	3.40	4.95	4.09	6.62	2.12
Na_2O	4.65	4.60	4.55	3.40	4.72
K_2O	2.11	1.72	1.65	0.52	1.52
P_2O_5	0.19	0.26	0.18	0.16	0.24
H_2O^+	1.62	0.14	0.29	0.27	0.60
H_2O^-	0.27	0.05	0.09	0.13	0.40
CO_2	<0.01	0.26	0.19	--	--
Total	99.23	100.13	99.88	100.38	100.72

[1]From Greeley and Hyde (1972).

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

Qt **Talus (Holocene and Pleistocene)**--Unsorted accumulations of loose, angular blocks of rock forming steep unvegetated to brushy slopes beneath cliffs; talus composed of porphyritic dacite common on flanks of Goat Mountain

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 cirques above about 2800 ft south of McBride Lake and east of Trouble Creek. Areas shown as alluvium in Castle Creek and South Fork Castle Creek valleys includes coarse-massive, unsorted, secondary blast-pyroclastic flow deposits shed from adjacent slopes during the May, 1980 eruption of Mount St. Helens (Lipman and Mullineaux, 1981; Hoblitt and others, 1981; Fisher and others, 1987)

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, poorly-drained surfaces. Large landslides west of Fossil Creek result from failure of fine-grained, clay- and zeolite-rich volcaniclastic rocks (Tvs) along northeast-dipping bedding planes

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

Deposits of 1980 eruptions --Divided into:

Qsl **Lahar deposits**--Flat-surfaced, unconsolidated deposits, mostly <2 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). Consist 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). Locally overlain by a light-gray highly pumiceous lahar deposit < 0.5 m thick formed in the afternoon of May 18 (Janda and others, 1981). Thin lobes of distal fine-grained lahar or lahar-runout deposits present east of Blue Lake and north of McBride Lake. Extensively reworked by posteruption fluvial processes

Qsda **Debris-avalanche deposits**--Varicolored, hummocky, polymictic volcanic diamicton generated by collapse of north flank of Mount St. Helens on May 18, 1980 (Voight and others, 1981). In this quadrangle, present only along Castle Creek in extreme northeast part. Unsorted chaotic mixture of basalt and andesite flows, dacite domes, and pyroclastic rocks from upper cone of Mount St. Helens volcano; contains minor admixtures of soil, colluvium, and woody debris (Glicken, 1986; Glicken and others, 1989). Extensively gullied and modified by post-1980 fluvial erosion

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

Qsk **Deposits of the Kalama eruptive period**--Unconsolidated deposits filling bottom of Kalama River valley. Small unmapped outcrops of Kalama-age pyroclastic-flow and lahar deposits are present in South Fork Toutle River and Castle Creek valleys as well (Crandell, 1987; Scott, 1989). Between McBride Lake and Kalama dome, fill consists largely of light- to medium-gray lithic and lesser pumiceous pyroclastic-flow deposits as much as 60 m thick overlying basalt of Kalama Falls; these deposits consist of angular to subrounded blocks, dominantly of hypersthene-hornblende dacite, as large as 1 m in a matrix of fine to coarse ash; valley fill downstream from Kalama dome consists chiefly of alluvium derived from the dacitic pyroclastic-flow deposits (Crandell, 1987). In the broad area between Goat Mountain and McBride Lake, the dacitic deposits are buried beneath andesitic deposits that include a lithic pyroclastic-flow deposit containing blocks of gray hypersthene- and hornblende-bearing andesite and a younger pyroclastic-flow deposit consisting largely of blocks of black scoriaceous hypersthene-augite andesite, many displaying breadcrusted surfaces (Crandell, 1987). Still-younger laharic deposits underlie the broad slope east of Goat Marsh; these are composed primarily of "summit-dome dacite" (Crandell, 1987), a distinctive light-gray and reddish-gray, fine-grained hypersthene dacite derived from the dome which occupied the pre-1980 summit of Mount St. Helens. Conflicting radiocarbon ages have been obtained from the pyroclastic-flow deposits (Crandell (1987) but all are younger than tephra layer Wn erupted in A.D. 1480 (Yamaguchi, 1983); tree-ring dating indicates that emplacement of the summit dome, marking the end of the Kalama eruptive period, occurred at about A.D. 1647 (Yamaguchi and Hoblitt, 1986)

