N A T U R A L R E S O U R C E S

GEOLOGIC MAP OF THE NORTHERN PORTIONS OF THE RIMROCK LAKE, TIETON BASIN, AND WESTERN TWO-THIRDS OF THE WEDDLE CANYON 7.5-MINUTE QUADRANGLES, YAKIMA COUNTY, WASHINGTON

by Paul E. Hammond

WASHINGTON
GEOLOGICAL SURVEY
Map Series 2017-03
November 2017

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WASHINGTON STATE DEPARTMENT OF
NATURAL RESOURCES
WASHINGTON GEOLOGICAL SURVEY

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Geologic Map of the Northern Portions of the Rimrock Lake, Tieton Basin, and Western Two-thirds of the Weddle Canyon 7.5-minute Quadrangles, Yakima County, Washington

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Geologic Map of the Northern Portions of the Rimrock Lake, Tieton Basin, and Western Two-thirds of the Weddle Canyon 7.5-minute Quadrangles, Yakima County, Washington

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INTRODUCTION

The Rimrock Lake, Tieton Basin, and Weddle Canyon 7.5-minute quadrangles are located in Yakima County on the central eastern slope of the Cascade Range, Washington, 34 km (23 mi) northwest of Yakima and 26 km (18 mi) east of the crest of the Cascade Range and Mount Rainier National Park. The quadrangles include part of the Mount Baker–Snoqualmie National Forest, administered by the Wenatchee National Forest, and the Oak Creek State Wildlife Area. The Rimrock Lake quadrangle includes a small part of the William O. Douglas Wilderness. U.S. Highway 12 between White Pass and Yakima forms the southern boundary of the map area in the Tieton Basin and Weddle Canyon quadrangles. The highway and a series of paved and graveled roads and foot and horse trails provide access to most parts of the quadrangles.

Mapping, aided by aerial photographs and topographic quadrangle maps, was conducted along roads and trails, ridge crests and slopes, and open stream courses. Field stations and geologic features were plotted by hand directly on the topographic quadrangles. Before 1996, field stations and sample sites were located by field inspection and recognition of landmarks, supplemented by altimeter readings. During the 1996 season and thereafter, field sites were located by the global positioning system (GPS).

Of the 466 samples collected in the quadrangles, 242 samples, listed in Table 3 (Data Supplement), were submitted for x-ray fluorescence (XRF) geochemistry analysis (Tables 4A–C), 44 for inductively coupled plasma mass spectrometry (ICP-MS) trace element analysis (Table 5), 14 for isotope age analysis (Table 6), and 27 for $^{40}Ar/^{39}Ar$ age-dating (Table 7). Tables 3–7 are in the accompanying Data Supplement in Excel format.

The names of rocks follow the classifications of Le Bas and others (1986) for volcanic rocks and Streckeisen (1974) for plutonic rocks. Fragmental volcanic rocks are named after the classification of Schmid (1981). One to ten thin sections were made of each map unit and point counted (1,000 points) to give a range of modes in the descriptions of the units.

DEPOSITIONAL AND DEFORMATIONAL HISTORY

The geologic map of the Rimrock Lake, Tieton Basin, and Weddle Canyon 7.5-minute quadrangles is representative of the stratigraphy and structure of the eastern slope of the Cascade Range from nearly the crest of the range eastward to the margin of the Columbia Basin of Washington. The rocks range in age from late Mesozoic to Cenozoic and include some of the youngest volcanic, plutonic, and sedimentary rocks in this part of the range. The rock units are briefly described below in stratigraphic order, first the Mesozoic basement rocks, then the Cenozoic rocks, in four stages of deposition and intrusion. Each stage of deposition is separated by a deformation episode (Hammond, 2013).

The oldest rocks, represented in the Mesozoic Rimrock Lake inlier (Miller, 1989), are surrounded by Cenozoic rocks. The inlier consists of the Russell Ranch complex (unit KJrr), formally named the Russell Ranch Formation, of chiefly clay-rich lithic sandstone and argillite, a small amount of chert and tuff, and lenses of pillow lava (greenstone, unit KJrg). Pervasively deformed, these rocks lack stratigraphic continuity and are interpreted as deep oceanic deposits on the slope of a volcanic arc. Forming a smaller part of the inlier in the quadrangles is the Indian Creek complex (unit KJif), formally named the Indian Creek Gneiss, of foliated hornblende diorite, an isolated unit lacking evidence of its host rock. All inlier rocks are late Jurassic to Early Cretaceous in age and were tectonically accreted to one another, probably in the Late Cretaceous, well before development of the Cascade volcanic arc.

First Stage of Deposition (~50–28 Ma, Middle Eocene to Middle Oligocene)

The rock overlying the Rimrock Lake inlier is a laterally extensive sedimentary unit of chiefly fluvially deposited lithic, micaceous, feldspathic sandstone and minor amounts of siltstone, mudstone, claystone, pebble conglomerate, tuff, and coal, called here the sandstone of Summit Creek (unit Tscs)(Vance and others, 1987). This name eliminates the many local names applied to the sandstone by Abbott (1953), Ellingson (1959, 1968), Swanson (1964, 1978), Schreiber (1981), and Clayton (1983). These sediments were derived from crystalline rocks of the Idaho batholith, Precambrian and Paleozoic rocks of northern Idaho and northeastern Washington, and Mesozoic rocks of the North Cascades of Washington (Winters, 1984; Byrnes, 1985). During the long period of time after accretion of the Rimrock Lake inlier, erosion reduced it to a low, flattish surface with several broad, shallow valleys in which southward- and eastward-flowing streams deposited sedimentary rocks. Also during this time, the region began to subside as a long north–south trough (Hammond, 1989; Swanson, 1994) in which as much as 900 m (3,000 ft)(Clayton, 1983) of sedimentary rock accumulated.

In the middle Eocene (~40 Ma), the first volcanic activity west of the map area deposited an extensive series of fragmental deposits across the fluvial plain of sedimentary rock, blocking and diverting the streams of sediments. This was the beginning of the Cascade arc. Over time the volcanic centers migrated eastward.

In Mount Rainier National Park, these late Eocene to middle Oligocene (~33–27 Ma) deposits are the Ohanapecosh Formation (unit To of Fiske and others, 1963). In the map area, these uniformly bedded and laterally extensive deposits are predominantly distal tuff and fine-grained volcanic sedimentary deposits, probably deposited chiefly in shallow lakes. The fine-grained character of these deposits differs from the coarse fragmental nature of the type Ohanapecosh Formation, prompting Swanson (1964, 1978) to name them the tuffaceous rocks of Wildcat Creek (unit Towc), a facies of the Ohanapecosh Formation. Mapping in the quadrangles revealed these deposits in the lower part of the Ohanapecosh Formation. Continued subsidence of the north–south trough accommodated an additional 3 km (10,000 ft) of volcanic deposits (Fiske and others, 1963).

First Episode of Deformation (~29–27 Ma, Middle Oligocene)

At the close of the first stage of deposition within the Cascade arc, an episode of mild deformation caused broad warping and faulting along northwest–southeast trends, with concurrent partial erosion of the earlier-deposited strata. This stage ended with the cessation of subsidence of the north–south trough beneath the Cascade arc.

Second Stage of Deposition (~26–22 Ma, Middle Oligocene to Early Miocene)

The second stage of deposition consisted of the volcanic rocks of the Fifes Peak Formation, also named by Fiske and others (1963), and several intrusions. This formation is a series of andesite and a few basalt deposits, chiefly lava flows, and minor amounts of laharic, debris avalanche, and tuff deposits. In the map area, locally thick, chiefly pyroclastic-flow deposits of rhyodacite to rhyolite interstratified with the lava flows are mapped and named separately. Volcanic units of the Fifes Peak Formation, in stratigraphic order, are: rhyolite tuff of Burnt Mountain (unit Tfbm)(Swanson, 1964, 1978); andesite of Cabin Creek volcano (unit Tfcc)(Swanson 1964, 1978); andesite of Tieton volcano—apron deposits (unit Tfta), deposits of the cone (unit Tftc), and dikes of the radial swarm (unit Tfti)(Swanson, 1964, 1966, 1978); rhyodacite-rhyolite tuff of Cash Prairie (unit Tfct); and the andesite of Timberwolf Mountain volcano (unit Tftm)(Shultz, 1988). Intraformational unconformities separate these units from one another. Remnant deposits of individual volcanoes range from about 90 to 245 m (300–800 ft) in thickness. No deposits of one volcano are stacked entirely atop another. Thickness of the Fifes Peak Formation is generally about 300 m (1,000 ft), with maximum thickness as much as 610 m (2,000 ft).

Accompanying the volcanic deposits of the Fifes Peak Formation are several prominent intrusions consisting of many andesite dikes, including a major one in Burnt Mountain ridge (unit Tia); microdiorite south of Shellrock Peak (unit Tisd) (Swanson, 1964, 1978); orthopyroxine microdiorite of Westfall Rocks (unit Tiwf)(Swanson, 1964, 1978); and rhyolite of Little Rattlesnake Creek (unit Tirr).

Second Episode of Deformation (~22–16 Ma, Early to Middle Miocene)

During this second episode of deformation, the map area was subject to intense folding, faulting, local uplifts of the basement rocks, and deep erosion. All previously deposited rock units were warped and faulted—those of the first stage of deposition more severely, having undergone two deformational intervals. Deformation was along axes of north–south compression (shortening) and east–west tension (lengthening). Several rock units of the earlier stage were extensively eroded. Most stratified units that covered the Rimrock Lake inlier were entirely stripped.

Third Stage of Deposition (~16–12 Ma, Middle Miocene)

The third stage in the geologic development of this part of the Cascade Range was not one of in-situ volcanism like the two previous stages. It was the invasion from the east of seven distinct lava flows and interbed deposits of the upper part of the Grande Ronde Basalt of the Columbia River Basalt Group between about 15.8 and 15.5 Ma (Barry and others, 2013). This basalt covers the Columbia Basin to the east and terminates on the eastern slope of the Cascade Range. Only a small part lies in the map area.

Because of the earlier tectonic deformation and deeply eroded surface with relief approaching 460 m (1,500 ft), the Grande Ronde Basalt lies unconformably upon all older rock units. The flows advanced up southeast-draining valleys (Swanson, 1964, 1978), completely buried Cabin Creek volcano, entirely surrounded Tieton volcano, and almost entirely surrounded Timberwolf Mountain volcano in the north adjacent quadrangle. In stratigraphic order, the lava flows are: Wapshilla Ridge lava flow (unit Tgw), Grouse Creek (local name Meeks Table; Swanson, 1967) lava flow (unit Tgg), Ortley lava flow (unit Tgo), McCoy Canyon lava flow (unit Tgm), upper McCoy Canyon lava flow (unit Tgum), Stember Creek lava flow (Tgsc), Museum 1 lava flow (unit Tgm1), and Museum 2 lava flow (unit Tgm2). In early mapping of the quadrangles, the upper McCoy Canyon and Stember Creek lava flows were considered parts of the extensive Cohassett lava flow, and the Museum 1 flow was thought to be correlative with the Rocky Coulee lava flow. The names have been changed where the lava flows correlate geochemically with the revised stratigraphy of the Sentinel Bluff Member (Reidel, 2005).

