Lidar–Revised Geologic Map of the Olalla 7.5' Quadrangle, King, Kitsap, and Pierce Counties, Washington

Pamphlet to accompany

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Contents

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Introduction to Revised Version of the Map

Our map is an interpretation of a 6-ft resolution lidar-derived digital elevation model combined with the geology depicted on the "Geologic map of the Olalla 7.5' quadrangle, King, Kitsap, and Pierce Counties, Washington," by Booth and Troost (2005), which was described, interpreted, and located on the 1953 1:24,000-scale topographic map of the Olalla 7.5-minute quadrangle. The original topographic base map, derived from 1951 aerial photographs, has 20-ft contours, nominal horizontal resolution of circa 40 ft (12 m), and nominal mean vertical accuracy of circa 13 ft (4 m). Similar to many geologic maps, much of the Booth and Troost (2005) geology—especially the distribution of surficial deposits—was interpreted from landforms portrayed on the topographic map, 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 Kitsap Peninsula and Vancouver Island. For a brief description of lidar (LIght Detection And Ranging) and this data acquisition program, see Haugerud and others (2003). This new DEM has a horizontal resolution of 6 ft (2 m) and mean vertical accuracy circa 1 ft (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.

Geologic Issues

We have done no additional field work to make this map. Most of the text in the Description of Map Units and elsewhere is quoted directly from Booth and Troost (2005). We modified table 1 slightly and moved sample and structural data points to fit the lidar topography and maintain identification within the original units. The reader may also refer to Booth and Troost (2005) for useful bluff sketches of the west coast of Vashon Island and the east coast of the Kitsap Peninsula that display stratigraphic relations between various Pleistocene-age deposits—illustrations that we have not reproduced here.

Base Map Issues

The positions of geographic features on the old contour base of the Olalla quadrangle, compared to the same features on the DEM, are displaced by as much as 1,000 ft (300 m). Many contacts are shown as approximately located, especially those copied directly from Booth and Troost (2005).

There is no digital depiction of stream locations that adequately matches the lidar DEM. We have therefore newly digitized the location of streams, rivers, and water boundaries on the DEM. We selected rivers and streams to digitize based on drainage shown on the published Olalla 1:24,000-scale topographic map. Most of the roads displayed on the map were added from digital coverages available from Kitsap County (http://www.kitsapgov.com/gis/metadata/). South of Kitsap County we digitized additional roads from the DEM. We referred mostly to 1:100,000-scale road depictions and Google Earth to select roads that are shown on this map.

Geologic Summary

Introduction

The Olalla 7.5' quadrangle, which lies almost in the center of the Puget Lowland, displays the broad range of geologic environments typical of the region. The upland plain is fluted by the passage of the great continental ice sheet that last covered the area about 17,000 (14,000 radiocarbon) years ago (Porter and Swanson, 1998). The plain is cut by channel deposits, both late glacial and postglacial in age, and it is cleaved even more deeply by one of the major arms of Puget Sound, Colvos Passage, which here separates the west coast of Vashon Island from the Kitsap Peninsula.

Beneath the deposits of the last ice sheet is a complex sequence of older Quaternary-age sediments that extends about 400 m below the modern ground surface (Jones, 1996). These older sediments are best exposed along the shorelines and beach cliffs of Puget Sound, where wave action and landslides maintain relatively fresh exposures. The older sediments typically are compact, having been loaded by ice during one or more episodes of glaciation subsequent to their deposition. Locally these sediments are also cemented by iron and manganese oxides and hydroxides, a consequence of many tens or hundreds of thousands of years of weathering and groundwater movement.

Previous Mapping

On Vashon Island, Booth and Troost (2005) used preexisting map data of Booth (1991). Previously published geologic maps by Sceva (1957), Garling and others (1965), and Deeter (1979) included much or all of the quadrangle at smaller scales; although not used by Booth and Troost (2005) or on this map, their data represent significant contributions for their time and have been valuable resources for establishing the general geologic context.

Along with much of the geology modified from Booth and Troost (2005), many geologic contacts within Kitsap County on this revised map have been adapted from Haugerud (2009).

Acknowledgments

We thank Trevor Contreas and Kevin Schmidt for extremely helpful reviews. The map is much improved due to their efforts.