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

Qsck **Basalt of Kalama Falls**--Black to dark-gray pahoehoe basalt flow in the Kalama River valley; in this quadrangle, largely buried by Kalama-age deposits (Qsk), but extends downvalley to near Kalama Falls in the adjacent Cougar quadrangle (Hyde, 1970; Evarts and Ashley, 1990). Petrographically and chemically similar to the Cave Basalt south of Mount St. Helens and probably extruded during the same eruption (Greeley and Hyde (1972; Evarts and Ashley, 1990). Drill hole data (Hyde, 1970), indicate that the unit consists of several flow units and is about 40 m thick near the south edge of the quadrangle where it is underlain by as much as 65 m of laharic deposits derived from Mount St. Helens

Qsak **Andesite of Kalama Springs**--Black, vitreous, sparsely-phyric silicic andesite lava flow that terminates in steep flow front at Kalama Springs, north of McBride Lake. Surface of flow covered by angular, concoidally fractured, polyhedral blocks as much as 2 m across; local red vesicular zones present at flow margins; flow thickness estimated to be about 10 m by Greeley and Hyde (1972). Flow contains sparse phenocrysts of plagioclase (as long as 1 mm) and microphenocrysts of hypersthene, orange-brown hornblende (with reaction rims of fine-grained magnetite and pyroxene), and Fe-Ti oxide in a strongly foliated hyalopilitic groundmass . Precise age unknown but upper end is overlain by basalt of Kalama Falls (Qsck) so flow is Castle Creek age or older; thick Cougar-age debris-avalanche(?) deposits (Qsc) crop out north and south of flow but do not overlie it, so flow is probably younger and flowed down valley incised into the fragmental deposits. Considered by C. A. Hopson (unpub. mapping) to be of early Castle Creek age

Qspc **Deposits in Kalama valley older than Castle Creek eruptive period, undivided**--Unconsolidated laharic and pyroclastic-flow deposits north of Kalama dome; downvalley exposures described by Crandell (1987) suggest that these deposits may include products of the the Castle Creek and Pine Creek eruptive periods of the Spirit Lake eruptive stage and possibly as old as the Swift Creek eruptive stage

Qsp **Deposits of the Pine Creek eruptive period**--Unconsolidated flowage deposits banked against bedrock ridge in Castle Creek drainage; unmapped deposits of Pine Creek age are also present in Coldspring Creek drainage (Crandell, 1987). Composed of dacitic lithic pyroclastic-flow and lahar deposits in erosional remnants of broad fan of Pine Creek-age fill; one of the pyroclastic-flow deposits has a radiocarbon age of 2840±100 yr (Crandell, 1987)

Qssc **Deposits of the Swift Creek eruptive stage**--Unconsolidated clastic deposits in remnants of thick fill in South Fork Toutle River and Coldspring Creek; largely buried by Kalama-age deposits south of Blue Lake. In Sheep Canyon area, crudely stratified lahar and lithic pyroclastic-flow deposits are at least 200 m thick; beds of fluvially reworked pumice of tephra set S, which was erupted approximately 13,000 years ago, crop out near the top of this section (Crandell, 1987). Laharic and fluvial deposits younger than set S but older than tephra set J (approximately 10,000-11,000 radiocarbon years old (Mullineaux, 1986)) form low terraces along South Fork Toutle River to west of Sheep Canyon

(Crandell, 1987; Scott, 1989); one of these lahar deposits yielded a radiocarbon age of 12,270±90 yr (Crandell, 1987). Low terrace remnants along South Fork Toutle River shown as Swift Creek in age locally contain some older and younger deposits as well (Scott, 1989)

