GEOLOGIC MAP OF THE CARNATION 7.5-MINUTE QUADRANGLE, KING COUNTY, WASHINGTON

by Joe D. Dragovich,
Heather A. Littke,
Megan L. Anderson,
Gregory R. Wessel,
Curtis J. Koger,
Jennifer H. Saltonstall,
James H. MacDonald Jr.,
Shannon A. Mahan,
and S. Andrew DuFrane

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WASHINGTON STATE DEPARTMENT OF NATURAL RESOURCES
Peter Goldmark—*Commissioner of Public Lands*

DIVISION OF GEOLOGY AND EARTH RESOURCES
David K. Norman—*State Geologist*
John P. Bromley—*Assistant State Geologist*

Washington Department of Natural Resources
Division of Geology and Earth Resources

Mailing Address:
MS 47007
Olympia, WA 98504-7007

Street Address:
Natural Resources Bldg, Rm 148
1111 Washington St SE
Olympia, WA 98501

Phone: 360-902-1450
Fax: 360-902-1785
E-mail: geology@dnr.wa.gov
Website: http://www.dnr.wa.gov/AboutDNR/Divisions/GER/

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Geologic Map of the Carnation 7.5-minute Quadrangle, King County, Washington

by Joe D. Dragovich[1], Heather A. Littke[1], Megan L. Anderson[2], Gregory R. Wessel[3], Curtis J. Koger[4], Jennifer H. Saltonstall[4], James H. MacDonald Jr.[5], Shannon A. Mahan[6], and S. Andrew DuFrane[7]

1 Washington Division of Geology and Earth Resources MS 47007 Olympia, WA 98504-7007

2 Colorado College Department of Geology 14 E Cache La Poudre St Colorado Springs, CO 80903

3 King County Department of Development and Environmental Services 900 Oakesdale Ave SW Renton, WA 98057

4 Associated Earth Sciences, Inc. 911 5th Avenue, Suite 100 Kirkland, WA 98033

5 Florida Gulf Coast University Department of Marine and Ecological Science Fort Myers, FL 33965

6 U.S. Geological Survey Box 25046 MS 974 Denver Federal Center Denver, CO 80225-5046

7 University of Alberta Department of Earth and Atmospheric Sciences 1-26 Earth Sciences Building, Edmonton Canada T6G 2E3

INTRODUCTION

Major sources of prior geologic mapping include Tabor and others (1993), Booth (1990), and Associated Earth Sciences (2001a,b, 2002, 2003, 2004, 2007, and unpublished mapping), Koger and Saltonstall (2009), Koger and others (2003), and Saltonstall and others (2003). The Snoqualmie Valley faults nos. 2 and 3 (SVF-2, SVF-3), Carnation faults nos. 1 and 2, the Cherry Valley fault, the Cherry Creek fault zone, and the Carnation basin are informally named herein. See Dragovich and others (2007, 2009a,b,c) for earlier mapping of the Snoqualmie Valley fault no. 1 (SVF-1) and the Rattlesnake Mountain faults no. 1 (RMF-1) through RMF-11 south of the map area. RMF-1 is the main strand of the Rattlesnake Mountain fault zone (RMFZ) and is herein correlated with the Cottage Lake lineament of Sherrod and others (2008) of the Southern Whidbey Island fault zone (SWIF), which is mapped within a mile of the map area.

A data supplement for this study (Dragovich and others, 2010) provides a compilation of radiocarbon ages (this study and previous work), tephrochronology data (this study), a single infrared stimulation luminescence (IRSL) age data (this study; Associated Earth Sciences, Inc. unpublished data), a bedrock top contour map, U-Pb age data (this study), and geochemical and petrographic data, as well as fault, neotectonic, potential field geophysical, and earthquake hypocenter information. This supplemental report also provides further interpretation of the sedimentary provenance, stratigraphy, sedimentology, structural geology, and neotectonics of the Carnation quadrangle and surrounding areas with an emphasis on the sedimentary provenance, geophysics, and earthquake hazards in the Snoqualmie River valley area.

GEOLOGIC OVERVIEW

Vashon Stade—The Last Major Continental Glaciation

Deposits related to the Vashon Stade of the Fraser Glaciation of Armstrong and others (1965) occur widely across the study area. Glacial flutes and drumlins show that the Puget lobe ice during the Vashon Stade advanced over the map area from northwest to southeast (azimuth ~140-150°). Ice advance occurred about 14,500 yr B.P. and blocked ancient rivers, creating an extensive temporary ice-dammed lake across much of the area (Mackin, 1941; Booth, 1990; Associated Earth Sciences, 2003). The resultant glacial lake deposits (unit Qgl_v) are widespread and complexly interlayered with proglacial river and delta sediments (unit Qga_v; for example, see cross sections A and B).

Vashon deglaciation of the map area commenced ~14,000 yr B.P. along the Cascade Range foothills directly to the east, and the map area was fully deglaciated by ~13,600 yr B.P. (Porter and Swanson, 1998).The Puget lobe ice front receded across the map area in a northwesterly direction, depositing recessional ice-contact, fluvial, deltaic, and lacustrine sediments. Many of these facies are laterally and vertically gradational and commonly interfinger.

During ice recession, a series of ice-marginal lakes and connecting glaciofluvial channels formed behind the retreating ice lobe; the geometry, inset relations, and elevation of these deposits reflect a general lowering of base level as lower valleys successively became deglaciated and new spillways emerged during ice recession. These spillways controlled the level of glaciolacustrine lakes and connecting channels that migrated westward and northward during deglaciation (Knoll, 1967; Booth, 1990; Porter and Swanson, 1998). Booth (1990) subdivided recessional outwash deposits into five stages of deglaciation and emphasized the importance of both ice-marginal and subglacial meltwater paths. For example, some of the small southwest-trending valleys traversing the glacial uplands may have originated as channels in subglacial tunnels. Glacial Lake Snoqualmie was a long-lived, ice-dammed lake that covered a substantial part of the map area during deglaciation (Mackin, 1941; Booth, 1990; Dragovich and others, 2007, 2009a,b). The varying elevation of this lake controlled the altitude of many delta tops and recessional channels and the distribution of most glaciolacustrine deposits. For example, it is apparent that delta tops are graded to a lowering glacial Lake Snoqualmie during deglaciation as ice receded in a north-northwesterly direction. Many of these features indicate a somewhat persistent lake surface elevation between 220 and 360 ft within the quadrangle. (Although ice dammed lakes are lowering during ice recession, geomorphic features such as simple delta morphology indicates relatively stable lake surface during parts of this recession.) Inset recessional outwash bodies are graded to a local base level that lowered over time and resulted in younger kame and delta deposits being deposited at successively lower elevations. Our mapping shows that ice-marginal meltwater followed several elevated pathways during the initial stages of glacial recession, depositing kame and lake sediments.

Tertiary to Quaternary Deformation and Sedimentation along the Rattlesnake Mountain Fault Zone

THE RATTLESNAKE MOUNTAIN FAULT ZONE—AN OVERVIEW

The Rattlesnake Mountain fault zone (RMFZ) of Dragovich and others (2007, 2009a,b,c, 2010):

(1) is a regional strike-slip fault zone as indicated by stratigraphic relationships and structural style including outcrop scale and larger structures; and

(2) correlates with the Southern Whidbey Island fault (SWIF) of Sherrod and others (2008).

The broad RMFZ encompasses most of the map area. Individual fault strands vary from strike-slip to oblique-slip faults. Many of these strands are active or potentially active (Dragovich and others, 2007, 2009a,b,c, 2010; Sherrod and others, 2008). Some Pleistocene deposits are distinctly deformed (folded and faulted) and liquefied, not as a result of landsliding or glacial ice shear, but as a result of recent tectonism (Dragovich and others, 2007, 2009a,b,c, 2010). See Dragovich and others (2010) for a detailed discussion of individual fault strands including fault strand geophysics, structure, certainty, and activity. Proposed major faults of the RMFZ in the Carnation 7.5-minute quadrangle include, from northeast to southwest, the Cherry Valley fault, Snoqualmie Valley faults no. 1, 2, and 3, and Rattlesnake Mountain faults no. 1 and 5. The Cherry Creek fault zone is an apparent conjugate fault to the RMFZ similar to the Tokul Creek fault in the Snoqualmie 7.5 minute quadrangle (Dragovich and others, 2009b,c). The 1996 Duvall earthquake epicenters (max. M_L=5.3) occur directly northeast of the Carnation quadrangle along Cherry Creek and may have originated along the Cherry Creek fault zone (Dragovich and others, 2010; Dragovich and others, unpublished data).The northwest-trending Cherry Valley fault, which may correlate with the Griffin Creek fault of Dragovich and others (2009b,c), is interpreted to be the northeastern boundary of the RMFZ in the Carnation 7.5-minute quadrangle (cross sections A and B). Also, the northeastern boundary of the Seattle basin is probably Snoqualmie Valley fault no. 1 of the RMFZ in the map area (cross sections A and B) as further discussed by Dragovich and others (2010). Snoqualmie Valley fault no. 2 bounds the western portion of the Carnation basin and is locally associated with intense liquefaction—including zones of diapiric injection—along a zone of tectonic deformation east of Tolt Hill. Rattlesnake Mountain fault no. 1 is the main strand of the RMFZ, is a well-defined geomorphic, stratigraphic, and geophysical feature, and is the locus of tectonic deformation, liquefaction, and shallow earthquake hypocenters. Rattlesnake Mountain fault no. 5 is also locally associated with tectonic deformation of pre-Vashon deposits in the southern part of the map area and is the continuation of a prominent structure mapped by Dragovich and others (2007). The Carnation faults are inferred on the basis of gravity-magnetic, seismic, and earthquake data and appear to be reverse faults formed within the RMFZ. Some earthquake data suggest that Carnation fault no. 1 is active (Dragovich and others, 2010).

GROWTH FOLDING AND PULL-APART AND INVERTED BASINS WITHIN THE RATTLESNAKE MOUNTAIN FAULT ZONE

Broad Quaternary deformation is implied by the occurrence of tilted and broadly folded ancient Snoqualmie River alluvium. This ancient alluvium has a distinct Snoqualmie River provenance (SP) as discussed in Dragovich and others (2007, 2009a,b,c; 2010). SP strata dominate the Olympia beds, Whidbey Formation, and older nonglacial deposits. (See Table 4 in Dragovich and others, 2010.) These strata occur at many stratigraphic levels, and at variable elevated positions along Snoqualmie valley. In some areas SP sediments are anomalously thick—this exceptional thickness is related to basin development within the RMFZ. Snoqualmie valley mapping by Dragovich and others (2007, 2009a,b,c, 2010), as well as our reconnaissance of nonglacial sediments in areas near the quadrangle, suggests fault-controlled sedimentation whereby the Snoqualmie River has been structurally trapped within the RMFZ basins during the Pleistocene, particularly the later part of the Pleistocene (see units Qc_{ws} and Qc_{pf} for example). However, fault-controlled basin deposition can be documented for some Miocene volcanic rocks in some areas of the Snoqualmie valley (see volcanic rocks of Snoqualmie Falls of Dragovich and others, 2009b,c).

The RMFZ as a strike-slip fault zone best explains our observations and data in the Snoqualmie valley in general. We apply the growth folding and pull-apart and inverted basin models to the structures and stratigraphic relations we observe within the broad RMFZ and extend these structural-stratigraphic concepts to Quaternary strata. (See Dragovich and others, 2010, for further information.) We suspect growth folding in the RMFZ initiated in the early Miocene—or perhaps in the late Eocene—but certainly can be documented for some blocks of Quaternary strata. The Union Hill and Tolt Hill growth folds are inferred on the basis of stratigraphy and structural arrangements (for example, bedding orientations). Bedrock top elevation data (Dragovich and others, 2010) demonstrate that some parts of these folds are cored by up-arched bedrock. We suspect that some of the other mapped folds in the study area are also growth folds. (See cross sections A and B.) A pull-apart basin is probably best illustrated southeast of the present map area where the deposition and intrusion of Miocene volcanic rocks of Snoqualmie Falls are controlled by Rattlesnake Mountain fault zone structural basins and basin bounding faults including Rattlesnake Mountain fault no. 1—the main strand of the RMFZ (Dragovich and others, 2009b,c). Other pull-apart basins are likely where we map thick ancient Snoqualmie River alluvium. The thickness and structural style of nonglacial SP sediment suggest that they are entrained in RMFZ pull-apart basins and were locally uplifted to form shortened—formerly extensional —inverted basins. This basin inversion is hypothesized to be operative along the length of the RMFZ (Dragovich and others, 2009a,b,c; Littke and others, 2009). (See ‘Quaternary Deformation’ in Dragovich and others, 2010, including figure 4 which shows our model of basin inversion.)