Stratigraphic Framework

Multiple invasions of glacial ice into the Puget Lowland have left a discontinuous record of Pleistocene glacial and nonglacial periods. Originating in the mountains of British Columbia, the ice was part of the Cordilleran ice sheet of northwestern North America. During each successive glaciation, ice advanced into the lowland as a broad tongue, first called the Puget lobe by Bretz (1913). Willis (1898) first presented evidence for multiple glaciations in the Puget Lowland.

Past mapping in the Olalla quadrangle reflected many of the uncertainties that have accompanied regional efforts to identify and to correlate the various glacial and nonglacial deposits. Garling and others (1965) correlated the older glacial deposits exposed along the shores of Puget Sound with the Salmon Springs Drift (Crandell and others, 1958), and Deeter (1979) called these same deposits "Possession" by virtue of stratigraphic position and presumed correlation with the Possession Drift of Easterbrook and others (1967); none of these early workers, however, could support their correlation with isotopic age determinations. Also problematic for making stratigraphic assignments are the fine-grained lacustrine sediments that both overlie and underlie these older glacial deposits. Early mappers named them the Kitsap Formation, and subsequent mappers have used this name as well; however, Deeter (1979) correctly noted that the deposits assigned to the Kitsap Formation span multiple depositional periods that likely are separated by multiple glacial intervals. Indeed, the term as used does not refer unequivocally to strictly glacial or strictly nonglacial deposits. Because of these imprecisions, we do not use the name in the current mapping, even though both the original type locality (Sceva, 1957) and its proposed redefinition (Garling and others, 1965) are located in the quadrangle, on the west side of Colvos Passage near the south map boundary.

Deposits Predating the Vashon Stade of the Fraser Glaciation of Armstrong and Others (1965)

The oldest exposed sediment (unit Qrgf) in the quadrangle is reversely magnetized and, so, is probably more than 774,000 years old. Hagstrum and others (2002; Table 1) report reversed paleomagnetic measurements of lacustrine silt and clay at three localities on the north Kitsap Peninsula coastline: near the mouth of Fragaria Creek (sample T8200), south of View Park (sample T9058), and just north of Wilson Creek (sample T8197). At Sandford Point on Vashon Island (unit Qpof; sample T1321) and to the north, near Lisabuela (unit Qpo; sample T7280), texturally similar sediments have transitional polarities (Hagstrum and others, 2002; Table 1), suggesting a more precise 774-ka age.

Where paleomagnetic determinations are mostly absent, deposits older than the Fraser glaciation of Armstrong and others (1965) (hereafter referred to as Fraser glaciation) are locally subdivided on the map (units Qpf and Qpo) by their inferred depositional environment. Where organic material or volcanic sediment is abundant, Booth and Troost (2005) inferred a likely nonglacial origin (units Qpfn and Qpon). Deposits inferred to be of glacial origin (Mullineaux and others, 1965) display a suite of sand and (or) gravel lithologies indicative of southward transport from the North Cascades or British Columbia (presumably by a continental ice sheet) or sedimentary features characteristic of glacial or proglacial environments, and they are included in units Qpog and coarse, fine, and till sub-units (units Qpogc, Qpogf, and Qpogt); note that all pre-Fraser glacial periods also precede the Olympia nonglacial interval. Booth and Troost (2005) did not assign stratigraphic names to these pre-Fraser glaciation-age deposits, however, because absolute age control was and still is very sparse. Normal-polarity sediments at scattered localities (samples T7001, T7004, T7007, T7010, T7277, and T8203) indicate that these mapped deposits are younger than 774 ka (Hagstrum and others, 2002; Table 1).

In the eastern part of the quadrangle, Booth and Troost (2005) recognized two, and possibly three, separate pre-Fraser glaciation-age tills. The two younger tills overlie normally magnetized sediment and so are younger than 774,000 years old; the age of the oldest pre-Fraser glaciation-age till is indeterminant. To the west, exposures are poorer, and Booth and Troost (2005) identified only one pre-Fraser glaciation-age till. Diamictons of presumed glacial origin whose deposition predates the Fraser glaciation are shown as discrete units ($Qpog_t$); layers or lenses within more generalized units are shown as a red line on the map. The absence of mapped diamictons elsewhere on the quadrangle reflects not only the likely discontinuity of these deposits but also the typically poor exposures across the map area, even under relatively favorable conditions of steep topography and sparse vegetation.

