WASHINGTON STATE DEPARTMENT OF
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Prepared in cooperation with the United States Department of Agriculture Forest Service

Geologic Map of the Timberwolf Mountain 7.5-minute Quadrangle, Yakima County, Washington

by Paul E. Hammond

WASHINGTON DIVISION OF GEOLOGY AND EARTH RESOURCES
GEOLOGIC MAP GM-60
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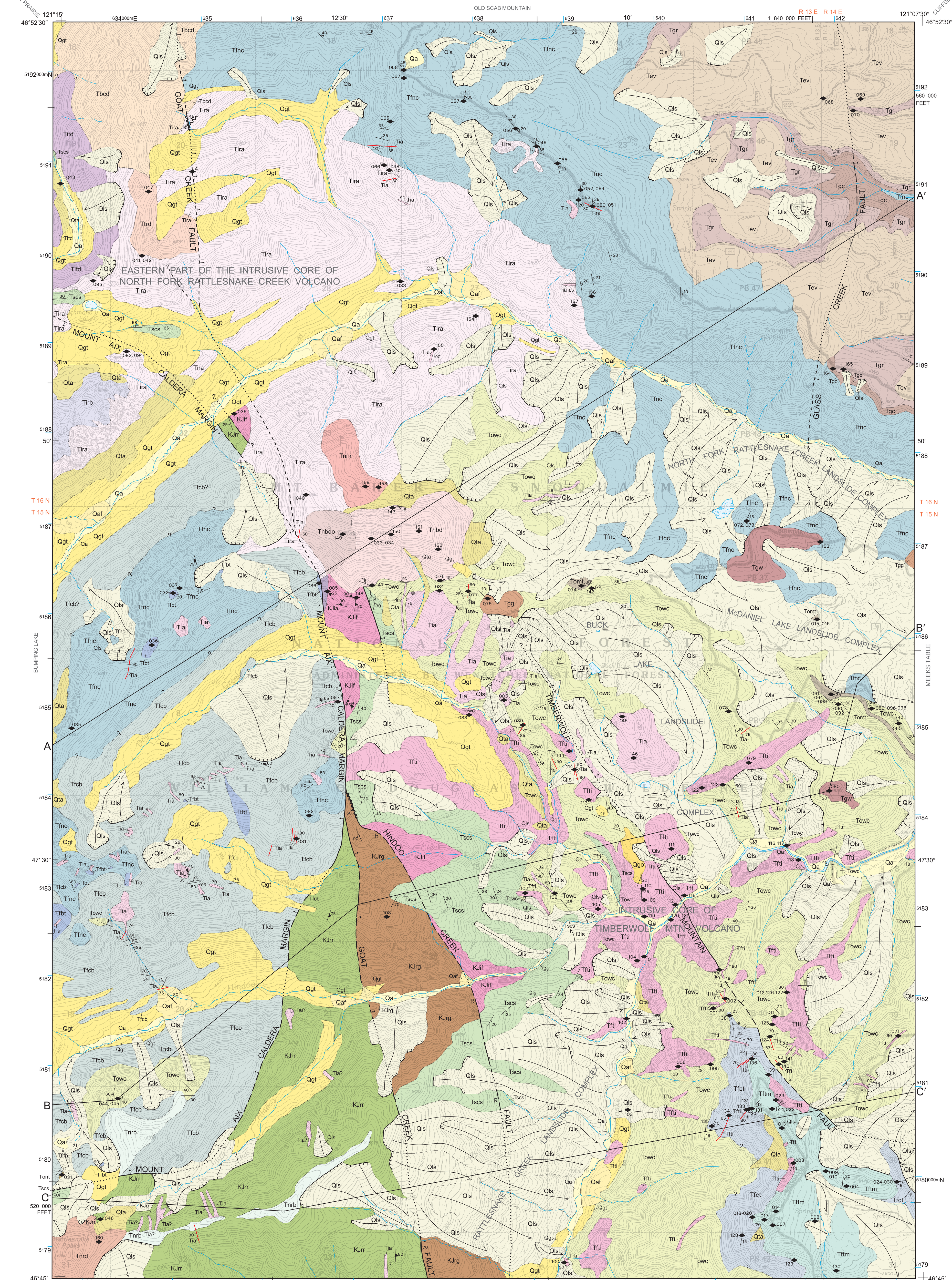
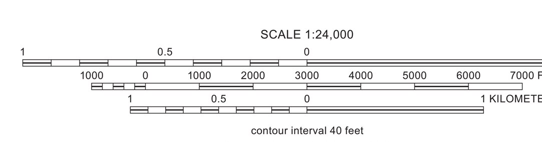


Lambert conformal conic projection
North American Datum of 1927; to place on North American Datum of 1983, move the projection lines 16 meters north and 90 meters east
Base map from scanned and rectified U.S. Geological Survey 7.5-minute Timberwolf Mountain quadrangle, 2000
Shaded relief generated from U.S. Geological Survey 10-meter Digital Elevation Model
Digital cartography by J. Eric Schuster
Editing and production by Jaretta M. Roloff and Karen D. Meyers



contour interval 40 feet
national geodetic vertical datum of 1929

INTRODUCTION

The Timberwolf Mountain 7.5-minute quadrangle is located in the Wenatchee National Forest in Yakima County on the eastern slope of the Cascade Range, about 16 km (10 mi) east of the crest. The western half of the quadrangle lies within the William O. Douglas Wilderness. The quadrangle is about 40 km (25 mi) west of Yakima, the nearest moderate-sized community.

Mapping, aided by study of aerial photos, was conducted along roads and trails, ridge crests, ridge slopes, and open, commonly steep, stream courses. Field-glass study of opposing slopes and photographs taken earlier aided in recognizing critical areas for examination and planning traverses. Field stations and geologic features were plotted directly on the topographic quadrangle. Field stations and sample sites were located before 1996 by field inspection and recognition of landmarks, and during the 1996 season and thereafter by global positioning system (GPS). An altimeter gave elevations. Of 210 samples collected in the quadrangle, nine were submitted for $^{40}Ar/^{39}Ar$ age-dating (Table 1) and 160 for x-ray fluorescence (Table 2) analyses. Names of rocks follow the classifications of Le Maitre and others (1989) for volcanic rocks and Wilson (1989) for plutonic rocks. Fragmental volcanic rocks are named after the classification of Schmid (1981).

STRATIGRAPHY

The Timberwolf Mountain quadrangle contains the most complete record of rock units in this region of the Cascade Range. All major units are represented except the Bumping Lake granite batholith, which crops out in the Bumping Lake 7.5-minute quadrangle to the west. Pre-Tertiary basement rocks, composed of the Russell Ranch (unit KJrr) and Indian Creek (units KJif and KJia) complexes of Upper Jurassic to Lower Cretaceous age, part of the Rimrock Lake inlier (Miller, 1989), occur in the western half of the quadrangle. They are overlain by a northeastward-dipping stratigraphic sequence of Tertiary sedimentary and volcanic rocks. At the base of this Tertiary sequence is the upper Eocene sandstone of Summit Creek (unit Tscs)(Vance and others, 1987), a name proposed herein to cover all similar sandstone units at this stratigraphic position in the area between the crest of the Cascade Range and the Naches River to the east. The sandstone of Summit Creek is overlain conformably by the Ohanapecosh Formation of upper Eocene to lower Oligocene age, named by Fiske and others (1963)(Swanson, 1964, 1978; Schreiber, 1981; Shultz, 1988). The rhyolite tuff of McDaniel Lake (unit Tomt), formerly called the vitric tuff of Rattlesnake Creek by Schreiber (1981) and Shultz (1988), forms a marker bed near the top of the Wildcat Creek beds. The andesite-dacite tuff of Nelson Ridge (unit Tont) is also considered a member of the Ohanapecosh Formation.

The Ohanapecosh beds are overlain unconformably by Fifes Peak Formation of upper Oligocene to lower Miocene age, also named in Mount Rainier National Park by Fiske and others (1963). The Fifes Peak Formation is represented in the quadrangle by the andesite of Nile Creek (unit Tfnc), andesite of Timberwolf Mountain volcano (unit Tftm), tuff of Bumping River (unit Tfbt), and collapse breccia of Mount Aix caldera (unit Tfcb). The Nile Creek andesite (unit Tfnc) erupted from the large volcano of North Fork Rattlesnake Creek, which has been reduced by erosion to a complex of intrusive andesite and quartz diorite (unit Tira). The tuff of Cash Prairie (unit Tfct) separates the overlying andesite of Timberwolf Mountain volcano from the underlying beds of Wildcat Creek (unit Towc). Erosion has also largely destroyed the volcano of Timberwolf Mountain, leaving a thin remnant of lava flows on its southern flank. The center of this volcano is represented by abundant sills, dikes, and plugs at the confluence of Dog and Rattlesnake Creeks. Eruption of the rhyolite tuff of Bumping River (unit Tfbt), of upper Oligocene age (24.7 Ma), caused the formation and collapse of the Mount Aix caldera, originally recognized by Schreiber (1981). After its collapse, the caldera was filled, possibly to its rim, by continuing eruption of Bumping River tuff. Blocks of this tuff within the caldera collapse breccia are remnants of the extensive, thick blanket of tuff that once probably covered the Timberwolf Mountain quadrangle. A huge block of the andesite-dacite tuff of Nelson Ridge (unit Tont) slid into the Mount Aix caldera in the Bumping Lake quadrangle. A small block of this tuff is present near the south margin of the caldera in the Timberwolf Mountain quadrangle.