Interbed deposits (unit Tgib), chiefly between the Meeks Table, Ortley, McCoy Canyon, upper McCoy Canyon, and Stember Creek lava flows, consist mostly of whitish rhyolitic tuff, orange to red to brown hyaloclastite, fine-grained volcanic sedimentary deposits, and a few occurrences of friable lithic, micaceous feldspathic sandstone. No Cascade-arc volcanism producing basaltic to andesitic stratovolcanoes occurred in the map area during this stage until near its end. Magmatic activity turned off about 22 Ma and did not renew until emplacement of many dacite and some silicic andesite domes about 11 Ma. Domal eruptions spread a blanket of as much as 300 m (1,000 ft) of lahar deposits, tuff, and fluvial conglomerate and sandstone across the Grande Ronde Basalt lava flows to the north and to a lesser thickness atop the basalt flows in the Bethel Ridge–Oak Creek area. These deposits constitute the volcanic facies of the Ellensburg Formation. They overlie the basalt flows with a slight angular unconformity. Only a small remnant of this formation remains at the east margin of the map area.

Third Episode of Deformation (~12–7 Ma, Late Miocene)

Toward the end of the third stage of deposition, mild deformation began to warp the lava flows along southwest–northeast axes, new faults developed along northerly strikes, and displacement in the western group of northwest- to north-striking faults was renewed. Deformation stresses of compression (shortening) along a northerly axis and tension (lengthening) along an easterly axis were enhanced. Faults showed increasing displacement, and anticlinal folds enlarged in magnitude, height, and length. The Yakima fold belt, including Bethel Ridge anticline, came into existence. As the folds narrowed, the brittle basalt flows in the flanks of the folds broke, developing a series of thrust faults—examples being the Carmack Canyon and Windy Point thrusts. Additional thrusts developed at the north base of Russell Ranch Ridge in the crystalline rocks of the Russell Ranch Formation. During this development, Grande Ronde Basalt flows underwent erosion. Some flows were locally removed; for example, in some places in the Oak Creek area, the Museum 1 flow (unit Tgm1) was eroded before deposition of the Museum 2 flow (unit Tgm2). Elsewhere flows were incised by newly formed stream courses.

Fourth Stage of Deposition (~12 Ma–Present, Late Miocene to Holocene)

Several intrusive units were emplaced during the late Miocene and Pliocene: hornblende andesite-dacite of Rattlesnake Peaks (units Tnrd and Tsrd), hornblende dacite of McNeil Ridge (unit Tmrd), hornblende dacite of Shellrock Peak (unit (Tspd)(Swanson, 1964, 1978), and dacite dikes (unit Tid). The andesite and dacite extrusive centers contributed some deposits to the Ellensburg Formation (unit Tev), but by about 5 Ma most of the Ellensburg Formation was eroded from anticlines—only a small part is preserved in synclinal basins in the Rattlesnake and Nile Creeks area in the adjacent Meeks Table and Nile quadrangles to the north (Hammond, 2009). The fourth and last stage of scattered deposition included several Pliocene to Pleistocene volcanic deposits (in stratigraphic order): olivine basalt of Bethel Ridge (unit Tbrb, lava flow)(Swanson, 1964, 1978), Tieton Andesite (unit Qtan, lava flow)(Swanson, 1964, 1978), and two olivine basalt lava flows of slightly different ages in the Wildcat Creek basin (units Qob1 and Qob2)(Swanson, 1964, 1978). Five Quaternary surficial deposits are the youngest: alluvium (unit Qa), alluvial fan (unit Qaf), talus (unit Qta), and landslides (unit Qls), all Holocene, and glacial till (unit Qgt), Pleistocene.

Fourth Episode of Deformation (~7–3 Ma, Late Miocene to Pliocene)

This final episode of deformation, essentially a continuation of the third episode overlapping the fourth stage of deposition, culminated with uplift of the Cascade Range between ~7 and 3 Ma (Reiners and others, 2002). The extensive folding and faulting was accompanied by deep erosion. Stress directions continued as before with greater intensity—compression (or shortening) along northerly axes and tension (or lengthening) along southwest–northeast axes.

STRUCTURAL AND IGNEOUS FEATURES

The principle features in the Rimrock Lake, Tieton Basin, and Weddle Canyon 7.5-minute quadrangles are the east–west-striking Bethel Ridge anticline, the Carmack Canyon thrust fault system in the north flank of this anticline, Oak Creek syncline, Cougar Canyon fault, Windy Point thrust, Russell Ridge thrust, a group of northwest- to north-striking faults in the western part of the map area, Tieton volcano (Swanson, 1964, 1978), and an array of intrusions in the western part of the map area. The folds and faults are individually described in Table 1. Some structures are described below. The structurally highest part of the map area is the exposed Rimrock Lake inlier in the west; the structurally lowest part is in the northeast corner of the map area. In the western part of the map area, the strata dip homoclinally to the northeast and are cut by many north-striking faults (Cross Section A–A′). Strata in the eastern two-thirds of the map area are warped by the broad, shallowly east-plunging Owl Creek syncline and offset by the vertical Cougar Canyon fault (Cross Section C–C′).

East-West Striking Folds and Thrust Faults

The broad, gradually east-northeast-plunging Bethel Ridge anticline, outlined by Grande Ronde Basalt lava flows (Cross Sections B–B′ and C–C′), is part of the Yakima fold belt of the western part of the Columbia Basin. The axis of the anticline splits near the trace of Cross Section B–B′, forming parallel or en echelon fold axes for a short distance. A group of northwest- to north-striking faults and folds terminates the eastern end of this major anticline. This narrow group of structures forms a transition zone between the Bethel Ridge anticline and the abruptly north-northwest-striking Cleman Mountain anticline to the east of the map area. The broad Oak Creek syncline south of Bethel Ridge is one of the longest structures traced in the map area. It extends well to the east through two additional quadrangles. The Cougar Canyon fault is of equal length, and to the east it transforms into the Waterworks thrust fault in the south flank of the Cleman Mountain anticline (Bentley and others, 1988). This fault separates Tieton volcano to the south from Grande Ronde Basalt and the Bethel Ridge anticline to the north. The South Fork Oak Creek fault is a splay of the Cougar Canyon fault. It is a southwest-striking normal fault and separates an uplifted block between Oak Creek and its south fork (Cross Section C–C′). The east–west-striking Windy Point thrust, at the south base of Tieton volcano, separates the volcano from the underlying deposits of Cabin Creek volcano (Cross Sections B–B′ and C–C′). The Russell Ridge thrust, not well exposed along the south side of Wildcat Creek valley in the western part of the map area, transects the Russell Ranch complex (unit KJrr) (Cross Section A–A′).

Displacements on some of these faults are uncertain, but the Carmack Canyon thrust shows about 300 m (1,000 ft) of displacement (Cross Section B–B′), the Cougar Canyon fault shows about 185 m (600 ft)(Cross Section B–B′), and the Windy Point thrust shows about 300 m (1,000 ft) to 600 m (2,000 ft) (Cross Sections B–B′ and C–C′ respectively).

Northwest- to North-Striking Faults

In the western part of the map area, the group of northwest- to north-striking normal faults, some of which may be high-angle reverse faults, cut all the pre–Grande Ronde Basalt rock units, including the crystalline rocks of the Rimrock Lake inlier (Cross Section A–A′). From west to east, the faults are: Shellrock Peak fault, Kitten Creek fault, Burnt Mountain fault, Thunder Creek fault, North Tieton Basin fault, Goat Creek fault and its branching Hindoo Creek fault at the north margin of the map, and the Soup Creek fault. These faults delineate the eastern margin of the Rimrock Lake inlier in the map area and the Timberwolf Mountain quadrangle (Hammond, 2005) to the north. The inlier and this group of northwest- to north-striking faults limited western extension of Bethel Ridge anticline.

Of the eight faults, Kitten Creek and Thunder Creek faults show stratigraphic displacement down to the west; the other faults show downward movement on the east side. The amount of displacement is unclear. Less than 90 m (300 ft) is shown on the faults in Cross Section A–A′. The significance of these faults is yet to be determined. The three western faults may extend southward and join with the faults shown in Miller's (1989) map, transecting the Rimrock Lake inlier in the eastern part of Rimrock Lake. Goat Creek fault and its splay, Hindoo Creek fault, are considered the most important because they have been traced the greatest distance northward. In Rattlesnake Creek valley, they separate Russell Ranch complex (unit KJrr) to the west from a huge lens of Russell Ranch pillowed greenstone (unit KJrg) and from the foliated diorite of the Indian Creek complex (unit KJif) to the east. Kitten Creek fault may separate a northern extension of the Kitten Creek dike. Burnt Mountain fault may have a south-extending splay; however, the lack of exposure at the south end of Burnt Mountain ridge makes this interpretation uncertain.

Other Structures

Other structures noted are the en echelon, discontinuous, unnamed north-striking faults of small displacement along the western margin of the landslide basin of Tepee Creek and the eastern margin of Tieton volcano between Oak Creek and South Fork Oak Creek. Another north-striking fault, a possible southern branch of the Timberwolf Mountain fault, is located along the north-central part of the map area. This fault passes through Bethel Ridge anticline without offsetting lava flows of Grande Ronde Basalt and extends along the eastern margin of the north Tieton Basin, possibly accounting for the abrupt steep eastern dip of strata (unit Tfta) of Tieton volcano shown in Swanson's (1964, 1978) maps. This fault predates the Grande Ronde Basalt flows.

Tieton Volcano

Tieton volcano is the largest volcano complex exposed in the three-quadrangle map area. It is oval shaped, extending about 21 km (13 mi) east–west and 10 km (6 mi) north–south. The structure of the volcano is well described by Swanson (1964, 1978), consisting essentially of a lower apron or shield and an upper cone with a present height of about 600 m (2,000 ft). A more detailed discussion of the deposits composing the volcano is given in the *Descriptions of Map Units*. The volcano has been little affected by the structures described above except the Windy Point thrust. The broad, shallow, east–west Oak Creek syncline, mainly warping the Grande Ronde Basalt lava flows, and the Cougar Canyon normal fault, separating Grande Ronde Basalt lava flows from deposits of Tieton volcano, lie north of the volcano. From here northward at depth, the volcano underlies Bethel Ridge anticline (Cross Section B–B′). Although difficult to trace amid the brecciated margins of the lava flows, the Windy Point thrust at the south base of Tieton volcano separates the eastern part of the volcano from the underlying similar lava flows of Cabin Creek volcano. The western part of the volcano unconformably overlies the tuffaceous beds of Wildcat Creek.

Major Dikes

Several dikes—Burnt Mountain, Thunder Creek, and an unnamed large dike to the east—are intruded along the northwest-striking faults mentioned above (Swanson, 1964, 1978). Many thin dikes, as thick as about 10 m (30 ft), were subsequently emplaced approximately normal to the strike of Burnt Mountain and Thunder Creek dikes. Analyses of the dikes at Burnt Mountain ridge reveal that the normal-striking dikes differ compositionally from the main dike, suggesting that the two sets of dikes were from different magmas and intruded at different times. In addition, petrographic study shows these two sets of dikes to be pervasively microfractured, suggesting they were subjected to later stress on the Burnt Mountain fault. Many thin dikes intrude the north- to northwest-striking faults, indicating that: (1) the faults preceded emplacement of the dikes, (2) that later movement on the faults was minor, or (3) that later fault movement offsetting the dikes was dip-slip and not strike-slip. The two other large dikes along faults to the east were not examined to determine if they show evidence for post-emplacement fault movement.