The Olympia nonglacial interval of Armstrong and others (1965) (hereafter referred to as Olympia nonglacial interval) immediately preceded the most recent ice-sheet advance into the Puget Lowland (Mullineaux and others, 1965; Armstrong and others, 1965; Minard and Booth, 1988; Troost, 1999). Booth and Troost (2005) identified deposits formed during this time (unit Qob) by radiocarbon dating at several localities in the Olalla quadrangle (table 1). Deposition of sediments may have been more widespread during Olympia time than is indicated by the distribution of unit Qob on the map, because some Olympia nonglacial interval-age sediments are probably lumped less precisely into the lithostratigraphic units Qpf or Qpfn. Conversely, deposits mapped as pre-Olympia nonglacial interval in age (and so assigned to unit Qpo) are separated from either Fraser glaciation-age or radiocarbon-dated Olympia nonglacial interval-age deposits by at least one pre-Fraser glaciation-age glacial unit.

Deposits of the Vashon Stade of the Fraser Glaciation of Armstrong and Others (1965)

Most deposits at or near the constructional land surface are assigned to the youngest glacial advance in the Puget Lowland, the Vashon stade of the Fraser glaciation (Armstrong and others, 1965). During this time an ice sheet advanced along the axis of the lowland from the north (Clague, 1981), reaching its maximum extent about 17,000 (14,000 radiocarbon) yr B.P. and covering the Puget Lowland to a maximum depth of about 5,000 ft (1,500 m) (Waitt and others, 1983; Booth, 1987; Porter and Swanson, 1998). As the ice first advanced, it blocked northward lowland drainage out of the Strait of Juan de Fuca, which now connects Puget Sound with the Pacific Ocean. In the impounded lakes that formed in the course of establishing southerly drainage out of the Puget Lowland, laminated silt and clay were deposited broadly across the Puget Lowland. Booth and Troost (2005) tentatively assigned such lacustrine deposits flanking Olalla Valley and Colvos Passage to the Lawton Clay Member of Vashon Drift (unit Qvlc) on the basis of their texture and their stratigraphic position relative to the underlying dated deposits of the Olympia nonglacial interval (unit Qob) and pre-Olympia nonglacial interval deposits.

Advance outwash deposits (Qva) deposited by streams derived from the advancing ice sheet mark the subsequent depositional interval. Sandy advance outwash deposits at least a few tens of meters thick (and locally as thick as 100 m [300 ft]) underlie the broad uplands in the central part of the quadrangle. This deposit (Qva) inundated the pre-Vashon stade topography of the lowland and resulted in a gently south-sloping landform (Booth, 1994), whose upper surface is as high as 430 ft (125 m) in the center of the quadrangle. The base of the advance outwash deposits is exposed along most of the deep valleys and coastal bluffs; its elevation varies between about 30 and 200 ft (10 and 60 m). This unit has been mapped by earlier workers (Mullineaux and others, 1965; Garling and others, 1965) as the Colvos Sand Member of Vashon Drift or the Esperance Sand Member of the Vashon Drift.

Table 1. ^{14}C ages from the Olalla quadrangle.

[Site names from source publication]