Only the easternmost part of the Mount Aix caldera lies within the quadrangle. The caldera is elliptical in shape, about 14 by 10 km (8.5 by 6 mi) in size, and elongated northwesterly. Most of the caldera west of the quadrangle is intruded by the lower Miocene Bumping Lake biotite granite batholith (23.8 Ma). Bumping River tuff and the granite are cogenetic; both contain the same minerals and are chemically similar. At the present level of erosion, the caldera breccia is largely debris that slid into the subsidence. This debris consists mostly of rock exposed around the margin of the caldera—fragmented Wildcat Creek beds (unit Towc), Nile Creek lava flows (unit Tfnc), and andesite dikes (unit Tia). One large block of Wildcat Creek beds in the southwest corner of the quadrangle was tightly folded as it slid into the caldera. A 3.7 km long by 2.4 km wide (2.3 by 1.5 mi) block of Nile Creek lava flows, located between North Fork Rattlesnake and Dog Creeks, also slid en masse into the caldera. The volcano of North Fork Rattlesnake Creek, truncated by collapse of the caldera, shed a talus fan into the caldera. Subsequent to the caldera collapse, this talus was intruded by more andesite (unit Tira) in a renewed episode of magmatism, forming an intrusive breccia (unit Tirb) now exposed north of North Fork Rattlesnake Creek. Also during this renewed magmatism, the hornblende quartz diorite of Thunder Creek (unit Titd) was intruded into the northern part of the andesite complex.

The next overlying rock unit is middle Miocene lava flows of Grande Ronde Basalt of the Columbia River Basalt Group in the eastern half of the quadrangle. Two flow units, Rocky Coulee (unit Tgr) and underlying Cohassett (unit Tgc), unconformably overlap Nile Creek lava flows and breccia (unit Tfnc) north of Rattlesnake Creek. Remnants of the two older flow units, Grouse Creek (locally called Meeks Table)(unit Tgg) and underlying Wapshilla Ridge (unit Tgw), unconformably overlap Wildcat Creek beds (unit Towc) and Nile Creek lava flows (unit Tfnc) south of Rattlesnake Creek.

Deposits of volcanic facies of the upper Miocene Ellensburg Formation (unit Tev) unconformably overlap Grande Ronde Basalt onto Nile Creek lava flows and breccia (unit Tfnc) in the northeast part of the quadrangle. In addition to basalt and andesite clasts, the formation contains abundant dacite clasts and a matrix of dacite tuff, which are very similar lithologically to the three dacite plugs in the western part of the quadrangle—Rattlesnake Peaks (unit Tnrd), Nelson Butte (unit Tnbd), and Barton Creek (unit Tbcd). The latter underlies the northern part of the ridge east of Thunder Creek in the northwest corner of the quadrangle. However, these dacites are 3.8 to 5.1 Ma (lower Pliocene) in age, younger than the 7 to 11 Ma (upper Miocene) Ellensburg Formation (Smith, 1988; Smith and others, 1989). Therefore, volcanic sources of Ellensburg Formation lie outside the quadrangle to the north and west, where there are older dacite plugs.

Common surficial deposits in the project area are alluvium (unit Qa), which mantles valley floors and terraces and forms fan deposits (unit Qaf) where side streams debouch into the valleys; talus (unit Qta); landslides (unit Qls); and glacial till (unit Qgt) and outwash (unit Qgo). Among these deposits, glacial and landslide deposits are prominent in the quadrangle. Uplift of the central Cascade Range during the upper Miocene, about 6 Ma (Reiners and others, 2002), and ensuing erosion, augmented by glaciation in the last million years or less, have sculpted the terrain. Snow accumulated at Nelson Ridge, just beyond the west margin of the quadrangle, from which glaciers advanced eastward into the tributary valleys of Rattlesnake Creek. The quadrangle contains evidence of possibly three alpine glaciations. The oldest is represented by glacial deposits as much as 5 m (15 ft) thick that mantle the slope north of the middle course of Hindoo Creek and lie discontinuously atop the ridge east of lower Dog Creek. During an intermediate glaciation, till deposits were left as terraces atop rims of sills along the middle course of Dog Creek. During a younger glaciation, between about 25,000 and 11,000 years ago, possibly equivalent to the Lakedale Glaciation (Porter, 1976), glaciers occupied the upper Rattlesnake Creek valley south of the quadrangle. In the quadrangle, a glacier in upper Dog Creek extended downvalley to the area south of Nelson Butte, and in upper North Fork Rattlesnake Creek, a glacier extended to the area of the bend where the creek turns to the southeast. Possibly glaciers of different ages advanced to about the same locations in these valleys. No extensive glacial deposits (more than 3 m or 10 ft thick and traceable for more than 30 m or 100 ft) are recognized at Timberwolf Mountain, Nelson Butte, or in the north part of the ridge east of North Fork Rattlesnake Creek, although each rises above the probable snowline (the elevation above which snow accumulates during glaciation) at 1500 m (5000 ft) elevation.

Landslide deposits (unit Qls) are extensive in the quadrangle. They include rockfalls, rock avalanches, rock streams (possibly underlain by ice), slumps, and earthflows. Most slides in the quadrangle are earthflows; they begin as slumps or rockfalls and transform downslope into earthflows as the rock mass disintegrates. They range in size from 0.1 to 5 km^2 (0.04–2.0 mi^2); most are less than 0.5 km^2 (0.2 mi) in area. Four landslide complexes, consisting of parallel and coalescing slides of different width and length and of differing periods of activity, occur in the quadrangle: (1) The North Fork Rattlesnake Creek landslide complex covers about 3 km^2 (0.7 mi^2) on the northeast-facing slope above North Fork Rattlesnake Creek. (2) The McDaniel Lake landslide complex is a very complicated moving mass atop the low ridge separating North Fork Rattlesnake Creek from Dog Creek and Rattlesnake Creek. It starts at the east base of Nelson Butte and moves eastward, partly feeding the slides descending into North Fork Rattlesnake Creek and following the course of FR 1502 at the east edge of the quadrangle. It is more than 6 km^2 (>2.3 mi^2) in area. (3) The Buck Lake landslide complex covers about 3.2 km^2 (0.8 mi^2) in the center of the quadrangle and gradually moves toward Rattlesnake Creek. (4) The Rattlesnake Creek landslide complex covers about 5.4 km^2 (1.3 mi^2) on the east-facing slope opposite Timberwolf Mountain and dumps into Rattlesnake Creek.

Many landslides were active before and during glaciation and have been intermittently active since then. Most were probably caused by oversteepening of slopes by glacial erosion and stream downcutting, commonly where the dip of the strata is toward an adjacent stream and especially in the terrain underlain by clay-rich Wildcat Creek beds (unit Towc) and the sandstone of Summit Creek (unit Tscs).

STRUCTURE

Major structures in the Timberwolf Mountain quadrangle are the Rimrock Lake inlier, the Mount Aix caldera, and five north- to northwest-striking faults. No folds are delineated in the quadrangle. A structural high, an uplift of pre-Tertiary rock in the Rimrock Lake inlier, lies in the southwest part of the quadrangle. The uplift elevated the Mount Aix caldera and tilted Eocene and most Oligocene volcanic strata homoclinally northeastward prior to deposition of the Fifes Peak Formation. Renewed uplift in the late Cenozoic has further tilted all volcanic strata to the northeast. This homocline curves slightly to the northwest as it is traced northward. The uplift plunges gradually northward. Additional outcrops of pre-Tertiary rock (units KJrr and KJif) occur to the north along North Fork Rattlesnake Creek. The rock also lies at shallow depth beneath the sandstone of Summit Creek (unit Tscs) east of Richmond Lake and in Thunder Creek valley. The outcrops of sandstone, although discontinuous, mark the eastern, northern, and western flanks of the Rimrock Lake inlier north and west of the quadrangle.

A curvilinear fault, marking the boundary of the Mount Aix caldera, separates caldera breccia (unit Tfcb), which slid into the caldera, from rock in place along its surrounding sides. The Goat Creek fault is a major north-northwest-striking tectonic break, one of several mapped in the upper Naches River basin. In the northwest corner of the quadrangle, this fault is intruded by the andesite complex of North Fork Rattlesnake Creek (unit Tira) and more recently by dacite of Barton Creek (unit Tbcd). Here the fault shows no displacement since emplacement of the intrusions, but can be traced as a fracture zone. In the middle of the quadrangle, the fault coincides with the east margin of the Mount Aix caldera. To the south the fault splits, with the Hindoo Creek fault forming the east branch and separating greenstone/pillow lava (unit KJrg) from foliated diorite of the Indian Creek complex (unit KJif). South of the quadrangle, the two branches rejoin. The amount of stratigraphic separation on the fault is not discernible in the quadrangle. However, vertical striations on the fault plane where it separates pre-Tertiary rock indicates that the west side has moved up.

The fault transecting Timberwolf Mountain separates sills on the north side of Rattlesnake Creek and is poorly exposed along the north ridge of Timberwolf Mountain. In both locations, the west side of the fault moved up, dragging the east side upward. The fault strikes toward, but is not traceable to, Nelson Butte.

