Prepared in cooperation with King County, Washington

Geologic Map of the Vashon 7.5' Quadrangle and Selected Areas, King County, Washington

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Pamphlet to accompany

Scientific Investigations Map 3328

2015

U.S. Department of the Interior
U.S. Geological Survey

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Introduction

This map is an interpretation of a 6-ft-resolution lidar-derived digital elevation model combined with geology by Derek B. Booth and Kathy Goetz Troost. Field work by Booth and Troost was located on the 1:24,000-scale topographic map of the Vashon and Des Moines 7.5' quadrangles that were published in 1997 and 1995, respectively. Much of the geology was interpreted from landforms portrayed on the topographic maps, supplemented by field exposures, where available. In 2001, the Puget Sound Lidar Consortium (see http://pugetsoundlidar.org/) obtained a lidar-derived digital elevation model (DEM) for Vashon Island and the Des Moines quadrangle. For a brief description of lidar and this data acquisition program, see Haugerud and others (2003). This new DEM has a horizontal resolution of 6 ft (1.83 m) and mean vertical accuracy of about 1 ft (about 0.3 m). The greater resolution and accuracy of the lidar DEM facilitated a much-improved interpretation of many aspects of the surficial geology, especially the distribution and relative age of landforms and the materials inferred to comprise them. Booth and Troost were joined by Tabor to interpret the new lidar DEM but have done no futher field work for this map.

This map, the Vashon quadrangle and selected adjacent areas, encompasses most of Vashon Island, Maury Island, and Three Tree Point in the south-central Puget Sound. One small area in the Vashon quadrangle on the east side of Puget Sound is excluded from this map but included on the adjacent Seattle quadrangle (Booth and others, 2005). The map displays a wide variety of surficial geologic deposits, which reflect many geologic environments and processes. Multiple ice-sheet glaciations and intervening nonglacial intervals have constructed a complexly layered sequence of deposits that underlie both islands to a depth of more than 300 m below sea level. These deposits not only record glacial and nonglacial history but also control the flow and availability of ground water, determine the susceptibility of the slopes to landslides, and provide economic reserves of sand and gravel. The islands are surrounded by channels of Puget Sound, some as deep as the islands are high (>600 ft (~200 m)). The shorelines provide many kilometers of well-exposed coastal outcrops that reveal abundant lithologic and stratigraphic details not ordinarily displayed in the heavily vegetated Puget Lowland.

Acknowledgments

We thank Russ Evarts and David Frank for review of an earlier version of this map. Ralph Haugerud helped interpret parts of the lidar DEM. This second version has improvements thanks to further reviews by Russ Evarts and Greg Wessel.

Previous Mapping

The geology of the Vashon quadrangle was first mapped by Willis (1898), who named the most recent glaciation after deposits he observed on Vashon Island. Subsequent work includes the regional mapping of Garling and others (1965) and a nearshore study by the Washington Department of Ecology (1979). This edition of the Vashon 7.5' quadrangle follows prior mapping by Booth (1991), conducted in 1987, 1988, and 1989 as part of a King County-supported groundwater study. Since that time, a wealth of new geologic data has become available through the digital compilation of geotechnical explorations and water-well logs. Additional fieldwork between 1996 and 2004 has emphasized reinterpretation of the stratigraphy along the coastal bluffs, supported by luminescence dating (Mahan and others, 2003; table 1) and paleomagnetic investigations (Hagstrum and others, 2002; table 2), together with careful reevaluation of stratigraphic relations in the surrounding area, particularly in the Gig Harbor and Tacoma North quadrangles immediately to the south and southwest (Troost, K.G., Booth, D.B., Borden, R., and Wells, R., unpub. field maps, 1994–2001).