Lab. No.	Site name	Location based on topo base	Location based on lidar base	Approx. elev. in ft Topo. base (Lidar base)	Sample type	Sample No.	Pretreatment	Conventional ^{14}C age, in yr B.P.[1]	$^{13}C/^{12}C$ Ratio (o/oo)	Calibrated age, in yr B.P.[2]	Map Unit	Reference
Beta-131069	Maplewood south	47.3940 N. 122.5531 W.	47.394 N. 122.554 W.	70 (64)	peat	DB-212-98 KT-13-98	acid/alkali/ acid	>41,420	-25.0[3]	>41,420	Qpon	Troost (1999)
W-1515	Crescent coast	47.3872 N. 122.5488 W.	47.386 N. 122.549 W.	80 (84)	peat		unknown	>38,000	Not avail.	>38,000	Qpon	Deeter (1979)
W-2028	Crescent coast	47.3872 N. 122.5488 W.	47.386 N. 122.549 W.	?80 ?(84)	peaty silt		unknown	>42,000	Not avail.	>42,000	Qpon	Deeter (1979)
Beta-128806	Fragaria road	47.4617 N. 122.5372 W.	47.461 N. 122.539 W.	80 (77)	peat	DB-235-97	acid/alkali/ acid	40,660±970	-25.0[3]	42,950–38,850	Qob	Troost (1999)
Beta-131071	Crescent driveway (upper)	47.3870 N. 122.5489 W.	47.386 N. 122.551 W.	140 (154)	organic sediment	KT-170-99, S-5	acid/alkali/ acid (low C required special handling)	38,790±790	-25.0[3]	40,650–37,250	Qob	Troost (1999)
Beta-131072	Crescent driveway (lower)	47.3870 N. 122.5489 W.	47.386 N. 122.551 W.	133 (154)	peat	KT-170-99, S-7	acid/alkali/ acid	>44,290	-25.0[3]	>44,290	Qob	Troost (1999)
UW-25	Maplewood coast	47.3989 N. 122.5533 W.	47.408 N. 122.552 W.	125 (128)	peat		unknown	--[4]	Not avail.	--[4]	Qob	Dorn and others (1962)
W-1982	Maplewood coast	47.3989 N. 122.5533 W.	47.408 N. 122.552 W.	125[5] (128)	peat		unknown	>42,000	Not avail.	>42,000	Qob	Yount and others (1980)
Beta-128805	Olalla Creek quarry	47.4265 N. 122.5542 W.	47.426 N. 122.556 W.	70 (78)	peat	KT-11-98 DB-78-98	acid/alkali/ acid	39,050±940	-25.0[3]	41,250–37,250	Qob	Troost (1999)

[1]B.P. (before present) is, by convention, years before 1950 A.D.

[2]Calibrated radiocarbon age (2-sigma range)

[3]Estimated $^{13}C/^{12}C$ ratio

[4]Originally reported finite date was tritium-contaminated (Fairhall and others, 1966); stratigraphic assignment based on field relations

[5]Elevation based on presumed duplication of site UW-25 (Deeter, 1979, p. 62–63)

Table 2. Infrared-stimulated luminescence (IRSL) ages from the Olalla quadrangle.

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

Lab No.	Location and year of collection	Elevation (ft)	Material	Average IRSL age, in ka	Map unit
WA-25	Sandford Point 2002	20	fine sand	127±6	Qpoc
WA-26	Sandford Point 2002	25	silt	185±9	Qpof

As ice covered the region, till (Qvt) was deposited by the meltout and reworking of debris at the base of the glacier. This heterogeneous and generally compact sediment blankets the area to depths that are, at most, tens of feet, but more typically are only 3 to 10 ft (1 to 3 m). Over much of the quadrangle, the ground surface underlain by this deposit is strongly fluted to the south-southwest. Remnants of this fluted texture on till and ice-contact deposits (Qvi) at lower valley elevations and in lower Olalla Valley on probable advance outwash (Qva) indicates significant scour beneath the ice.

Deposits on the west side of the quadrangle, formerly mapped by Booth and Troost (2005) as recessional outwash, appear in the lidar topography to be mostly ice-contact deposits (Qvi), an interpretation supported by a sinuous ridge interpreted to be an esker (Qvie), located north of SE Burley Olalla Road on the west edge of the quadrangle.

Shortly after 17,000 (14,000 radiocarbon) years ago, the ice margin, which by this time had advanced about 44 mi (70 km) south of the quadrangle, began to melt back. Recession of the ice sheet was accompanied by both outwash streams and ice-dammed lakes, analogous to those formed during the ice advance. When the Olalla quadrangle was uncovered by the retreating glacier, a proglacial lake already had inundated much of the central and southern Puget Lowland because water was impounded by the ice that still filled the northern Lowland. This water body, glacial Lake Russell, drained out through Black Lake, south of Olympia. into the Chehalis River many tens of kilometers to the south of the quadrangle (Thorson, 1980). Although the elevation of the Black Lake spillway is now only about 135 ft (42 m), the ancient level of glacial Lake Russell is now higher because the entire Puget Lowland has rebounded since the removal of the ice sheet. More rebound occurred in the north than in the south because the ice load was greater to the north. Rebound in the Olalla quadrangle, relative to the Black Lake spillway, ranges from about 130 ft in the south to 165 ft in the north (40 to 50 m), and so the level of glacial Lake Russell during earliest deposition of recessional outwash deposits (Qvr) was at about 260 to 300 ft (80 to 90 m) above the present-day elevation.