North-striking Glass Creek fault, in the northeast part of the quadrangle, is not traceable except where it cuts lava flows of Grande Ronde Basalt. On the north rim of Glass Creek, the Rocky Coulee flow is offset about 2 m (6 ft), west side up. Where the fault passes southward through the rim of the ridge northeast of North Fork Rattlesnake Creek, southeast of Schneider Springs, pre-Ellensburg stream erosion has followed the fault and cut a valley at least 25 m (80 ft) deep, truncating the western extent of two Grande Ronde Basalt flows. Upward displacement on the west side of the Goat Creek, Hindoo Creek, Timberwolf Mountain, and Glass Creek faults indicates that uplift of the Rimrock Lake inlier was accommodated by both uparching and faulting of the overlying strata.

At the southwest base of Nelson Butte, a short north-northwest-striking fault separates hornblende diorite of the Indian Creek complex (unit KJif) from sandstone of Summit Creek (unit Tscs) and lowermost Wildcat Creek beds (unit Towc). Here about a 2 m (6 ft) width of light-colored phyllite, a dynamically metamorphosed fine-grained sandstone or tuff, occurs along the fault. Forceful emplacement of the dacite of Nelson Butte (unit Tnbd) at 3.8 Ma accounts for the generally steeper dip of the strata, the deformation along the fault, and the higher topographic level of the strata here. Inward dipping fault planes around the base of Nelson Butte, at 15 to 45 degrees with down-dip striations, clearly show that the dacite plug expanded upward in its emplacement.

DESCRIPTION OF MAP UNITS

Quaternary Surficial Deposits

Qa — **Alluvium**—Gravel, sand, silt, and clay deposited in stream flow, sheet flood, overbank, and lake environments; gray to pale brown; clasts are subangular to rounded, with boulders up to 1 m (3 ft) in diameter, and consist of diverse volcanic and plutonic rocks and some pre-Tertiary metamorphic rocks; poorly stratified and sorted in coarser deposits, well stratified and sorted in finer deposits, locally cross bedded; generally poorly consolidated; may include glacial outwash; covers all major valley bottoms and underlies terraces where dissected by streams; thickness is 0.1 to 50 m (1–165 ft).

Qaf — **Alluvial fan**—Rock and sand; gray; clasts consist of diverse volcanic and plutonic rocks and some pre-Tertiary metamorphic rocks; contains angular boulders over 1 m (3 ft) in diameter; unsorted and chaotic; includes some channel and cut-and-fill deposits; poorly consolidated; restricted lateral extent at or near mouth of tributary stream at marked change in gradient; thickness is 1 to 20 m (3–65 ft).

Qta — **Talus**—Rock, generally monolithic; brown to gray to white, depending on color of composing rock; clasts are angular and pebble to boulder size, some larger than 1 m (3 ft) in diameter; lacks fine-grained matrix; unsorted or poorly sorted, generally coarser downslope; most surface blocks unstable; restricted extent at base of cliff or steep, rocky slope; commonly partly overgrown; thickness ranges from 1 to >30 m (3 to >100 ft), thicker at base.

Qls — **Landslide**—Intact masses, up to a kilometer in width or length, of boulders and cobbles in matrix of sand, silt, and clay; brown to dark gray; consists of rock avalanche, slump, or earthflow deposits composed of locally derived rock and soil, commonly with woody debris; angular to rounded clasts; chaotic to poorly sorted and unstratified; generally forms a hummocky topography; ranges in area from 0.1 to >5 km^2 (0.04 to >1.2 mi^2) and in thickness from 1 to 100 m (3–300 ft) at the toe; covers about 51 km^2 (20 mi^2), which is about 25 percent of the area of the Timberwolf Mountain quadrangle.

Qgt — **Glacial till**—Boulders, gravel, and abundant sand, silt, and clay; brown where deeply weathered, to gray where unweathered, to bluish gray if recently exposed; clasts consist of diverse rock types, mostly volcanic with lesser plutonic and sparse pre-Tertiary metamorphic rocks; clasts vary in size and rounding; unsorted to poorly sorted; massive to poorly stratified; commonly includes lenses or continuous thin beds of well-sorted, finer grained stream deposits; generally poorly consolidated; clasts commonly faceted and striated; distributed along valley floors and well up valley slopes; thickness is 1 to 50 m (3–165 ft).

Qgo — **Glacial outwash**—Boulders and abundant cobbles, commonly in a sand-silt matrix; gray; clasts rounded to well rounded; poorly to moderately well sorted; stratified, commonly cross bedded, contains lenses of finer grained deposits; resembles alluvial gravel deposits; commonly forms terraces downvalley from glacial till (unit Qgt); thickness is 1 to 50 m (3–165 ft).

Pliocene Intrusive and Volcanic Rocks

Dacite and rhyodacite—Consists chiefly of dacite plugs, dikes, and sills; contains fine- to medium-grained phenocrysts of whitish plagioclase (8–20%), black (commonly opacitized) hornblende (2–7%) and (or) black biotite (0.5–2%), rounded glassy quartz (1–6%), locally black orthopyroxene (hypersthene)(0.5%), rarely dark green to dark brown hornblende, and ilmenite-magnetite (0.1–2%) in a glassy to inflated fine-grained granular groundmass; locally contains 1- to 3-cm (0.3–1.3 in.) clots of hornblende and plagioclase and angular to subrounded inclusions of host rock; very light to dark gray, very pale brown where weathered, pale reddish brown where oxidized (fumarolically altered) in the west part of Nelson Butte (unit Tnbdo); dikes and sills range from 5 to 100 m (15–300 ft) wide, with sharp, locally brecciated contacts and well-fractured, displaced wall rock; narrow apophyses extend only a few meters into wall rock; all intrusions are of similar chemical composition (Table 2), yet plugs were emplaced as single to multiple intrusive masses; interpreted as feeders to domal volcanoes that stood 1 to 2 km (0.6–1.5 mi) above present erosion surface; where exposed, basal 5 to 15 m (15–50 ft) of plug consists of fluidly layered dacite with lenses of breccia, dipping inward 15 to 75°; blocky to slabby and locally columnar jointed, generally surrounded by steep slopes and an apron of talus; plugs range in area from about 0.35 to 15 km^2 (0.1–5.9 mi^2), with the Barton Creek plug being the largest in the upper Naches River basin; plugs generally rise more than 250 m (820 ft) above adjacent topography, with the Barton Creek plug being the tallest, rising to 1100 m (3600 ft); mounds of dacite debris-avalanche deposits or angular till (unit Tnrb), 10 to 115 m (30–375 ft) high, cap ridges northeast of north Rattlesnake Peaks. An rhyodacite plug (unit Tnnr) north of Nelson Butte contains medium- to fine-grained phenocrysts of whitish, epidotized plagioclase and black, opacitized hornblende in a fine-grained, medium greenish-gray to pale brown groundmass. It is propylitically altered, blocky jointed and poorly exposed. Divided into:

Tnbd — **Hornblende-plagioclase dacite of Nelson Butte**—Age is 3.2 ±0.3 to 3.82 ±0.08 Ma (Table 1).

Tnbdo — **Hornblende-plagioclase dacite of Nelson Butte, fumarolically altered and oxidized**—Age is same as unit Tnbd (Table 1).

Ttrd — **Hornblende-plagioclase dacite of Thunder Creek ridge**—Age is 4.00 ±0.15 Ma (Table 1).

Tbcd — **Biotite-quartz-hornblende-plagioclase dacite of Barton Creek**—Age is 4.69 ±0.17 Ma (Table 1).

Tnrd — **Hornblende-plagioclase dacite of north Rattlesnake Peaks**—Age is 5.13 ±0.11 Ma (Table 1).

Tnrb — **Breccia of hornblende-plagioclase dacite of north Rattlesnake Peaks**—Age may be same as unit Tnrd (Table 1), or if breccia is found to be till, then it is the age of a younger glaciation.

Tnnr — **Hornblende-plagioclase rhyodacite north of Nelson Butte**—Age unknown, but possibly 4 to about 10 Ma, based on its similarity in composition and texture to other intrusions of this age range in the region.

Middle to Upper Miocene Stratified Deposits

Tev — **Ellensburg Formation, volcanic facies**—Interstratified conglomerate, breccia, sandstone-siltstone, and volcanic ash (tuff) of dacite composition (Table 2); generally very light gray to white, yellowish to very pale brown where weathered; includes debris avalanche, laharic flow, stream flow, and airfall deposits; well stratified but poorly sorted; in beds 1 cm to 15 m (0.03–50 ft) thick; clasts of abundant dacite and less common andesite and basalt are supported in a fine-grained matrix of biotite-hornblende-plagioclase dacite tuff; forms steep, smooth to ribbed slopes; unconformably overlies andesite of Nile Creek (unit Tfnc) and Grande Ronde Basalt (unit Tgr) with sharp contact, conglomerate and breccia upon a scoured surface, or finer-grained beds atop about 5 m (~15 ft) of brown pebbly clay paleosol; thickness is 65 to 120 m (200–400 ft); age is 7 to 11 Ma (Smith, 1988).