Geologic Setting

During the Pleistocene, the Puget Lowland was glaciated several times by ice originating in the mountains of British Columbia (Crandell and others, 1958; Easterbrook and others, 1967). By analogy to the most recent glaciation, a lobe of the Cordilleran ice sheet (named the ”Puget lobe” by Bretz, 1913) advanced down the trough now occupied by Puget Sound, filling the lowland from the Cascade Range to the Olympic Mountains. During glacial times, lithologically distinctive clasts, particularly high grade metamorphic rocks, were carried southward by ice and meltwater and were subsequently deposited in the Puget Lowland. These exotic lithologies are now found in tills (typically impermeable and laid down beneath the ice sheet itself) and in glacial outwash (permeable sand and gravel deposits laid down by water originating from the ice sheet). During intervening nonglacial times, drainage from the mountains surrounding the Puget Lowland transported a more limited suite of rock types, particularly unmetamorphosed sandstones and lavas. In the Vashon quadrangle, however, many of the nonglacially transported sedimentary clasts are reworked from lowland glacial deposits, so nonglacial deposits also include exotic lithologies.

The existing channels of Puget Sound currently isolate the islands from the mainland sediment supply, so sediments being deposited here today do not display the local, nonglacial lithologies derived from the adjacent Olympic Mountains and Cascade Range. Yet the widespread presence of this material in older deposits on both Vashon and Maury Islands suggests that the present channel configuration did not necessarily exist before the most recent glaciation. Nonglacial deposits in the map area, therefore, form a discontinuous, incomplete record of lowland drainage courses, and they are interbedded with the (also discontinuous) deposits that record regional glacial advances.

Stratigraphic Relations and Nomenclature

The naming and regional correlation of the individual glacial advances in the Puget Lowland has a long and still-evolving history. Willis (1898) first presented evidence for multiple episodes of glaciation in the Puget Lowland. Crandell and others (1958) proposed a sequence of four glaciations separated by nonglacial intervals based on stratigraphic sequences in the southern Puget Lowland, about 20 km southeast of Vashon and Maury Islands. Easterbrook and others (1967) named and described deposits north of the map area, assigning them to three glaciations and their intervening interglacial periods. The earliest efforts to date these separated stratigraphic sequences (Easterbrook and others, 1981; Easterbrook, 1982) did not provide demonstrable correlations beyond the most recent ice-sheet advance. Further work by Westgate and others (1987) also found no correlation between these northern and southern sequences except for that of the most recent glacial advance, the Vashon stade of the Fraser glaciation, which reached a maximum about 14,000 ^{14}C yr B.P. (or about 17,000 calendar years ago) (Porter and Swanson, 1998).