DESCRIPTION OF MAP UNITS

We used the Udden-Wentworth scale (Pettijohn, 1957) to classify unconsolidated sediments, Dickinson’s (1970) terminology for sandstones, and Le Maitre and others’ (2002) terminology for volcanic rocks. Clinopyroxenes are collectively described as ‘augite’ but may include other petrographically similar varieties. We use the time scales of the U.S. Geological Survey (USGS Geologic Names Committee, 2007) and Wolfe and others (1998). Description of weathering rinds on basaltic clasts follows the methodology of Colman and Pierce (1981). Thin-section point-count data on the sand-size fractions aids differentiation of several glacial and nonglacial units (Dragovich, 2007; Dragovich and others, 2009c). An important compositional discriminator for Quaternary strata is the average percentage of monocrystalline quartz (Qm) versus quartz mica tectonite / polycrystalline quartz / chert (Qp) versus potassium feldspar (PF) normalized to just the three-component system and shown as $Qm_xQp_xPF_x$ (Dragovich, 2007; Dragovich and others, 2009a,b,c). Percentages given for individual mineral or lithic grains in the unit descriptions are not normalized and represent the whole population. Geochemically, nonglacial samples can be distinguished from glacially derived samples because: (1) nonglacial samples have higher abundances of the low field strength elements Th and Pb; (2) nonglacial samples have higher chondrite-normalized La/Lu ratios; and (3) glacially derived samples have a narrower range of Zr (Dragovich and others, 2010). These, along with other lines of evidence, indicate that the nonglacial sands were derived from more varied sources than the glacial sands (Dragovich and others, 2010).

Quaternary Sedimentary Deposits

HOLOCENE NONGLACIAL DEPOSITS

af **Artificial fill and modified land (Holocene)**—Mixed earth materials, including sand and gravel fill and natural deposits that have been disturbed at major construction sites where the original strata have been significantly obscured; includes artificial fill along parts of State Route 203.

Qp **Peat (Holocene)**—Peat, muck, and organic silt and clay, with local thin beds of tephra; loose or soft. Knoll (1967) reports that Mazama ash is interstratified with peat in the Patterson Creek valley. Peat occurs in abandoned channels in the Snoqualmie River valley as well as in the Patterson Creek and Harris Creek alluvial plains, and in upland depressions, hummocks, and kettles over low-permeability glacial deposits (Booth, 1990). Probable uplifted unit Qp in an elevated terrace directly north of critical site 49H contains organic ashy silty clay; although further work is warranted, we suspect these Holocene organic deposits were uplifted during Holocene displacement of the Cherry Valley fault and subsequently incised by Harris Creek, leaving the terrace.

Qa **Alluvium (Holocene)**—Sand and silt with lesser gravelly sand, sandy pebble gravel, peat, and organic sediments; sands are yellowish green-gray weathering to an orange gray; subrounded to rounded clasts; loose; well stratified and sorted; plane-bedded sands common. Tolt River alluvium is mostly gravel and gravelly sand. Snoqualmie River alluvium contains clay, sand, organic mud, and peat. Wood debris and detrital wood are common. Snoqualmie River sand ($Qm_{59\text{-}65}Qp_{12\text{-}29}PF_{12\text{-}26}$) contains distinct monocrystalline quartz, plagioclase, and potassium feldspar, and minor but significant mica and hornblende. Snoqualmie River sands have fewer metamorphic lithic clasts, chert, and polycrystalline quartz than northern-sourced glacial deposits. These sands (1) are compositionally similar to ancient Snoqualmie River alluvium in pre-Fraser nonglacial alluvium (units Qc_o, Qc_{ws} and Qc_{pf}), and (2) have a Snoqualmie batholith and Tertiary volcanic igneous signature (Dragovich, 2007; Dragovich and others, 2007, 2009a,b,c). Their sand geochemistry suggests that they were derived from an intermediate, continental arc source (Dragovich, 2007; Dragovich and others, 2010). Tolt River alluvial sands are lithic rich and contain significant volcanic and metasedimentary lithic grains, greenstone, and metachert eroded from local Tertiary volcanic rocks and the Western mélange belt. Alluvium is relatively thin, but we suspect it might thicken near RMF-1 as shown on cross section A. Subsurface information indicates that the Snoqualmie River alluvium is typically thin (10-50 ft thick) over much of the map area (cross sections A and B), particularly below Carnation where dense glacial diamictons and outwash deposits are described from shallow depths in well and boring reports. Associated Earth Sciences, Inc., obtained a radiocarbon age of 1,760 ±70 yr B.P. from wood in Snoqualmie River alluvium directly west of the quadrangle near the intersection of Novelty Hill Road and Snoqualmie Valley Road (Dragovich and others, 2010).

Qls **Landslide deposits (Holocene to latest Pleistocene)**—Diamicton or boulder gravel; contains minor sand or gravel beds where locally modified by stream processes; includes a few areas of thick colluvium; loose or soft; typically poorly sorted and nonstratified. Clasts are angular to subangular where derived from bedrock, but may contain rounded clasts where landslides originate in Quaternary deposits. Landslides include slump-earthflows, debris slumps, debris flows, and lateral spreads. (See Varnes, 1978a,b, for the classification system used during this study.) This unit may include chaotic, stratified slump blocks or debris-flow aprons originating from unstable recessional deposits perched on hillsides, particularly kames and recessional deltas. Only landslides large enough to show at map scale are shown. Also not shown are the numerous thin debris-flow chutes evident in LIDAR (Light Detection and Ranging) elevation data on the steep slopes north of Union Hill, south of Novelty Hill, and south of Cherry Valley. Some landslides may be seismically induced and (or) initiated during late Pleistocene deglaciation (see unit Qaf). For example, the large deep-seated landslides above Tolt River in the southeastern part of the map area have lateral-spread morphology and could be seismically induced. In some areas, we show only landslide scarps where the gross stratigraphy is preserved within lateral spreads or deep-seated landslide complexes.

Qaf **Alluvial fan deposits (Holocene to latest Pleistocene)**—Debris-flow diamicton and alluvial sand, gravel, and local boulder gravel; loose; mostly poorly to moderately sorted; massive to weakly stratified. The reduced gradients where streams emerge from confining valleys cause some of the sediment load to be deposited as a fan. Deposits mapped as unit Qaf were distinguished from those in unit Qls by the regular lobate geomorphology of alluvial fans. The Carnation alluvial fan and many smaller fans were partly mapped using LIDAR elevation data. Some fans may have initiated as fan deltas that graded to glacial Lake Snoqualmie at the close of the last glaciation.

PLEISTOCENE GLACIAL AND NONGLACIAL DEPOSITS

Recessional Deposits of the Vashon Stade of the Fraser Glaciation

Recessional sands have a mixed local 'Cascade' and northern metamorphic-granitic provenance. Recessional deposits in the eastern part of the area have a more distinct Cascade provenance than the recessional sediments to the west which are polymictic (variable) and contain more exotic and (or) northerly derived clasts. For example, recessional sediments fed by the informally named Tolt River meltwater system contain more local Cascade-provenance mélange belt and Tertiary volcanic provenance clasts such as metasandstone, meta-argillite, metachert, greenstone, volcanic lithic clasts, amphibolite, and serpentinite, with low monocrystalline-quartz grain content. Recessional sands in general contain mostly northerly derived polycrystalline quartz (~20%), plagioclase (~15%), metamorphic lithic clasts (~9%), granitic lithic clasts (~10%), volcanic lithic clasts (~15%), and sedimentary lithic clasts (~8%) (this study, Dragovich, 2007; Dragovich and others, 2009c). As compared to average Snoqualmie River–provenance strata (for example, units Qc_o and Qa; $Qm_{56\text{-}59}Qp_{26\text{-}31}PF_{13\text{-}14}$), average recessional sands contain little potassium feldspar ($Qm_{\sim41}Qp_{\sim56}PF_{\sim3}$) due to the scarcity of this mineral in metamorphic and plutonic rocks north and northeast of the map area. However, some kames contain slightly elevated potassium feldspar content due to the erosion of adjacent nonglacial Snoqualmie River deposits during deglaciation. (See 'Vashon Stade—The Last Major Continental Glaciation' for more information.)

Qgl_r **Recessional glaciolacustrine (glacial lake) deposits (Pleistocene)**—Silt, clayey or sandy silt, and silty sand, typically with scattered dropstones; may contain lenses and beds of sand or gravel; loose or soft; massive, laminated to thinly bedded, with some varve-like rhythmites; kame lake deposits may contain some soft-sediment deformational features; deposited in large glacial lakes, such as glacial Lake Snoqualmie, or in smaller proglacial lakes formed in kettles or kames or other upland ice-marginal settings. Upward-coarsening sequences may begin as glacial-lake deposits (units Qgl_r and Qgos) grading into overlying terrestrial deposits (unit Qgof) resulting from progradation of fluvial-deltaic complexes. Upward-fining sequences record waning lake sedimentation during ice recession.

Qgos **Outwash sand (Pleistocene)**—Sand and pebbly sand, with some interbeds of silty sand, silt, or gravel; sands typically dark blue-gray; loose or soft; varies from nonbedded to weakly stratified to plane bedded, laminated, and rarely crossbedded. Vertical and horizontal fining trends indicate deposition mostly as shallow-water glaciolacustrine deposits. Unit Qgos complexly interfingers with recessional lake deposits (unit Qgl_r), fluvial deposits (unit Qgof) and deltaic deposits (unit Qgod). Some unit Qgos sands coarsen upward into unit Qgod sands and gravels, and often fine downward to unit Qgl_r silty lake deposits due to deltaic progradation. Sands at critical site 23N display probable tectonic deformation associated with RMF-1 north of Ames Lake as described in Dragovich and others (2007). Geochemically, this unit was derived primarily from an intermediate arc source (Dragovich and others, 2010).

Qgod **Deltaic outwash and kame deltas (Pleistocene)**—Sandy cobble gravel, gravel, pebbly sand, and minor sand; sands typically dark blue-gray weathering to yellowish brown; loose; moderate to well sorted; thin to very thickly bedded and well stratified. Deltas have high-amplitude planar foreset beds graded to temporary ice-dammed lake levels. This unit includes either deltaic front portions of kames or ice-free deltas graded to varying glacial Lake Snoqualmie levels. The delta-front beds of Tolt River and Harris Creek dip west and southwest, respectively (Knoll, 1967). Deltas were fed by upland streams and rivers (represented by unit Qgof) that vigorously incised the newly exposed and unstable upland surfaces. Tolt River delta sediments have a distinct Cascade provenance. Geochemically, sands from this unit are dacitic to rhyolitic and were predominantly derived from an intermediate volcanic arc source (Dragovich and

others, 2010). It is common for deltaic deposits to grade laterally to bottomset beds of glaciolacustrine sand (unit Qgos) and silt or clay (unit Qglr). Braided river gravels (unit Qgof) cap deltas. Non-kame deltas are not kettled and lack other evidence for near-ice deposition and are thus mostly younger than nearby ice-contact deposits. The compound Tolt River delta of Knoll (1967) is a large complex of glaciofluvial, deltaic, and glacial-lake deposits that was sourced by the early Tolt River outwash channel (unit Qgof). The Tolt River delta (1) is likely preserved as a result of the western deflection of the Snoqualmie River by the Holocene Carnation alluvial fan, (2) prograded over older ice-contact deposits in the southeastern part of the map area, and (3) has a persistent glaciofluvial-delta front interface at about 280 to 300 ft in elevation. This elevation is somewhat higher than the Harris Creek (~200-220 ft) or the Cherry Creek (~190-220 ft) delta tops. The Harris Creek delta is also a compound delta and has an inset delta with a dominant delta top of at about 140 ft elevation. The glaciofluvial portion of this delta incised downward into early glacial Lake Snoqualmie deposits (unit Qgl_r) mapped to an elevation of about 300 ft along Harris Creek.