Qscg **Deposits of the Cougar eruptive stage**--Sequence of unconsolidated to slightly indurated flowage deposits on south side of South Fork Toutle River valley upstream from mouth of Disappointment Creek, and erosional remnants north of McBride Lake (Hyde,1975; Crandell, 1987). Deposits in South Fork Toutle River are overlain by Fraser-age till (Qem) and consist chiefly of gray to pink lithic and pumiceous pyroclastic flows which contain prismatically jointed lithic blocks of hypersthene-hornblende dacite as large as 3 m across and pumice clasts as large as 1 m across. Occurrences near McBride Lake (older Swift Creek assemblage of Hyde (1975)) include dacitic lithic and pumiceous pyroclastic-flow and laharic deposits that are overlain by Fraser-age till (Qet), as well as a fragmental deposit considered by Mullineaux and Crandell (1981), Newhall (1982), and Crandell (1987) to be a debris-avalanche deposit. Cougar eruptive stage probably extended from about 21,000 to 18,000 years ago (Crandell, 1987)

Qdk **Dacite of Kalama Dome (Holocene or Pleistocene)**--Light-gray to pink porphyritic to seriate hypersthene-hornblende dacite forming Kalama dome (informal name for small dome along Kalama River 4.2 km southwest of Goat Mountain). Dome carapace consists of large angular dacite blocks as much as 2 m across. Phenocrysts include conspicuous slender prisms of shiny black hornblende (4-5 percent; as long as 1 cm; pale orange to red-brown in thin section, with rims of fine-grained magnetite and pyroxene), blocky white plagioclase (20-25 percent; as much as 3 mm across), and ragged, elongate hypersthene (less than 1 percent; as long as 2 mm; charged with minute Fe-Ti oxide inclusions); dacite also contains rare anhedral xenocrysts(?) of biotite as much as 2 mm across. Microporphyritic groundmass composed of plagioclase, hornblende, hypersthene, Fe-Ti oxide, apatite, and interstitial cryptocrystalline feldspar and quartz; rare irregular vesicles less than 1 mm across. Age of emplacement unknown but apparently postdates Fraser glaciation and is petrographically and chemically similar to dacites erupted from Mount St. Helens (Crandell, 1987; Smith and Leeman, 1987)

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; 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 characteristic of 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 lateral moraine near 3000 ft along south valley wall of South Fork Toutle River (where they overlie Cougar-age pyroclastic-flow deposits of Mount St. Helens (Qsc) and are overlain by tephra set S (Crandell, 1987)) and small terminal moraines in tributary of Fossil Creek and south of McBride Lake

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; in Kalama River valley, includes as much as 3 m or more of variably oxidized and weathered Mount St. Helens ash. 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. Correlated with the Hayden Creek Drift of the Mount Rainier region, which possesses similar weathering characteristics (Crandell and Miller, 1974; Colman and Pierce, 1981), although 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) north end of small lateral moraine is present in Kalama valley bottom southeast of Kalama dome. Considered by Hyde (1975) and Crandell (1987) to be of Fraser (Evans Creek) age but deposit is lithologically identical to drift exposed in roadcut 0.6 km to southeast in Cougar quadrangle (Evarts and Ashley, 1990) which is overlain by tephra set C, so must be older

QPdg **Dacite of Goat Mountain (Pleistocene or Pliocene)**--White to light-gray, highly jointed, easily broken, coarsely porphyritic biotite-hornblende dacite forming steep-sided, sparsely vegetated, glaciated plug-dome of Goat Mountain and a small elongate hill northeast of Blue Lake. Samples from Goat Mountain contain abundant phenocrysts of blocky white plagioclase (25-35 percent; as large as 1 cm), equant to embayed grayish quartz (1-2 percent; as much as 1 cm across), conspicuous hexagonal biotite (2-3 percent; as much as 1 cm across), acicular brown hornblende (2-3 percent; as long as 3 mm), and microphenocrysts of pyroxene, apatite, and Fe-Ti oxide in a felty groundmass; locally microvesicular. Samples from hill northeast of Blue Lake are similar but lack hornblende and pyroxene. Discordant K-Ar ages (Engels and others, 1976) on hornblende (3.18±0.3 Ma[1]) and biotite (1.06±0.6 Ma[1] and 0.76 ± 0.6 Ma[1]) from west side of Goat Mountain indicate a late Pliocene to early Pleistocene age of emplacement.

---

[1] Published ages recalculated using currently accepted decay constants in Steiger and Jager (1977).