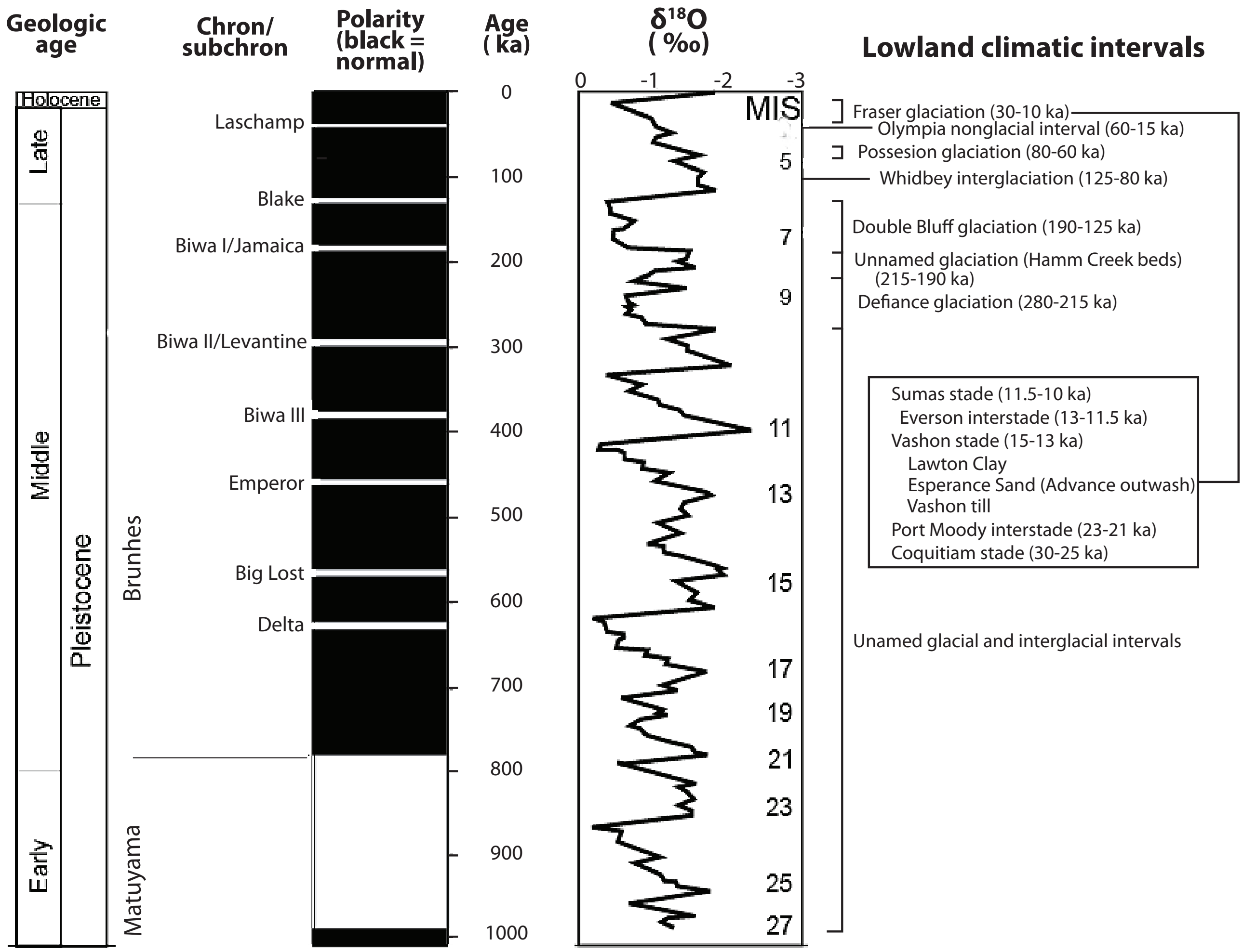

Figure 1. Comparison of the marine oxygen-isotope curve (MIS, marine isotope stage) using the deep-sea oxygen-isotope data from core ODP 677 from Shackleton and others (1990), global magnetic polarity curve (Mankinen and Dalrymple, 1979; Barendregt, 1995; Cande and Kent, 1995), and ages of climatic intervals in the Puget and Fraser Lowlands. Ages for deposits of the Possession glaciation through Double Bluff glaciation are from Easterbrook and others (1981), Easterbrook (1986), Blunt and others (1987), and Easterbrook (1994); ages for older units are from Troost and others (2003, 2005). Ages for the Olympia nonglacial interval are from Armstrong and others (1965), Mullineaux and others (1965), Pessl and others (1989), and Troost (1999). Ages for the Coquitlam stade are from Hicock and Armstrong (1985); ages for the Port Moody interstade are from Hicock and Armstrong (1981). Ages for the Vashon stade are from Armstrong and others (1965) and Porter and Swanson (1998). Ages for the Everson interstade are from Dethier and others (1995) and Kovanen and Easterbrook (2001). Ages for the Sumas stade are from Clague and others (1997), Kovanen and Easterbrook (2001), and Kovanen (2002). Modified from Booth and others (2004a).

On this map, deposits of pre-Fraser glaciation age (see fig. 1) are assigned specific lithostratigraphic names, if they can be traced laterally from localities with luminescent dates (Mahan and others, 2003) that correspond to formally or informally defined deposits. These correlations are supported by paleomagnetic measurements (Hagstrum and others, 2002, table 1) that locally permit correlation of widely separated deposits by virtue of unusual pole directions. These determinations, in combination with extensive subsurface data and concurrent mapping of the adjacent quadrangles to the south and west, permit the recognition and naming of deposits in the quadrangle as old as marine isotope stage 8 (MIS 8; see also Booth and others, 2004a). Deposits in the map area include all of the named glacial and nonglacial intervals that Easterbrook and others (1967) identified on Whidbey Island, 30 km to the north.