Qgof **Fluvial outwash deposits (Pleistocene)**—Bouldery cobble gravel, gravel, pebbly sand, sand, and rare silt; loose; moderately to well stratified; commonly contains medium to very thick subhorizontal beds, local bar or ripple crossbedding, and rip-up clasts, and lacks ice-contact sedimentary structures and other geomorphic and stratigraphic evidence for nearby ice. Deposited as broad braided-river outwash sediments along valley trains or as topset beds on deltas (unit Qgod), including the Tolt River, Harris Creek, and the Cherry Creek deltas. Valley trains are typically southwest-trending recessional meltwater pathways incised into older glacial deposits. Outwash terraces and meltwater channels generally decrease in elevation to the west and southwest. A complex of terraced fluvial outwash horizons within parts of the Tolt River, Cherry Creek, and Harris Creek deltas, demonstrate that these deltaic complexes are a series of nested deltas with topset fluvial deposits that graded to falling glacial Lake Snoqualmie levels.

Qgic **Ice-contact deposits, undivided (Pleistocene)**—Bouldery cobble gravel, diamicton, silty pebbly gravel, and pebbly sand with lesser sand and silt; loose; mostly moderately stratified and medium to very thickly bedded; variably sorted with abrupt grain-size changes common. Ice-contact primary structures include oversteepened and contorted bedding and other ice-shear or slump features producing variably dipping strata. Soft melt-out, flow, and water-laid diamictons are interstratified with granular supraglacial, englacial, and subglacial meltwater deposits (see subglacial depositional model of Booth, 1984, 1986, 1990). The upper surface is typically hummocky and contains numerous kettle depressions indicating sedimentation in, around, and on stagnant or active ice in moraine and pitted outwash-plain settings. Ice-contact deposits locally are overlain by, or laterally grade into, ice-marginal sandy or silty lake deposits (units Qgos and Qgl_r). Large ice-contact complexes are mapped south of the Tolt River, around Ames Lake and Lake Marcel, and south of Cherry Creek. Includes unit Qgi diamictons of Dragovich and others (2007, 2009a) and some ice contact deposits of Booth (1990). Locally divided into:

Qgik **Ice-contact kames (Pleistocene)**—Sand and gravel, pebbly sand, sand, and cobble gravel, with scattered lenses of diamicton (mostly flow till or melt-out till from buried sediment-laden ice blocks); sands typically dark yellowish gray; loose; medium to very thickly bedded and rarely massive; moderately to well stratified; commonly contains local till or silt rip-up clasts, crossbedding, cut-and-fill structures, and localized oversteepened or slumped bedding; may include some kame delta deposits. Weathering rinds on basalt clasts are 0 to 0.8 mm. Sands from this unit are intermediate to felsic and geochemical affinities suggest that they were predominantly derived from an intermediate arc source (Dragovich and others, 2010). These elevated fluvial-deltaic deposits were mapped where sedimentary structures, geomorphology, and (or) geologic setting imply lateral ice buttressing. A wasting ice tongue occupied the Snoqualmie River and Cherry Creek valleys during ice recession, resulting in perched ice-contact deposits, such as kames, veneering parts of the valley walls (this study; Minard, 1985; Minard and Booth, 1988). Some kames grade laterally into or overlie kame deltas (unit Qgod) and (or) proglacial lake deposits (units Qgos and Qgl_r) forming coarsening-upward deposits. Some kames near RMF-1 contain liquefaction features including chaotic and (or) folded bedding.

Qgog **Outwash gravel deposits, undivided (Pleistocene)**—Poorly exposed bouldery pebble cobble gravel to pebbly sand; loose; massive to crudely bedded; deposited mostly as ice-contact deposits including kame outwash bodies but may include any of the gravelly Vashon recessional facies described above. The map area apparently lacks the distinct late-glacial strandlines mapped as glacial Lake Snoqualmie beach deposits south and southeast of the map area (unit Qgog in Dragovich and others, 2007, 2009a,b).

Advance Proglacial and Subglacial Deposits of the Vashon Stade of the Fraser Glaciation

Sands are a mixture of northern and local Cascade detritus. Advance outwash and lake deposits are characterized as polycrystalline quartz-rich, polymictic sediments—sands contain volcanic lithic clasts (~18%), granitic lithic clasts (~11%), chert–polycrystalline quartz (~17%), plagioclase (~12%), metamorphic lithic clasts (~10%), and sedimentary lithic clasts (~9%) (this study, Dragovich, 2007; Dragovich and others, 2009c). Sands contain more volcanic and sedimentary lithic clasts where deposited near local underlying bedrock. Advance outwash (average ~$Qm_{40}Qp_{54}PF_6$) is similar to other northern-provenance outwash deposits. Advance outwash contains lower amounts of monocrystalline quartz (10–13%) and potassium feldspar (1–3%) than Snoqualmie River–provenance deposits such as the Olympia beds (unit Qc_o, average $Qm_{59}Qp_{26}PF_{14}$). (See 'Vashon Stade—The Last Major Continental Glaciation' for more information.) Bedding is common in Vashon deposits. Beds in advance outwash and lake deposits commonly have a primary dip to the east, southeast and south as a result of glaciofluvial or deltaic deposition away from the advancing ice and into temporary glacially dammed lakes. (See bedding in unconsolidated sedimentary deposits on the map sheet.) Locally, some of this bedding may be tectonically tilted but in general southeasterly dip of the strata records primary bedding sloping away from the ice (for example, along the lee side of fluvial bar deposits or in foreset-bottomset positions of deltas)—thus dipping strata shown by most of the bedding measurements in Vashon Stade strata record modest paleocurrent directions or slopes and not tectonic tilting.

Qgt_v **Vashon lodgment till (Pleistocene)**— Mixture of clay, silt, sand, and gravel (diamicton); grayish blue to very dark gray; locally slightly weathered to mottled yellow-brown; dense; matrix-supported; unsorted with disseminated cobbles and boulders in a silt-sand matrix; unstratified; rare lenses of sand and gravel; locally contains a friable shear fabric. Clast types include both northern-source and local rounded to subangular clasts. This unit may contain angular clasts where directly overlying local bedrock. Basalt-clast weathering rinds are 0 to 0.3 mm (avg. 0.2 mm). Till is generally about 5 to 50 ft thick (cross sections A and B) and was accreted at the base of Vashon ice. Till on the uplands unconformably overlies advance deposits, older Quaternary deposits, and bedrock. Geotechnical borehole data indicate that till locally overlies older Quaternary deposits at shallow depths in the Snoqualmie valley. (In most areas, Vashon deposits mantle valley walls near the wells suggesting that the subsurface diamictons are Vashon till and outwash; however, where nearby stratigraphic constraints are not available some of these deposits could older glacial deposits.)

Qga_v **Vashon advance outwash (Pleistocene)**—Sandy (pebble) gravel, sand, and cobble gravel, with local silt interbeds; sands typically are dark green-gray, weathered yellowish brown; dense; mostly well sorted and stratified; thinly to very thickly bedded; local laminated silt interbeds and (or) rip-up clasts; contains southeasterly dipping deltaic and bar foreset beds, cut-and-fill structures, sand dikes, minor faults, and rare ice-shear structures in some outcrops; may include some kame deposits where advance outwash was deposited against paleogeographic highs such as Union Hill. Basalt clast weathering rinds are 0 to 0.9 mm (avg. 0.1 mm). Sands have a northern provenance (this study, Dragovich, 2007). One sand layer has a predominantly intermediate igneous provenance geochemistry (Dragovich and others, 2010). Unit Qga_v was deposited by streams emanating from the advancing ice front and is complexly interlayered with, conformably overlies, or may locally underlie glacial-lake deposits (unit Qgl_v). Advance outwash is overlain by Vashon lodgment till (unit Qgt_v) along a sharp contact. Composite sections of fluvial-deltaic advance outwash and glacial-lake deposits are fairly thick in the Snoqualmie valley where deltaic deposits graded to local proglacial lake levels during the Puget lobe ice advance to the east-southeast (cross sections A and B). Local radiocarbon ages are 14,500 ±130 yr B.P. (Associated Earth Sciences, 2003; Dragovich and others, 2007) and 14,450 to 14,560 yr B.P. (Porter and Swanson, 1998). Radiocarbon ages for the older Olympia beds (unit Qc_o) provide additional age constraints.

Qgl_v **Vashon advance glaciolacustrine deposits (Pleistocene)**—Silt, clayey silt, pebbly silt, and diamicton; typically contains scattered dropstones and beds or lenses of massive diamicton that may be iceberg melt-out till or flow till; stiff or dense; stratification and sorting variable; varies from massive to thinly bedded, laminated, or varved. Some outcrops contain contorted or folded bedding, sand dikes, fractures and faults. Some lenticular diamicton beds in unit Qgl_v have a till-like appearance. Several exposures are mostly diamicton with thin wispy interbeds of silt or laminated silt and fine sand. Ice-shear structures such as recumbent folds with a vergence to the east-southeast are locally evident in this unit (critical site 51M). Basalt clast weathering rinds are 0 to 1.0 mm (avg. 0.2 mm). Unit Qga_v typically overlies unit Qgl_v regionally, but unit Qga_v underlies thick successions of unit Qgl_v in some areas; in other areas, the two units are complexly interbedded. Facies relations between units Qga_v and Qgl_v, as well as thickness and areal distribution, indicate that one or more large proglacial lakes progressively occupied significant portions of the map area during ice advance (Knoll, 1967; Dragovich and others, 2007, 2009a,b). Unit Qgl_v includes some of the transitional beds of Booth (1990) and correlates with the Lawton Clay mapped elsewhere in the Puget Lowland.

Deposits of the Olympia Nonglacial Interval

Qc_o **Olympia beds of Minard and Booth (1988), Snoqualmie River provenance (Pleistocene)**—Sand, sandy silt, silty sand, silt, clay with some organic silt-clay and minor peat, lesser sand and gravel, and rare cobble gravel; typically yellowish brown-gray with distinctive orange-gray oxidation; dense; laminated to very thickly bedded and mostly well stratified. This unit contains charcoal, disseminated detrital organic matter, trough and ripple crossbedding, graded beds, sand dikes and diapirs, chaotic or folded bedding, and flutes with rare dish structures. Thick exposures of orangish well-bedded sand and silt (fluvial overbank deposits) that form thick upward-fining pebbly sand–sand–silt sequences typical of meandering river systems are the norm. Lenticular beds of sand and gravel represent channel deposits; some exceptionally thick beds of sand are probably levee overbank deposits. Unit Qc_o is the "ancient Snoqualmie River alluvium" ($Qm_{40\text{-}82}Qp_{10\text{-}46}PF_{8\text{-}26}$) of Dragovich (2007) and Dragovich and others (2007, 2009a,b,c). Olympia bed sands at critical site 57H contain monocrystalline quartz (~23%), plagioclase (~21%), volcanic lithic clasts (~16%), granitic lithic clasts (~7%), potassium feldspar (~3%), hornblende-pyroxene (~2%), and mica (~1%) (Dragovich, 2007). Compared to glacial deposits, ancient Snoqualmie River alluvium contains more potassium feldspar (up to 10%) and limited amounts of chert–polycrystalline quartz, and has the same Snoqualmie batholith and Tertiary volcanic signature as units Qc_{pf} and Qc_{ws}. Sands from this unit are geochemically dacitic to rhyolitic, and were predominantly derived from an intermediate arc source (Dragovich, 2007; Dragovich and others, 2010). A few Olympia bed sands on Tolt Hill contain a higher percentage of more diverse lithic grain types. We suspect these beds incorporated older Quaternary sediment as the ancient Snoqualmie River eroded the emerging Tolt Hill growth fold. In other areas, some sands contain slightly more serpentinite, metasedimentary lithic clasts, and polycrystalline quartz suggestive of mixing of ancient Snoqualmie River alluvium with alluvium derived from the Western mélange belt to the east. Unit Qc_o is likely faulted, folded, and uplifted within the RMFZ, forming 'inverted basins' (Dragovich and others, 2007, 2009a,b,c, 2010; Littke and others, 2009). Multiple radiocarbon ages were obtained previously by Associated Earth Sciences (2003, 2005) and Dragovich and others (2007, 2009a,b,c) in quadrangles south of the map area. Olympia bed ages there range from 17,150 yr B.P. to >44,020 yr B.P.. We have obtained several new radiocarbon ages from unit Qc_o in the present quadrangle. Ages of 25,900 ±170 yr B.P. and 27,620 ±200 yr B.P. were obtained from age site 73D (Dragovich and others, 2010). An infinite age (>45,570 yr B.P.) was obtained from a pebbly sand diapir from the same area suggesting that this sedimentary intrusion may be sourced from older nonglacial beds below the Olympia beds. We also obtained two infinite radiocarbon ages of >44,000 yr B.P. from possible Olympia beds south of Duvall at age sites 41C and 41E (Dragovich and others, 2010). A compilation of radiocarbon ages in the Carnation quadrangle and westernmost part of the Redmond quadrangle, including detailed radiocarbon date information and some radiocarbon ages not cited here, are provided in Dragovich and others (2010). We tentatively correlate ancient Snoqualmie River alluvium in this area west of SVF-1 with the Olympia beds because the underlying glacial deposits have weathering characteristics most consistent with the Possession Glaciation. Finally, we obtained a single infrared-stimulated luminescence (IRSL) age of 47.4 ±2.76 ka (~47,400 yr B.P.) from age site 81Z

east of Duvall (Dragovich and others, 2010). Olympia beds include some of the advance outwash or transitional beds of Booth (1990) and correlates with the deposits of the Olympia nonglacial interval of Pessl and others (1989). Locally divided into:

