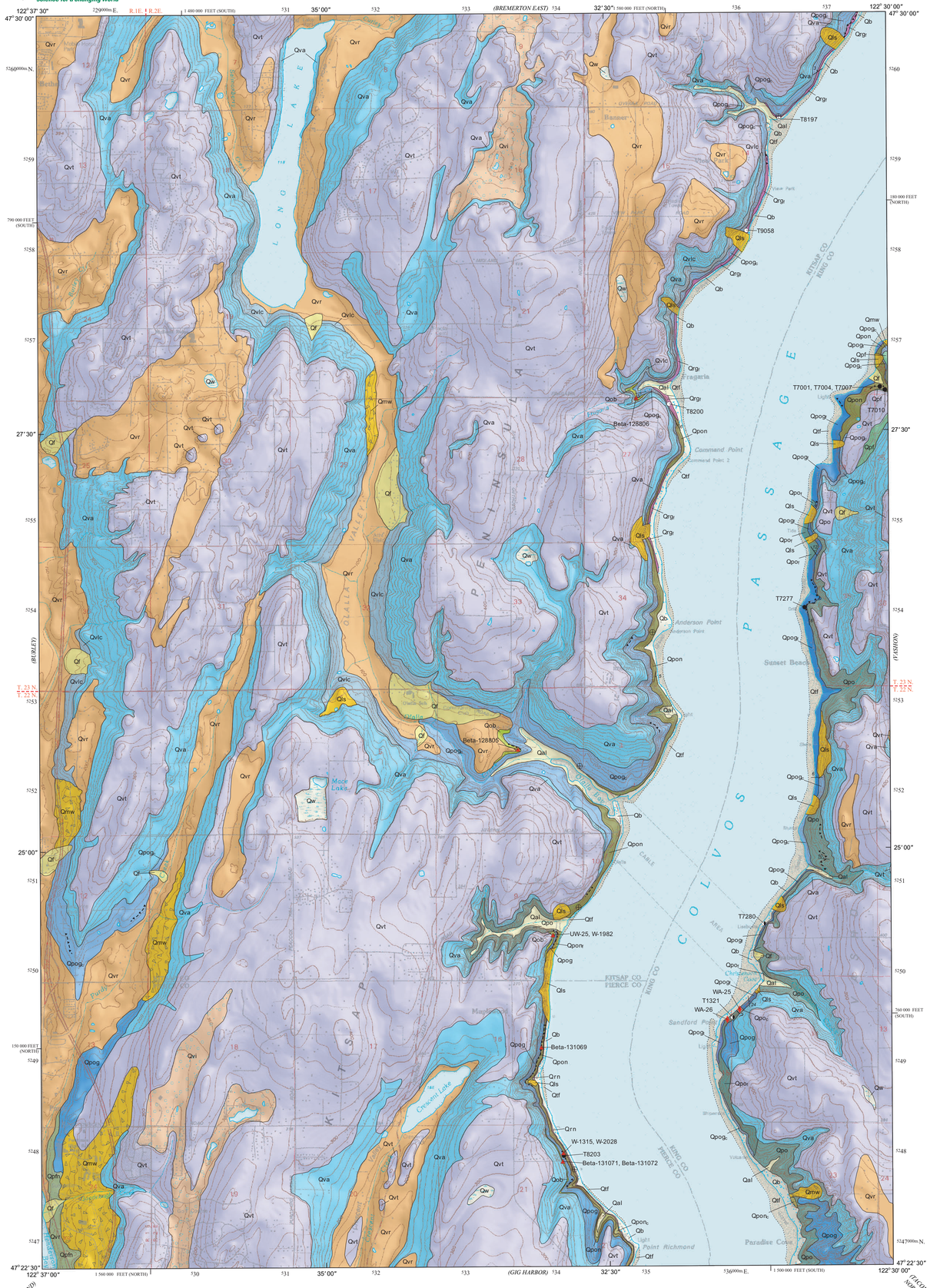
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

SCIENTIFIC INVESTIGATIONS MAP 2902



Base extracted from U.S. Geological Survey 1:24,000-scale Digital Raster Graphic (DRG), Olalla, WA, 1994. Original 1:24,000-scale published map from U.S. Geological Survey, 1953 (revised 1994); topography compiled from aerial photographs taken 1951 (revised 1990). Field-checked 1992

Shaded relief from U.S. Geological Survey 10-meter Digital Elevation Model (DEM), Olalla, WA, 1994