Table 1. IRSL (infrared stimulated luminescence) data for sites in the Vashon 7.5' quadrangle, Washington.

[Dates from S. Mahan., U.S. Geological Survey. Denver, CO, and Mahan and others, 2003. Samples collected in 2002. Ages reflect average of 10-minute bleach (minimum age) and 60-minute bleach (maximum age) using CS-3-67 orange filter]

Site and lab No.	Site name	Location (GPS NAD27)	Location on lidar base (NAD83)	Elevation feet (meters)	Material	Average IRSL age (yrs)	Unit label
WA-28	Wingehaven Park	47.4979 N 122.4592 W	47.4975 N 122.4602 W	60 (19.7)	Silt	400,000	Qrm
WA-29	Wingehaven Park	47.49783 N 122.45771 W	47.49783 N 122.4591 W	5 (1.6)	Silt	400,000	Qrm

In addition, deposits at several localities exposed along the east shore of Vashon Island from Klahanie north to Dolphin Point exhibit reversed polarity, indicating they are of even greater antiquity than those in table 1, (>774 ka). Although these reversely polarized deposits could have been deposited during the Blake reversal at about 130 ka, their exposure at the core of an anticline associated with crustal deformation south of the Seattle Fault (Booth and others, 2004b) and their isolation from younger deposits lead us to interpret them as older, Matuyama-age deposits.

Table 2. Paleomagnetic data for sites in the Vashon 7.5' quadrangle, Washington.

Site No.	Lab No.	Site name	Location (GPS NAD27)[1]	Location on lidar base (NAD83)	Approximate elevation in feet (meters) [feet[2]]	Polarity	Unit label
N37	T0145	Winghaven Park	47.497 N 122.463 W	47.4977 N 122.4642 W	73 (24) [221]	Normal	Qva
R18	T0142	Winghaven Park	47.497 N 122.457 W	47.4977 N 122.4590 W	0 [8]	Reversed	Qrm
T9	T9046	Winghaven Park	47.497 N 122.457 W	47.4977 N 122.4590 W	0 [8]	Transitional	Qrm
T12	T0133	Winghaven Park	47.497 N 122.457 W	47.4977 N 122.4590 W	3 (1) [8]	Transitional	Qrm
T14	T1309	Winghaven Park	47.497 N 122.457 W	47.4977 N 122.4590 W	3 (1) [8]	Transitional	Qrm
T15	T1312	Winghaven Park	47.497 N 122.457 W	47.4977 N 122.4590 W	3 (1) [8]	Transitional	Qrm
T16	T1315	Winghaven Park	47.497 N 122.457 W	47.4977 N 122.4590 W	2 (0.66) [8]	Transitional	Qrm
T17	T1318	Winghaven Park	47.497 N 122.457 W	47.4977 N 122.4590 W	0 [8]	Transitional	Qrm
N36	T0139	Sylvan Beach	47.501 N 122.477 W	47.4983 N. 122.5012 W	0 [3.6]	Normal	Qva

[1] Hagstrum and others (2002, table 1).
[2] Lidar elevation, in feet, at DB station site location.

Deposits of Vashon age are widely distributed and dated throughout the lowland region. They are well exposed on Vashon and Maury Islands and are so named here. In contrast, the Colvos Sand

Member (Walters and Kimmel, 1968) of the Vashon Drift (equivalent to the Colvos Sand of Garling and others, 1965), described as the lowermost member of the advance outwash deposits of the Vashon-age ice sheet, has been abandoned as a lithostratigraphic unit because it lacks both lithologic or textural distinction and stratigraphic significance (Booth, 1991). This follows convention in geologic mapping throughout the central Puget Lowland for the past 20 years (for example, Minard, 1983; Pessl and others, 1989). We reassigned these strata to the Vashon advance outwash (Qva).