CHRONOLOGY OF STRUCTURAL DEVELOPMENT

Contacts and spatial relations between these structures define a sequence of stages in their development. The north- to northwest-striking faults appear to have developed first. A few are truncated by folds and especially by the east–west thrust faults, commencing possibly during the first deformational episode and at least by the second episode. The east–west-striking structures developed during the second episode of deformation and were enhanced, along with the north- to northwest-striking faults, by the third and fourth episodes. The northwest-striking shear folds of the Olympic–Wallowa lineament (OWL), which is east of the map area and includes the Cleman Mountain anticline, developed during the third and fourth episodes.

Table 1. Major structures in the northern parts of the Rimrock Lake, Tieton Basin, and western two-thirds of Weddle Canyon 7.5-minute quadrangles, Yakima County, Washington. All northerly striking faults may have some right-lateral separation.

FOLDS

Name	Location	Length	Width	Height (amplitude)	Dip of flanks	Axial plane strike and dip	Fold axis plunge and trend	Comments
Bethel Ridge anticline	north part of Tieton Basin 7.5-minute quadrangle; Cross Sections B–B′, C–C′	~8.9 km ~5.5 mi	~3.7 km ~2.3 mi	~1,000 ft ~300 m	5° N & S	N55°E 90°	plunges 2° NE	Extends east into Nile 7.5-minute quadrangle; axial plane and fold axis split (en echelon) near west end; upright, open, symmetric
Oak Creek syncline	Tieton Basin and Weddle Canyon 7.5-minute quadrangles; Cross Sections B–B′, C–C′	~10.9 km ~6.8 mi	~3.7 km ~2.3 mi	~90 m ~300 ft	2–3° N & S	N85°E 90°	plunges 2° ENE	Extends northeast in Tieton 7.5-minute quadrangle; upright, open, shallow, symmetric

FAULTS*

Name (from west to east)	Location	Length	Orientation	Displacement	Comments
Russell Ridge thrust	southwest corner of Rimrock Lake 7.5-minute quadrangle along south side of Wildcat Creek; Cross Section A–A′	6.1 km 3.8 mi	N70–90°W; dips S	Unknown; Russell Ranch complex (unit KJrr) on both sides; south side down	Not exposed; extends west to northwest into Spiral Butte 7.5-minute quadrangle; forms part of south side of Cenozoic embayment in Rimrock Lake inlier
Shellrock Peak fault (normal)	west part of Rimrock Lake 7.5-minute quadrangle; Cross Section A–A′	6.4 km 4.0 mi	N35°W 90°	Unknown; cuts Russell Ranch complex (unit KJrr), separates intrusions and Wildcat Creek tuff (unit Towc); northeast side down	Extends unknown distance north-northwest and south
Kitten Creek fault (normal)	west part of Rimrock Lake 7.5-minute quadrangle; Cross Section A–A′	8.4 km 5.2 mi	N15–25°W 90°	Unknown; cuts Russell Ranch complex (unit KJrr) and Wildcat Creek tuff (unit Towc); surficial deposits cover contact between the two units; west side down	Extends unknown distance south
Burnt Mountain fault (normal)	central part of Rimrock Lake 7.5-minute quadrangle; Cross Section A–A′	6.3 km 3.9 mi	N10–65°W 90°; possibly dips steeply E	Intruded by Burnt Mountain and Thunder Creek dikes; separates dikes from Wildcat Creek tuff (unit Towc) and Wildcat Creek from Burnt Mountain tuff (unit Tfbm), the latter by 35 m (120 m); east side down	Terminated at north end by Thunder Creek fault
Thunder Creek fault (normal)	central part of Rimrock Lake 7.5-minute quadrangle; Cross Section A–A′	8.3 km 5.1 mi	N30–40°W 90°; possibly inclined to SW	Separates Burnt Mountain tuff (unit Tfbm) and Wildcat Creek tuff (unit Towc); southwest side down; vertical displacement ~120 m (400 ft)	Cut off by Thunder Creek dike at southeast end
North Tieton Basin fault (normal)	in Rimrock Lake and southwest Tieton Basin 7.5-minute quadrangles; Cross Section A–A′	6.4 km 4.0 mi	N50–60°W 90°	Separates Wildcat Creek tuff (unit Towc), Burnt Mountain tuff (unit Tfbm), and Tieton volcano (unit Tfta); possible offset between Russell Ranch complex (unit KJrr) and Summit Creek sandstone (unit Tscs); fault is concealed by landslide to the southeast; northeast-side down; vertical displacement ~185 m (~600 ft)	Northwest terminus cut by Thunder Creek fault and covered by landslide to southeast
Goat Creek fault and Hindoo Creek fault (branch of Goat Creek fault)(normal)	in Rimrock Lake 7.5-minute quadrangle; Cross Section A–A′	9.0 km 5.6 mi	N50°W to N5°E 90°	Separates parts of Tieton volcano, Wildcat Creek tuff (unit Towc), Russell Ranch complex (unit KJrr), and Indian Creek complex (unit KJif); east side down; vertical displacement 90 to 120 m (300–400 ft); a reactivated late Cretaceous fault	Extends north through several quadrangles; fault is chiefly a breccia zone between Thunder Creek and Rattlesnake Creek; a major fault in the area

Table 1. *(cont.)* Major structures in the northern parts of the Rimrock Lake, Tieton Basin, and western two-thirds of Weddle Canyon 7.5-minute quadrangles, Yakima County, Washington. * All northerly striking faults may have some right-lateral separation.

Name (from west to east)	Location	Length	Orientation	Displacement	Comments
FAULTS*					
Soup Creek fault (normal)	in Rimrock Lake and southwest Tieton Basin 7.5-minute quadrangles	7.9 km 4.9 mi	N20–90°W 90°	Separates parts of Tieton volcano, Wildcat Creek tuff (unit Towc), Russell Ranch complex (unit KJrr), and Indian Creek complex (unit KJif); northeast-side down; vertical displacement ~40 m (130 ft)	Truncated by the Goat Creek–Hindoo Creek faults to the northwest and covered by a landslide to the southeast
Timberwolf Mountain fault (normal)	in Tieton Basin 7.5-minute quadrangle north of Bethel Ridge anticline; Cross Section B–B′	6.7 km 4.2 mi	N50°W 90°; possible S extension is N–S 90°	Separates Cash Prairie tuff (unit Tfct), Wildcat Creek tuff (unit Towc), and rhyolite of Little Rattlesnake Creek (unit Tirr); possible southern extension may separate Tieton volcano (unit Tfta) and Wildcat Creek tuff (unit Towc); northeast side down; vertical displacement ~245 m (800 ft)	Extends northward 7.4 km (4.5 mi) in adjacent Timberwolf Mountain 7.5-minute quadrangle; may extend or branch south through Bethel Ridge anticline and along east side of North Tieton Basin landslide, accounting for steep east dip of Tieton volcano (unit Tfta) lava flows there.
Carmack Canyon thrust (two slices/branches)	in northeast part of Tieton Basin 7.5-minute quadrangle; thrust terminates in this area	3.7 km 2.3 mi	N65–75°E ~20°SE	Separates segments of Grouse Creek (Meeks Table) basalt (unit Tgg), displacement about 300 m (1,000 ft) in Cross Section B–B′	Extends north into in Meeks Table and Nile 7.5-minute quadrangles; major thrust fault on north flank of Bethel Ridge anticline
Cougar Canyon fault (thrust and normal)	in northern parts of Tieton Basin and Weddle Canyon 7.5-minute quadrangles; Cross Section C–C′	10.8 km 6.7 mi	N65–80°E 90°	Separates Grande Ronde Basalt from Tieton volcano (unit Tftc), dying out to west; north-side down; vertical displacement 60–185 m (200–600 ft)	Extends two quads to east to south flank of Cleman Mountain anticline; there possibly becomes a thrust (Bentley and others, 1988)
South Fork Oak Creek fault (branch of Cougar Canyon fault)(normal)	in northern Weddle Canyon 7.5-minute quadrangle; Cross Section C–C′	3.5 km 2.2 mi	N45°E 90°	Separates Grande Ronde Basalt flows; south side down; vertical displacement 60 m (200 ft)	Terminates at unnamed N40°W fault
Windy Point thrust (shallow thrust fault)	in southeastern part of the map above Tieton River and US 12	~16 km ~10 mi (see comments)	N90°E 10°N	Separates Grande Ronde Basalt flows and Tieton volcano (unit Tftc) from Cabin Creek volcano (unit Tfcc); stratigraphic displacement about 600 m (2,000 ft) in Cross Section C–C′, about 300 m (1,000 ft) in Cross Section B–B′	Difficult to trace, poorly exposed fault zone <5 m thick, breccia zone <1 m thick, in brecciated lava flows of volcanoes; better traced in Grande Ronde Basalt; accurately located near west end and at east end near twin bridges over Tieton River
Two north-striking en echelon normal faults	in Weddle Canyon 7.5-minute quadrangle; northern fault along west side of Tepee Creek landslide; southern fault lies between Oak Creek and South Fork Oak Creek	4.1 km 2.6 mi (together)	N–S 90°	Separates Grande Ronde Basalt flows and Tieton volcano (unit Tftc); stratigraphic displacement only a few meters	Not well demarked in field but stand out in aerial photographs
Unnamed northwest-striking fault (normal)	in Weddle Canyon 7.5-minute quadrangle between South Fork Oak Creek fault and Bear Canyon	1.0 km 0.6 mi	N45°W90°	Separates Grande Ronde Basalt flows in hill 4034 from plateau to northeast; stratigraphic displacement ~60 m (200 ft)	Not well demarked in field

LANDSLIDES

Landslides are common and are the major erosional process in the map area. Most are earthflows, have active talus at their head scarp, vary in size and shape, and formed thousands to possibly as much as two million years ago, during the first widespread glaciation. Rock slides and block flows are the next most common landslides. An earthflow is a water-saturated mass of soil and generally friable rock that has become too heavy to hold its slope and is lubricated within and especially at its base by moisture. Rock slides are composed of incoherent rock masses, whereas block flows consist of coherent rock masses. Each can be loosened by water or expanding ice in fractures. Nine prominent landslides are titled on the map and listed and described in Table 2. Several landslides are unique and warrant discussion. They are: South Rattlesnake Peaks, Bear Lake, North Tieton Basin, Tepee Creek, and 10-Mile.

South Rattlesnake Peaks and Rubble Landslides

South Rattlesnake Peaks and Rubble landslides are catastrophic landslides. The slides were sudden, without warning, and fast moving. South Rattlesnake Peaks is a rock avalanche. A large mass of the peak broke off, shattered, and spread across the slope below. It left a scar on the south side of the peak readily visible from many viewpoints. It also left a 75 m (250 ft)-wide ledge at 6,000 ft on the cliff, which could give way any time. The debris partly blocks Rattlesnake Creek, indicating that the avalanche post-dated the last glaciation (12–16 ka). This and the Rubble landslide may be the most recent major landslides in the map area. Rubble landslide (a slide of rock rubble with no nearby geographic landmark after which to name it) is composed entirely of rock of the hackly jointed Museum 1 lava flow of Grande Ronde Basalt. It is about 15 m (50 ft) thick. The lava flow lost cohesion, probably caused by ice-wedging during the winter. Landsliding was possibly instigated by an earthquake and flowed as a rubbly mass. Momentum carried it 15 m (50 ft) up the opposing valley slope. It turned downvalley, spread across

Table 2. Major landslides in the northern portions of the Rimrock Lake, Tieton Basin, and western two-thirds of the Weddle Canyon 7.5-minute quadrangles, Yakima County, Washington.