The lidar DEM reveals deposits whose morphology suggests deposition underwater. Typically, the topographic features of such deposits are more rounded and fluid-looking than their subaerial equivalents. We mapped sublacustrine alluvial fans (Qvrlf) and landslides (Qvrls). Some alluvial fans are included in the sub-lacustrine group, because they not only occur at elevations that would have been below lake level, but also they are built out from drainages that could have flourished only while fed by melting ice.

Most horizontal lake deposits (Qvrl) in valley bottoms are probably covered by Holocene alluvium, but, on a promontory northwest of Olalla Bay, probable lake deposits are perched above Holocene depositional environments.

The shoreline of glacial Lake Bretz has a present-day elevation of about 35 to 65 ft (10 to 20 m) across the quadrangle, 230 ft (70 m) lower than that of glacial Lake Russell. Glacial Lake Bretz was impounded by a spillway at the south end of Chimacum Valley, 30 mi (50 km) northwest of the quadrangle on the northeastern Olympic Peninsula. Continued ice retreat ultimately opened Admiralty Inlet, drained glacial Lake Bretz, and connected Puget Sound to the world ocean. At the time glacial

Lake Bretz drained, the ice margin appears to have been far to the north of the Olalla quadrangle, thus fluvial activity could have consisted of only small creeks draining the local uplands, similar to the present day. This history leaves no mechanism for fluvial erosion of the large, roughly north–south valleys that traverse the map area, thus Booth and Troost (2005) deduced that they were formed by subglacial erosion. This was almost certainly subglacial fluvial erosion, because these valleys partly crosscut the upland indicators of ice-flow direction (Booth, 1994). As such, these large valleys are the central lowland equivalents of the "channelways" previously mapped along the eastern margin of the Puget Lowland (Booth and Hallet, 1993).

Recessional outwash deposits are scattered across the upland areas, notably south and west of Long Lake, above Wilson Creek and Fragaria Creek in the northeast corner of the map, east of Purdy Creek, and on the upland areas of Vashon Island. The elevation of these deposits indicates they were probably graded to Lake Russell (Haugerud, 2009). We have approximated their relative ages by visualizing the retreat of the ice front in a northeasterly direction across the quadrangle (see for instance, Thorson, 1989). The lidar topography reveals multiple terraces in some of these deposits, indicating a change in base level or local uplift during terrace formation. A terrace-like deposit southwest of Long Lake (Qvis) with a down-to-the-northeast gradient is likely to be subglacial outwash from pressurized water flow uphill to the southwest. It nests in extensive ice-contact deposits (Qvi), supporting a subglacial origin, but it could be the youngest outwash of associated outwash terraces (Qvrla1, Qvrla2), but draining northeast after ice in the Olalla Valley to the northeast melted back or down and was deposited by melt from stagnant ice in the surrounding area.

Booth and Troost (2005) identified relatively low elevation outwash materials in major valleys that lie lower than the maximum levels of Lake Russell, which they ascribed to outwash graded to a lowering Lake Russell or Lake Bretz. We now show some of these deposits as post-glacial alluvium (Qa), notably in Olalla Valley, Crescent Valley, and the valley of lower Purdy Creek. Some of this alluvium may overlie outwash or lake deposits. In some valleys lacking terrace morphology and that, in the lidar DEM, show glacial grooving, we interpret the materials to be eroded advance outwash (unit Qva). Some terraces may only be a thin veneer of outwash gravels on eroded older materials, and these are similarly included in the older deposit unless the present-day landforms suggest significant late-glacial or postglacial reworking. Probable wave-cut notches (primarily adapted from Haugerud, 2009) indicate lake shorelines above sublacustrine features discussed previously. Multiple terrace deposits in Burley, Goodnough, Olalla, Purdy, and Salmonberry Creeks are all too low to have been cut by water from the melting ice sheet, although the materials of the terraces are most likely remnants of recessional outwash (Qvrw) that built up in the valleys at one time. These terrace levels, similar to the higher outwash terraces, may represent change in base levels due to glacial rebound or, for some, rebound and (or) lowering of glacial Lake Bretz. Although individual terraces may correlate from drainage to drainage, their number designations here do not imply correlation.