The Kitsap Formation (Armstrong and others, 1965; see also Garling and others, 1965) is also abandoned, following recent usage elsewhere in the region (see, for example, Booth and Troost, 2005; Troost and others, 2005). Its utility as a stratigraphic marker is hampered, in part, by the formation's definition as fine-grained sediments lying between two other units of uncertain value, the Salmon Springs Drift and herein-abandoned Colvos Sand Member. The formation as defined may also be substantially time-transgressive, possibly spanning more than one glaciation. For example, Garling and others (1965, p. 31) suggest that it may be correlative with any of several other units: the 15,000-year-old Lawton Clay Member of the Vashon Drift (Mullineaux and others, 1965); the Quadra Sand of Clague (1976), identified as advance outwash of the Vashon-age ice advance; interglacial deposits of finite radiocarbon (for example, Olympia) age in the Seattle area (Stark and Mullineaux, 1950); or deposits of the Whidbey Formation, which predate even the Possession glaciation of Easterbrook and others (1967). Deeter (1979) mapped the Kitsap Formation northwest of Vashon Island but also noted ambiguities in its definition and usage. Abandonment of this unit follows recent regional stratigraphic convention (for example, Blunt and others, 1987). We reassign its strata to either the earliest deposit of the Vashon-age glacial advance (Qvlc) or to pre-Fraser-age deposits.

Landslide and related deposits make up most of the post-Vashon-age deposits in the map area. Of particular interest is the large block slide of the Dilworth area. Although shown as a coherent block on the map, subsidiary block displacements are common along the Glen Acres-Dilworth road (Gres Wessel, written commun., 2013). Concentric arcuate scarps on the southwest side of the Burton Peninsula suggest a block slide, but without evidence of unit offset or other morphological change in the down-dropped blocks, this slide is less certain.

Structure

The eastern tip of Maury Island is cut by a strong northeast-trending lineament revealed by lidar that we interpret to be a fault with the east side dropped down. The fault cuts pre-Vashon-age units (Qpff and Qpdt) and offsets a Holocene and Pleistocene landslide (Qols). It is buried by a younger, probably Holocene, landslide. The lineament (fault) definitely cuts the ice-grooved pavement, indicating post-ice-advance movement. The older landslide does not have the smoothed morphology characteristic of sublacustrine landslides, indicating the latest fault movement is older than glacial Lake Bretz age or about 16,000 calendar years ago (R.A. Haugerud, written commun, 2011).

DESCRIPTION OF MAP UNITS

[MIS, marine isotope stage]

POSTGLACIAL DEPOSITS

m **Modified land (Holocene)**—Gravel, sand, silt, and other materials of substantial areal extent or thickness placed or modified as a direct result of human activity, including extensively graded natural deposits. Mapped where borehole data provide sufficient information to delineate extent and where greater than about 2 m in thickness, or where topography and overlying development suggests likelihood of fill. Thin deposits of fill are present throughout map area but are not mapped due to lack of information. Loose to weakly consolidated. Extensive areas of unit Qva on Maury Island shown as modified land

hs **Hard surface (Holocene)**—Mostly continuous hard surface, includes major roads, parking lots, and large building. Includes minor landscaped areas

Qls **Landslide deposits (Holocene)—**Diamicts composed of broken to internally coherent surficial deposits derived from upslope

Qols **Old landslide deposits (Holocene and Pleistocene)—**Diamict similar to Qls, but morphology less distinct and (or) significantly eroded. Queried where uncertain

Qlsq **Landslide deposits, questionable (Holocene)—**Materials similar to Qls, but some features determined from lidar DEM, such as concave head scarp and irregular morphology, indistinct or lacking

Qmw **Mass-wasting deposits (Holocene)—**Colluvium, soil, or landslide debris with indistinct morphology, mapped where sufficiently continuous and thick enough to obscure underlying deposits. Many deposits mapped from lidar DEM, mainly on the northern end of Vashon Island in gullies. Gradational contacts with units Qa, Qf, and Qls