Name of Landslide[1]	Size (km^2/mi^2)	Length (m/ft)	Maximum width (m/ft)	Maximum thickness (m/ft)[2]	Average grade (%)[3]	Geologic unit(s)[7]	Type[4]	Active/ Inactive[5]
South Rattlesnake Peaks	2.9/1.1	1,745/ 5,740	2,375/ 7,800	120/400	34	Tsrd	talus/slump –rockslide	inactive[6]
Wildcat Creek (north side)	2.8/11.1	3,050/ 10,000	1,370/ 4,500	50/160	12	Towc	earthflow	active
North Bethel Ridge	4.6/1.8	1,675/ 5,500	3,930/ 12,900	90/300	14	Tgrb, Tfct	talus/slump– earthflow	inactive[6]
North Tieton Basin	17.3/6.7	4,115/ 13,500	5,030/ 16,500	60/200	upper part 42, lower part 11	Tgrb, Tfta, Towc	talus/earthflow	active locally, especially west side
Rubble	0.8/0.3	1,280/ 4,200	700/ 2,300	~30/100	18	Tgr	rockslide (rock flow)	inactive
Bear Lake	2.4/0.9	2,745/ 9,000	2,255/ 7,400	90/300	12	Tgrb	talus/earthflow	active
Tepee Creek	5.0/1.9	2,440/ 8,000	1,755/ 9,800	60–120/ 200–400	11	Tgrb	rockslide (block flow)	inactive[6]
10-Mile	0.8/0.3	2,285/ 7,500	450/ 1,500	35/120 at toe	21	Tgrb	earthflow	inactive
North Fork Oak Creek	5.6/2.2	2,440/ 8,000	3,200/ 10,500	60–90/200–300	upper part 23, lower part 9	Tgrb	block flow to earthflow	inactive[6]

[1] Described from west to east

[2] Based on relief of landslide surface or height between the slide plane and the top of the landslide

[3] Measured between base of headscarp and toe of landslide

[4] Some landslides have active talus at head

[5] Active during a time between the 1989 and 2008 mapping. Evidence of recent activity is shown by: scarplets exposing soil profile and roots, trees sheared at their base by differential slide movement, longitudinal ridges (levees) exposing roots and fresh rock, caused by differential movement, stands of 'drunken' trees, and ponds submerging vegetation, especially shrubs and grasses.

[6] Landslide could easily become active in times of high precipitation because of loose rubble on steep slopes, weathered volcanic debris on steep slopes, or a smooth, impermeable, underlying slope.

[7] Grande Ronde Basalt

the valley floor, formed levees, and ended in a narrow snout in the constricted valley to the east.

Bear Lake Landslide

Bear Lake landslide is a large slide of nearly equal width and length. About 120 m (400 ft) of Grande Ronde Basalt collapsed in the movement of this slide, creating an irregular lobate surface and three sag ponds, with possibly more sag ponds in times past. Remarkably, most of the slide squeezed through the 150 m (500 ft) wide outlet to Oak Creek.

North Tieton Basin Landslide

North Tieton Basin landslide is the largest slide in the map area, but not the largest in the immediate area. To the south, the Tieton Basin landslide, also underlain by incompetent tuffaceous rock of Wildcat Creek (unit Towc), is about three times larger. What is unique about the North Tieton Basin landslide is the almost total lack of landslide debris for a slide of this dimension in the North Tieton basin and along the Tieton River. This debris was transported east downvalley by the three glaciations and glacial outwash in the area (Long, 1951; Clayton, 1983). The last major movement on this slide probably occurred after the 1.39 Ma Tieton andesite flow descended the valley.

Tepee Creek Landslide

Tepee Creek landslide is unique for its transport mechanism. Huge masses of Grande Ronde Basalt split off from the sides and headwall of the landslide basin and moved very slowly southward. In recent years, there has perhaps been no movement at all. Near the scarp, the blocks show the layering of the lava flows, such as the one block adjacent to the west wall. But as the blocks move downvalley, the flows disintegrate and are reduced to a mound of disoriented rock. At least seven blocks and mounds can be discerned in the landslide.

10-Mile Landslide

The 10-Mile landslide is unique because it involves almost entirely the marginal lava flows of Grande Ronde Basalt where they accumulated against the eroded margins of Cabin Creek volcano and the overlying Tieton volcano. Water seeping along the contact into the Grande Ronde Basalt and the fragmented nature of the older volcanoes probably led to the formation of the landslide. Here, too, most of the landsliding occurred before the 1.39 Ma Tieton andesite lava flow descended the Tieton River valley.

Two additional points: in the lower Wildcat Creek landslide, glacial till occurs at the mouth of Wildcat Creek, indicating that landsliding in the valley has occurred post-glaciation and continues actively. The North Fork Oak Creek landslide, an older rendition of the Tepee Creek landslide, extends northward into the adjacent Nile 7.5-minute quadrangle and into the northeast part of the Weddle Canyon 7.5-minute quadrangle.

DESCRIPTION OF MAP UNITS

Map units are described in descending stratigraphic order from youngest to oldest. Additional information is summarized in Data Supplement Tables 3 through 7.

Quaternary Surficial Deposits

Qa **Alluvium**—Gravel, sand, and mud in stream flow, sheet flood, overbank, and lake deposits; includes wind-blown silt (loess) and colluvium (mixed soil and weathered rock in downslope creep); gray to pale brown; subangular to rounded, with boulders as much as 1 m (3 ft) in diameter; consists 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 crossbedded; generally poorly consolidated; with the exception of loess and colluvium, covers all stream valley bottoms and underlies terraces where dissected by streams, as much as 100 m (325 ft) above present stream levels; 0.1 to 75 m (4 in.–250 ft) thick; loess and colluvium, 0.1 to 5 m (4 in.–15 ft) thick. An unusual boulder-rich deposit within alluvium was uncovered by the 2009 excavations for two new bridges on U.S. Highway 12 at Windy Point along the east margin of the map. In the southwest corner of the construction area, about a 60 m (200 ft) thickness of these boulders veneers the east-facing slope below topographic point 2650. About 50 percent of the angular to subrounded boulders, as much as 2 m (6 ft) in size, consist of gray porphyritic pyroxene-plagioclase andesite (map nos. 218, 219, and 223, Table 4A); about 25 percent are from the older lava flow of Tieton Andesite and 25 percent are Grande Ronde Basalt. The gray andesite boulders could be part of the Goat Rocks volcanoes (Swanson and Clayton, 1983), swept down the South Fork Tieton River by a possible debris avalanche.

Qaf **Alluvial fan**—Rock and sand; gray; clasts consist of diverse volcanic and plutonic rocks; angular boulders more than 1 m (3 ft) in diameter; unsorted and chaotic; 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 as much as 20 m (65 ft).

Qta **Talus**—Rock, generally monolithologic; brown to gray to white, depending on color of composing rock; clasts 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 as much as 30 m (100 ft) or more.

Qls **Landslide**—Boulders and cobbles, commonly with intact rock masses, in a matrix of sand, clay, and silt; brown to dark gray; includes rock avalanche, slump, and earthflow deposits composed of locally derived rock and soil, commonly with woody debris; clasts angular to rounded; chaotic to poorly sorted and unstratified; generally forms a hummocky topography; commonly in a complex of coalescing and nested landslides, generally ranging in area from 0.1 to 5 km² (0.04–1.2 mi²), as much as a kilometer (0.6 mi) in width or length, and from 1 to 180 m (3–600 ft) in thickness at the toe, with some slides in the complex having distinct margins and others having poorly defined margins along the length of the slide.

Qgt **Glacial till**—Boulders, cobbles, and pebbles in a matrix of abundant sand, silt, and clay; brown, generally deeply weathered to depths of 1 to 1.5 m (3–5 ft) and rich in clay; clasts of diverse volcanic, plutonic, and some metamorphic rocks, varying in size and rounding; unsorted to poorly sorted; poorly consolidated; clasts commonly faceted and striated; forms scattered remnant deposits along valley floors, slopes, and ridge tops bordering Little Rattlesnake and Wildcat Creeks; product of two (Long, 1951) to three (Clayton, 1983) glaciations in the Tieton River valley, possibly equivalent to Evans Creek and Hayden Creek (Crandell and Miller, 1974), Kittitas (Porter, 1976), or older glaciations; thickness 1 to 5 m (3–15 ft).

Pliocene to Pleistocene Volcanic Deposits and Intrusions

Qob2 **Olivine-clinopyroxene-plagioclase basalt lava flow**—Abundantly porphyritic lava flow; medium gray; contains phenocrysts of olivine (2.4–3.1%), clinopyroxene (3.8–8.4%), and plagioclase (13.7–14.7%) in an intergranular, subophitic to intersertal groundmass; chemical composition basaltic andesite (map no. 119, Table 4A); crudely columnar to platy jointed; scoriaceous and rubbly along its probable margin north of Tieton River, with vesicular top; thickness 6 to 35 m (20–120 ft), 60 m (200 ft) in its northern location; occupies surfaces at 823 to 945 m (2,700–3,100 ft) elevation, indicating a possible 120 m (400 ft) maximum thickness; unconformably overlies tuffaceous rocks of Wildcat Creek (unit Towc); source unknown, presumably from the west (Swanson, 1964, 1978); flow appears to have descended Wildcat Creek valley, spreading out in Tieton River valley; age is 1.31 ±0.04 Ma (map no. 119, Table 7).

Qob1 **Olivine basalt lava flow**—A probable single lava flow, remnants of which crop out north and northeast of Westfall Rocks (south of the map area) and to the east, south of Tieton River; light-gray; nearly aphyric, containing fine-grained phenocrysts of olivine (0–4.5%) and plagioclase (2.3–5.4%) in an intergranular groundmass, varying from subophitic to diktytaxitic; chemical composition is basalt (map nos. 112 and 172, Table 4A); blocky to columnar jointed, especially well-developed on the south side of Wildcat Creek; vesicular top with pipe vesicles; fills a 50 m (165 ft)-deep channel cut into Tieton andesite (unit Qtan) at south Wildcat Creek locality, 15 to 30 m (50–100 ft) thick elsewhere; unconformably overlies tuffaceous rocks of Wildcat Creek (unit Towc) and Tieton andesite (unit Qtan)(Clayton, 1983); flowed from Tieton River valley through pass west of Westfall Rocks (south of the map area) into Wildcat Creek valley, then eastward into Tieton River valley (Swanson, 1964, 1978); source to the west; age is 1.38 ±0.25 Ma (map no. 112, Table 7).

Qtan **Tieton Andesite**—Consists of two lava flows containing abundant medium-grained phenocrysts of orthopyroxene (2.7–3.6%), clinopyroxene (3.4–6.3%), and plagioclase (22.5–26%) in a hyalopilitic groundmass; dark gray to nearly black; chemical composition andesite and slightly alkalic trachyandesite (map nos. 54, 117, 220, and to east of the map area, Table 4A); platy, blocky to columnar jointed, spectacularly jointed in remnant occurrences along Wildcat Creek and Tieton River canyon; compact lava interior with vesicular top and rubbly base (Sparks and others, 1993), locally hollowed out by gravity above steep slopes; thickness is 25 to 60 m (80–200 ft); ages are 1.64 ±0.07 (map no. 117, Table 7) and 1.39 ±0.10 Ma (southeast of map area, Table 6); older flow is in map area (Swanson, 1964, 1978); second and younger flow is at a lower elevation south and east of the map area.