BEDROCK

Intrusive rocks

Tia **Intrusive basaltic andesite and andesite (Oligocene)**--Dikes and sills of porphyritic and aphyric, commonly amygduloidal, pyroxene andesite and basaltic andesite; also includes rare basalt dikes not distinguished separately; most abundant north of South Fork Toutle River. Petrographically similar to and probably feeders for nearby andesite, basaltic andesite, and basalt flows (Ta, Tba and Tb) but commonly more highly altered to assemblages of albite, smectite, chlorite, carbonate, quartz, titanite, prehnite, and zeolites such as laumontite, chabazite, stilbite, epistilbite

Intrusive complex of Spud Mountain (Oligocene)--Group of irregular multiphase intrusions exposed east and south of Spud Mountain. Divided into:

Tsqm **Quartz monzodiorite phase**--Light- to dark- gray, coarse-grained, hypidiomorphic-granular pyroxene quartz monzodiorite. Composed of plagioclase (50-60 percent; as long as 6 mm), quartz (10-15 percent; 1-3 mm), K-feldspar (5-7 percent; ≤1 mm; forms micrographic intergrowths with quartz), augite (10-13 percent; as long as 3 mm), hypersthene (10-12 percent; as long as 3 mm), and Fe-Ti oxide (1-2 percent; 0.5-1 mm) with minor to trace amounts of brown hornblende (replacing augite), biotite, apatite, zircon, and allanite; rare miarolitic cavities contain quartz, chlorite, epidote, fibrous amphibole, calcite; moderately to intensely deuterically altered to assemblages of albite, montmorillonite, calcite, epidote, prehnite, actinolite, chlorite, magnetite, titanite, talc and pyrite. Contact relations indicate this is youngest phase of intrusive complex; a fission-track determination on metamorphic titanite in coarse-grained hornfels adjacent to the northernmost quartz monzodiorite body gave an age of 31.0±1.5 Ma (R.C. Evarts, unpub. data)

$Tsqd_2$ **Coarse-grained quartz diorite phase**--Light- to medium-gray, coarse-grained, hypidiomorphic granular pyroxene quartz diorite east of Spud Mountain. Consists of plagioclase (60-70 percent; 1 to 7 mm long), augite (10-15 percent; 1 to 3 mm across), hypersthene (10-15 percent; 1 to 3 mm long), and Fe-Ti oxide (1-2 percent; 0.5 to 1 mm across), with interstitial biotite (1 percent; as large as 1 mm across), micrographic to granophyric intergrowths of quartz and K-feldspar, and apatite (as long as 1 mm). Pyroxenes largely uralitized but plagioclase generally fresh

$Tsqd_1$ **Medium-grained quartz diorite phase**--Light- to dark-gray, medium-grained, hypidiomorphic-granular to intergranular pyroxene quartz diorite. Composed of plagioclase (60-70 percent; 1-3 mm long), augite (10-15 percent; ≤1 mm across), hypersthene (5-15 percent; ≤1 mm across), and Fe-Ti oxide (2-4 percent; 0.5 mm across) with interstitial quartz (4-7 percent; ≤0.5 mm), minor K-feldspar (0-2 percent), and traces of biotite, apatite, and green or pale brown hornblende. Miarolitic cavities common. Typically altered to assemblages of albite, epidote, prehnite, chlorite, actinolite, biotite, titanite, calcite, and pyrite. Chemically very similar to coarse-grained quartz diorite phase ($Tsqd_2$), but recrystallized where in contact with it, hence older

Tsdi **Diorite phase**--Light- to dark-gray to grayish-green, fine- to medium-grained, porphyritic to seriate pyroxene diorite. Contains phenocrysts of plagioclase (10-20 percent; as long as 5 mm), augite (3-6 percent; 1 to 2 mm long), and, hypersthene (2-4 percent; 1 mm long), and Fe-Ti oxide (1-2 percent; ≤0.5 mm across) in a fine-grained intergranular groundmass. Generally intensely altered to albite, chlorite, prehnite, epidote, actinolite, calcite, quartz, and pyrite; recrystallized where in contact with medium-grained quartz diorite phase ($Tsqd_1$)