Qw **Wetland deposits (Holocene)—**Peat and fine-grained(?) alluvium; poorly drained and intermittently wet. Compiled from King County (1983). Grades into unit Qa

Qbtf **Beach deposits and tidal flats (Holocene)—**Sand, pebbles, and shells deposited or reworked by wave action; locally well sorted. Grades at stream mouths into unit Qa. Tidal flats deposits are silt, sand, and organic sediment and detritus. Loose to weakly(?) consolidated

Qbo **Beach deposits, old (Holocene)**—Mapped north of Cedarhurst near Burton, at Three Tree Point, and at Point Robinson on Maury Island. Terraces bearing such deposits are about 10–12 ft (3–4 m) above sea level but are commonly covered by artificial fill (m). Equivalent deposits may be present elsewhere but are obscured by development

Qf **Fan deposits (Holocene)—**Boulders, cobbles, and sand forming poorly sorted(?) lobate deposits where streams emerge from confining valleys and reduced gradients cause some of the sediment loads to be deposited. Gradational with unit Qa

Qfo **Fan deposits, old (Holocene)**—Materials similar to Qf, but partially eroded. Commonly separated from other valley deposits by low scarp. Many modified by man

Qa **Alluvium (Holocene)—**Moderately sorted deposits of cobble gravel, pebbly sand, and sandy silt along rivers and streams. Also includes alluvial fans, common particularly where streams reach the coastline. Surfaces generally unvegetated. Grades into units Qf, Qw, and Qbtf

Qoa **Older alluvium (Holocene and Pleistocene)—**Texturally equivalent to unit Qa but deposits lie at higher altitudes and typically have greater relief than the younger alluvium. Some form terraces above modern valleys, especially along Judd and Shake Mill Creeks. May locally include deposits of late Fraser-age glaciation that cannot be unequivocally assigned a pre-Holocene origin

YOUNGER GLACIAL DEPOSITS

Deposits of Vashon stade of Fraser glaciation of Armstrong and others (1965) (Pleistocene)

Qvr **Recessional outwash deposits**—Stratified sand and gravel, moderately to well sorted, with less common silty sand and rare silty clay. Mantles the upland till surface; accumulated predominantly as outwash plains and valley trains

Qvrc **Outwash channels and deposits**—Deposits in channels mostly crosscutting regional glacial grooves, determined from lidar DEM. Probable subglacial origin. Channel fills may not contain outwash deposits, but all channels and deposits probably mantled by Holocene deposits. Smaller channels not mapped

Qvrl **Recessional lacustrine deposits**—Laminated silt and fine sand, deposited in proglacial lakes. Parentheses around label on map indicate unit preserved in block slide

Qvrls **Sublacustrine landslide deposits**—Mostly deposited under glacial Lake Russell, but slides below ~250 ft (~ 76 m) elevation may have been deposited under glacial Lake Bretz. Mapped from lidar DEM on basis of elevation and subdued, fluid appearance. May include some subaerial landslides (Qls)

Qvi **Ice-contact deposits**—Similar in texture to unit Qvr, but containing collapse features and rare till lenses that suggest deposition near stagnant or active glacial ice. In lidar DEM, characterized by relatively rough topography and many complex channels

Qvt **Till**—Mainly compact diamict with subangular to rounded clasts, glacially transported and deposited. Unit is typically at most a few tens of meters thick and deposited as an undulating layer that has over 100 m of relief across the islands. Contact with unit Qvr is gradational where mantled by outwash. Parentheses around label on map indicate unit preserved in block slide

Qva **Advance outwash deposits**—Well-bedded sandy gravel to more common medium- and fine-grained sand, generally firm and unoxidized; deposited by proglacial streams. Tends to grade downward from gravelly sand to uniform medium-fine sand; unit includes, in part, the Colvos Sand of Garling and others (1965) and is correlative with the Esperance Sand Member of the Vashon Drift (Mullineaux and others, 1965). Base of unit is placed at either uppermost appearance of silt or clay (assigned to unit Qvlc or pre-Fraser deposits) or an abrupt transition to more oxidized clasts of typically nonglacial origin. Parentheses around label on map indicate unit preserved in block slide