Qc_{ol} **Olympia beds of Minard and Booth (1988), local provenance (Pleistocene)**—Silt, sand, (pebble) gravel, and cobble gravel with some peat and organic sediments; dark yellow-gray with oxidation typical; dense; thickly to thinly bedded and well stratified and sorted. These sediments are located in the subsurface on Union Hill (cross section A) and are exposed in the northeastern part of the map area. These sediments are deposited in alluvial, alluvial fan, and swamp settings and likely represent small ancient tributary basin deposits of limited extent. Unit Qc_{ol} detritus is eroded and recycled from nearby older glacial and nonglacial units and bedrock and has a provenance that is distinct from ancient Snoqualmie River alluvium. For example, unit Qc_{ol} sediments around critical site 31S in the northeastern part of the map area are thinner than ancient Snoqualmie River alluvium and have a lithic mélange belt metamorphic and Tertiary volcanic provenance including clasts derived from the volcanic rocks of Mount Persis of Tabor and others (1993). Geochemically, one sand sample from this unit is rhyolitic, has a predominantly intermediate arc affinity, and is similar to the Holocene Tolt River alluvium sand (Dragovich and others, 2010). These sediments were deposited by westerly flowing streams or rivers. Sand dikes and small faults in unit Qc_{ol} at critical site 31S may be related to the Cherry Creek fault zone (see unit Qtz and Dragovich and others, 2010). Several finite radiocarbon ages derived from the unit Qc_{ol} in boreholes on Union Hill and the informally named Redmond Ridge (west of the map area) range from 29,730 ±260 B.P. to 45,540 ±1,930 B.P. (n = 11). Several radiocarbon infinite ages were also obtained (n = 19) from unit Qc_{ol} from along the westernmost part of the Carnation quadrangle and near the quadrangle in the Redmond 7.5-minute quadrangle (Saltonstall and others, 2003; Associated Earth Sciences, 2001a,b, 2002, 2003, 2004, 2007, and Associated Earth Sciences, Inc., unpublished data). Of the above-described samples, six finite samples and nine infinite samples are located within 1 mile of the Carnation quadrangle in the Redmond quadrangle as documented in Dragovich and others (2010). For example, an infinite age (>45,600) was obtained from a site west of EB-3 by Associated Earth Sciences (2007). Associated Earth Sciences (2004) also obtained ages of 38,430 ±200 and 35,210 ±200 yrs B.P. from borings west of critical sites B16 and G-1,H-2 as well as ages of 39,750, >45,850, >45,220, and >46,310 yrs B.P. from exploration pits at age site AESI-7. (See appendix 1 of Dragovich and others, 2010, for a more detailed compilation of the radiocarbon ages.)

Deposits of the Possession Glaciation

Qgt_p **Lodgment till (Pleistocene)**—Nonstratified, unsorted mixture of clay, silt, sand, and gravel (diamicton), commonly with disseminated cobbles and boulders in a silt-sand matrix; weathered to light tannish brown; very dense; massive and matrix-supported. Clast types include northern-provenance and locally derived, rounded to subangular clasts. Basalt clasts have 0.1 to 3.0 mm (avg. 0.9 mm) weathering rinds. See unit Qgo_p for age and correlation information.

Qgo_p **Outwash (Pleistocene)**—Fluvial (cobble) gravel to pebble gravel and (pebbly) sand and minor silt; sands typically yellowish to brownish to gray or green weathered to orange or reddish; very thick crudely stratified beds are typical; gravels imbricated locally; sands laminated or medium bedded with crossbedded and scoured surfaces; very dense. Basalt clast weathering rinds are non-existent to 0.8 to 1.0 mm (avg. 0.9 mm). This unit contains northern-provenance and locally derived, rounded to subangular clasts. Sands contain chert-polycrystalline quartz (~21%), volcanic lithic clasts (~15%), granitic lithic clasts (~11%), plagioclase (~9%), metamorphic lithic clasts (~9%), and sedimentary lithic clasts (6–15%) (this study; Dragovich, 2007; Dragovich and others, 2009c). Sands contain low amounts of monocrystalline quartz and potassium feldspar relative to nonglacial units and have, on average, $Qm_{35}Qp_{61}PF_4$ composition similar to other glacial outwash such as advance outwash and recessional glacial deposits ($Qm_{40\text{-}41}Qp_{54\text{-}56}PF_{3\text{-}6}$). Geochemically, sands from this unit are rhyolitic and have

intermediate arc province affinities (Dragovich and others, 2010). Relative stratigraphic position for the deposits of the Possession Glaciation in the map area are best constrained on the eastern slopes of Union Hill where older silty glaciomarine diamicton (reactive to dilute hydrochloric acid [HCl]), till, and outwash deposits occur under well-dated Olympia beds (unit Qc_{ol}) and above the Whidbey Formation (unit Qc_{ws}), which is dated at about 120 to 128 ka (cross section A). Elsewhere, this unit is tentatively correlated with the Possession Glaciation on the basis of stratigraphic position and weathering characteristics, but may include Double Bluff Drift in some areas. The Possession Glaciation occurred from about 60,000 to 80,000 yr B.P. This unit includes part of the transitional beds or advance outwash of Booth (1990).

Qgl_p **Glaciomarine and glaciolacustrine deposits (Pleistocene)**—Silt, silty clay, and silt with scattered gravel (dropstones) with lesser sand and diamicton; hard or dense; moderately to well sorted and typically massive or moderately stratified with laminations common. Basalt clast weathering rinds are 0.2 to 1.2 mm (avg. 0.8 mm) but clayey glaciomarine deposits have little or no rind development due to impermeability. Diamictons and silts with scattered gravels on Union Hill and Redmond Ridge west of the study area are probable glaciomarine drift (reacts with HCl). These deposits are probable distal marine deposits with dropstones (stones dropped from melting icebergs). Elsewhere in the quadrangle, sandier textures and non-reaction with HCl suggests deposition as glaciolacustrine sediments. This unit may include submarine flow tills or lodgment till. This unit is commonly interstratified with outwash (unit Qgo_p) and in some areas the nature of the interfingering between glaciolacustrine and outwash bodies suggests deltaic deposition. See unit Qgo_p for additional age and correlation information. This unit may include portions of the Pepper Creek diamict of Associated Earth Sciences (2004).

Whidbey Formation

Qc_{wp} **Whidbey Formation, Puget Group provenance (Pleistocene)**—(Cobble) gravel and pebble gravel with lesser sand and locally with silt, clay, peat, and rare thin beds of tephra; sands are yellowish gray to brown weathering to an orange-gray and typically mildly iron-stained; some strata contain disseminated organic material, logs, or sticks; dense or hard; mostly well stratified and sorted and thinly laminated to very thickly bedded; subangular to subrounded clasts typical. Some sands have ripple cross bedding. Thick to very thick beds of interstratified cobble gravel, gravel, and sandy gravel with thin lenses and beds of coarse sand dominate this unit. Gravels are typically clast supported with a weathered coarse sand matrix. Gravels clasts are dominantly andesite and basaltic andesite (31-55%), with some feldspathic or volcanic sandstone, siltstone, tuff, minor vein quartz, basalt, porphyry, granite, shale, chert, and quartzite. Andesite and basalt weathering rinds are 0.2 to 1.9 mm (avg. 0.9 mm). Sands ($Qm_{35\text{-}42}Qp_{50\text{-}60}PF_{5\text{-}8}$) are distinctly volcanic lithic and contain volcanic clasts (69-77%), sedimentary lithic clasts (2-8%), polycrystalline quartz (~6%), monocrystalline quartz (~3%), plagioclase (~2%), granitic lithic clasts (1-4%), and potassium feldspar (~1%) with some hornblende, pyroxene, biotite, and serpentinite (Dragovich and others, 2007; critical sites 23L and 51Z). Dragovich and others (2010) demonstrate that the sands are dacitic to rhyolitic and were predominantly derived from an intermediate arc source with a mafic component. The mild to strong weathering observed in the field is confirmed both petrographically and geochemically (moderate chemical index of alteration) (Nesbitt and Young, 1984; Dragovich and others, 2010). Unit Qc_{wp} is mapped in the southwestern part of the study area where it is about 100 to 200 ft thick (cross section B). Dominance of coarse gravel and cobbles and stratigraphic style suggests deposition as moderate- to high-energy braided-river deposits. A Puget Group provenance is indicated by the andesite–feldspathic ('arkosic') sandstone–siltstone provenance of gravel and sand deposits and northerly paleoflow indicators. We envision a drainage system emanating from the Seattle uplift similar to, but likely wider than, the modern Raging River valley (Raging River alluvium has a strong Puget Group provenance). Some two-pyroxene andesite gravel clasts are petrographically similar to the volcanic rocks of Snoqualmie Falls south of the map area (Dragovich and others, 2009b,c) and thus that formation may also be a source of detritus for the unit. Bedding plane geometries, stratigraphic relationships, and unit thicknesses suggest the Snoqualmie River–provenance Olympia beds (unit Qc_o) on Tolt Hill overlie the Whidbey Formation along an angular unconformity, and were deposited as inset beds against the Whidbey Formation. On cross section B we infer (1) deposition of the Olympia beds over an emerging

growth fold resulting in a presently inverted Olympia basin, and (2) that unit Qc_{wp} interfingers with Snoqualmie River–provenance fluvial deposits of the Whidbey Formation (unit Qc_{ws}) along the eastern limb of the Tolt Hill anticline. This interface between these river systems could have produced a large alluvial fan similar to the Raging River fan under Fall City (Dragovich and others, 2007). We obtained an infinite radiocarbon age (>44,000 yrs B.P.) from peat at age site 30E above Patterson Creek in the southwestern part of the map area (Dragovich and others, 2010). As further described in Dragovich and others (2010), a tephra bed adjacent to the peat contains homogenous white pumice that is likely correlative with Glacier Peak pumice found in the Whidbey Formation (~80,000–130,000 yr B.P.) on Whidbey Island, southwest of Oak Harbor, where the pumice has been Ar-Ar age dated to about 128,000 ka. This age is similar to the IRSL age of unit Qc_{ws} (~122-128 ka). See Dragovich and others (2007, 2009a,b) for previous mapping of the Whidbey Formation south of the map area.