Grande Ronde Basalt—Consists here of four units that are individual lava flows, although some flows show evidence of multiple injections of lava and (or) inflated, invasive lava; contains abundant fine-grained plagioclase and clinopyroxene in a fine-grained groundmass, some flows having additional sparse plagioclase phenocrysts; dark gray to black. All flows are basaltic andesite (Table 2) rather than true basalt. Flows vary in internal structure and in number and position of tiers. Jointing is stubby to splintery to radiating columnar, blocky, or, most commonly, hackly. Bases and tops are non-vesicular to vesicular to pillow lava. All flows terminate abruptly against rising topography except the Rocky Coulee flow (unit Tgr), which thins out, its basal contact rising toward the top where the unit grades into scoria. Where exposed, flows are separated by interbeds, generally up to 10 m (30 ft) thick, of whitish fine-grained to pumice-lapilli tuff, yellowish to brownish fine-grained sandstone, or palagonitic hyaloclastite. The two top flows (units Tgr and Tgc) are part of the Sentinel Bluffs N_2 unit (Reidel and others, 1989), containing more than 4% MgO and having normal magnetic polarity; they unconformably overlie andesite of Nile Creek (unit Tfnc) in the northeast corner of the quadrangle. The lower two flows (units Tgg and Tgw) are part of the Grouse Creek and Wapshilla Ridge R_2 units (Reidel and others, 1989), have higher TiO_2 and Ba content and reversed magnetic polarity; they unconformably overlie andesite of Nile Creek (unit Tfnc) and tuffaceous rocks of Wildcat Creek (unit Towc) south of North Fork Rattlesnake Creek. The Grouse Creek unit is locally referred to as the Meeks Table flow (Swanson, 1967). Age is middle Miocene (15.6–16 Ma)(Reidel and others, 1989). Divided into:

Tgr — **Rocky Coulee lava flow**—Thickness is as much as 55 m (180 ft), averaging 30 m (100 ft).

Tgc — **Cohassett lava flow**—Thickness is as much as 90 m (300 ft), averaging 70 m (230 ft).

Tgg — **Grouse Creek lava flow**—Thickness is as much as 150 m (500 ft), averaging 80 m (260 ft); locally referred to as the Meeks Table flow.

Tgw — **Wapshilla Ridge lava flow**—Thickness is as much as 50 m (160 ft), averaging 30 m (100 ft).

Upper Oligocene to Lower Miocene Intrusions

Intrusive complex of North Fork Rattlesnake Creek—Consists of two intrusions that are the roots of the volcano of North Fork Rattlesnake Creek, a deeply eroded, large volcanic center from which the andesite of Nile Creek (unit Tfnc) erupted, and a breccia deposit formed of talus shed into the Mount Aix caldera from the same truncated volcano. Divided into:

Titd — **Hornblende quartz diorite of Thunder Creek**—Uniformly fine- to medium-grained, with whitish plagioclase (55%), black to dark-green hornblende (20%), grayish quartz (14%), dark-green augite (10%), and ilmenite-magnetite(1%); basaltic andesite in composition (Table 2); propylitically altered; varies from dark gray to dark green to light greenish gray; blocky to irregular jointing; forms steep, cliffed slopes with aprons of talus; intrudes the northern part of the andesite intrusive complex of North Fork Rattlesnake Creek (unit Tira), forming an oval stock, 1 by 2.5 km (0.6 x 1.6 mi), most of which lies outside the quadrangle; not radiometrically dated because of pervasive alteration; age estimated between 25.67 Ma, age of unit Tira (Table 1), and 23.75 Ma, age of Bumping Lake granite located west of the quadrangle.

Tirb — **Breccia (consolidated talus) of the andesite intrusive complex of North Fork Rattlesnake Creek**—A chaotic mass of angular to rounded fragments, chiefly of porphyritic andesite (unit Tira), with a lesser amount of tuff of Bumping River (unit Tfbt) and diverse volcanic rock; clasts up to 5 m (15 ft) in size, most less than 1 m (3 ft), in well-indurated matrix of intrusive fine-grained porphyritic to aphanitic andesite; varies from dark gray to dark green to light greenish gray; propylitically altered and silicified; blocky to irregular jointing; forms steep, cliffed slopes with aprons of talus; massive although crudely layered, tens of meters thick, dipping shallowly west; exposed thickness is about 215 m (700 ft); breccia was an extensive apron of talus shed into the caldera from the truncated volcano of the North Fork Rattlesnake Creek, mapped separately from the collapse breccia of Mount Aix caldera (unit Tfcb); age is younger than 24.7 Ma, age of eruption of tuff of Bumping River (unit Tfbt) and formation of Mount Aix caldera; constitutes the type Richmond breccia of Abbott (1953).

Tira — **Andesite intrusive complex of North Fork Rattlesnake Creek**—Consists of a labyrinth of irregular dikes, abundant sills, and plugs; aphanitic to fine- to medium-grained porphyritic andesite (Table 2) with medium- to coarse-grained phenocrysts of whitish plagioclase (25–35%), black orthopyroxene (3–9%), dark-green augite (2–5%), and ilmenite-magnetite (0.5–2%) in a fine-grained groundmass with abundant rounded inclusions; propylitically altered; dark gray to dark green to light greenish gray; blocky to irregular jointing; forms steep, cliffed slopes with aprons of talus; intrusions vary greatly in width, thickness, and size, from 1 to about 100 m (3–300 ft), forming a complex that covers about 25 km^2 (6 mi^2) and extends west and north into adjacent quadrangles; age is 25.67 ±0.49 to 26.61 ±0.55 Ma (Table 1). This unit, together with the breccia of the intrusive complex of North Fork Rattlesnake Creek, forms the North Fork Rattlesnake Creek volcano.

Tia — **Miscellaneous andesite intrusions**—Commonly porphyritic with medium- to fine-grained, abundant whitish plagioclase and lesser dark-green augite in a fine-grained, aphanitic to glassy groundmass; less commonly aphanitic with or without fine-grained phenocrysts of plagioclase; commonly of basaltic andesite composition (Table 2); dark green to light grayish green where propylitically altered; in narrow, irregular to discontinuous dikes and plugs, many of which in the collapse breccia of Mount Aix caldera (unit Tfcb) are possibly detached blocks; a large plug south of Nelson Butte consists chiefly of fine- to medium-grained pyroxene diorite. Age has not been determined, but is estimated at about the same age as the intrusions of Timberwolf Mountain (unit Tfti) and the andesite complex of North Fork Rattlesnake Creek (unit Tira), 24.0–25.7 Ma (Table 1).

Tfti — **Intrusions of Timberwolf Mountain volcano**—Consist of dikes, sills, and plugs of basaltic andesite to rhyolite (Table 2); diorite and quartz diorite occur in cores of some thick sills and plugs; granite occurs only in the plug northwest of Timberwolf Mountain at Rattlesnake Creek; phenocrysts in basaltic andesite and andesite consist of white plagioclase (20–30%), dark-green augite (2–7%), ilmenite-magnetite (2%), and rarely black orthopyroxene; phenocrysts in diorite and quartz diorite consist of similar percentages of white plagioclase, dark-green augite, and ilmenite-magnetite with black orthopyroxene (0.5%); dacite contains phenocrysts of white plagioclase (25%), black orthopyroxene (11%), quartz (4%), and ilmenite-magnetite (1%); granite contains phenocrysts of similar percentages of plagioclase and quartz with black hornblende (5%) and ilmenite-magnetite (0.1%); varies in color from black to dark green to pale greenish gray where fresh, pale to dark brown to yellowish orange gray where weathered; dikes and sills are aphanitic to porphyritic; groundmass is generally fine to medium grained, glassy in some dikes and margins of sills; plugs grade from porphyritic in the margin to medium to coarse grained internally; dikes range from 2 to 500 m (6–1650 ft) in width, sills generally from 8 to 80 m (2.5–265 ft) in thickness, and plugs up to 515 m (1700 ft) in breadth; age is same as andesite of Timberwolf Mountain volcano (unit Tftm), 24.0 ±0.8 to 24.73 ±0.46 Ma (Table 1).

Upper Oligocene to Lower Miocene Volcanic Deposits

Fifes Peak Formation—Divided into:

Tfcb — **Collapse breccia of Mount Aix caldera**—Chaotic assemblage of diverse volcanic and other rocks, ranging widely in size from fine grains to blocks 4.5 km (2.7 mi) wide, most of which collapsed and avalanched into Mount Aix caldera as it subsided; consists most abundantly of tuffs and volcanic sedimentary rocks of Wildcat Creek (unit Towc) and andesite lava rock of Nile Creek (unit Tfnc), but includes fragments of all rocks surrounding caldera; color varies between white, gray, green, and brown; well indurated, silicified, and argillized; massive although irregularly jointed; forms steep, rough slopes; bounded by peripheral fault of caldera; only easternmost part of caldera lies in the Timberwolf Mountain quadrangle. Important constituents of caldera fill in the quadrangle are the huge block of highly fractured lava flows of Nile Creek (unit Tfnc) that underlies the ridge extending west from Nelson Butte, and the 1.5 by 0.5 by 0.35 km (0.9 x 0.3 x 0.2 mi) block of Wildcat Creek beds (unit Towc) that tightly folded during its slide into the caldera. Smaller blocks, as large as about 150 by 240 m (500 x 800 ft) but generally much smaller, and slivers, up to 10 m (30 ft) wide and 30 m (100 ft) long, consist of rhyolite tuff of Bumping River (unit Tfbt) and andesite-dacite tuff of Nelson Ridge (unit Tont). Thickness is unknown, probably more than 1.2 km (4000 ft)(cross section A). The caldera was formed during eruption of rhyolite tuff of Bumping River (unit Tfbt) at 24.7 Ma.