We recognized most landslides from the lidar DEM by their arcuate headwalls and bulbous toes, although the toes are not always obvious. We have queried 53 of 187 mapped landslides, indicating uncertainty in their identification. Some subaerial landslides (unit Qls) are incised by creeks or otherwise eroded, indicating greater age. Some of these may have formed as stagnant ice melted away in terrane mapped as unit Qvi. Composite landslide masses may have a large age range. Sublacustrine landslides (unit Qvrls) are generally more subdued, look smoothed, occur on lower slopes, and are at an appropriate elevation to have been under Lake Russell. Although older landslides may be more stable than younger ones, no implication of stability is intended in this landslide classification. This map is not suitable for site-specific land-use decisions.

Structure

The Olalla quadrangle occupies a region of known Holocene seismicity, deformation, and surface faulting (Bucknam and others, 1992; Johnson and others, 1996; Barnett and others, 2010). Most apparent displacements and truncations within the quadrangle, however, likely are the result of Holocene landsliding, depositional unconformities, or glacial overriding rather than tectonic movement. One fault of likely tectonic origin is mapped in the beach cliff north of Sandford Point, where pre-Fraser-glaciation-age silt (Qpof) abuts sand (Qpoc) along a vertical surface. Bedding is strongly distorted along this fault; the deformation extends about 2 m into the adjacent silt. In contrast, the relatively gentle deformation that is widespread throughout the quadrangle almost certainly reflects longterm folding during the Quaternary period. Pre-Vashon-stade-age deposits in and around the map area define a regional pattern of fold axes striking west to west-northwest (Johnson and others, 2004; Booth and others, 2004b); the axis of an anticline is expressed by opposing dips just north of Sandford Point on Vashon Island, and a syncline axis is suggested by dips just south of Fragaria Creek. No such folding has been observed in sediments of Vashon stade age, but deposits of Olympia nonglacial interval age and older are deformed here and throughout the southern Puget Sound region.

DESCRIPTION OF MAP UNITS

NONGLACIAL DEPOSITS

af **Artificial fill (Holocene)**—Manmade deposits of gravel, silt, sand, and soil. Includes broken rock. Areas mapped include rearranged or graded native materials and some excavated surfaces

Qbtf **Beach and tidal flat deposits (Holocene)**—Shoreward side of deposit is mostly well sorted sand, pebbles, and shells, deposited or reworked by wave action. Includes upper-beach deposits above mean high water line and local thin veneer of modern beach sediment that overlies older deposits. At stream mouths, grades into unit Qa or Qf, Grades seaward to silt, sand, and organic sediment and detritus; exposed in broad coastal intertidal benches at low tide. Contact with water is approximate; at low tide exposed width of these deposits may be 2 to 3 times that shown here. Occurs along shores of Colvos Passage

Qw **Wetland deposits (Holocene)—**Peat and alluvium; poorly drained and intermittently wet

Qmw **Mass-wasting deposits (Holocene)—**Colluvium, soil, and landslide debris that has indistinct morphology, both in the field and on lidar DEM. Mapped by Booth and Troost (2005) where sufficiently thick and continuous to obscure underlying material. Numerous unmapped areas of mass-wasting deposits are present along coastal bluffs. Deposits, both mapped and unmapped, may include discrete landslides 3 to 35 ft (1 to 10 m) in lateral extent. Largest mapped areas are in southwest part of quadrangle

Qa **Alluvium (Holocene and Pleistocene)**—Moderately well sorted deposits of cobble gravel, gravel, sand, gravelly sand, and sandy silt; found along floodplains of lowland streams. Unit is gradational with, and locally includes, sediment equivalent to units Qf and Qb. Locally mapped as terrace sequences

Terrace sequences—Terrace sequences are numbered oldest to youngest (unit 1 to n); except for the youngest deposits associated with modern streams, unit numbers do not imply correlation between drainages