Qc_{ws} **Whidbey Formation, Snoqualmie River provenance (Pleistocene)**—Sand, silt, and silty sands with lesser pebbly sand, clay, gravel, organic sediments including peat, and rare lenses or beds of diamicton and (cobble) gravel; sands are yellow-gray or brown and weathered to a distinctive orange-gray; dense or hard; well sorted and stratified; mostly occurs as laminated to thickly bedded sands and silts with thin beds or laminae of clay locally; commonly plane bedded; may contain charcoal, disseminated organic matter, trough and ripple crossbedding, graded beds, flutes, flames, sand dikes, and dish structures; folds and chaotic bedding are evident in liquefied areas (see unit Qtz). Sands are generally lithic poor and contain abundant monocrystalline quartz (~20%) with lesser plagioclase and potassium feldspar with some polycrystalline quartz and sedimentary, metamorphic, volcanic, and granitic lithic clasts. Fine sands and silty fine sands contain minor but significant hornblende and mica similar to other ancient Snoqualmie River–provenance and modern Snoqualmie River sands (units Qa, Qc_o, and Qc_{pf}). Geochemically, the sands are rhyolitic and predominantly derived from an intermediate arc source (Dragovich and others, 2010). Sedimentary structures, stratification style, and provenance indicate that the unit was deposited as ancient Snoqualmie River alluvium. Unit Qc_{ws} is exposed on the eastern limb of the Union Hill anticline in the western part of the map area where the unit is inferred to be about 25 to 200 ft thick and generally tilted to the east-northeast. The thinning of the easterly dipping strata towards the Union Hill fold axis suggests the inferred structure is a growth fold (cross section A). The position of the unit directly west of the main strand of the RMFZ combined with deformation and liquefaction of this unit adjacent to this regionally active fault zone suggest uplift of the Whidbey Formation in this locale. In this model, the unit may represent another inverted basin within the broad RMFZ-SWIF (Dragovich and others, 2007, 2009b,c). We obtained an infinite radiocarbon age of >43,000 yrs B.P. at age site 25C-1 from tectonically deformed and liquefied organic sands and silts (Dragovich and others, 2010). We obtained an IRSL age of 120 ±10.9 to 128 ±14.1 ka (~120,000–128,000 yrs B.P.) at age site WA-47 (Dragovich and others, 2010; Associated Earth Sciences, Inc., unpublished data) and correlate these strata with the Whidbey Formation on the basis of this age and stratigraphic position.

Double Bluff Drift

Qgd_d **Double Bluff Drift (Pleistocene)**—Dominantly pebbly silt and silty diamicton, with some silt, gravel, and gravelly sand, and locally with coarse sandy pebble gravel and sand; sands are dark yellowish to brownish gray with orange-gray weathering; dense to very dense; moderately to well sorted and stratified; medium to thickly bedded with thick beds of silty diamicton common. Exposures near RMF-1 are faulted, fractured, and liquefied and contain pervasive sand dikes and disrupted bedding (see unit Qtz). Basaltic clasts have 0.6 to 1.2 mm weathering rinds. Sands are polymictic with significant polycrystalline quartz and variable lithic clasts including metamorphic and granitic lithic grains consistent with a northern glacial source. Sands from this unit are rhyolitic and predominantly have intermediate arc geochemical affinities (Dragovich and others, 2010). Sand dikes and other injection features in some exposures near RMF-1 have a Snoqualmie River provenance. We suspect these sands are sourced by older nonglacial deposits (unit Qc_{pf}) inferred to be locally under unit Qgd_d on cross section A. Double Bluff Drift is inferred to be up to about 75 ft thick on cross section A, and may extend to the southeast near Ames Lake (cross section B). This unit was deposited mostly as glaciolacustrine dropstone-bearing silty sediments but also includes some lodgment till and probable gravelly fluvial-deltaic deposits. This drift is only

mapped west of RMF-1 but we cannot exclude the possibility that some glacial deposits mapped as Possession are Double Bluff Drift (see unit Qgo_p). The best exposures occur on the eastern limb of the Union Hill anticline underneath unit Qc_{ws} in the western part of the map area, where the unit is tilted to the east-northeast (cross section A). Subsurface data suggests that the unit was eroded off the axis of the Union Hill fold prior to deposition of the Possession glacial deposits (cross section B). Weathering characteristics as well as stratigraphic position below nonglacial deposits dated at about 122 to 128 ka (unit Qc_{ws}) suggest correlation with the Double Bluff Drift (~130-180? ka) of Easterbrook and others (1967). These deposits are distinctly less weathered than some older glacial tills in the Snoqualmie valley such as unit Qgd_{pd} (described below) or tills in unit Qgn_{pf} of Dragovich and others (2009b,c) south of the map area.

PRE-FRASER GLACIAL AND NONGLACIAL DEPOSITS, UNDIVIDED

Qc_{pf} **Continental nonglacial deposits, pre-Fraser (Pleistocene)**—Snoqualmie River–provenance sand, silt, clay with some organic silt-clay and peat, lesser pebbly sand and gravel, and rare cobble gravel deposited prior to the Fraser Glaciation; sands typically yellow-brown-gray, weathering to a distinctive orange-gray; dense; laminated to very thickly bedded and mostly well stratified; may contain charcoal, disseminated organic matter, trough and ripple crossbedding, graded beds, flutes with sand dikes, and flames; distorted or destroyed bedding evident in liquefied areas (see unit Qtz). This "ancient Snoqualmie River alluvium" (Dragovich, 2007; Dragovich and others, 2007, 2009a,b,c) is very similar stratigraphically and compositionally to other Snoqualmie River–provenance units such as the Olympia beds (unit Qc_o); their geochemistry is also broadly similar (Dragovich, 2007; Dragovich and others, 2010). Sands have a Snoqualmie batholith and Tertiary volcanic compositional signature and contain significant monocrystalline quartz (~10–20%), plagioclase, volcanic and sedimentary lithic clasts, granitic lithic clasts, and potassium feldspar. Similar to the Olympia beds, the silty fine sands and silts contain significant green pleochroic hornblende and biotite. The ratio of monocrystalline quartz to polycrystalline quartz is distinctly high and comparable to units Qc_{ws}, Qc_o, and Qa. Geochemically, sands are dacitic to rhyolitic and were predominantly derived from an intermediate arc source (Dragovich and others, 2010). However, one sample is andesitic in composition, and has an immature "island-arc" geochemical affinity (geochemical sample 37D in Dragovich and others, 2010). Unit Qc_{pf} is mapped in the subsurface across much of the quadrangle and is inferred to be up to 500+ ft thick on cross sections A and B. On these cross sections, thick successions of sand and silt with some clay and a few beds of gravel are correlated with unit Qc_{pf}. Strata in these intervals contain many reports of peat, wood, sticks, and logs indicative of nonglacial deposition, and lack reports of diamictons, hardpan, or thick beds of coarse (cemented) gravels as are commonly correlated with glacial intervals. We suspect but cannot prove that the full thickness of this unit is ancient Snoqualmie River alluvium—some could be correlative with the "Puget Group provenance" Whidbey Formation (unit Qc_{wp}) or have a Cascade provenance similar to the modern Tolt River or unit Qc_{ol}. Stratigraphic style and dominance of sands and silts suggests deposition as thick fining-upward gravel-sand-silt sequences typical of meandering river systems, such as the modern Snoqualmie River where thick successions of thinly bedded sand and silt likely represent overbank deposits. Sand dikes are widespread and very commonly have a Snoqualmie River provenance. This observation suggests that ancient Snoqualmie River alluvium occurs widely in the subsurface. Although shown as a semi-continuous geologic unit on cross sections A and B, we suspect the unit represents several nonglacial intervals and thus would have many lateral and horizontal unconformities. Dragovich and others (2007, 2009a,b,c) postulate ancient Snoqualmie River sequences up to 800 ft thick south of the quadrangle within fault-controlled transpressional or transtensional basins along the RMFZ; later uplift has inverted some of these basins. The widespread occurrence of fault-trapped alluvial basins containing ancient Snoqualmie River alluvium suggests long-term fault control of the Snoqualmie River within the RMFZ–SWIF. This is supported by the wide distribution and thickness of Snoqualmie provenance units of variable age (see 'Qc' units). Above Cherry Creek, we obtained a radiocarbon age of >44,000 yr B.P. at age site 43G. This site is east of the approximately 47 ka IRSL age site derived from the Olympia beds (unit Qc_o), but because the 'infinite' age is on the opposite side of the Cherry Valley fault, we include strata around age site 43G in the undivided unit Qc_{pf}, not the Olympia beds. In the map area, unit Qc_{pf} deposits are older than Fraser glacial deposits and thus are correlative with the Olympia beds (unit Qc_o) or

pre-Olympia nonglacial units. Where unit Qc_{pf} occurs under glacial deposits we correlate with the Possession Glaciation, unit Qc_{pf} is likely equivalent to the Whidbey Formation or pre-Whidbey nonglacial sequences.

Qgn_{pf} **Glacial and nonglacial deposits, pre-Fraser, undivided (Pleistocene to Pliocene?) (cross sections only)**—Mostly (boulder) gravel, sand and gravel, sand, silt, clay, diamicton, and some wood or peat; dense to very dense. The few wells or boreholes that penetrated this undivided geologic unit encountered mostly coarse gravels and diamicton or hardpan suggestive of glacial deposits. However, available data are limited and can be used only to suggest undivided glacial or nonglacial deposits that are older than pre-Fraser continental deposits (unit Qc_{pf}) on cross sections A and B. Unit Qgn_{pf} is mostly overlain by unit Qc_{pf} and thus is demonstrably older than the Olympia nonglacial interval or the Possession Glaciation depending upon the inferred local stratigraphic arrangement. Because unit Qgn_{pf} locally occurs below units Qgd_{d} and Qgd_{pd} on the cross sections, we infer that these deposits locally are older than the Double Bluff Drift or could be correlative with older glacial deposits elsewhere in the Snoqualmie valley, including the highly weathered tills and outwash in unit Qgn_{pf} of Dragovich and others (2009b,c) southeast of the map area. Dragovich and others (2007, 2009a), Booth (1990), and Knoll (1967) also describe older glacial and nonglacial deposits elsewhere in the region.

Qgd_{pd} **Glacial drift, pre–Double Bluff Drift (Pleistocene)**—Poorly exposed gravelly clayey silty gravel (diamicton) and cataclasite exposed northeast of Carnation along 329th Avenue NE ; reddish brown; medium dense to dense; angular to subrounded clasts; massive and poorly sorted. This unit contains evidence of deformation including minor faults, slickensides, and associated fracturing. Gravel clasts include andesite, basaltic andesite, and basalt with lesser gabbro, granite, amphibolite, tuff, and ultramafite. Basalt clasts have weathering rinds up to 2 to 4 mm. Deposits are likely sheared and faulted within and adjacent to unit Qtz of SVF-1. Shallow bedrock under the mapped outcrops is suggested by the presence of angular andesite clasts in the till. Weathering characteristics and stratigraphic position suggest a mid- to early Pleistocene age older than the Double Bluff glacial deposits, which are significantly less weathered. We tentatively correlate a few diamicton beds described only in well reports to unit Qgd_{pd} as shown the cross sections. See unit Qgn_{pf} above for references to older glacial deposits in the region.