Tfbt — **Biotite-hornblende-quartz-plagioclase rhyolite tuff of Bumping River**—Lithic- and pumice-lapilli crystal-vitric rhyolite tuff (Table 2) with abundant fine- to medium-grained plagioclase (2.5–3.5%), ilmenite-magnetite (0.5–3.5%), quartz (0.5–1%), and few grains of biotite and hornblende generally altered completely to iron oxide and yellowish to greenish clay minerals, all in a very fine grained vitroclastic groundmass with lapilli of yellowish to brownish pumice and angular dark-colored lithic fragments, commonly of andesite, in sufficient abundance to call the deposit a tuff-breccia in and within about 2 km (1¼ mi) of the Mount Aix caldera; light gray, yellowish to pale brown where vapor-phase altered; locally silicified; composed of multiple pyroclastic flow, surge, and air-fall deposits; blocky and irregularly jointed; forms cliffs and steep, rough slopes; occurs as isolated blocks, up to about 150 by 240 m (500 x 800 ft) in size but generally much smaller, and slivers, up to 10 m (30 ft) wide and 30 m (100 ft) long, in the collapse breccia (unit Tfcb) and along the fault margin of the Mount Aix caldera, and as smaller fragments in the matrix of the breccia of the andesite intrusive complex of North Fork Rattlesnake Creek (unit Tirb); possibly erupted from the perimeter of the Mount Aix caldera, although no vents or feeder dikes have been found in this location; after collapse of the caldera, most tuff erupted from a kilometer-wide (0.6 mi) vent at the north base of Bismarck Peak in the west-adjacent Bumping Lake quadrangle; age 24.7 ±0.23 Ma (upper Oligocene) determined from samples from quadrangles west and north of the Timberwolf Mountain quadrangle.

Tftm — **Andesite of Timberwolf Mountain volcano**—Porphyritic andesite to dacite (Table 2) with moderate to abundant medium- to fine-grained phenocrysts of white plagioclase (6–24%), black orthopyroxene (1.5–4.5%), dark green augite (1–2%), and ilmenite-magnetite (0.5–2.5%) in a fine-grained to glassy groundmass; very dark gray (almost black) to gray, brown where weathered; forms isolated, remnant, blocky-jointed lava flows and breccia, 35 to 65 m (115–215 ft) thick, with rare interbeds of whitish to pale green plagioclase crystal-vitric tuff, 0.5 to 2 m (2–6 ft) thick. A 100-m (300 ft)-thick, dark gray debris-avalanche deposit, with abundant angular fragments up to 1 m (3 ft) in size in a fine-grained matrix and at least one interbedded lava flow, forms a blanket at the southeast base of the volcano in the east-adjacent quadrangles. Lava flows and fragmental deposits were supplied by intrusive rocks of Timberwolf Mountain volcano (unit Tfti), which are concentrated north of Timberwolf Mountain at the confluence of Dog and Rattlesnake Creeks and are probably the center of the former volcano. The deposits unconformably overlie the quartz-plagioclase rhyodacite-rhyolite tuff of Cash Prairie (unit Tfct) and probably the tuffaceous rocks of Wildcat Creek (unit Towc) on a surface of low relief without an intervening paleosol. Average thickness of deposits is about 150 m (500 ft). Age is 24.0 ±0.8 to 24.73 ±0.46 Ma (upper Oligocene)(Table 1).

Tfct — **Quartz-plagioclase rhyodacite-rhyolite tuff of Cash Prairie**—Lithic- and pumice-lapilli crystal-vitric rhyolite tuff (Table 1) with fine- to medium-grained crystals of plagioclase (3–8%), quartz (0.5%), ilmenite-magnetite (<0.5–2%), and trace amount of hornblende, with lapilli of pumice (<0.5–6%), lithic fragments (8–16%), chiefly of plutonic and metamorphic rocks, and sparse red scoria, in a devitrified, non-welded matrix; very light gray, light brown to yellowish white to yellowish brown, weathering pale orangish brown to dark brown;. a series of pyroclastic flows with a few lenses of andesite pebble conglomerate and thin cross-bedded sandy tuff; poorly exposed in rounded to smooth-weathering slopes; blocky to slabby jointed; contacts not exposed but unconformably overlies tuffaceous rocks of Wildcat Creek (unit Towc) and overlain unconformably by andesite lava flows of Timberwolf Mountain volcano (unit Tftm); source unknown but believed to have been derived from the south because tuff thins and contains decreasing amount of lithic clasts to north; thickness at least 450 m (1500 ft) probably as valley fill; age is 25.5 to 24.7 Ma , upper Oligocene, determined from samples in Rimrock Lake quadrangle to southwest.

Tfnc — **Andesite of Nile Creek**—Porphyritic andesite (Table 2) with abundant fine- to coarse-grained phenocrysts of whitish plagioclase (20–30%), black orthopyroxene (2–6.5%), greenish-black augite (0.3–3.5%), and ilmenite-magnetite (0.2–2.8%) in a very fine grained to glassy groundmass; dark gray where fresh, brown to reddish brown where weathered; forms blocky lava flows with brecciated base, dense flow-layered platy- to blocky-jointed interior, and brecciated to scoriaceous top, varying in thickness from 5 to 60 m (15–200 ft); contains interbeds up to 10 m (30 ft) thick of whitish and grayish to reddish plagioclase-vitric tuff and lithic-pumice lapilli tuff to tuff-breccia of andesite-dacite composition (Table 2); lava flows grade eastward into thick sequences of laharic lithic tuff-breccia, 5 to 60 m (15–200 ft) thick, with subrounded boulders of lava up to 10 m (30 ft) in size and interbedded tuff; lava flows erupted from the volcano of North Fork Rattlesnake Creek (unit Tira) before formation of Mount Aix caldera; lava flows also compose a large, intricately fractured mass, 3.7 by 2.4 km (2.3 x 1.5 mi) wide and at least 180 m (600 ft) thick, that caps the ridge west of Nelson Butte within the Mount Aix caldera and is mapped separately from the caldera breccia (unit Tfcb); a 610 by 760 m (2000 x 500 ft) block of lava flows occurs at the east margin of the caldera; lava also forms many smaller blocks up to 60 m (200 ft) in size within the collapse breccia; unconformably overlies tuff of McDaniel Lake (unit Tomt) and tuffaceous rocks of Wildcat Creek (unit Towc) with a sharp undulating contact on a surface of low relief without an intervening palesol; thickness is about 760 m (2500 ft) on the ridge northeast of North Fork Rattlesnake Creek (cross section A); age is 24.6 to 27.3 Ma (upper Oligocene), based on age determinations to north and east of the quadrangle.

Upper Eocene to Upper Oligocene Volcanic and Sedimentary Rocks

Ohanapecosh Formation—Divided into:

Tont — **Hornblende-quartz-plagioclase andesite-dacite tuff of Nelson Ridge**—Lithic- and pumice-lapilli crystal-vitric andesite-dacite tuff (Table 2) with abundant fine- to medium-grained phenocrysts of whitish epidotized plagioclase (17%), gray quartz (16%), dark-green chloritized hornblende (0.5%), and trace amount of ilmenite-magnetite in a fine-grained vitroclastic groundmass with dark-colored, generally aphanitic, lithic fragments up to 30 cm (1 ft) in size and greenish, flattened pumice lapilli; pale greenish gray, weathering to grayish white; propylitically altered and thermally metamorphosed; eutaxitically layered; well indurated but extensively fractured; occurs in a 30-m (100 ft)-long block in the caldera breccia (unit Tfcb) in the southeast margin of the caldera; age unknown but similar lithologically and chemically to quartz-bearing tuffs in the Ohanapecosh Formation west of the quadrangle (upper Oligocene).

Tomt — **Plagioclase rhyolite tuff of McDaniel Lake**—Lithic- and pumice-lapilli crystal-vitric rhyolite tuff (Table 2) with fine- to medium-grained phenocrysts of whitish plagioclase (3.5–8%), quartz (0.5%), and ilmenite-magnetite (0.2–2.3%) in a fine-grained vitroclastic groundmass with abundant pale-brown pumice lapilli and lithic fragments; light gray to pale brownish gray to pale greenish gray; pyroclastic-flow deposit; has a sharp undulating unconformable basal contact atop a 15 cm (6 in) brown paleosol on tuffaceous rocks of Wildcat Creek (unit Towc); forms a marker bed; thickness is 35 m (115 ft); three determinations indicate an age between 26.02 ±0.18 and 26.8 ±1.4 Ma (upper Oligocene)(Table 1).