Tqmd **Quartz monzodiorite (Oligocene)**--Light- to dark greenish gray, medium- to coarse-grained hypidiomorphic-granular pyroxene quartz monzodiorite forming large sill-like body south of Goat Mountain. Composed of plagioclase (50-55 percent; as long as 6 mm), quartz (10-15 percent; ≤ 1 mm across), K-feldspar (6-9 percent; <1 mm across), augite (8-10 percent; as large as 3 mm), hypersthene (7-10 percent; as long as 2 mm), Fe-Ti oxide (1-2 percent; 0.5-1 mm across), brown or green hornblende (≤2 percent; <1 mm across; chiefly as ragged crystals partially replacing augite), and traces of biotite and apatite. Quartz and K-feldspar form interstitial, coarse-to fine-grained micrographic or granophyric intergrowths. Secondary minerals include albite, smectite, laumontite, stilbite, and titanite; veins of laumontite common. Intrusion exhibits pronounced spheroidal weathering; adjacent country rocks contact metamorphosed

Tdi **Diorite (Oligocene)**--Widespread dikes and sills of light- to dark-gray to greenish-gray to brown, medium-grained, coarsely porphyritic to seriate to hypidiomorphic granular pyroxene diorite; locally includes minor quartz diorite. Consists of plagioclase (about 60-70 percent; 1 to 5 mm long), augite (5-10 percent; 1 to 2 mm across), and, in some samples, hypersthene (as much as 10 percent; 1 to 2 mm long) or totally altered olivine (≤2 percent; 1 mm across), with interstitial Fe-Ti oxide (1-2 percent; 0.5 mm across), quartz (0-5 percent), smectite (replacing mafic minerals and (or) glass), apatite; only plagioclase and augite are common as phenocrysts. Locally amygduloidal. Moderate to intense alteration is typical; secondary minerals include albite, chlorite, prehnite, pumpellyite, calcite, quartz, laumontite, smectite, titanite. Intrusions north of South Fork Toutle probably related to Spud Mountain intrusive complex

Tha **Hornblende andesite (Oligocene)**--North- and northwest-striking, 2.5-m-wide dikes of light-gray, seriate, amygdular, hornblende andesite cutting volcanic breccia (Tvbc) in Disappointment Creek; dike northwest of Disappointment Creek intruded along fault zone marked by brecciated clay-altered rock. Contains conspicuous prisms of fresh brownish-green hornblende (3-8 percent; as long as 1.3 cm) and augite (1-2 percent; as much as 3 mm across), partially altered phenocrysts of plagioclase (5-15 percent; as long as 3 mm) and hypersthene (trace-1 percent; as long as 1 mm), and microphenocrysts of Fe-Ti oxide (0.5 percent) in an intergranular groundmass variably altered to albite, kaolinite, quartz, laumontite, stilbite, and calcite

Tid **Intrusive dacite (Oligocene)**--Columnar-jointed dike, 22 m wide, of black, vitreous, sparsely-phyric, pyroxene-bearing dacite cutting weathered basaltic andesite flow breccia on ridge west of Castle Lake. Contains phenocrysts of plagioclase (4 percent; 1 to 2 mm long) and augite (<1 percent; as long as 1 mm), and equant microphenocrysts of hypersthene (<1 percent), and Fe-Ti oxide (<1 percent) in a glassy trachytic groundmass with abundant reddish glass slightly altered to smectite; vugs as large as 10 cm across are filled with euhedral quartz crystals. Pyrite deposited on fractures in dike

Tiba **Intrusive basaltic andesite (Oligocene)**--Sills of porphyritic to seriate basaltic andesite cropping out on ridgecrest north and northwest of Blue Lake. Contain phenocrysts of plagioclase (about 20 percent; as long as 5 mm), olivine (3-4 percent; 0.5 to 1 mm across; completely replaced by microcrystalline quartz+smectite; contains minute inclusions of chromian spinel and is rimmed by fine-grained granular augite), and augite (<1 percent; as long as 5 mm) in an intergranular groundmass of plagioclase, augite, Fe-Ti oxide, and minor altered interstitial glass. Locally amygduloidal. The three outcrops are probably erosional remnants of a single intrusion

Volcanic and sedimentary rocks

Tcp **Andesite of Cinnamon Peak (Oligocene)**--Sequence of coarsely porphyritic pyroxene andesite flows and very minor interbedded conglomerate in southeast part of quadrangle; informally named for Cinnamon Peak in Cougar quadrangle to south (Evarts and Ashley, 1990). Overlies volcanic breccia and conglomerate (Tvbc) 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 significantly less altered than flows in subjacent strata. Plagioclase from one flow yielded a $^{40}Ar/^{39}Ar$ age of 32.0±1.0 Ma (L. G, Pickthorn, written communication, 1988)