Tertiary Volcanic and Sedimentary Rocks

Mvc **Volcanic and sedimentary rocks (Miocene) (cross sections only)**—Nonmarine volcanic to tuffaceous sandstone, volcanic to polymictic conglomerate, tuff, claystone, siltstone, and lignite; may locally contain andesite flows and breccia with some petrified logs (petrified wood is common in the map area and not restricted to this unit). These rocks are mostly friable, well sorted, and massive to crossbedded where described south to southwest of the map area (Yount and Gower, 1991; Dragovich and others, 2007). Porphyritic andesite or basalt is the most common rock type in the conglomerate. Dragovich and others (2007) report that some of the volcanic Miocene sandstones and conglomerates southwest of the map area are hyperconcentrated flood deposits (lahar runout) deposited in a fluvial basin; these sandstones are composed of moderate to well-sorted andesitic clasts (~85%), plagioclase ± quartz, and minor exotic clasts. Dragovich and others (2009b, fossil site 61E) map a poorly lithified tuffaceous siltstone directly southeast of the present study area; these rocks contain deciduous leaf fossils and could be a small exposure of Miocene sediments. Miocene deposits exposed along the eastern part of the Seattle basin are predominantly fluvial volcaniclastic deposits with interbedded tuffs that are distal to volcanic centers. However, the Miocene volcanic rocks of Snoqualmie Falls mapped by Dragovich and others (2009b) located south-southeast of the map area are mostly andesitic flows and breccias that emanated from a volcanic center near Snoqualmie Falls. We infer that unit Mvc overlies the Blakeley Formation on cross sections A and B. Ages south and southwest of the map area include (1) hornblende K-Ar ages of 9.3 to 14.7 Ma (Yount and Gower, 1991), (2) an Ar-Ar laser fusion age of 11.40 ±0.61 Ma (Dragovich and others, 2002), and (3) middle Miocene pollen flora in lignites and siltstones (Sherrod, 2002). Pebbly sandstones and lithic vitric lapilli tuff are exposed 1,000 to 2,000 ft directly north of the northwest corner of the Carnation quadrangle on Snoqualmie Valley Road. We obtained a preliminary $^{206}Pb/U^{238}$ zircon age

of ~18 Ma from sample 09-54Z. from the lapilli tuff (See Dragovich and others, 2010, for further details). This age is derived from the youngest zircons in the zircon population and is interpreted to reflect the deposition of this pyroclastic deposit. The dark gray-green lapilli tuff is composed of andesite (~40%), plagioclase (~20%), pumice (~10%), and a few scattered exotic grains of polycrystalline quartz and sedimentary lithic grains set in a matrix of volcanic glass. The poor sorting, angularity of most grains, high proportion of volcanic clasts, and glassy matrix suggests deposition of the tuff as a pyroclastic flow. The brown-gray pebbly sandstones outcrops near the lapilli tuff are very thickly bedded and contain about 95 to 98 percent subrounded andesite clasts with a few plagioclase, polycrystalline quartz, and greenstone clasts, and are probably fluvial deposits or volcanic hyperconcentrated flood deposits. The bedding style of the sandstones and pebbly sandstones near the pyroclastic deposits suggests deposition in a fluvial or deltaic setting. The age indicates the sample is Miocene and, given the pyroclastic nature of the deposit, likely a distal equivalent of the volcanic rocks of Snoqualmie Falls of Dragovich and others (unit Mva_s; 2009b,c) mapped in the Snoqualmie quadrangle southeast-southeast of the sample site. The volcanic rocks of Snoqualmie Falls are named in Dragovich and others (2009a). Dragovich and others (2009a,b,c) obtained U-Pb zircon ages of 18.25 ±0.43 Ma, 22.26 ±0.57 Ma, and 22.76 ±0.33. We suspect that distal Miocene volcanic and volcaniclastic deposits are preserved in restricted strike-slip basins of the SWIF (cross sections A and B). Unit Mvc may be chronostratigraphically equivalent to the volcanic rocks of Snoqualmie Falls of Dragovich and others (2009b,c) directly southwest of the map area, the nonmarine Blakely Harbor Formation of Fulmer (1975) near Seattle, and (or) the informally named Vasa Park tuff of Sherrod (2002).

OEn, OEc **Blakeley Formation (Oligocene to latest Eocene?) (cross sections only)**—The two subunits are separated by their depositional environments. Unit OEn includes nearshore to marine feldspathic to lithic (tuffaceous) sandstone, conglomerate, tuff, and minor siltstone and shale. Unit OEc includes fluvial-deltaic lithofeldspathic to lithic volcanic sandstone or conglomerate, tuffaceous siltstone, siltstone, claystone, tuff, and lapilli tuff. Both units are mostly well bedded and stratified, and laminated to thickly bedded. The Blakeley Formation in the eastern part of the Seattle basin is rich in volcanic lithic sedimentary and tuffaceous rocks derived from Cascade volcanic provenance to the east, and generally contains quartz, feldspar, and lithic volcanic grains in varying amounts. The depositional environment for the formation near the study area suggests that the nearshore marine-deltaic-fluvial transition occurs within the map area (cross sections A and B). For example, sedimentary rocks southeast of the map area may be equivalent to the fluvial portion of the Blakeley Formation (Dragovich and others, 2009b,c). In that area, poorly to well sorted sandstones and siltstone contain abundant coalified plant fossils, including *Equisetum* fossils. Oil-bearing strata reported from a deep water well (Walsh and Phillips, 1982) near the city of Snoqualmie southeast of the map area are tentatively correlated with the marine portion of the Blakeley Formation by Dragovich and others (2009b,c). This apparently "live oil" is inferred to be trapped in an anticlinal structure within the Snoqualmie basin preserved within the RMFZ. Dragovich and others (2007) inferred thrusting of the Puget Group over mostly Blakeley Formation within the Seattle fault zone directly south of the map area. Directly northwest of the map area in the Maltby quadrangle, Minard (1985), Capps and others (1973), and Yount and Gower (1991) correlate shale, siltstone, sandstone, pebble conglomerate, fossiliferous shale, and thin nonmarine coal beds to the Blakeley Formation and (or) rocks of Bulson Creek of Marcus (1981). In the Fiddlers Bluff area of the Maltby quadrangle, siltstones and sandstones contain middle to upper Oligocene shallow-water (0-120 ft) pelecypods and other marine fossils (Lindquist, 1957). More generally, in the axial part of the Seattle basin west of the map area, the Blakeley is up to about 5,000 to 7000 ft thick and transitions upward from nonmarine sedimentary rocks (fluvial-deltaic) in the lower part of the section to neritic and bathyal (deep water) sedimentary rocks in the upper part of the section (Fulmer, 1975; Rau and Johnson, 1999). The Blakeley may thin to about 1,600 ft thick over the Kingston arch in the northern part of the Seattle basin west of the Carnation quadrangle. Turbidites are common in the marine part of the section. Gravity and aeromagnetic data combined with our mapping suggest that the edge of the Seattle basin is the broad SWIF-RMFZ in the map area (Dragovich and others, 2010; Sherrod and others, 2008). On the basis of geophysical modeling and local field relations, we infer on cross sections A and B that (1) the Seattle basin is fully truncated by SVF-1, (2) that a thick section of nearshore and marine Blakeley strata occurs west of RMF-1, (3) marine Blakeley rocks on the western border of the map likely contain interbedded

magnetic pyroclastic deposits, (4) the lower nonmarine portion of the Blakeley (unit OEc) interfingers with the shallow- to deep-water marine Blakeley (unit OEn) in the subsurface, and (5) the lateral gradation from nonmarine to marine-deltaic occurs in and near the study area. We thus postulate an increased thickness of nonmarine strata (unit OEc) to the east on cross sections A and B. Middle to late Oligocene foraminifera (Zemorrian Stage) are typical (Fulmer, 1975; Walsh, 1984), but there are late Eocene foraminifera (Refugian Stage) in the lower part of the unit (Walsh, 1984; Yount and Gower, 1991; Rau and Johnson, 1999). However, the Restoration Point Member of the Blakeley Formation on Bainbridge Island may span only the latest Oligocene to earliest Miocene (Prothero and Nesbitt, 2008). Near the map area, Sherrod (2002) report a fission-track age of 31.6 ±2.1 Ma from the Blakeley Formation.

Evs_p **Volcanic rocks of Mount Persis of Tabor and others (1993), volcaniclastic and volcanic rocks, undivided (Eocene)**—Interbedded volcanic lithic (tuffaceous) sandstone, tuffaceous siltstone, lahar and volcanic (boulder) conglomerate, porphyritic andesite flows, andesitic to dacitic lithic to crystal lithic breccia, tuff breccia, and crystal lithic to lithic to vitric tuff, with minor silty shale, claystone, and coal; dark brown-gray to yellow-brown, buff, or maroon; flows are andesitic but tuffs are rhyolitic (Dragovich and others, 2009c, 2010). The geochemistry of this unit suggests that it originated from a calc-alkaline arc that had an enriched mafic source which underwent minor amounts of assimilation (Dragovich and others, 2009b,c, 2010). Although we have not observed them, rare basalts have been reported by Tabor and others (1993) from the unit. Volcaniclastic sections are mostly moderately to well stratified and typically contain interbedded flows, tuffs, and breccias (some described in detail below). Cataclasite is common within the broad Cherry Creek fault zone. Strata vary from massive to medium to thickly bedded, with leaves, stems, and fragments of black carbonized or brown petrified wood most common in volcaniclastic sections. Plant remains consist mostly of fragments of broadleaf trees and stems of rushes similar to modern *Equisetum* (Danner, 1957, and this study). Lithic sandstones are distinctly volcanic rich with abundant andesite clasts, but also locally contain altered volcanic glass, plagioclase, and a few grains of polycrystalline quartz and sandstone-siltstone. However, sedimentary-metamorphic clast-rich lithic sandstones with a local Tertiary volcanic and (or) Western mélange belt (unit KJm) provenance occur in this unit southeast of the map area (Dragovich and others, 2009b). Danner (1957) estimates the formation to be up to about 900 ft thick directly north of the map area, which is consistent with our maximum thickness shown on cross sections A and B. The volcanic rocks of Mount Persis in the map area are mostly distal volcaniclastic fluvial deposits (unit Evs_p) with lesser pyroclastic and airfall deposits (tuffs and breccias; unit $Evbx_p$) distal to the volcanic center(s) which lie east or northeast of the map area (cross sections A and B). As is typical of fluvial deposits, unit Evs_p strata commonly thicken, thin, or pinch out along strike. The dominance of tuffs and volcanic-rich sedimentary rocks over coarse volcanic breccias and flows suggests a distal volcanic fluvial depositional setting for the map area. Conversely, the dominance of flows and coarse breccia towards Mount Persis and Youngs Creek headwaters (Tabor and others, 1993) points to a volcanic center or centers east to northeast of the study area, which is also supported by more strongly magnetic units on the eastern ends of the cross sections from geophysical modeling (Dragovich and others, 2010). The volcanic rocks of Mount Persis unconformably overlie the Western mélange belt across a broad area northeast, east, and southwest of SVF-1 (Dragovich and others, 2009b,c; Tabor and others, 1993; Danner, 1957). West of SVF-1 on cross sections A and B, we infer that the Mount Persis unit underlies the Blakeley Formation (units OEn and OEc). Tabor and others (1993) assigned a late Eocene age to the volcanic rocks of Mount Persis on the basis of a poor apatite fission-track age (47.4 Ma), a hornblende K-Ar age (38.1 Ma), and the observation that our unit Eva_p is intruded by the Index batholith (34 Ma) and mafic dikes (33 Ma) east of the map area. Dragovich and others (2009b,c) obtained a U-Pb zircon age of 36 ±2.3 Ma (late Eocene) from a thick felsic tuff bed located 4 miles southeast of the map area. We suggest that the actual age of the Mount Persis unit is best represented by our 36 ±2.3 Ma age because this determination is based upon individual zircon grain ages. (Some K-Ar and fission track ages effected by post-depositional alteration and similar problems.) We further suggest that the unit overall is late Eocene in age (~35-38 Ma). Because of this inferred age we suggest that the distal volcanic rocks of Mount Persis interfinger with the top of the youngest part of the undivided Puget Group (Renton Formation; unit Evs_{pg}) on the western parts of the cross sections. We suspect that the Mount Persis unit (1) thins to the west, (2) contributes volcaniclastic detritus to Eocene

rocks within the Seattle basin, and (3) is dominated by distal volcaniclastic and tuffaceous strata in subsurface below the westernmost part of this quadrangle. (See gravity and magnetic data in Dragovich and others, 2010.) Locally divided into:

Eva_p **Volcanic rocks of Mount Persis, andesite flows (Eocene)**—Calc-alkaline andesite flows (~59-62% SiO_2) and rare flow breccia; greenish gray, dark green, or gray, weathered to dark reddish brown-gray to bluish black and locally weathered or altered to maroon-gray or yellow-brown-gray; flows typically massive but locally show flow structure and well-formed columns; flows rarely amygdaloidal and pillowed (this study; Danner, 1957); contains phenocrysts of plagioclase and augite ± hypersthene and rare chloritized hornblende; locally contains quartz microphenocrysts and a glomerophyric texture. Geochemically, these flows most likely originated from a continental arc source (Dragovich and others, 2010). Magnetically, hand samples have a moderately strong susceptibility (greater than 11 x 10^{-3} SI). Rocks are locally strongly chloritized, silicified, and (or) generally altered, particularly near tectonic zones (unit tz). Flows are approximately 30 to 100+ ft thick. Thick flows are likely compound lava flows. Unit Eva_p flows mapped in the area are likely lenticular canyon flows. Magnetic highs in the northeastern part of the map area east of SVF-1 likely reflect a greater percentage of unit Eva_p flows in the shallow subsurface (Dragovich and others, 2010). cross sections A and B show a greater concentration of andesite flows to the northeast consistent with (1) magnetic susceptibility data (Dragovich and others, 2010), and (2) regional field information indicating an overall greater amount of proximal volcanic rocks to the northeast (this study; Danner, 1957; Tabor and others, 1993). We suspect the volcanic center(s) for the volcanic rocks of Mount Persis is towards Mount Persis and may be discovered near the Youngs Creek headwaters east to northeast of the study area

$Evbx_p$ **Volcanic rocks of Mount Persis, volcanic breccia (Eocene)**—Andesitic to dacitic lithic tuff breccia and lapilli tuff; multicolored but generally gray-brown to dark green-gray with brownish weathering; volcanic clasts vary from subrounded to subangular; mostly moderately to poorly sorted and stratified. Breccia beds are generally very thick and massive. Clasts are mostly two-pyroxene andesite similar to the andesite flows in the complex (unit Eva_p), but some pyroclastic breccias also contain clasts of semi-vesicular light green dacite (~66% SiO_2) set in a clear glassy matrix with scattered small grains of augite. Geochemically, a breccia from this unit is very similar to unit Eva_p flows, and most likely originated from a continental arc source (Dragovich and others, 2010). Some andesitic tuff breccia also contains greenstone, metasandstone, and metachert clasts (Danner, 1957). Volcanic breccia is typically poorly exposed but likely mostly represents pyroclastic flow deposits including possible dome collapse breccia, but may include some flow breccia. The dacitic composition of some clasts in the map area suggests that part of the unit may correlate with the hornblende dacite breccia of the volcanic rocks of Mount Persis of Tabor and others (1993) northeast of the map area.