Tbrb **Pyroxene-olivine basalt of Bethel Ridge**—Probable single lava flow atop and 1.5 km northeast of Cash Prairie; includes underlying reddish scoria and bombs, at least 11 small plugs and dikes west of Cash Prairie, and a possible plug (unit Tib) and lava flow atop Russell Ridge, 1.5 km southeast of Ironstone Mountain (Swanson, 1978); light gray; contains fine-grained phenocrysts of plagioclase (0.1–1.0%), olivine (1–1.3%), and clinopyroxene (0.7–3.5%) in an intersertal groundmass; chemical composition is basalt (map nos. 57, 92, 107, and 121, Table 4A); platy to blocky jointed, flow layered; lava and underlying scoria partly fill a channel in underlying tuff of Cash Prairie (unit Tfct); lava flow 2 to 12 m (7–40 ft) thick; underlying reddish scoria 2 to 45 m (7–150 ft) thick; plugs and dikes roughly aligned N35°W for a distance of 1.5 km (1 mi); columnar to blocky jointed; 0.3 to 30 m (1–100 ft) wide, with little thermal metamorphism in wall rock; age is 3.34 ±0.04 Ma (map no. 92, Table 7).

Tib **Olivine basalt intrusion**—A small intrusion or remnant of a lava flow of olivine basalt, 90 by 400 m (300 by 1,300 ft) atop Russell Ridge in the southwest corner of map area; covered contacts prevent verification as an intrusion and not a lava flow (Swanson, 1964); age undetermined.

Upper Miocene to Pliocene Intrusive Andesite–Dacite

Tspd **Hornblende dacite of Shellrock Peak**—A sharply ridged, steep-sided peak, 2,083 m (6,835 ft) in elevation, towering about 300 m (1,000 ft) above its basal contact in the northwest part of the map area; extensive talus around most sides; abundant phenocrysts, commonly lineated, of orthopyroxene (1.8%), mostly as replacement of hornblende (4.9%), plagioclase (33.1%) locally altered to clay, and scattered coarse-grained clusters of these minerals and opaques in a felty, near seriate groundmass; light gray, brownish where weathered or altered; dacite in chemical composition (map nos. 95 and 96, Table 4A), very similar in composition to hornblende dacite of McNeil Ridge (unit Tmrd) and hornblende dacite of South Rattlesnake Peak (unit Tsrd), possibly of the same magma; main mass vertically columnar jointed, becoming vertically platy jointed near summit ridge; body near oval in plan, about 2.0 by 2.5 km (1.25 by 1.6 mi) long; possibly emplaced and cooled as a uniform mass except for its north-northeast projecting apophysis, which is more altered and platy jointed; hosts two cirques on its northeast flank; intruded through broken strata of pre-Tertiary Russell Ranch complex (unit KJrr) along the Shellrock Peak fault at its southwest side and through 20- to 25-Ma-old orthopyroxene microdiorite (unit Tisd) along its southeast side; shows effect of late-stage alteration in its core; age is 3.20 ±2.00 Ma (map no. 96, Table 7).

Tmrd **Hornblende dacite of McNeil Ridge**—A glacially rounded, steep-sided plug, about 200 m (670 ft) in diameter, at the nose of the ridge separating Little Wildcat Creek from Rattlesnake Creek in the northwest part of the map; medium- to coarse-grained in contrast to most dacite intrusions in the region; randomly oriented phenocrysts of biotite (2.7%) and hornblende (3.1%) with reaction rims of biotite and some alteration to chlorite, quartz (4.6%), and plagioclase (33.8%) in very fine-grained granular groundmass; very light gray, weathering to pale brown; dacite in chemical composition (map no. 100, Table 4A); very similar to hornblende dacite of South Rattlesnake Peak (unit Tsrd) and hornblende dacite of Shellrock Peak (unit Tspd), possibly of the same magma; blocky jointed; intruded through broken strata of Russell Ranch complex (unit KJrr) adjacent to a dike of orthopyroxene-bearing andesite (unit Tia); age is 5.00 ±0.06 Ma (map no. 100, Table 7).

Tnrd
Tsrd **Hornblende andesite-dacite of Rattlesnake Peaks**—Prominent, sharp-pointed twin peaks at northwest corner of map, 0.7 km (0.4 mi) apart, aligned north–south, 6,850 and 6,583 ft in elevation, respectively, rising about 300 m (1,000 ft) above basal intrusive contacts with Russell Ranch complex (unit KJrr); most of north peak lies in Timberwolf Mountain quadrangle (Hammond, 2005); both peaks consist of medium- to fine-grained phenocrysts of orthopyroxene (0.4–1.3%) and pale brown hornblende (2.5–7.1%) surrounded or replaced by aggregates of very fine grained orthopyroxene and opaques, and plagioclase (13.9–20.8%) in a fine-grained, felty, near-seriate groundmass; very light gray, weathering to pale brown; chemical composition of north peak is andesite (north of map area, sample no. 00109), south peak is dacite (map no. 97, Table 4A) similar in composition to hornblende dacite of McNeil Ridge (unit Tmrd) and hornblende dacite of Shellrock Peak (unit Tspd), possibly of the same magma; both Rattlesnake Peaks are blocky to columnar jointed, the latter predominating; north peak almost entirely vertically jointed; south peak has columns inclined to the north, becoming vertical toward the summit; large landslide on the northeast side of south peak has removed about half of the upper part of the intrusion; both peaks are oval in plan, about 1.2 km (0.66 mi) in diameter; both peaks are surrounded by an apron of talus; age of north peak (unit Tnrd) is 5.13 ±0.22 Ma, age of south peak (unit Tsrd) is 4.95 ±0.04 Ma (map no. 97, Table 7).

Tssd **Hornblende dacite south of Shellrock Peak**—Glacially rounded intrusion, roughly oval in plan, 1 km (0.6 mi) south of Shellrock Peak in western part of map area; composed of randomly oriented, fine-grained crystals of hornblende (~5%) and plagioclase (~15%) in a fine-grained groundmass of chiefly equigranular plagioclase, hornblende, quartz, and opaques; light brown; altered; dacite in chemical composition (map no. 154, Table 4A); blocky jointed, weathering to meter-size rounded boulders in brownish white sandy soil; landslides on northwest and southeast flanks form steep slopes with talus; intruded broken strata of Russell Ridge complex (unit KJrr), tuffaceous rocks of Wildcat Creek (unit Towc), and dikes along Shellrock Peak fault and southwest side of orthopyroxene microdiorite of south Shellrock Peak (unit Tisd)(Swanson, 1978); not dated but estimated at 3 to 9 Ma.

Tid **Dacite dike**—North-northwest-striking dike in the Shellrock Peak fault zone, composed of randomly oriented, medium-grained, prismatic phenocrysts of hornblende (3.4%) and plagioclase (28.7%) in a fine-grained granular groundmass; lightly altered; light gray to pale brown; dacite in chemical composition (map no. 156, Table 4A); blocky jointed; 5 m (16 ft) wide with an exposed length of about 400 m (1,300 ft); disappears to the north and south in steep landslide slopes. On its southwest side, the dacite dike is in sharp contact with a completely altered, plagioclase-phyric basaltic andesite dike (unit Tia)(map no. 155, Table 4A) about 1.5 m (5 ft) wide, very dark gray, and lacking recognizable ferric minerals. On its northeast side, the dacite dike is in sharp contact with orthopyroxene microdiorite south of Shellrock Peak (unit Tisd). Age of the dacite dike is 9.25 ±0.56 Ma (map no. 156, Table 7).

Middle to Upper Miocene Stratified Volcanic Deposits

Tev **Ellensburg Formation, volcanic facies**—Two small patches of boulder gravels overlying Grande Ronde Basalt along east margin of the map area between Oak Creek and Tieton River; gravels extend several kilometers east of the map area; consists chiefly of weathered, rounded clasts of Grande Ronde Basalt, some as much as 1 m (3 ft) in diameter, minor amount of andesite, a minor metamorphic rock, and hornblende-bearing dacite; Grande Ronde Basalt clasts more prevalent toward top of deposit; as much as 35 m (120 ft) thick; overlies a scoured surface atop Grande Ronde Basalt; north of Bear Canyon deposit partly fills a broad channel eroded about 75 m (250 ft) deep into Grande Ronde Basalt to a level below top of upper McCoy Canyon lava flow (unit Tgum); originally mapped as gravel by Swanson (1964, 1968), but much of deposit is lag gravel of Grande Ronde Basalt; mineralogy and composition of dacite in channel deposit similar to dacite intrusions to west; deposit assigned to Ellensburg Formation based on unconformable stratigraphic relation to underlying Grande Ronde Basalt and presence of dacite clasts, which are marker lithology for Ellensburg Formation (Hammond, 2005); deposit probably equivalent to lower part of Ellensburg Formation, about 10–12 Ma in age.

GRANDE RONDE BASALT

Consists of eight basalt lava flows; light gray to grayish black to black; some flows consist of multiple injections of lava or inflated, invasive lava, especially the upper McCoy Canyon (unit Tgum) and Grouse Creek (unit Tgg) lava flows. All flows contain fine-grained plagioclase (23.9–30.5%) and clinopyroxene (15.6–26.3%) in a very fine-grained black groundmass of tightly interwoven crystallites of plagioclase, clinopyroxene, granular ilmenite-magnetite, and glass; parts and tiers of some flows contain fine-grained phenocrysts of plagioclase (1.0–4.0%) and clinopyroxene (0.4–3.0%).

All flows are compositionally basaltic andesite rather than basalt (Table 4B). Individual flows vary in internal structure, in number, position, and thickness of tiers, in stubby to splintery to radiating columnar jointing, blocky jointing, or most commonly hackly jointing, in vesicular to non-vesicular bases and tops, and in vesicular layers within a flow to vesicular pillow lavas. Where flows terminate against gently rising topography, they grade into scoria; against steep topography, flows have blocky to columnar jointing normal to the contact.

All flows generally form steep benched slopes, rims, and cliffs. Although rarely exposed, interbeds (unit Tgib) separate lava flows. They range from 1 to 30 m (3–100 ft) thick and consist of whitish fine-grained tuff, generally of rhyolite composition, containing phenocrysts of plagioclase (8.9%), hornblende (5.3%), quartz (0.3%), biotite (0.3%), ilmenite-magnetite (0.7%), pumice (0.3%), and lithics (8.3%); yellowish to brownish fine-grained micaceous sandstone, containing quartz (16.1–17.8%), biotite (5.1–7.5%), K-feldspar (4.6–7.4%), muscovite (2.6–5.0%), plagioclase (2.2–4.1%), hornblende (0.6–0.9%), ilmenite-magnetite (1.0–2.2%), and lithics (1.6–2.3%); and siltstone or dark gray to yellowish brown palagonitic hyaloclastite, the latter up to 10 m (30 ft) thick. The thickest interbed, 10 to 30 m (35–100 ft), separates the lower McCoy Canyon flow (unit Tgm), or where it is missing, the Ortley flow (unit Tgo) from the underlying Grouse Creek flow (unit Tgg). Another thinner interbed separates the upper McCoy Canyon flow (unit Tgum) from the lower McCoy Canyon (unit Tgm) or Ortley flow (unit Tgo).