Towc — **Tuffaceous rocks of Wildcat Creek**—Diverse volcaniclastic airfall and pyroclastic-flow deposits consisting of fine-grained tuff, pumice-rich lapilli tuff, and lapillistone, with less common reworked stream deposits of sandstone, siltstone, and mudstone, rare conglomerate, and few lake deposits; reddish and brownish in lower part, greenish in middle part, and greenish blue, grayish brown, and pale brown in upper part; contains crystals of plagioclase, quartz, pyroxene, hornblende, and ilmenite-magnetite, and abundant lithic, pumice, and accretionary lapilli; varies in composition from basaltic andesite to rhyolite, with most rocks being andesite to dacite (Table 2); vitroclastic matrix altered extensively to smectites and zeolites, weakening coherence within matrix of deposit and increasing susceptibility to landsliding; in thin beds less than 1 m (3 ft) to a few meters thick, laterally continuous and varying little in thickness; forms many blocks of variable size within the collapse breccia of Mount Aix caldera (unit Tfcb), one about 1500 m (5000 ft) long by 500 m (1500 ft) wide by 300 m (1000 ft) thick (cross section B) was tightly folded during its slide into the caldera; another block 150 by 300 m (500 x 1000 ft) is against the east margin of the caldera; forms smooth to locally rimmed slopes; conformably overlies sandstone of Summit Creek (unit Tscs) with a narrow gradational contact zone, although a 98-m (320 ft)-thick lens of sandstone (unit Tscs) partly enclosed in andesite sills (unit Tfti) lies above the contact along the east side of lower Dog Creek (Schreiber, 1981), here possibly uplifted along a fault; thickness of lower part is about 600 m (2000 ft), middle part 300 m (1000 ft), and upper part 150 m (500 ft), color being the primary distinction in the division of the beds; total thickness about 1050 m (3500 ft)(cross sections A, B, and C); age is about 29 to 34 Ma (lower Oligocene) based on age determinations in the quadrangle (Table 1) and outside the quadrangle (Vance and others, 1987; Lander and Swanson, 1989).

Tscs — **Sandstone of Summit Creek**—Subangular to subrounded, medium- to fine-grained lithic mica (muscovite)-quartz-feldspar sandstone, siltstone, mudstone, and rare conglomerate; light to dark gray, brownish where weathered; in beds 2 cm to 20 m (1 in.–65 ft) thick; forms smooth to steep, rimmed slopes; nonconformably overlies pre-Tertiary rocks with sharp contact, locally with 1 to 2 m (3–6 ft) of dark brown paleosol atop older rock; name from Vance and others (1987), who described these deposits in the White Pass 7.5-minute quadrangle; thickness is 195 to 295 m (640–970 ft)(cross sections A and B); older than about 34 Ma (upper Eocene) based on stratigraphic relationship to the tuffaceous rocks of Wildcat Creek (unit Towc).

Upper Jurassic to Lower Cretaceous Rocks of the Rimrock Lake Inlier

KJrr — **Russell Ranch complex of Miller (1989)**—Dark-gray argillite, feldspathic sandstone, graywacke, conglomerate, local pods of dark-green pillow basalt lava (greenstone), lenses of gray-green basalt-andesite tuff, and scattered small grayish-green hornblende diorite (tonalite) intrusions; bedded units, 5 to 200 m (16–665 ft) thick, with gradational contacts; greenstone and diorite in pods and lenses 10 to 50 m (30–165 ft) thick; occurs as structurally disrupted, bedded units lacking stratigraphic continuity; blocky to irregular jointing; forms steep, rough slopes; interpreted as a tectonic mélange (Miller, 1989); forms a belt, 3000 m (10,000 ft) wide and at least as thick, between the fault margin of Mount Aix caldera and Goat Creek fault; age is Upper Jurassic to Lower Cretaceous, based on fossil radiolaria in bedded chert exposed outside quadrangle (Miller, 1989). Locally divided into:

KJrg — **Pillow lava (greenstone) of the Russell Ranch complex**—Dark-green, fine-grained, massive basaltic pillow lava (Table 2); primary minerals of pyroxene, plagioclase, and olivine are almost entirely altered to chlorite, epidote, actinolite, calcite, iron oxides, and zeolites, with abundant clay; contains abundant veinlets of quartz and actinolite; irregularly jointed; forms steep to cliffed slopes; lies in a north-striking belt 1220 m (4000 ft) wide, bounded on the west by Goat Creek fault and Russell Ranch complex (unit KJrr), and on the east by Hindoo Creek fault and foliated diorite of the Indian Creek complex (unit KJif); more than 1200 m (4000 ft) thick; age is Upper Jurassic to Lower Cretaceous (Miller, 1989).

KJif — **Foliated diorite of the Indian Creek complex**—Dark-green to grayish-green, gneissic (well to weakly foliated), medium- to coarse-grained, biotite-hornblende quartz diorite of andesite composition (Table 2); contains plagioclase (50%), quartz (25%), hornblende (15%), biotite (9%), and ilmenite-magnetite (1%), partly altered to chlorite, epidote, and sericite; blocky jointed; forms steep, cliffed slopes; lies in a parallel belt east of the Hindoo Creek fault, separated by the fault from pillow lava of the Russell Ranch complex (unit KJrg); maximum exposed width of belt is 600 m (2000 ft); age is 132 ±13 to 154 ±2 Ma (Upper Jurassic to Lower Cretaceous), as determined outside quadrangle (Miller, 1989).

KJia — **Amphibolite of the Indian Creek complex**—Dark-gray amphibolite of basalt composition (Table 2); consists essentially of fine- to medium-grained, green hornblende (58%), plagioclase (41%), and ilmenite-magnetite (1%); well layered and hornblende lineated; slabby jointed; occurs as 60-m (200 ft)-wide lens between foliated diorite of the Indian Creek complex (unit KJif) and marginal fault of Mount Aix caldera at southwest base of Nelson Butte; probable lens in foliated diorite of the Indian Creek complex truncated by Mount Aix caldera fault; same age as foliated diorite of the Indian Creek complex (unit KJif), Upper Jurassic to Lower Cretaceous.

GEOLOGIC SYMBOLS

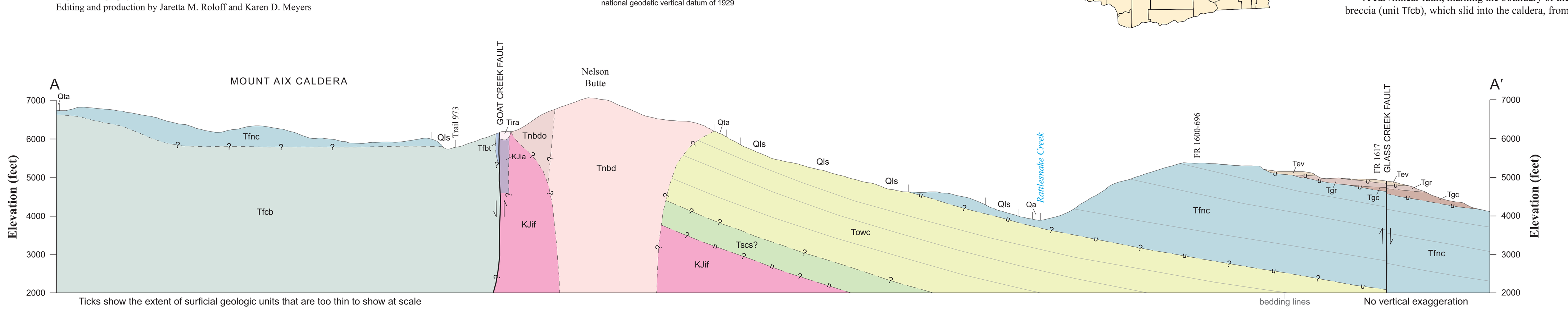
- Contact—Long-dashed where approximately located; short-dashed where inferred; queried where uncertain; showing dip
- Unconformity—Queried where uncertain; cross sections only
- Nonconformity—Queried where uncertain; cross sections only
- Fault, unknown offset—Long-dashed where approximately located; short-dashed where inferred; dotted where concealed; queried where uncertain
- Normal fault—Bar and ball on downthrown side; long-dashed where approximately located; short-dashed where inferred; dotted where concealed; queried where uncertain; showing dip; in cross sections arrows show relative movement
- Reverse fault—R on upthrown side; long-dashed where approximately located; dotted where concealed; in cross sections arrows show relative movement
- Shear—Showing dip
- Inclined bedding—Showing strike and dip
- Inclined bedding—Showing approximate strike and dip
- Flow layering in lava flow or fluidal layering in plutonic rock—Showing strike and dip
- Foliation in metamorphic rock—Showing strike and dip
- Joint—Showing strike and dip
- Dike or sill—Showing dip and geologic unit
- Landslide scarp—Hachures on downslope side
- Direction of landslide movement
- Geochemistry sample location

Table 1. Radiometric age determinations. NMGRL–NMBGMR, New Mexico Geochronology Research Laboratory–New Mexico Bureau of Geology and Mineral Resources; COAS–OSU, College of Oceanic and Atmospheric Sciences–Oregon State University; – – –, no data. $^{40}Ar/^{39}Ar$ date shown with 2σ error.