Evl_p **Volcanic rocks of Mount Persis, lahars (Eocene)**—Cohesive to noncohesive lahar and volcanic (boulder) conglomerate; clasts dark gray commonly weathered or altered to gray-green; contains subrounded to subangular cobbles to boulders of andesite (~60% SiO_2) with a few rip-up clasts of petrified wood or volcanic sandstone and siltstone fragments; varies from matrix-supported lahar to clast-supported hyperconcentrated flood deposits or volcanic alluvium; weathering masks some original textures, but the lahar matrix generally varies from volcanic sand to ashy, silty, clayey sand and is locally semi-cohesive. Geochemically, one clast from unit Evl_p most likely originated from a continental arc source; however, it has a higher aluminum saturation index and more depleted mantle signature than other Mount Persis samples, which could be the result of more extensive chemical weathering (chemical index of alteration = 0.67) (Dragovich and others, 2010). Unit Evl_p occurs as very thick massive beds with possible subtle overall grading. Clast composition (~95-100% andesite) and moderate to poor sorting suggest deposition mostly as lahars. Danner (1957) describes andesitic boulder conglomerate with shale lenses directly north of the map area that are likely fluvial deposits.

Contacts are generally poorly exposed, but in Cherry Creek a thick lahar overlies dark red tuffaceous siltstone. The spatial association with volcaniclastic fluvial sedimentary rocks suggests deposition as lenticular beds within valleys emanating from a volcanic highland east-northeast of the map area. (See 'volcanic center' in units Evs_p and Eva_p.) Geochemical and petrographic analyses of lahar clasts indicate that the original flows were sourced by andesitic lavas exhibiting pervasive silica, K-feldspar, and clay alteration (Dragovich and others, 2010). Zones of alteration around andesitic stratovolcanoes can lead to edifice instability and collapse, and can lead to the generation of high-volume cohesive mudflows (lahars) or hyperconcentrated flood deposits (lahar runouts) similar to the deposits in the map area.

Evs_{pg} **Puget Group, undivided (Eocene) (cross sections only)**—Continental feldspathic to volcanic lithic subquartzose sandstone, siltstone, claystone, andesitic flows, breccia, lapilli tuff, and tuff and lesser carbonaceous shale, pebble conglomerate, and coal. The Puget Group is exposed south (Dragovich and others, 2007, 2009a,b,c; Dragovich and Walsh, 2008) and southwest of the map area and includes the Renton, Tukwila, and Tiger Mountain Formations. The middle to late Eocene Renton and older middle Eocene Tiger Mountain Formations were deposited as meandering-river fluvial-deltaic sediments on a coastal plain. The andesitic volcanic deposits of the Tukwila Formation erupted onto this coastal plain and interrupted the fluvial deposition of the Renton and Tiger Mountain Formations. Rau and Johnson (1999) showed the Puget Group to be locally at least about 4,000 ft thick in the Seattle basin west of the map area. This thickness is similar to that given by ten Brink and others (2002), who showed the undivided Eocene sediments in the basin to be about 3500 to 4,200 ft thick. We infer on cross sections A and B that the middle and late Eocene Puget Group (1) thins or is truncated by faulting to the east, and (2) interfingers with distal fluvial rocks of the late Eocene volcanic rocks of Mount Persis (unit Evs_p and subunits). In this model, the eastern edge of the Seattle basin in the map area is defined by RMF-1 and (or) SVF-1.

Mesozoic Low-Grade Metamorphic Rocks (Prehnite–Pumpellyite Facies)

KJm **Western mélange belt of Tabor and others (1993) (Cretaceous to Jurassic) (cross sections only)**—Dominantly metamorphosed argillite, sandstone, greenstone, metagabbro, and diabase with minor metachert, metatonalite, slate, phyllite, marble, and rare ultramafite (Dragovich and others, 2007, 2009a,b,c). Most metasedimentary rocks were deposited as turbidites along an accretionary wedge. The Western mélange belt is inferred to underlie the eastern portion of map area east of RMF-1 (cross sections A and B). The volcanic rocks of Mount Persis unconformably overlie the Western mélange belt basement northeast, east, and southwest of the map area (Tabor and others, 1993; Dragovich and others, 2009b; Danner, 1957). Thick "shale" under Quaternary unconsolidated deposits described in water well reports in the northeastern part of the map area could be Western mélange belt meta-argillite. Near-surface meta-argillite suggests that the volcanic rocks of Mount Persis were locally completely removed by erosion in the eastern part of the map area—however, the aeromagnetic map and geophysical modeling suggests that the volcanic rocks of Mount Persis overlie the mélange belt over much of the eastern part of the map area (Dragovich and others, 2010).

Tertiary to Holocene Tectonic Zones

tz, Qtz **Tectonic zone (Tertiary to Holocene)**—Cataclasite, fault breccia, clay-rich fault gouge, protomylonite, and strongly slickensided and fractured rocks in fault zones; variously colored, mottled, and veined as a result of local hydrothermal alteration or strong weathering. Dragovich and others (2007, 2009a,b,c) map tectonic zones along faults south of the map area. Sherrod and others (2008) map many strands of the SWIF northwest of the map area. Most kinematic indicators south of the map area, such as shallow slickenlines on steep shear planes and (or) en echelon vein arrays, suggest strike-slip or oblique-slip offset along strands of the RMFZ and Snoqualmie Valley faults. Wide zones of cataclasis are common in the Cherry Creek fault zone. Some of these tectonic zones have hydrothermal alteration. **Quaternary tectonic zones** (unit Qtz) are mapped in areas of Quaternary deformation and (or) liquefaction. Tectonic deformation is characterized by high-angle fractures and (or) discrete faults with bedding offsets.

Liquefaction features include sand dikes, flames, destroyed or chaotic bedding, (rootless) tight to isoclinal folding, and rare dish structures. Some of the best-exposed areas of intense liquefaction and (or) probable tectonic deformation are located at critical sites 14E, 14H, 24N, 25A, 25C, 43H, 45L, 45P, 53B, and 66H, and at age site 81Z (Dragovich and others, 2010). Deformation in these areas differs from the ice-shear soft-sediment deformation noted in advance lake deposits and is interpreted to be of tectonic origin, based on deformational style and association with liquefaction features. Generally: (1) Quaternary tectonic deformation and numerous (locally intense) liquefaction features are associated with RMF-1, RMF-5, SVF-1, SVF-2, and the Cherry Valley fault; and (2) shallow seismicity is associated with RMF-1 and the Cherry Creek fault zone and probably the Carnation fault. More information related to the mapping of faults, fault deformational structures, and correlation with earthquake hypocenters, focal mechanisms, and geophysical lineaments are provided in Dragovich and others (2010).

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REFERENCES CITED

Armstrong, J. E.; Crandell, D. R.; Easterbrook, D. J.; Noble, J. B., 1965, Late Pleistocene stratigraphy and chronology in southwestern British Columbia and northwestern Washington: Geological Society of America Bulletin, v. 76, no. 3, p. 321-330.

Associated Earth Sciences, Inc., 2001a, Subsurface exploration, geologic hazard, and geotechnical engineering report, Trilogy at Redmond Ridge, Project B vault, West Snoqualmie Valley Road NE and Novelty Hill Road, King County, Washington: Associated Earth Sciences, Inc., 1 v.

Associated Earth Sciences, Inc., 2001b, Proposed borrow pit dewatering impact analysis, Trilogy at Redmond Ridge, King County, Washington: Associated Earth Sciences, Inc., 1 v.

Associated Earth Sciences, Inc., 2002, Final hydrogeologic and geotechnical assessment report—Pegasus Thoroughbred Training Center, King County, Washington: Associated Earth Sciences, Inc., 1 v.

Associated Earth Sciences, Inc., 2003, Proposed Snoqualmie Ridge II project—Environmental impact statement—Technical report on geology, soils, and groundwater: Associated Earth Sciences, Inc., [Kirkland, Wash., under contract to] Quadrant Corporation, 1 v.

Associated Earth Sciences, Inc., 2004, Environmental impact statement—Technical report on geology, soils and ground water, Redmond Ridge East UPD/FCC and Panhandle preliminary plat, King County, Washington: Associated Earth Sciences, Inc., 1 v.

Associated Earth Sciences, Inc., 2005, Proposed Snoqualmie Ridge II N1 and N2 infiltration ponds—Technical report on geology and groundwater: Associated Earth Sciences, Inc, [Kirkland, Wash., under contract to] Quadrant Corporation, 1 v.

Associated Earth Sciences, Inc., 2007, Summary of SRS-1 No. 1 infiltration pond, general geologic hazard, and geotechnical engineering recommendations, recreation complex, Redmond Ridge East, King County, Washington: Associated Earth Sciences, Inc., 1 v.

Booth, D. B., 1984, Glacier dynamics and the development of glacial landforms in the eastern Puget Lowland, Washington: University of Washington Doctor of Philosophy thesis, 217 p., 1 plate.

Booth, D. B., 1986, The formation of ice-marginal embankments into ice-dammed lakes in the eastern Puget Lowland, Washington, U.S.A., during the late Pleistocene: Boreas, v. 15, no. 3, p. 209-264.

Booth, D. B., 1990, Surficial geologic map of the Skykomish and Snoqualmie Rivers area, Snohomish and King Counties, Washington: U.S. Geological Survey Miscellaneous Investigations Series Map I-1745, 2 sheets, scale 1:50,000, with 22 p. text.

Capps, Gerald; Simmons, J. D.; Videgar, F. D., 1973, Preliminary report on the geology of southern Snohomish County, Washington: Washington Division of Geology and Earth Resources Open File Report 73-1, 11 p., 8 plates.

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

Danner, W. R., 1957, A stratigraphic reconnaissance in the northwestern Cascade mountains and San Juan Islands of Washington State: University of Washington Doctor of Philosophy thesis, 3 v. [562 p.], 7 plates.

Dickinson, W. R., 1970, Interpreting detrital modes of graywacke and arkose: Journal of Sedimentary Petrology, v. 40, no. 2, p. 695-707.