Terraces along Burley Creek

Qab3 **Alluvium of Burley Creek, unit 3 (Holocene)**

Qab2 **Alluvium of Burley Creek, unit 2 (Holocene and Pleistocene)**

Qab1 **Alluvium of Burley Creek, unit 1 (Holocene and Pleistocene)**

Terraces along Goodnough Creek

Qag3 **Alluvium of Goodnough Creek, unit 3 (Holocene)**

Qag2 **Alluvium of Goodnough Creek, unit 2(Holocene and Pleistocene)**

Qag1 **Alluvium of Goodnough Creek, unit 1 (Holocene and Pleistocene)**

Terraces along Olalla Creek

Qao2 **Alluvium of Olalla Creek, unit 2 (Holocene)**

Qao1 **Alluvium of Olalla Creek, unit 1 (Holocene and Pleistocene)**

Terraces along lower Purdy Creek

Qap2 **Alluvium of Purdy Creek, unit 2 (Holocene)**

Qap1 **Alluvium of Purdy Creek, unit 1 (Holocene and Pleistocene)**

Terraces along Salmonberry Creek

Qasb2 **Alluvium of Salmonberry Creek, unit 2 (Holocene)**

Qasb1 **Alluvium of Salmonberry Creek, unit 1 (Holocene and Pleistocene)**

Qf **Fan deposits (Holocene)**—Boulders, cobbles, pebbles, and sand deposited in lobate form where streams emerge from confining valleys and where reduced gradients cause sediment loads to be deposited

Qoa **Older alluvium (Holocene and Pleistocene)**—Similar to unit Qa. Mapped from lidar DEM where modern drainage insufficient for transport

Qfo **Fan deposits, older (Holocene and Pleistocene)**—Similar to Qf. On southwest coast of Vashon Island near Paradise Cove, separated from younger materials by low scarp. In Qlalla Valley, mapped where modern drainage insufficient for amount of material in fan

Qls **Landslide deposits (Holocene and Pleistocene)**—Diamictons composed of broken to internally coherent surficial deposits that are derived from upslope. Origin uncertain where queried (Qls?). Largely mapped on basis of topographic expression. Numerous unmapped areas of both landslide and related mass-wasting deposits also are found elsewhere in quadrangle, particularly where coarse deposits (units Qva and Qpog) overlie fine deposits (particularly units Qvlc, Qpogf, and Qpfn)

YOUNGER GLACIAL DEPOSITS

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

Qvrlf **Sublacustrine alluvial fans**—Alluvial fans built under recessional lakes. Mapped from lidar based on shape and elevation. Although these fans, as mapped, may include some post-glacial alluvial fans (Qf), they occur at canyon mouths with limited drainage

Qvrls **Sublacustrine landslides**—Mostly built under Lake Russell, but slides at elevation under about 250 ft may have been built under Lake Bretz. Mapped from lidar DEM on basis of elevation and subdued, fluid appearance. May include some subaerial landslides (Qls)

Qvrl **Sublacustrine deposits**—Probable bedded sands and silts deposited in Lake Russell and (or) Lake Bretz on a promontory northwest of Olalla Bay. Mapped from lidar DEM and identified by surface texture and elevation

Qvrw **Recessional outwash deposits graded to Lake Russell**—Stratified sand and gravel, moderately well sorted to well sorted; less common silty sand and silt. Exposed primarily in narrow sinuous channels, locally cross-cutting glacial flutes, and as irregular upland bodies having no obvious channelized form. Recessional outwash rarely exposed on floors of broad south-southwest-trending valleys (for instance, Purdy and Salmonberry Creeks), where floor sediments are mostly topped by alluvium (unit Qa) as mapped here. Narrow channel deposits are probably subglacial. Deposits less than about 1 m thick commonly overlie till but are not mapped. In north-central part of map, may include outwash of Lake Bretz age

Outwash in the SE Mullenix Road area—Three terraces graded to Lake Russell via Burley Creek

Qvrm3 **Outwash of SE Mullenix Road, unit 3**

Qvrm2 **Outwash of SE Mullenix Road, unit 2**

Qvrm1 **Outwash of SE Mullenix Road, unit 1**

Outwash in Bethel area—Four terraces graded to Lake Russell via Burley Creek

Qvrb4 **Outwash of Bethel, unit 4**

Qvrb3 **Outwash of Bethel, unit 3**

Qvrb2 **Outwash of Bethel, unit 2**

Qvrb1 **Outwash of Bethel, unit 1**

Outwash southwest of Long Lake—Two terraces graded to Lake Russell via Purdy Creek

Qvrla2 **Outwash of Long Lake, unit 2**

Qvrla1 **Outwash of Long Lake, unit 1**

Outwash terraces and channel fills west of Peacock Hill Road SE—Three terraces graded to Lake Russell via Purdy Creek