Tvbl **Volcanic breccia of Lost Creek (Oligocene)**--Massive, varicolored, very poorly sorted, polymict volcanic breccia and conglomerate in southeast part of quadrangle; more abundant in Cougar quadrangle to south (Evarts and Ashley, 1990). As much as 250 m thick; 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 purplish to reddish brown. Locally interbedded with minor amounts of finer-grained bedded sedimentary rocks, tuff (Tt), and small lava flows of basaltic andesite (Tba) andesite (Ta) and dacite (Td); 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 commonly 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 apparently consist largely of autobrecciated lava flows

Tba **Basaltic andesite (Oligocene)**--Flows and flow-breccia of porphyritic to seriate to aphyric basaltic andesite; unit locally includes a few basalt and andesite flows as well. Contain phenocrysts of plagioclase (as much as 35 percent; 1 to 4 mm long; locally as long as 7 mm; commonly containing abundant minute inclusions of altered glass), olivine (as much as 6 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 (0-6 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 (0-2 percent; 0.5 to 2 mm long) present in some basaltic andesite flows. Aphyric varieties typically exhibit pronounced flow-foliation. Slight to moderate alteration, especially in flow-breccia zones, to zeolite-facies assemblages including albite, laumontite, stilbite, smectites, quartz, prehnite, titanite, hematite, and, rarely, calcite, epistilbite, heulandite, mesolite, pumpellyite

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. 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, plagioclase, olivine, and pyroxene crystals, vitric ash, fine-grained plutonic rocks (most commonly dioritic), 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, kaolinite, carbonate, quartz, leucoxene, and hematite is typical; prehnite, pumpellyite present in a few samples; laumontite and heulandite or clinoptilolite are common cements. In northern two-thirds of quadrangle, consists largely of:

Tvbc **Volcanic breccia and conglomerate facies**--Massive, varicolored, well-indurated, very poorly sorted to moderately well-sorted, polymict volcanic breccia and conglomerate, mainly interbedded with mafic flows in north half of quadrangle. Over 500 m of breccia and conglomerate, with a few basaltic andesite flows, exposed in Disappointment Creek area, consisting of individual beds as much as 35 m thick, some of which form prominent clifflines. 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 (identical to interbedded basalt and basaltic andesite lava flows) ranging up to 2 m across in a dark sandy matrix of similar composition; because of similar appearance, distinguishing clast from matrix in many outcrops is difficult; clastic nature typically more obvious on weathered surfaces. Locally contains lenses of well-bedded sandstone and fine-grained conglomerate as much as 3 m thick. Beds of similar composition south of South Fork Toutle River are more commonly clast-supported conglomerates containing well-rounded volcanic clasts as large as 1.5 m. 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

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 that are relatively lithic-rich. 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, hornblende, or biotite. 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. Porphyritic varieties contain phenocrysts of plagioclase (as much as 30 percent; 1-5 mm long), augite (0-7 percent; 0.5 to 3 mm across) and (or) hypersthene (0-8 percent; 0.5 to 2 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; altered olivine present in a few samples. Commonly vesicular

Tb **Basalt (Oligocene)**--Flows and flow-breccia of porphyritic basalt scattered throughout area dominated by basaltic andesite. Petrographically and chemically gradational to basaltic andesite (Tba); shown as basalt are those analyzed flows that contain less than 52.0 weight percent SiO_2 on an anhydrous basis, virtually all of which have SiO_2 greater than 51 percent (Table 1). Most basalts contain at least 4 percent olivine phenocrysts and lack augite phenocrysts (although clinopyroxene microphenocrysts may be present)

Td **Dacite (Oligocene)**--Widely scattered flows of fresh black or altered pinkish-brown to purplish-gray, sparsely phyric pyroxene dacite containing phenocrysts and microphenocrysts of plagioclase (5-10 percent; as long as 2 mm), hypersthene (<1 percent; as long as 1 mm), augite (trace-2 percent; as long as 1 mm), and Fe-Ti oxide (<1 percent; < 1 mm) in hyalopilitic to pilotaxitic groundmass. In more-altered samples, flow banding accentuated by hematitic streaks