Dragovich, J. D.; Logan, R. L.; Schasse, H. W.; Walsh, T. J.; Lingley, W. S., Jr.; Norman, D. K.; Gerstel, W. J.; Lapen, T. J.; Schuster, J. E.; Meyers, K. D., 2002, Geologic map of Washington—Northwest quadrant: Washington Division of Geology and Earth Resources Geologic Map GM-50, 3 sheets, scale 1:250,000, with 72 p. text. [accessed Jun. 22, 2010 at http://www.dnr.wa.gov/publications/ger_gm50_geol_map_nw_wa_250k.pdf]

Dragovich, J. D., 2007, Sand point count and geochemical data in the Fall City and Carnation 7.5-minute quadrangles, King County, Washington: Washington Division of Geology and Earth Resources Open File Report 2007-3, 2 Microsoft Excel files with 6 p. text. [accessed Jun. 22, 2010 at http://www.dnr.wa.gov/Publications/ger_ofr2007-3_fallcity_supplement.zip]

Dragovich, J. D.; Anderson, M. L.; MacDonald, J. H., Jr.; Mahan, S. A; DuFrane, S. A.; Littke, H. A.; Wessel, G. R.; Saltonstall, J. H.; Koger, C. J.; Cakir, Recep, 2010, Supplement to the geologic map of the Carnation 7.5-minute quadrangle, King County, Washington—Geochronologic, geochemical, point count, geophysical, earthquake, fault, and neotectonic data: Washington Division of Geology and Earth Resources Open File Report 2010-2, 42 p., 8 digital appendices. [http://www.dnr.wa.gov/Publications/ger_ofr2010-2_carnation_supplement.zip]

Dragovich, J. D.; Anderson, M. L.; Walsh, T. J.; Johnson, B. L.; Adams, T. L., 2007, Geologic map of the Fall City 7.5-minute quadrangle, King County, Washington: Washington Division of Geology and Earth Resources Geologic Map GM-67, 1 sheet, scale 1:24,000. [accessed Jun. 22, 2010 at http://www.dnr.wa.gov/Publications/ger_gm67_geol_map_fallcity_24k.zip]

Dragovich, J. D.; Littke, H. A.; Anderson, M. L.; Hartog, Renate; Wessel, G. R.; DuFrane, S. A.; Walsh, T. J.; MacDonald, J. H., Jr.; Mangano, J. F.; Cakir, Recep, 2009b, Geologic map of the Snoqualmie 7.5-minute quadrangle, King County, Washington: Washington Division of Geology and Earth Resources Geologic Map GM-75, 2 sheets, scale 1:24,000. [accessed Jun. 22, 2010 at http://www.dnr.wa.gov/Publications/ger_gm75_snoqualmie_24k.zip]

Dragovich, J. D.; Littke, H. A.; MacDonald, J. H., Jr.; DuFrane, S. A.; Anderson, M. L.; Wessel, G. R.; Hartog, Renate, 2009c, Geochemistry, geochronology, and sand point count data for the Snoqualmie 7.5-minute quadrangle, King County, Washington: Washington Division of Geology and Earth Resources Open File Report 2009-4, 35 p. text, 3 Microsoft Excel files. [accessed Jun. 22, 2009 at http://www.dnr.wa.gov/Publications/ger_ofr2009-4_snoqualmie_suppl.zip]

Dragovich, J. D.; Walsh, T. J., 2008, Geochemical sample analyses of Tertiary and pre-Tertiary volcanic rocks in and around the North Bend 7.5-minute quadrangle, King County, Washington: Washington Division of Geology and Earth Resources Open File Report 2008-4, 6 p. text with 1 Excel file on DVD. [accessed Jun. 22, 2009 at http://www.dnr.wa.gov/Publications/ger_ofr2008-4_northbend_geochem.zip]

Dragovich, J. D.; Walsh, T. J.; Anderson, M. L.; Hartog, Renate; DuFrane, S. A.; Vervoot, Jeff; Williams, S. A.; Cakir, Recep; Stanton, K. D.; Wolff, F. E.; Norman, D. K.; Czajkowski, J. L., 2009a, Geologic map of the North Bend 7.5-minute quadrangle, King County, Washington, with a discussion of major faults, folds, and basins in the map area: Washington Division of Geology and Earth Resources Geologic Map GM-73, 1 sheet, scale 1:24,000. [accessed Jun. 22, 2010 at http://www.dnr.wa.gov/Publications/ger_gm73_geol_map_northbend_24k.zip]

Easterbrook, D. J.; Crandell, D. R.; Leopold, E. B., 1967, Pre-Olympia Pleistocene stratigraphy and chronology in the central Puget Lowland, Washington: Geological Society of America Bulletin, v. 78, no. 1, p. 13-20.

Fulmer, C. V., 1975, Stratigraphy and paleontology of the type Blakeley and Blakely Harbor Formations. IN Weaver, D. W.; Hornaday, G. R.; Tipton, Ann, editors, Paleogene symposium and selected technical papers—Conference on future energy horizons of the Pacific coast: American Association of Petroleum Geologists Pacific Section, 50th Annual Meeting, p. 210-271.

Knoll, K. M., 1967, Surficial geology of the Tolt River area, Washington: University of Washington Master of Science thesis, 91 p., 1 plate.

Koger, C. J.; Saltonstall, J. H., 2009, Maintaining ground water recharge in master planned communities—Case histories from eastern King County, Washington: Geological Society of America Abstracts with Programs, v. 41, no. 7, p. 215.

Koger, C. J.; Saltonstall, J. H.; Baumgarten, D. J., 2003, Hydrogeology of the eastern Bear Creek Plateau, King County, Washington [abstract]: Geological Society of America Abstracts with Programs, v. 35, no. 6, p. 488.

Le Maitre, R. W.; Streckeisen, A.; Zanettin, B.; Le Bas, M. J.; Bonin, B.; Bateman, P., eds., 2002, Igneous rocks—A classification and glossary of terms; 2nd ed.: Cambridge University Press [Cambridge, U.K.], 256 p.

Littke, H. A.; Dragovich, J. D.; Anderson, Megan; Hartog, Renate; Wessel, G. R.; Dufrane, S. A.; Walsh, T. J.; MacDonald, J. H., Jr.; Cakir, Recep, 2009, Geologic map of the Snoqualmie 7.5-minute quadrangle, King County, Washington—Active faulting, basin inversion and Miocene volcanic extrusion of the Snoqualmie batholith along the Rattlesnake Mountain fault zone [abstract]: Geological Society of America Abstracts with Programs, v. 41, no. 7, p. 457.

Lindquist, J. W., 1957, Molluscan paleontology of Fiddlers Bluff, Washington: University of Washington undergraduate research thesis, 38 p.

Mackin, J. H., 1941, Glacial geology of the Snoqualmie–Cedar area, Washington: Journal of Geology, v. 49, no. 5, p. 449-481.

Marcus, K. L., 1981, The rocks of Bulson Creek—Eocene–Oligocene sedimentation and tectonics in the Lake McMurray area, Washington: Western Washington University Master of Science thesis, 84 p., 1 plate.

Minard, J. P., 1985, Geologic map of the Maltby quadrangle, Snohomish and King Counties, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF-1746, 1 sheet, scale 1:24,000.

Minard, J. P.; Booth, D. B., 1988, Geologic map of the Redmond quadrangle, King County, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF-2016, 1 sheet, scale 1:24,000.

Nesbitt, H. W.; Young, G. M., 1984, Prediction of some weathering trends of plutonic and volcanic rocks based upon thermodynamic and kinetic considerations: Geochimica et Cosmochimica Acta, v. 48, no. 7, 1523-1534.

Pettijohn, F. J., 1957, Sedimentary rocks; 2nd ed.: Harper & Row, 718 p.

Pessl, Fred, Jr.; Dethier, D. P.; Booth, D. B.; Minard, J. P., 1989, Surficial geologic map of the Port Townsend 30- by 60-minute quadrangle, Puget Sound region, Washington: U.S. Geological Survey Miscellaneous Investigations Series Map I-1198-F, 1 sheet, scale 1:100,000, with 13 p. text.

Porter, S. C.; Swanson, T. W., 1998, Radiocarbon age constraints on rates of advance and retreat of the Puget lobe of the Cordilleran ice sheet during the last glaciation: Quaternary Research, v. 50, no. 3, p. 205-213.

Prothero, D.R., Nesbitt, E.A. 2008, Paleomagnetism and tectonic rotation of the Restoration Point member of the Blakeley Formation (type Blakeley stage), Bainbridge Island, Washington, and the Pacific Coast Oligocene–Miocene boundary: New Mexico Museum of Natural History and Science Bulletin 44, p. 315-322.

Rau, W. W.; Johnson, S. Y., 1999, Well stratigraphy and correlations, western Washington and northwestern Oregon: U.S. Geological Survey Geologic Investigations Series Map I-2621, 3 sheets, with 31 p. text.

Saltonstall, J. H.; Koger, C. J; Sweet, Suzanne; Thompson, S. S., 2003, Olympia age paleotopographic influences on Vashon glaciofluvial sedimentation beneath eastern Bear Creek plateau, King County, Washington [abstract]: Geological Society of America Abstracts with Programs, v. 35, no. 6, p. 109.

Sherrod, B. L., 2002, Late Quaternary surface rupture along the Seattle fault zone near Bellevue, Washington [abstract]: Eos (American Geophysical Union Transactions), v. 83, no. 47, Supplement, p. F1074-F1075.

Sherrod, B. L.; Blakely, R. J.; Weaver, C. S.; Kelsey, H. M.; Barnett, Elizabeth; Liberty, Lee; Meagher, K. L.; Pape, Kristin, 2008, Finding concealed active faults—Extending the southern Whidbey Island fault across the Puget Lowland, Washington: Journal of Geophysical Research, v. 113, B05313, doi:10.1029/2007JB005060, 2008.

Tabor, R. W.; Frizzell, V. A., Jr.; Booth, D. B.; Waitt, R. B.; Whetten, J. T.; Zartman, R. E., 1993, Geologic map of the Skykomish River 30- by 60-minute quadrangle, Washington: U.S. Geological Survey Miscellaneous Investigations Series Map I-1963, 1 sheet, scale 1:100,000, with 42 p. text. [accessed Jun. 22, 2010 at http://pubs.usgs.gov/imap/i1963/]

ten Brink, U. S.; Molzer, P. C.; Fisher, M. A.; Blakely, R. J.; Bucknam, R. C.; Parsons, T. E.; Crosson, R. S.; Creager, K. C., 2002, Subsurface geometry and evolution of the Seattle fault zone and the Seattle basin, Washington: Seismological Society of America Bulletin, v. 92, no. 5, p. 1737-1753.

Walsh, T. J., 1984, Geology and coal resources of central King County, Washington: Washington Division of Geology and Earth Resources Open File Report 84-3, 24 p., 2 plates. [accessed Jun. 22, 2010 at http://www.dnr.wa.gov/publications/ger_ofr84-3_central_king_co_coal_24k.pdf]

Walsh, T. J.; Phillips, W. M., 1982, Coal rank and thermal maturation in King County, Washington: Washington Geologic Newsletter, v. 10, no. 1, p. 9-19. [accessed Jun. 22, 2010 at http://www.dnr.wa.gov/Publications/ger_washington_geology_1982_v10_no1.pdf]

Wolfe, J. A.; Forest, C. E.; Molnar, Peter, 1998, Paleobotanical evidence of Eocene and Oligocene paleoaltitudes in midlatitude western North America: Geological Society of America Bulletin, v. 110, no. 5, p. 664-678.

U.S. Geological Survey Geologic Names Committee, 2007, Divisions of geologic time—Major chronostratigraphic and geochronologic units: U.S. Geological Survey Fact Sheet 2007-3015, 2 p. [accessed Jun. 22, 2010 at http://pubs.usgs.gov/fs/2007/3015/]

Varnes, D. J., 1978a, repr. 1995, Landslide classification system. *In* Dragovich, J. D.; Brunengo, M. J., Landslide map and inventory, Tilton River–Mineral Creek area, Lewis County, Washington: Washington Division of Geology and Earth Resources Open File Report 95-1, 165 p., Plate 3. [accessed Jun. 22, 2010 at http://www.dnr.wa.gov/publications/ger_ofr95-1_lewis_co_landslides_plates.pdf and http://www.dnr.wa.gov/publications/ger_ofr95-1_lewis_co_landslides_text.pdf]

Varnes, D. J., 1978b, Slope movement types and processes. *In* Schuster, R. L.; Krizek, R. J., editors, Landslides—Analysis and control: National Academy of Sciences Transportation Research Board Special Report 176, p. 11-33, 1 plate.

Yount, J. C.; Gower, H. D., 1991, Bedrock geologic map of the Seattle 30' by 60' quadrangle, Washington: U.S. Geological Survey Open-File Report 91-147, 37 p., 4 plates. [accessed Jun. 22, 2010 at http://pubs.er.usgs.gov/usgspubs/ofr/ofr91147]