Unit	Age (Ma)	Site	Lab no.	Method	Laboratory	Comments
Tnbd	3.2 ±0.3	– – –	– – –	fission-track, zircon	(Schreiber, 1981, D)	
Tnbd	3.82 ±0.08	147	51665-01	$^{40}Ar/^{39}Ar$, groundmass	NMGRL–NMBGMR	
Ttrd	4.00 ±0.15	41	51648-01	$^{40}Ar/^{39}Ar$, hornblende	NMGRL–NMBGMR	
Tbcd	4.69 ±0.17	A	UAKA87-89	K/Ar, biotite	(Smith and others, 1989)	Location description puts sample in Tira; A is location shown in report map
Tnrd	5.13 ±0.11	160	52548-01	$^{40}Ar/^{39}Ar$, hornblende	NMGRL–NMBGMR	
Tftm	7.8 ±3.7	14	– – –	K/Ar, whole rock	(Shultz, 1988, STM-10-24-2B)	Sample contains abundant atmospheric argon
Tftm	8.1 ±3.5	14	– – –	K/Ar, whole rock	(Shultz, 1988, STM-10-24-2B)	Sample contains abundant atmospheric argon
Tftm	24.0 ±0.8	4	– – –	K/Ar, whole rock	(Shultz, 1988, TM 10-8-4A)	
Tftm	24.73 ±0.46	29	99C1393	$^{40}Ar/^{39}Ar$, plagioclase	COAS–OSU	
Tira	25.67 ±0.49	48	01C684	$^{40}Ar/^{39}Ar$, plagioclase	COAS–OSU	
Tira	26.61 ±0.55	38	01C722	$^{40}Ar/^{39}Ar$, plagioclase	COAS–OSU	
Tomt	26.02 ±0.18	63	97C963	$^{40}Ar/39Ar$, plagioclase	COAS–OSU	
Tomt	26.38 ±0.41	92	98C660	$^{40}Ar/^{39}Ar$, plagioclase	COAS–OSU	
Tomt	26.8 ±1.4	– – –	– – –	fission-track, zircon	(Schreiber, 1981, C)	
Towc	29.15 ±0.40	78	04C3421	$^{40}Ar/^{39}Ar$, plagioclase	COAS–OSU	
Towc	30.1 ±1.5	– – –	– – –	fission-track, zircon	(Schreiber, 1981, A)	

Table 2. Chemical determinations of bedrock units. Units are identified by map symbol and listed in approximate stratigraphic order. Where several samples are averaged, 'n' indicates the number of samples. A sample site number (#) indicates a representative sample. Major elements are normalized with total Fe expressed as FeO. All determinations were performed at the GeoAnalytical Laboratory, Washington State University (Johnson and others, 1999).

		MAJOR ELEMENTS—NORMALIZED (in weight percent)											TRACE ELEMENTS (in parts per million)									
Unit		SiO_2	Al_2O_3	TiO_2	FeO	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5	Unnormalized total	Ni	Cr	Sc	V	Ba	Rb	Sr	Zr	Y	Nb
Tnbd	avg	65.54	16.68	0.606	4.16	0.081	4.89	1.70	1.75	4.41	0.189	98.81	7	8	10	81	411	32	686	147	15	8.9
(n=9)	std dev	0.53	0.23	0.010	0.15	0.006	0.40	0.18	0.08	0.23	0.011	1.59	1	3	3	9	26	3	51	3	1	0.9
Ttrd	avg	68.37	16.04	0.423	3.11	0.072	3.98	1.23	2.06	4.59	0.123	95.82	6	10	6	46	473	42	480	121	13	8.6
(n=2)	std dev	0.11	0.06	0.008	0.08	0.002	0.00	0.06	0.07	0.13	0.001	3.33	2	1	0	12	37	1	8	3	1	0.4
Tnrd	avg	61.91	17.89	0.756	4.06	0.081	6.67	2.47	1.48	4.34	0.322	99.03	18	21	14	99	414	21	1350	180	13	4.3
(n=2)	std dev	0.56	0.12	0.003	0.59	0.009	0.08	0.16	0.02	0.13	0.001	1.21	1	2	2	12	16	0	18	16	0	1.2
Tnnr	avg	69.52	14.75	0.461	5.30	0.167	1.97	0.50	2.39	4.83	0.120	98.66	3	0	28	5	733	66	180	244	46	14.4
(n=2)	std dev	0.17	0.03	0.006	0.13	0.001	0.16	0.04	0.13	0.10	0.004	0.35	1	0	0	2	1	10	5	6	1	0.3
Tev	avg	62.23	18.73	0.760	5.29	0.140	5.75	1.96	0.89	4.10	0.142	99.12	21	27	17	114	348	12	604	138	10	8.4
(n=2)	std dev	1.10	0.17	0.098	0.37	0.075	0.12	0.39	0.04	0.05	0.023	0.75	1	11	0	14	25	1	88	13	2	2.5
Tgr	avg	54.81	14.24	1.788	11.03	0.200	8.53	4.72	1.38	2.97	0.332	99.23	6	45	37	297	537	33	312	158	34	12.4
(n=2)	std dev	0.05	0.31	0.017	0.49	0.004	0.35	0.18	0.12	0.12	0.026	0.14	7	9	1	5	13	1	6	6	0	1.9
Tgc	#164	54.44	14.29	1.856	11.05	0.205	8.95	4.84	1.21	2.83	0.334	99.16	11	53	42	311	517	27	313	155	36	11.3
Tgg	#75	54.92	13.89	1.911	11.09	0.189	8.49	3.89	1.45	3.85	0.323	100.79	9	20	31	342	629	41	314	160	33	13.5
Tgw	#80	54.41	13.70	2.179	12.51	0.196	7.67	3.90	1.64	3.40	0.392	99.02	9	17	35	385	635	46	326	172	35	13.6
Titd	#43	56.71	17.68	0.964	7.44	0.158	8.43	4.14	1.39	2.93	0.165	94.68	11	45	34	189	373	38	231	134	27	10.6
Tira	avg	59.78	17.58	0.956	7.00	0.144	6.28	2.76	1.75	3.55	0.210	97.47	6	18	21	137	518	50	293	167	30	8.9
(n=13)	std dev	1.87	0.81	0.158	0.89	0.031	1.20	0.74	0.47	0.64	0.023	1.68	3	12	5	49	81	15	36	18	3	1.5
Tia	avg	56.54	18.25	1.146	7.96	0.190	7.06	3.25	1.05	4.30	0.270	96.90	12	39	20	176	396	31	320	148	28	9.7
(n=10)	std dev	3.34	0.83	0.143	0.94	0.083	1.66	1.33	0.80	1.65	0.077	1.88	22	50	7	40	268	24	66	23	4	1.5
Tfti basalt-andesite	avg	57.16	18.11	1.170	7.67	0.154	7.35	3.35	1.30	3.47	0.264	98.65	9	31	23	173	546	32	343	155	29	9.4
(n=36)	std dev	2.17	0.85	0.136	0.76	0.026	1.16	0.87	0.39	0.58	0.086	1.00	7	26	5	37	157	13	45	34	6	3.1
Tfti dacite-rhyolite	avg	68.58	15.34	0.560	4.28	0.093	3.09	1.12	2.78	4.01	0.153	99.21	4	6	12	49	769	88	223	186	28	10.3
(n=6)	std dev	3.67	0.72	0.319	1.53	0.039	1.29	0.81	0.54	0.63	0.108	0.42	1	10	8	43	197	23	52	38	6	2.3
Tfbt	avg	75.93	13.50	0.209	1.77	0.050	1.96	0.57	2.08	3.89	0.044	96.75	6	2	7	11	617	62	179	124	23	11.0
(n=4)	std dev	3.62	1.39	0.109	1.00	0.021	0.84	0.12	1.27	0.66	0.020	1.36	3	3	5	15	349	33	53	12	3	1.0
Tftm andesite	avg	59.32	17.51	1.061	6.89	0.147	6.59	2.97	1.56	3.67	0.292	97.78	8	26	22	142	541	41	358	176	28	10.1
(n=10)	std dev	0.99	0.37	0.040	0.51	0.019	0.35	0.35	0.20	0.24	0.041	1.70	5	11	3	18	83	4	28	13	2	1.4
Tftm dacite	avg	65.63	16.26	0.686	5.11	0.115	4.18	1.24	2.11	4.49	0.203	98.65	5	6	16	35	795	85	321	228	31	11.7
(n=8)	std dev	0.99	0.22	0.047	0.45	0.012	0.54	0.32	0.57	0.19	0.010	0.49	3	4	3	12	61	62	121	8	1	0.5
Tfct	avg	68.51	15.47	0.640	4.85	0.108	3.23	1.27	2.20	3.58	0.142	97.20	7	11	17	68	671	72	207	184	31	10.5
(n=6)	std dev	1.87	0.38	0.151	1.07	0.030	0.90	0.40	0.49	0.40	0.041	1.70	2	6	2	19	253	15	65	14	2	0.8
Tfnc lava flow	avg	59.39	17.88	1.036	6.94	0.131	6.39	2.33	1.80	3.88	0.224	98.38	4	13	22	147	507	53	303	158	30	8.5
(n=11)	std dev	1.74	0.58	0.127	1.03	0.027	0.71	0.88	0.38	0.33	0.028	2.01	3	8	6	57	84	13	39	21	4	1.0
Tfnc tuff	avg	65.00	17.25	0.805	6.04	0.111	4.33	1.70	2.16	2.42	0.173	96.13	3	7	17	82	556	70	234	184	30	8.7
(n=4)	std dev	2.62	0.69	0.130	1.10	0.026	0.94	0.88	0.34	0.78	0.028	4.11	3	4	1	32	90	21	31	41	10	0.4
Tont	#31	62.42	17.75	1.131	7.58	0.173	4.05	1.79	1.42	3.48	0.204	91.95	16	25	22	135	608	40	209	195	33	15.2
Tomt	avg	75.33	13.26	0.362	2.20	0.060	3.29	0.40	2.91	2.11	0.079	92.93	8	3	8	48	622	70	185	261	41	16.5
(n=10)	std dev	1.89	1.22	0.053	0.82	0.044	0.97	0.36	0.75	0.36	0.036	1.80	3	3	3	88	293	20	116	27	4	2.1
Towc	avg	64.19	16.27	0.948	6.97	0.135	4.73	1.69	1.55	3.16	0.356	92.71	5	13	18	104	460	44	240	206	36	12.5
(n=10)	std dev	6.67	2.10	0.405	2.32	0.052	2.22	0.78	0.72	1.13	0.574	3.32	2	10	8	65	99	23	105	53	9	4.2
KJrg	#108	52.02	14.79	2.169	9.46	0.161	12.70	4.67	0.11	3.62	0.308	98.13	85	183	40	288	41	2	140	164	33	15.1
KJif	avg	62.84	16.67	0.565	6.11	0.157	5.19	3.40	1.49	3.45	0.128	98.49	13	34	24	161	521	34	446	105	24	3.0
(n=2)	std dev	0.65	0.14	0.081	0.03	0.021	0.55	0.72	0.75	0.08	0.002	0.08	5	5	2	27	187	21	57	8	0	0.7
KJia	#85	49.83	17.19	0.745	8.40	0.175	13.15	8.48	0.13	1.82	0.075	98.20	51	131	44	247	59	3	201	35	17	2.9