Universal Transverse Mercator projection; North American Datum of 1927

Geology mapped by D.B. Booth, 1987-1989, 1997-2000; K.G. Troost, 1996-2000

Database and digital cartography by Elizabeth A. Barnett, Ralph A. Haugerud, Karen L. Wheeler, Evan E. Thoms, Matt D. Anders, and Alison R. Duvall

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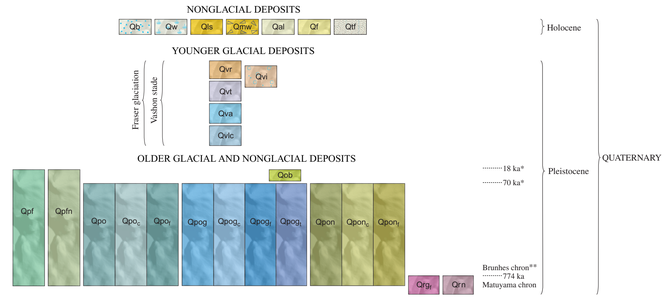
CORRELATION OF MAP UNITS



* Dates correspond to boundaries of the Olympia nonglacial interval (Booth and others, 2004a)
** Age of boundary from Sarna-Wojcicki and others (2000)

DESCRIPTION OF MAP UNITS

NONGLACIAL DEPOSITS

Qb **Beach deposits (Holocene)**—Locally well-sorted sand, pebbles, silt, 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 Qal; in intertidal zone, grades into unit Qtf

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

Qls **Landslide deposits (Holocene)**—Diamictons composed of broken to internally coherent surficial deposits that are derived from upslope. Numerous unmapped areas of both landslide and related mass-wastage deposits also are found elsewhere in quadrangle, particularly where coarse deposits (units Qva and $Qpog_c$) overlie fine deposits (particularly units Qvlc, $Qpog_f$, and Qpfn). Shown by arrows on bluff sketches

Qmw **Mass-wastage deposits (Holocene)**—Colluvium, soil, and landslide debris that has indistinct morphology; mapped where sufficiently thick and continuous enough to obscure underlying material. Numerous unmapped areas of mass-wastage deposits are found elsewhere in quadrangle along coastal bluffs of Puget Sound. Deposits, both mapped and unmapped, may include discrete landslides 1 to 10 m in lateral extent

Qal **Alluvium (Holocene)**—Moderately well sorted deposits of cobble gravel, pebbly sand, and sandy silt; found along floodplains of lowland streams. Unit is gradational with, and locally includes, sediment equivalent to units Qf and Qb

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

Qtf **Tideflat deposits (Holocene)**—Silt, sand, and organic sediment and detritus; exposed in broad coastal benches at low tide

YOUNGER GLACIAL DEPOSITS

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

Qvr **Recessional outwash deposits**—Stratified sand and gravel, moderately well sorted to well sorted; less common silty sand and silt. Exposed primarily on floors of broad outwash channels that trend south-southwest between flutes molded by glacial flow; also exposed as irregular upland bodies having no obvious channelized form. Deposits less than about 1 m thick commonly overlie till but are not mapped

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

Qvt **Till**—Compact diamicton containing subrounded to well-rounded clasts; glacially transported and deposited. Generally forms undulating surface a few meters to a few tens of meters 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 the Esperance Sand Member 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 only 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. Locally mapped as:

Qpfn **Nonglacial deposits**—Abundant organic debris or pumice indicating nonglacial origin

Qpo **Olympia beds of Minard and Booth (1988) (Pleistocene)**—Sand and silt thinly interbedded with some gravel layers and, locally, with abundant organic material; deposited by lowland streams or in floodplain and (or) lacustrine environments

Qpo **Deposits of pre-Olympia age (Pleistocene)**—Locally mapped as:

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

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

Qpog **Glacial deposits**—Weakly to strongly oxidized silt, sand, and rare gravel of glacial origin. Underlies all Vashon-age deposits and thus must be of pre-Olympia age

$Qpog_c$ **Coarse-grained deposits**—Predominantly gravel and sand

$Qpog_f$ **Fine-grained deposits**—Predominantly silt and clay

$Qpog_t$ **Till deposits**—Predominantly till or other diamict

Qpon **Nonglacial deposits**—Abundant organic debris or pumiceous deposits indicating nonglacial origin

$Qpon_c$ **Coarse-grained deposits**—Predominantly gravel and sand

$Qpon_f$ **Fine-grained deposits**—Predominantly silt and clay

Reversely magnetized deposits (Pleistocene)—

Glacial deposits—

Qrg_f **Fine-grained deposits**—Fine silt that contains dropstones, and so of likely glacial origin. Reversely magnetized and thus presumably more than 774,000 years old