Qvlc **Lawton Clay Member of the Vashon Drift**—Stiff to hard, laminated to massive silt, clayey silt, and silty clay deposited in lowland or proglacial lakes. Marks transition from nonglacial to earliest glacial time, although unequivocal evidence for glacial or nonglacial origin may be absent. Deposits of similar age and texture are included in unit Qpff where evidence of age and (or) depositional environment is absent

OLDER GLACIAL AND NONGLACIAL DEPOSITS

Qpf **Deposits of pre-Fraser glaciation age (Pleistocene)**—Massive to laminated silt and clay, and variably oxidized bedded sand and gravel. May locally include deposits (Qpon, Qponf) predating the Olympia nonglacial interval of Mullineaux and others (1965), where exposures are inadequate to identify at map scale

Qpfc **Coarse-grained facies**—Predominantly sand and gravel, fluvially deposited

Qpff **Fine-grained facies**—Predominantly silt and clay, deposited in lakes or marine environments. Parentheses around label on map indicate unit preserved in block slide

Qpof **Pre-Olympia deposits, fine-grained (Pleistocene)**—Predominantly silt and clay, deposited in lakes or marine environments. Very dense and hard

Qpog **Glacial deposits of pre-Olympia age (Pleistocene)**—Weakly to strongly oxidized silt, sand, gravel, and local till of glacial origin. Underlies Vashon-age deposits and thus must also be of pre-Olympia age. Sediment is of inferred glacial origin, based on presence of clasts requiring southward ice-sheet transport

Qpogt **Till**—Predominantly till or other diamict where thick enough to show at map scale

Qpogc **Coarse-grained facies**—Predominantly gravel and sand. Located on western edge of quadrangle, where it is continuous with more extensive exposures in the Olalla 7.5' quadrangle

Qpogf **Fine-grained facies—**Predominantly silt and clay, deposited in lakes or marine environments

Qpon **Nonglacial deposits of pre-Olympia age (Pleistocene)**—Sand, silt (locally organic rich), gravel, and peat, discontinuously and thinly interbedded. Generally very dense and hard

Qponf **Fine-grained facies**—Predominantly silt and clay, deposited in lakes or marine environments

Possession Drift of Easterbrook and others (1967) (Pleistocene)—Weakly to strongly oxidized silt, sand, and gravel of glacial origin, including lacustrine and ice-contact deposits, outwash, and till. Identified only where absolute age control or dated stratigraphic position provides stratigraphic control; therefore, Possession-age deposits are likely more extensive than mapped. Correlative with MIS 4, with ages from approximately 80 to 70 ka. Very dense and hard

Qpdt **Till**—Predominantly till or other diamict where thick enough to show at map scale

Qpdc **Coarse-grained facies**—Predominantly sand and gravel, fluvially deposited

Qpdf **Fine-grained facies**—Predominantly silt and clay, deposited in lakes or marine environments

Qwb **Whidbey Formation (Pleistocene)**—Interbedded clay, silt, sand, and gravel layers; locally includes abundant organic material, paleosols, peat, tephra, and pumice-rich layers. Deposited by lowland streams or in floodplain environments during the nonglacial period prior to the Possession glaciation. Correlative with MIS 5, from 125 to 80 ka. Mapped only where absolute age control is available; therefore, Whidbey Formation deposits are likely more extensive than mapped. Very dense and hard

Qwbc **Coarse-grained facies**—Predominantly sand and gravel, fluvially deposited

Qrm **Reversely magnetized deposits (Pleistocene)—**Interbedded silt and sand. Reversely magnetized and thus presumably more than 774,000 years old; optical ages from samples WA-28 and WA-29 (Mahan and others, 2003; table 1) are indeterminate but likely >400,000 years old

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