The top lava flow, the Museum 2 (unit Tgm2), is the most diverse flow of the group. It occurs only in the eastern part of the map area, has a thickness of 25 to 30 m (85–105 ft), and locally overlies the fourth flow down, the upper McCoy Canyon flow (unit Tgum), where the Museum 1 flow (unit Tgm1) and the Stember Creek flow (unit Tgsc) have been eroded. The Museum 2 flow (unit Tgm2) generally consists of a rarely exposed lower hyaloclastite, then a layer of pillow lava overlain by one to two layers of columnar jointing or thin layers of platy lava separated by thin seams of vesicles, rarely with a hackly jointed to vesicular top. The columns are of light gray rock, more coarsely grained than most Grande Ronde Basalt, and are commonly 4 to 10 m (12–35 ft) tall and more than 1 m (3 ft) thick. The columnar jointing weathers to huge blocks of columnar rock; the platy layers often break out, exposing thin seams or patches of drusy quartz crystals.

The Museum 1 lava flow (unit Tgm1) is the most uniform of the group and is probably representative of a sheet flow. It has a thin scoriaceous base, a short colonnade, generally less than 6 m (20 ft) tall, overlain by a much thicker hackly jointed entablature, and topped by a 2 to 5 m (6–17 ft) blocky jointed cap that in the map area is commonly eroded and not well exposed. The upper McCoy Canyon flow (unit Tgum) commonly consists of pillow lava separated by thin flows with blocky and columnar jointing or a sequence of thin flows with scoriaceous tops and bases, separated by a lower tier of well-developed columnar jointing and an upper tier of hackly to splintery columnar jointing. Because of its thickness, the Grouse Creek flow (unit Tgg) also shows variation in its outcrops, from thin tiers of pillow lava to one to three tiers of columnar jointing, with some tiers as much as 60 m (200 ft) tall, to overlapping lobes of vesicular, hackly jointed lava.

The top five flows (units Tgm2, Tgm1, Tgsc, Tgum, and Tgm) are part of the Sentinel Bluffs Member, N_2 (Reidel and others, 1989; Reidel, 2005), which contains more than 4.2% MgO (Table 4B) and has a normal magnetic polarity. The Ortley flow (unit Tgo) is lower in the N_2 sequence and is probably a unit of the Winter Water Member (Reidel, 2005). The lower two flows (units Tgg and Tgw) are part of the Grouse Creek and Wapshilla Ridge R_2 units respectively (Reidel and others, 1989), having reversed magnetic polarity. All three lower flows are identified by difference in high TiO_2 and low MgO content (Table 4B).

All flows overlap the eastern and northern flanks of Tieton volcano. Only the Museum 1 (unit Tgm1), upper McCoy Canyon (unit Tgum), and Grouse Creek (unit Tgg) extend westward to about the end of Bethel Ridge. Preservation of the flat Cash Prairie surface suggests that the three flows once extended further west. The Grande Ronde Basalt lava flows in the map area unconformably overlie rhyolite of Little Rattlesnake Creek (unit Tirr), andesite of Timberwolf Mountain volcano (unit Tftm), tuff of Cash Prairie (unit Tfct), andesite of Tieton volcano (units Tfta and Tftc), and tuffaceous rocks of Wildcat Creek (unit Towc). The stratigraphic sequence of the Grande Ronde Basalt lava flows in the map area includes about half the total of Grande Ronde Basalt flows. Therefore, the age of this upper sequence of Grande

Ronde Basalt lava flows is estimated at 15.75 to 15.67 Ma, about 180,000 years in duration (Barry and others, 2013). Divided into:

Tgm2 **Museum 2 lava flow**—Thickness is 0 to 30 m (100 ft), averaging 20 m (65 ft).

Tgm1 **Museum 1 lava flow**—Thickness is 0 to 55 m (180 ft), averaging 25 m (80 ft).

Tgsc **Stember Creek lava flow**—Thickness is 0 to 45 m (150 ft), averaging 25 m (80 ft).

Tgum **Upper McCoy Canyon lava flow**—Thickness is 0 to 90 m (295 ft), averaging 45 m (150 ft).

Tgm **Lower McCoy Canyon lava flow**—Thickness is 0 to 35 m (115 ft), averaging 25 m (80 ft).

Tgo **Ortley lava flow**—Thickness is 0 to 40 m (130 ft), averaging 25 m (80 ft).

Tgg **Grouse Creek lava flow**—Locally referred to as the Meeks Table lava flow; thickness is 0 to 180 m (590 ft), averaging 125 m (410 ft).

Tgw **Wapshilla Ridge lava flow**—Thickness is 0 to 85 m (280 ft), averaging 40 m (130 ft).

Tgib **Interbeds in Grande Ronde Basalt**—Thickness is 1 to 85 m (3–280 ft).

Upper Oligocene to Lower Miocene Intrusions

Tirr **Rhyolite of Little Rattlesnake Creek**—Porphyritic rhyolite; generally white to dark gray, reddish to brownish where altered; with medium- to fine-grained phenocrysts of plagioclase (7.7–19.3%), quartz (0.5–8.1%), hornblende (0–0.2%), biotite (0–0.2%), sanidine (0–0.2%), and trace amounts of clinopyroxene and orthopyroxene in a finely lineated and layered, microfolded, glassy, perlitic to spherulitic to totally devitrified, argillitized groundmass; phenocrysts commonly shattered and in strings or lenses paralleling lineation; layering generally forms vertically extending concentric sheaths 5 to 25 cm (2–10 in.) thick; rhyolite in composition (map nos. 79–81, 85, 87, 88, 200, and 217, Table 4A); forms low, rounded to pointed domes, 12 to 250 m (40–825 ft) high and 12 to 900 m (40–3,000 ft) wide, and steep-sided taller plugs with fluted slopes; intrudes tuffaceous rocks of Wildcat Creek (unit Towc) and tuff of Cash Prairie (unit Tfct) with sharp, vertical, slickensided contacts; age is 23.8 ±0.05 Ma (map no. 88, Table 7) or lower Miocene.

Tia **Andesite dikes, sills, and intrusive complexes**—Basaltic andesite to andesite in chemical composition (Table 4A), with few exceptions; include many scattered intrusions west of Tieton volcano and Bethel Ridge; composed generally of randomly oriented phenocrysts of medium- to fine-grained clinopyroxene (0.7–9.9%) and plagioclase (19.6–26.4%), commonly in clusters in an aphanitic intergranular groundmass; gray to very dark gray, weathering to green, dark green to brown; almost all propylitically altered; major dikes strike northwest, many emplaced along fault zones; blocky jointed, a few columnar or cordwood jointed; sharp, clean to irregular to brecciated contacts; chill zones up to 50 cm (20 in.) wide, thermally affected wall rock up to 5 m (15 ft) from the contact; form prominent chinawall to flat outcrops; some susceptible to erosion, producing narrow trenches; width ranges from 1 to 50 m (3–165 ft) for most, up to 2.5 km (1.6 mi) long and 0.5 km (0.3 mi) wide for larger dikes.

Several dikes or groups of dikes show unusual relationships. Dikes at Burnt Mountain Ridge and two dikes between Westfall Rocks and the North Tieton Basin fault include many fragments of tuff of Burnt Mountain (unit Tfbm), causing originally andesitic dikes to be altered to hybrid dacitic composition (Tables 4A, 4C). Kitten Creek dike and dikes along North Tieton Basin fault, Thunder Creek, and Burnt Mountain ridge are narrow dikes striking perpendicularly to the strike of their major intrusion (Cross Section A–A′). In the northwest corner of the map area, a dike about 40 m (130 ft) wide at the south bank of Rattlesnake Creek narrows to about 12 m (40 ft) atop McNeil Ridge. It has blocky jointing and sharp eastern contacts with an adjacent light-colored dike of biotite-hornblende-quartz-plagioclase dacite of McNeil Ridge (unit Tmrd) and an irregular, brecciated west contact with metasedimentary strata of Russell Ranch complex (unit KJrr). Its age was not determined. A dike-sill complex south of Rattlesnake Creek forms an oval-shaped intrusion with randomly oriented, medium- to fine-grained phenocrysts of about 20 percent plagioclase, 5 percent orthopyroxene, and 2 percent hornblende in a very fine grained granular groundmass. The light gray rock weathers brown and is andesitic in composition (map no. 122, Table 4A). Its age has not been determined. All of these intrusions were emplaced into Russell Ranch complex (unit KJrr) and pillow lava (greenstone) of Russell Ranch complex (unit KJrg) or into possible Indian Creek complex (unit KJif), sandstone of Summit Creek (unit Tscs), tuffaceous rocks of Wildcat Creek (unit Towc), or tuff of Burnt Mountain (unit Tfbm). Age of these intrusions is 25 to 26 Ma, approximately the age range of nearby larger intrusions and volcanoes.

Additional dikes and intrusive complexes that occur south of the Tieton Basin quadrangle warrant mentioning. Two large, oval intrusions are Westfall Rocks (unit Tiwf) and Goose Egg Mountain (unit Tige), both south of the map area; two smaller intrusions, Chimney Peaks (unit Ticp) and Kloochman Rock (unit Tikr)(both south of the map area) are a dike and a dike-sill complex respectively. Westfall Rocks, Goose Egg Mountain, and Chimney Peaks are orthopyroxene-bearing microdiorites; Kloochman Rock is a dark-colored, much finer-grained andesite. Westfall

Rocks and Goose Egg Mountain have almost identical andesite composition (Table 4A); Chimney Peaks and Kloochman Rock are basaltic andesites. Kloochman Rock is the most spectacular of the four intrusions; it is a beautifully columnar-jointed remnant of a sill hanging to the southwest margin of its feeding dike. All four were emplaced in tuffaceous rocks of Wildcat Creek (unit Towc) within 0.45 million years of each other (Table 7). Westfall Rocks, Goose Egg Mountain, and Kloochman Rock are aligned northwest. Chimney Peaks is oriented northeast, normal to the other three. All could have been feeders to another Tieton- or Cabin Creek–like volcano, yet no lava flows have been found related to these intrusions (Swanson, 1964, 1978).

Tisd **Orthopyroxene microdiorite south of Shellrock Peak (Swanson, 1964, 1978)**—Consists of randomly oriented medium-grained phenocrysts of orthopyroxene (3–4%), clinopyroxene (5%), and plagioclase (10%) in a medium- to fine-grained intergranular groundmass; reddish brown to dark brown; chemical composition basaltic trachyandesite; extensive alteration affects all minerals; blocky jointed; rounded to angular outcrops; most surfaces covered by grus-like sandy soil; steep-sided in its outer perimeter; about 1.4 km (0.85 mi) in diameter; oval in plan, although partly covered by landslide; emplaced into Russell Ranch complex (unit KJrr), tuffaceous rocks of Wildcat Creek (unit Towc), and sandstone of Summit Creek (unit Tscs), although unit Tscs is not exposed, and into contact zone between pre-Tertiary and Tertiary rocks; unit is intruded by two probable apophyses of dacite of Shellrock Peak (unit Tspd) at its southwest fault contact; capped by a small patch of tuffaceous rocks of Wildcat Creek (unit Towc); represented by sample no.153 (Table 4A); age is approximately 25 to 26 Ma.