Qvrp3 **Outwash of Peacock Hill Road, unit 3**

Qvrp2 **Outwash of Peacock Hill Road, unit 2**

Qvrp1 **Outwash of Peacock Hill Road, unit 1**

Outwash terraces and channel fills southeast of 160th Sreet NW—Two terraces graded to Lake Russell via Goodnough Creek

Qvro2 **Outwash of 160th Steet, unit 2**

Qvro1 **Outwash of 160th Steet, unit 1**

Qvi **Ice-contact deposits**—Deposits similar in texture to unit Qvr but locally containing much higher percentage of silt intermixed with granular sediments; also includes lenses and pods of till. Locally characterized by hummocky topography and (or) closed depressions. Distribution of unit depicted by Booth and Troost (2005) modified extensively using lidar topography

Qvie **Esker**—Recognized by sinuous form and positive relief. Found at westernmost edge of quadrangle

Qvis Probable subglacial outwash—Southwest of Long Lake

Qvt **Till**—Compact diamicton containing subrounded to well-rounded clasts is glacially transported and deposited. Generally forms undulating surface. Unit is 3 to 10 ft (1 to 3 m) thick. Also found sporadically within areas mapped as unit Qvi

Qva **Advance outwash deposits**—Well-bedded sand and gravel deposited by streams and rivers that issued from front of advancing ice sheet. Generally unoxidized; almost devoid of silt or clay, except near base of unit. Includes deposits previously mapped by others as Colvos Sand or Esperance Sand Members of the Vashon Drift

Qvlc **Lawton Clay**—Laminated to massive silt, clayey silt, and silty clay deposited in proglacial or lowland lakes. Unequivocal evidence for glacial or nonglacial origin rarely present. Mapped deposits are assigned to this unit primarily on the basis of stratigraphic position, but some localities have nearby absolute age control

OLDER GLACIAL AND NONGLACIAL DEPOSITS

Qpf **Sedimentary deposits of pre-Fraser glaciation age (Pleistocene)**—Weakly to moderately well oxidized sand and gravel, lacustrine sediments containing local peat layers, and moderately well to strongly oxidized diamicton composed of silty matrix and rounded gravel clasts. Exposed on northern part of Vashon Island

Qpfn **Nonglacial deposits**—Abundant organic debris or pumice indicating nonglacial origin. Exposed in southwest corner of map

Qob **Olympia beds of Minard and Booth (1988) (Pleistocene)**—Sand and silt thinly interbedded with some gravel layers and, locally, with abundant organic material. Deposited during the Olympia nonglacial interval by lowland streams or in floodplain and (or) lacustrine environments. Crops out in isolated areas on west side of Colvos Passage

Qpo **Deposits of pre-Olympia age (Pleistocene)**—Interbedded sand, gravel, silt and diamict. Very dense and hard Unit Qpo and its subunits crop out predominantly along the Colvos Passage, in the lower Olalla Valley, and in the southwest Purdy Creek drainage

Qpoc **Coarse-grained deposits**—Predominantly gravel and sand, exposed in one small stretch of beach cliff on the west side of Vashon Island

Qpof **Fine-grained deposits**—Predominantly silt and clay

Qpog **Glacial deposits**—Weakly to strongly oxidized silt, sand, and rare gravel of glacial origin. Underlies Vashon Drift till or Vashon Drift advance outwash deposits and, thus, must also predate the last interglacial period (be of pre-Olympia nonglacial interval age)

Qpogc **Coarse-grained deposits**—Predominantly gravel and sand

Qpogf **Fine-grained deposits**—Predominantly silt and clay

Qpogt **Till deposits**—Predominantly till or other diamict

Qpon **Nonglacial deposits**—Deposits with abundant organic debris or pumiceous material indicating nonglacial origin

Qponc **Coarse-grained deposits**—Predominantly gravel and sand

Qponf **Fine-grained deposits**—Predominantly silt and clay

Reversely magnetized deposits (Pleistocene)—Mapped along west side of Colvos Passage

Qrgf **Fine-grained glacial deposits**—Fine silt that contains dropstones, so likely has glacial origin. Reversely magnetized and thus presumably more than 774,000 years old (Hagstrom and others, 2002)

Qrn **Nonglacial deposits**—Interbedded silt, sand, and gravel with local pumice clasts. Likely of nonglacial origin. Reversely magnetized and thus probably more than 774,000 years old (Hagstrom and others, 2002)

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