Additional information is available as Open File Report 2005-5, Supplement to Geologic Map GM-60, Geologic Map of the Timberwolf Mountain 7.5-minute Quadrangle, Yakima County, Washington, which contains: Table 3. Description and location of sample sites by map units; Table 4. XRF analyses of samples; Table 5. ICP-MS analyses of samples; Table 6. Nd, Sr, and Pb isotope compositions of samples; Table 7. Summary of $^{40}Ar/^{39}Ar$ dates; and Figure 1. $^{40}Ar/^{39}Ar$ age plateau and inverse isochron diagrams of samples.

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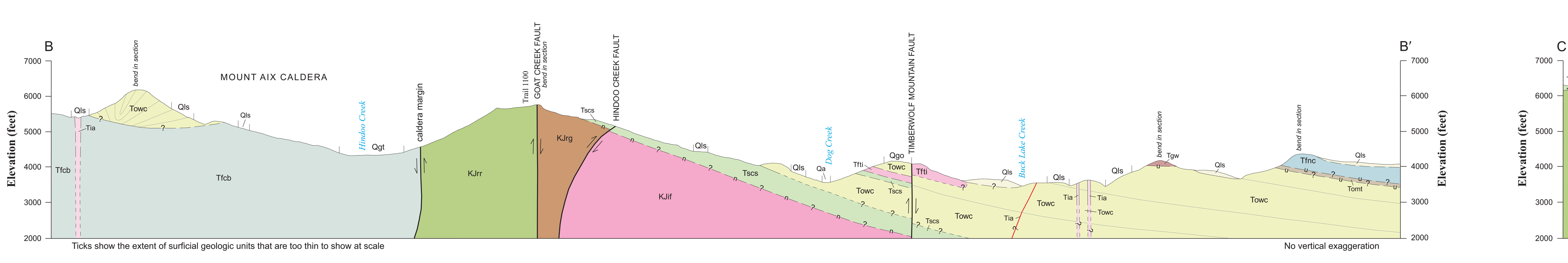

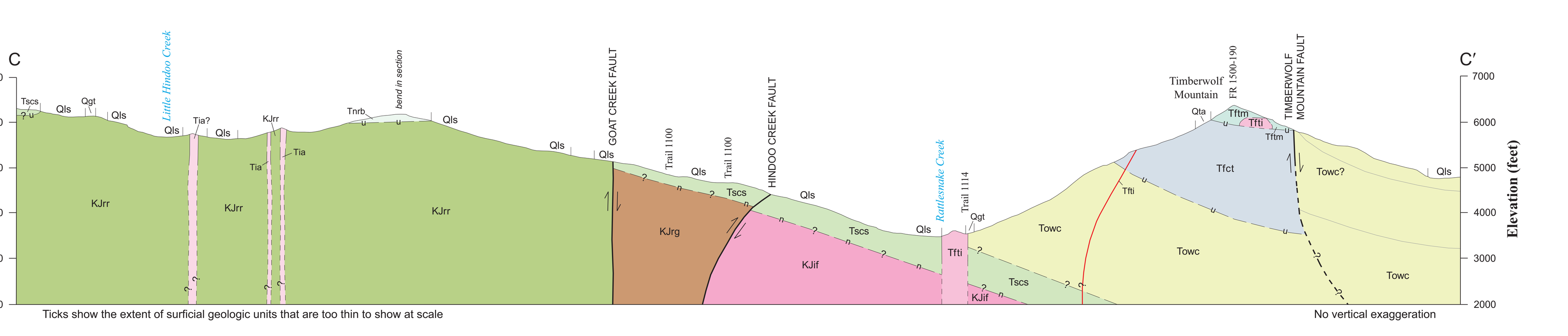

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REFERENCES CITED

Abbott, A. T., 1953, The geology of the northwest portion of the Mt. Aix quadrangle, Washington: University of Washington Doctor of Philosophy thesis, 256 p., 6 plates.

Fiske, R. S.; Hopson, C. A.; Waters, A. C., 1963, Geology of Mount Rainier National Park, Washington: U.S. Geological Survey Professional Paper 444, 93 p., 1 plate. [accessed Apr. 10, 2002 at http://vulcan.wr.usgs.gov/Volcanoes/Rainier/Publications/PP444/framework.html]

Johnson, D. M.; Hooper, P. R.; Conrey, R. M., 1999, XRF analysis of rocks and minerals for major and trace elements on a single low dilution Li-tetraborate fused bead: Advances in X-ray Analysis, v. 41, p. 843-867.

LeMaitre, R. W., and others, editors, 1989, A classification of igneous rocks and glossary of terms–Recommendations of the International Union of Geological Sciences Subcommission on the Systematics of Igneous Rocks: Blackwell Scientific Publications [Oxford, U.K.], 193 p.

Lander, E. B.; Swanson, D. A., 1989, Chadronian (early Oligocene) and early Arikareean (late Oligocene) land mammal assemblages from the Ohanapecosh Formation, Tieton basin area, central Cascade Range, south-central Washington, U.S.A. [abstract]: Geological Society of America Abstracts with Programs, v. 21, no. 5, p. 104.

Miller, R. B., 1989, The Mesozoic Rimrock Lake inlier, southern Washington Cascades—Implications for the basement to the Columbia Embayment: Geological Society of America Bulletin, v. 101, no. 10, p. 1289-1305.

Porter, S. C., 1976, Pleistocene glaciation in the southern part of the north Cascade Range, Washington: Geological Society of America Bulletin, v. 87, no. 1, p. 61-75.

Reidel, S. P.; Tolan, T. L.; Hooper, P. R.; Beeson, M. H.; Fecht, K. R.; Bentley, R. D.; Anderson, J. L., 1989, The Grande Ronde Basalt, Columbia River Basalt Group; Stratigraphic descriptions and correlations in Washington, Oregon, and Idaho. *In* Reidel, S. P.; Hooper, P. R., editors, Volcanism and tectonism in the Columbia River flood-basalt province: Geological Society of America Special Paper 239, p. 21-53.

Reiners, P. W.; Ehlers, T. A.; Garver, J. I.; Mitchell, S. G.; Montgomery, D. R.; Vance, J. A.; Nicolescu, Stefan, 2002, Late Miocene exhumation and uplift of the Washington Cascade Range: Geology, v. 30, no. 9, p. 767-770; Data Repository item 2002088.

Schmid, R., 1981, Descriptive nomenclature and classification of pyroclastic deposits and fragments—Recommendations of the IUGS Subcommission on the Systematics of Igneous Rocks: Geology, v. 9, no. 1, p. 41-43.

Schreiber, S. A., 1981, Geology of the Nelson Butte area, south-central Cascade Range, Washington: University of Washington Master of Science thesis, 81 p., 1 plate.

Shultz, J. M., 1988, Mid-Tertiary volcanic rocks of the Timberwolf Mountain area, south-central Cascades, Washington: Western Washington University Master of Science thesis, 145 p., 1 plate.

Smith, G. A., 1988, Sedimentology of proximal to distal volcaniclastics dispersed across an active foldbelt—Ellensburg Formation (late Miocene), central Washington: Sedimentology, v. 35, no. 6, p. 953-977.

Smith, G. A.; Shafiqullah, Muhammad; Campbell, N. P.; Deacon, M. W., 1989, Geochronology of the Ellensburg Formation—Constraints on Neogene volcanism and stratigraphic relationships in central Washington: Isochron/West, no. 53, p. 28-32.

Swanson, D. A., 1964, The middle and late Cenozoic volcanic rocks of the Tieton River area, south-central Washington: Johns Hopkins University Doctor of Philosophy thesis, 329 p., 3 plates.

Swanson, D. A., 1967, Yakima Basalt of the Tieton River area, south-central Washington: Geological Society of America Bulletin, v. 78, no. 9, p. 1077-1109.

Swanson, D. A., 1978, Geologic map of the Tieton River area, Yakima County, south-central Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF-968, 1 sheet, scale 1:48,000.

Vance, J. A.; Clayton, G. A.; Mattinson, J. M.; Naeser, C. W., 1987, Early and middle Cenozoic stratigraphy of the Mount Rainier–Tieton River area, southern Washington Cascades. *In* Schuster, J. E., editor, Selected papers on the geology of Washington: Washington Division of Geology and Earth Resources Bulletin 77, p. 269-290.

Wilson, B. M., 1989, Igneous petrogenesis—A global tectonic approach: Unwin Hyman [London], 466 p.