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

Strike and dip of beds

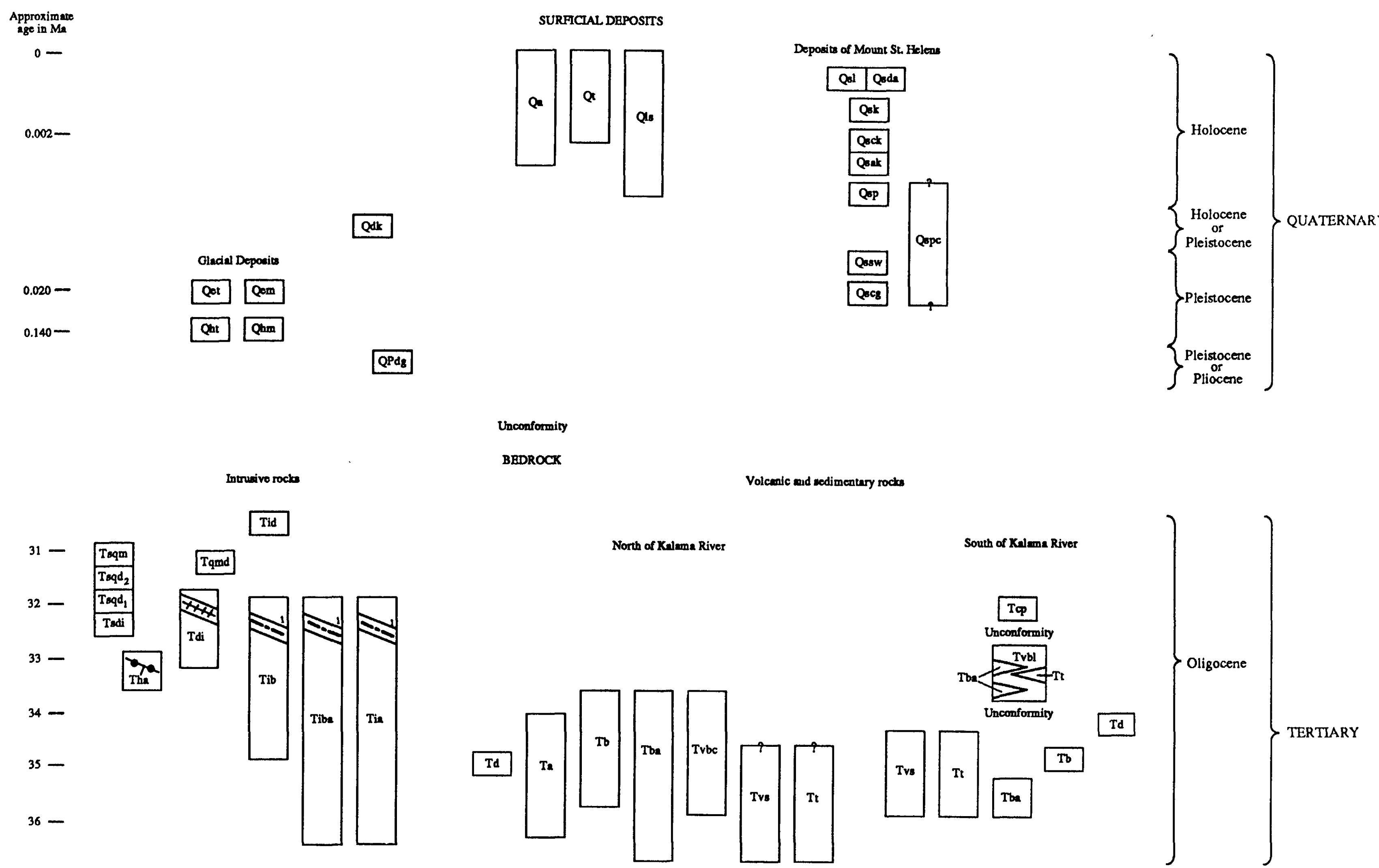
- **Inclined**
- **Horizontal**

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 Tib, Tiba, and Tia not distinguished on this map.