Tiwf **Orthopyroxene microdiorite of Westfall Rocks (Swanson, 1964, 1978)**—Microdiorite (Table 4A) contains abundant randomly oriented medium-grained phenocrysts of prismatic plagioclase (23.5%), clinopyroxene (3.3%), and orthopyroxene (2.7%) in a fine- to medium-grained intergranular groundmass; medium gray, altered propylitically to dark greenish gray; irregular to blocky to slabby jointed, the latter paralleling steep-sided slopes; emplaced into Russell Ranch complex (unit KJrr), tuffaceous rocks of Wildcat Creek (unit Towc), and possibly Indian Creek complex (unit KJif); elevation is about 4,890 ft, protruding about 600 m (1,970 ft) above surface of Rimrock Lake; oblong in plan, 2.4 km (1.5 mi) long northeast–southwest by 1.6 km (1.5 by 1 mi) wide; age is 26.13 ±0.22 Ma (sampled south of map area, Table 7).

Tfti **Dikes and plug of Tieton volcano**—More than 200 dikes define a radial dike pattern at Tieton volcano; composition and mineral content similar to lava flows, range from 1.5 to 6 m (5–20 ft) thick, are traceable to lengths of 1,065 m (3,500 ft); commonly occur in groups of three or more dikes. These dikes generally have sharp, well-defined contacts, narrow chill margins, and coarse-grained, commonly vesicular, more altered dike interiors. The majority of the dikes are exposed in a narrow area of the volcano in the walls of Tieton River canyon. Many occur in the older Cabin Creek volcano (unit Tfcc) in the south wall of the canyon and below 3,500 ft elevation. Most crop out as discontinuous chinawalls in the steep canyon slopes; projection northward of the dikes indicates possibly two centers aligned approximately north–south, the south one is in the SE¼ sec. 18 and NE¼ sec. 19, T14N R15E, the other is in the NE¼ sec. 18, T14N R15E, near point 4613. No central plug of Tieton volcano is exposed.

Tfci **Intrusions of Cabin Creek volcano**—Two small oval intrusions above U.S. 12 and Trout Lodge in southeast part of the map area (Swanson, 1964, 1966, 1978); both oriented approximately north-south; the smaller measures about 90 by 150 m (300 by 500 ft); the larger, about 120 by 300 m (400 by 1,000 ft), lies to the southeast; similar to lava flows (unit Tfcc), composed of phenocrysts of plagioclase, clinopyroxene, and orthopyroxene in a fine-grained intersertal groundmass; dark gray, weathering yellowish brown to reddish brown; blocky jointed; in rough, angular outcrops; intrude lava flows and tuff interbeds of Cabin Creek volcano along poorly exposed, irregular contacts; age is 25.73 ±0.32 Ma (map no. 28, Table 7) or upper Oligocene.

Upper Oligocene to Lower Miocene Volcanic Deposits

FIFES PEAK FORMATION

Tftm **Andesite of Timberwolf Mountain volcano**—Porphyritic andesite to dacite with moderate to abundant, medium- to fine-grained phenocrysts of plagioclase (6–24%), orthopyroxene (1.5–4.5%), and dark green clinopyroxene (1–2%) in a fine-grained intergranular to intersertal groundmass; very dark gray 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; in chemical composition lava flows and dikes are basaltic andesite (map nos. 62, 63, 66, 83, 84, 89, Table 4C), tuffs are andesite to dacite; remnant lava flows along north-central margin of map area; caps ridges and forms rims and benched steep slopes; erupted from several plugs north of Timberwolf Mountain in adjacent Old Scab Mountain quadrangle to north; 120 to 365 m (400–1,200 ft) thick; unconformably overlies tuffaceous rocks of Wildcat Creek beds (unit Towc) and rhyodacite-rhyolite tuff of Cash Prairie (unit Tfct); age is 25.4 ±0.6 to 24.73 ±0.46 Ma or upper Oligocene, determined in Timberwolf Mountain and Meeks Table quadrangles to the north (Hammond, 2005, 2009).

Tfct **Rhyodacite-rhyolite tuff of Cash Prairie**—Pumice pyroclastic-flow deposits interstratified with laharic deposits of Tieton volcano (Swanson, 1964, 1966, 1978); lithic- and pumice-lapilli crystal-vitric rhyodacite-rhyolite tuff; very light gray, light brown to yellowish white to yellowish brown, weathers to pale orangish brown to dark brown; consists of fine- to medium-grained crystals of plagioclase (4.8–9.1%), quartz (0–3.5%), hornblende (0–0.8%), orthopyroxene and clinopyroxene (each 0.1%), and ilmenite-magnetite (0.1–0.9%), with lapilli of pumice (10.5–34.4%), lithics (8.6–12.7%), and sparse carbon fragments and red scoria in a devitrified, non-welded, very fine-grained vitroclastic matrix; rhyodacite to rhyolite in composition (Table 4C); composed of at least eight pyroclastic-flow deposits, separated by tongues of laharic breccia from Tieton volcano to the east, 10 to 60 m (35–200 ft) thick; 225 m (740 ft) total thickness of tuff excluding laharic interbeds; occurs chiefly in western part of Bethel Ridge underlying Cash Prairie; flows thin out toward core of Tieton volcano; extends to the north, capping ridges in the Rattlesnake Creek drainage, and into the headwater basin of Little Rattlesnake Creek, partly filling a broad valley that existed between Tieton volcano and Timberwolf Mountain volcano to the north; banked against Wildcat Creek beds and not extending beneath lava flows of Timberwolf Mountain as previously mapped (Hammond, 2005); not present east of Tieton volcano; poorly exposed in rounded to smooth-weathering steep slopes, well exposed locally in cliff rims; blocky to slabby jointed; susceptible to landsliding; unconformably overlies tuffaceous rocks of Wildcat Creek (unit Towc) and laharic breccia of Tieton volcano (unit Tfta); unconformably overlain by laharic breccia of Tieton volcano (unit Tfta) and lava flows of Grande Ronde Basalt (units Tgm1, Tgum, and Tgg); source unknown but believed to have been derived from an eruptive center within 10 km (6 mi) because of its thickness and abundance of plutonic and metamorphic clasts similar to rocks in the Rimrock Lake inlier (Miller, 1989); age is 24.66 ±0.41 to 25.81 ±0.22 Ma (map nos. 90 and 52, Table 7) or upper Oligocene; first mapped and described as rhyolitic pumice-flow deposit of Tieton volcano by Swanson (1964, 1966, 1978).

Andesite of Tieton Volcano

Interbedded lava flows and breccia, laharic deposits, and tuff and tuff-breccia; initially mapped, described, and the volcano named by Swanson (1964, 1966, 1978). Divided into:

Tftc **Cone facies**—Lithic tuff, lapilli-tuff, and tuff-breccia; most deposited by air-fall, some in mudflows, a few as avalanche deposits; fine-grained crystals of plagioclase and lesser pyroxene are sparse; pumice is locally abundant; lithic fragments are ubiquitous, ranging from sand to boulder size, angular, and almost entirely of lava-rock; poorly sorted and graded; bedding ranges from 2 cm to more than 3 m (0.8 in.–10 ft) thick and dips away from a broad volcano center, although no central plug is exposed. Deposits of the cone facies generally underlie smooth, graded slopes, but where incised by streams have steep, rugged slopes. They rest entirely upon deposits of the apron facies (unit Tfta) along an unconformable contact. Thickness ranges from 255 m (830 ft) to 330 m (1,075 ft) in Cross Section B–B′.

Two unusual features atop Tieton volcano that have not been noted before are: (1) a lava platform on the western side of the cone, and (2) the composition of the 15° to 35° southwest-, south-, to southeast-dipping beds along the south side of the cone. The lava platform is about 1.3 km² (0.5 mi²) in area, flat yet dipping 10°SW. It is no more than 30 m (100 ft) thick and has a sharp, eroded margin. It erupted from a narrow, curved fissure about 0.6 km (1 mi) in length along the northeast margin of the platform. The platform rock, composed of andesite (map no. 224), consists of two generations of phenocrysts: medium-grained plagioclase (23.3%) and fine-grained plagioclase (22.2%), together with orthopyroxene (2.0–3.8%), clinopyroxene (5.9–24.6%) phenocrysts, and opaques (0.4–1.5%), and a very finely stippled, almost black groundmass.

The southward-dipping tuffs and lithic tuff-breccias, illustrated in Swanson (1966, fig. 2, pl. 3), are more like hyaloclastites. They are pale brownish gray, in poorly defined beds generally between 0.25 to 2.0 m (6 ft) thick. The beds pinch and swell, are locally crossbedded, and elsewhere have thin layers of rounded to angular lithic clasts or unsorted thick beds of abundant clasts with a coarse sand matrix. The tuffs have a sand matrix consisting chiefly of abundant plagioclase crystals and grains of black glass. Many are surge beds. They appear to have been erupted from a series of vents or one large, shallow, water-containing eruptive vent, extending east from the lava platform at the western end, about 4.7 km (3 mi), now obliterated by erosion.

Tfta **Apron facies**—Base (shield) of volcano; consists of lava flows, interbedded lava flows, breccia, and some tuff, and laharic deposits interbedded with rhyolitic pumice [pyroclastic] flows (Swanson, 1964, 1966, 1978); blocky lava flows and breccia of basalt, basaltic andesite, and andesite; grayish black, weathers to brownish gray; dark grayish green where propylitized; predominantly andesite; contains fine- to medium-grained phenocrysts in a very fine-grained hyalopilitic to pilotaxitic groundmass; some basalt with plagioclase

(9.9%), clinopyroxene (1.0%), olivine (trace), and ilmenite-magnetite (26.4%); some basaltic andesite with plagioclase (22.1–29.3%), clinopyroxene (1.9–7.8%), orthopyroxene (2.3–4.6%), and ilmenite-magnetite (1.1–2.7%); and andesite with plagioclase (19.8–29.2%), clinopyroxene (0.9–12.5%), orthopyroxene (0–10.4%), and ilmenite-magnetite (0.9–2.4%); lava flows and dikes; basaltic andesite in chemical composition (Table 4C), only one tuff analyzed (map no. 179).

Lava flows are crudely stratified, ranging in thickness from 4 to 60 m (13–200 ft), with thick flow-top breccia and thinner bottom breccia composing up to half the thickness of a lava flow. They are blocky jointed and commonly flow layered. Lava flows are locally interbedded with yellowish gray lithic-pumice-vitric andesite tuff, commonly varying from lapilli-tuff to tuff-breccia and oxidized red by overlying devitrified basal lava-flow breccia. The tuff is of ash-fall origin, 0.5 to 7 m (2–25 ft) thick, with poorly defined bedding and irregular contacts; it is generally poorly exposed. Lava flows form steep, benched slopes, chiefly in the north slopes of Tieton River canyon. Interbedded lava flows, breccia, and tuff form the transition between the basal sequence of lava flows and the overlying cone facies of the volcano, marked by a higher percentage of lava-breccia and interbedded tuff. These deposits underlie steep upper slopes at the west end of Tieton River canyon and in north Tieton Basin, and probably comprise the deposits of the volcano in Little Rattlesnake Creek valley north of Bethel Ridge.

The laharic deposits are interbedded with rhyolitic pumice [pyroclastic] flows (unit Tfct) to form the outer northwest flank of Tieton volcano, west of north Tieton basin, underlying and north of Cash Prairie. The laharic deposits consist almost entirely of andesite lava-flow fragments, ranging from pebbles to rounded boulders as much as 5 m (15 ft) in diameter. They are poorly sorted and stratified. Channel-filling and local cross bedding indicate a westward flow direction, originating from the center of Tieton volcano. Beds range up to 6 m (20 ft) in thickness, and contacts with interbedded tuff (unit Tfct) are irregular but readily traceable. Laharic deposits enclose fragments of tuff, and short spiracles of lithic clasts penetrate overlying tuff beds. The laharic beds thin northwestward and pinch out below Cash Prairie but are traceable northward as thin lithic beds in tuff of Cash Prairie (unit Tfct). The beds generally underlie steep, rough slopes. Deposits of apron facies of Tieton volcano unconformably overlie tuff of Burnt Mountain (unit Tfbm) and tuffaceous rocks of Wildcat Creek (unit Towc) and are overlain unconformably by cone facies of the volcano (unit Tftc) and lava flows of Grande Ronde Basalt. Maximum thickness of apron facies is 670 m (2,200 ft) in Cross Section B–B′. It thins eastward to 305 m (600 ft). The age of Tieton volcano is 25.26 ±0.26 to 26.0 ±0.8 Ma (map nos. 33 and 59, Table 7) or upper Oligocene.

Tfcc **Andesite of Cabin Creek volcano**—A small part of the older volcano overlain by Tieton volcano is exposed in Tieton River canyon along the Tieton River in the southeast part of the map area (Swanson, 1964, 1966, 1978). Most of the volcano and a parasitic eruptive center occur south of the river, almost aligned north–south with the approximate center of Tieton volcano. Its name is taken from a major northward-flowing stream that dissects the volcano before joining the Tieton River. Composed chiefly of blocky lava flows with irregularly distributed interbeds of tuff (lapilli-tuff, tuff-breccia) that contain abundant prismatic phenocrysts, generally randomly oriented, of plagioclase (23.4%), clinopyroxene (9.5%), orthopyroxene (2.2%), and opaques (0.4%) in a fine-grained hyalopilitic to pilotaxitic groundmass; similar chemically and mineralogically to Tieton volcano. The flows are basaltic andesite to andesite in chemical composition, bordering on trachyandesite (map nos. 24, 26, 28, 29, 40, 41, 174, and 175, Table 4C); gray to dark gray, weathering to yellowish brown to reddish brown; propylitized; bottom and top breccia, enclosing interior of blocky to platy jointing; 1.5 to 15 m (5–50 ft) thick. Tuff interbeds are yellow and orange to red and consist of poorly sorted, abundant lithics and pumice; crystals are sparse. Tuff interbeds are 0.3 to 1.5 m (1–5 ft) thick. Contacts with enclosing lava flows are irregular. Lava flows and tuffs underlie steep, rimmed and cliffed slopes; in the map area, they are separated from overlying apron deposits of Tieton volcano (unit Tfta) by the Windy Point thrust. The base of Cabin Creek volcano is not exposed in the map area, but to the south the unit unconformably overlies tuffaceous rocks of Wildcat Creek (unit Towc). Maximum exposed thickness in the map area is 335 m (1,100 ft)(Cross Section B–B′). Age is 25.73 ±0.32 Ma (map no. 28, Table 7) or upper Oligocene.

Tfbm **Rhyolite tuff of Burnt Mountain**—Interstratified tuff, lapilli tuff, tuff-breccia, and some volcanic sandstone, chiefly pyroclastic-flow deposits, some partly welded, forming separate cooling units (ash-flow tuffs of Swanson, 1964, 1978); consists of a few crystals of plagioclase (0.8–18.2%), orthopyroxene (0–0.2%), clinopyroxene (0–2.4%), quartz (0.5–0.8%), and hornblende (trace) in a vitroclastic groundmass of abundant pumice (11–21.5%) and lithic (3.7–15.7%) fragments, with some carbon chips; commonly argillized or propylitized and silicified; rhyolite in chemical composition (map nos. 12, 13, 192, 205, and 210, Table 4C); gray to pale grayish green to pale brown; pumice generally pale green; poorly exposed; in beds 2.5 cm to 30 m (1 in.–100 ft) thick; poorly sorted and graded, with more lithic fragments in lower part of unit; commonly massive in appearance; blocky to slabby jointed, but extensive shear fractures northeast of Thunder Creek; diffuse contacts between units; variable induration; locally fragments of reddish flow-layered, lithophysal rhyolite, granitic quartz-feldspar aggregates, black glassy droplets, and pyroxene andesite, the latter up to 2 m (6 ft) in diameter; forms smooth weathering slopes; in fault contact with and unconformably overlies tuffaceous rocks of Wildcat Creek (unit Towc); in fault contact with and unconformably overlain by deposits of apron facies of Tieton volcano (unit Tfta); thickness 275 m (900 ft)(Cross Section A–A′); age is 26.97 ±0.30 (from underlying unit Towc, map no. 196, Table 7) to 28.21 ±0.2 Ma (map no. 192, Table 7) or upper Oligocene.

OHANAPECOSH FORMATION

Towc, Towt **Tuffaceous rocks of Wildcat Creek**—Chiefly interstratified airfall and pyroclastic-flow deposits of fine-grained tuff, pumice lapilli tuff, and lapillistone of dacite to rhyolite (map nos. 69, 120, 196, 110, 111, and 216, Table 4C) deposited in shallow water and lesser beds of sandstone, siltstone, claystone, and rare pebble conglomerate reworked by streams; originally studied and formationally named by Swanson (1964, 1978); divided into three members; reddish and brownish in lower member, greenish in middle member, and greenish blue, grayish brown, and pale brown in upper member; contains crystals of plagioclase (2.2–10.9%), pyroxenes (0.3–5.9%), quartz (0.4–0.9%), ilmenite-magnetite (0.5–0.8%), hornblende (trace), carbon particles (trace), and abundant lithic (8.8–16.7%) and pumice (5.4–23.7%); vitroclastic matrix altered extensively to montmorillonitic clays, zeolites, calcite, and opal (now crystallized to quartz), forming indurated beds in the Thunder Creek and lower Wildcat Creek area, but weakening coherence between grains and increasing susceptibility to landsliding in the upper Wildcat Creek area and Rattlesnake Creek area to the north.

The lower member is best exposed between the mouth of Wildcat Creek and confluence of Thunder Creek and generally has thin beds less than 1 m (3 ft) to a few meters thick. The middle member (unit Towt) is one pyroclastic-flow unit, a pumice lapilli-tuff, serving as a turquoise marker bed separating the lower and upper members. The upper member is best exposed in steep slopes and has thicker beds, 1.5 to 6 m (5–20 ft) thick, with upward fining lithology.

The volcanic source of unit Towc was to the north and northwest but is unknown, possibly Cowlitz Chimney volcano 45 km (28 mi) northwest in the Chinook Pass 7.5-minute quadrangle in Mount Rainier National Park (Fiske and others, 1963). Unit Towc conformably overlies sandstone of Summit Creek (unit Tscs) and is overlain unconformably by tuff of Burnt Mountain (unit Tfbm) and apron facies of Tieton volcano (unit Tfta). The lower member has about 40 m (125 ft) of exposed thickness. The middle member (unit Towt) is 12 m (40 ft) thick, and the upper member has 215 to 305 m (700–1,000 ft) of exposed thickness. Total thickness is 600 to 750 m (2,000–2,500 ft)(Cross Sections A–A′, B–B′). Age is about 27 to 33 Ma or lower Oligocene (Table 7; Vance and others, 1987; Lander and Swanson, 1989). Unit Towc is the lower part of the Ohanapecosh Formation of Mount Rainier National Park (Fiske and others, 1963) because its base, where exposed, conformably overlies upper Eocene sandstone to the north in the Timberwolf Mountain 7.5-minute quadrangle (Hammond, 2005), and elsewhere the formation is overlain conformably by coarse volcaniclastic deposits characteristic of and of the same age as the Ohanapecosh Formation.

Tscs **Sandstone of Summit Creek**—Subangular to subrounded, medium- to fine-grained lithic mica (muscovite)-quartz-feldspar sandstone, siltstone, mudstone, and rare conglomerate; exposed only in northwest part of map area south of upper Rattlesnake Creek; dips 20–30° NE; 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 metamorphic (units KJrr and KJrg) and plutonic rocks (unit KJif) with sharp contact, locally with 1 to 2 m (3–6 ft) of dark brown paleosol atop older rock; overlain conformably with thin transition into tuffaceous rocks of Wildcat Creek (unit Towc); name adopted from Vance and others (1987), who initially described these deposits in the White Pass 7.5-minute quadrangle; exposed thickness is 25 m (80 ft); older than about 33 Ma (upper Eocene), based on stratigraphic relationship to overlying 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, dark-gray lithic sandstone, conglomerate, few beds and lenses of bedded chert and chert-pebble 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; sandstone composed of angular quartz, feldspar, muscovite, and lithic grains; dark-gray lithic sandstone composed of similar grains in a matrix of chlorite, sericite, and calcite, commonly with iron oxide–bearing quartz veinlets; greenstone contains scattered phenocrysts of plagioclase and pyroxene, totally replaced by albite and chlorite respectively, in a groundmass of chlorite, epidote, and opaques, also commonly with veinlets of chlorite, carbonate, albite, and quartz (Swanson, 1964, 1978); one chemical analysis (map no. 98) in Table 4C; bedded units 5 to 200 m (16–665 ft) thick, with gradational contacts; greenstone and diorite in pods and lenses with sharp contacts, 10 to 50 m (30–165 ft) thick; occurs as structurally disrupted and sheared bedded units lacking stratigraphic continuity; blocky to irregular jointing; upholds steep, rough slopes; interpreted as a tectonic mélange (Miller, 1989); in fault contact with large mass of greenstone (unit KJrg) in northwest part of map area; estimated thickness 3,000 m (10,000 ft); age is Upper Jurassic to Lower Cretaceous, based on fossil radiolaria in bedded chert exposed west of map area (Miller, 1989). Formally named the Russell Ranch Formation. Divided into:

KJrg **Pillow lava (greenstone) of the Russell Ranch complex**—Dark-green, fine-grained, massive pillow lava of basalt composition; primary minerals of pyroxene, plagioclase, and olivine altered to chlorite, epidote, actinolite, calcite, iron oxides, and zeolites, with abundant clay; contains abundant veinlets of quartz and actinolite; irregularly jointed; upholds steep to cliffed slopes; in only a small area along the northwest margin of the map area, bound 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); thickness is more than 910 m (3,000 ft); age is Upper Jurassic to Lower Cretaceous (Miller, 1989).

KJif **Foliated diorite of the Indian Creek complex (Miller, 1989)**—Dark-green to grayish-green, gneissic, well to weakly foliated, medium- to coarse-grained, biotite-hornblende quartz diorite (Hammond, 2005) containing 50% plagioclase, 25% quartz, 15% hornblende, 9% biotite, and 1% ilmenite-magnetite, partly altered to chlorite, epidote, and sericite; blocky jointed; forms steep, cliffed slopes; in a very small area along northwest margin of map area east of the Hindoo Creek fault and separated by this fault from pillow lava of the Russell Ranch complex (unit KJrg); exposed width of 215 m (700 ft); age is 132 ±13 to 154 ±2 Ma (Upper Jurassic–Lower Cretaceous)(Miller, 1989). Formally named the Indian Creek Gneiss.

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