Qrn **Nonglacial deposits**—Interbedded silt, sand and gravel, and local pumice clasts suggesting likely nonglacial origin. Reversely magnetized and thus presumably more than 774,000 years old

Contact—Dotted where concealed; queried where uncertain (in bluff sketch)

Fault—Dotted where concealed; queried where uncertain. U, upthrown block; D, downthrown block. Arrows (in bluff sketch) show relative motion

Strike and dip of beds
Inclined
Horizontal

Pre-Vashon till—Mapped within units Qpo, Qpog, and Qrg where exposed on valley walls or coastal bluffs. Queried where uncertain (in bluff sketch)

Peat bed or other organic-rich layer

Paleomagnetic sample localities
Normal magnetization
Transitional magnetization
Reversed magnetization

^{14}C age locality—See table 1 for ages

Infrared-stimulated luminescence (IRSL) age localities—See table 2 for ages

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

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

[1] Present is considered to be 1950 A.D.
[2] Calibrated radiocarbon age (2-sigma range)
[3] Estimated $^{13}C/^{12}C$ ratio
[4] Originally reported finite date probably tritium-contaminated (Fairhall and others, 1966) and so not reported here; stratigraphic assignment based on field relationships
[5] Elevation based on presumed duplication of site UW-25 (Deeter, 1979, p. 62-63)

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

Lab No.	Location	Elevation (ft)	Material	Average IRSL-Age, in 1000 yrs	Map Unit
WA-25	Sandford Point	20	Fine sand	127±6	Qpo_c
WA-26	Sandford Point	25	Silt	185±9	Qpo_f

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

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

The oldest exposed sediment in the quadrangle is reversely magnetized, and so it is probably more than 774,000 years old. This age determination is based on direct paleomagnetic measurement of lacustrine silt and clay at three localities on the north Kitsap Peninsula coastline (samples T8197, T8200, and T9058). Near the mouth of Fragaria Creek, at View Park, and to the north past Wilson Creek (Hagstrum and others, 2002), these older deposits are mapped as unit Qrg. At Sandford Point, texturally similar sediment has a transitional polarity (sample T1321), suggesting a more precise 774 ka age; here the deposits are mapped in unit Qpog.

Where paleomagnetic determinations are absent, deposits whose ages predate the Fraser glaciation of Armstrong and others (1965), mapped as units Qpf and Qpo, are subdivided on the map, if at all, by their presumed depositional environment; scattered localities of normal-polarity sediment (samples T7001, T7004, T7007, T7010, T7277, and T8203) suggest that these mapped deposits are younger than 774 ka. Where organic material or volcanic sediment is abundant, we infer a likely nonglacial origin (units Qpfn and Qpon). Those deposits displaying 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, are of presumed glacial origin. Because all pre-Fraser glacial periods also precede the Olympia nonglacial interval (Mullineaux and others, 1965), these deposits are mapped as unit Qpog because the designation "Qpfg" (in other words, "Quaternary pre-Fraser glacial") is unnecessarily broad. We make no effort to assign stratigraphic names to these pre-Fraser-age deposits, however, because absolute age control is very sparse at present.

In the eastern part of the quadrangle, we recognize two, and possibly three, separate pre-Fraser-age tills. The two younger tills overlie normally polarized sediment and so are younger than 774,000 years old; the age of the oldest pre-Fraser-age till is indeterminant. To the west, exposures are poorer, and only one pre-Fraser-age till has been identified. Diamictons of presumed glacial origin whose deposition predates the Fraser glaciation are shown as discrete units ($Qpog_t$); layers or lenses are shown as triangle-dash lines 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 immediately preceded the most recent ice-sheet advance into the Puget Lowland (Mullineaux and others, 1965; Armstrong and others, 1965; Troost, 1999). Deposits formed during this time, mapped as unit Qob, have been identified by radiocarbon dating at several localities in the Olalla quadrangle (table 1). Deposition of these sediments may have been more widespread during this time than is indicated by the distribution of unit Qob on the map because some Olympia-age sediments are probably lumped less precisely into the lithostratigraphic units Qpf or Qpfn. Conversely, deposits mapped as pre-Olympia in age (and so assigned to unit Qpo) are separated from either Fraser-age or radiocarbon-dated Olympia-age deposits by at least one pre-Fraser-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 readily assigned to the youngest regionally recognized glacial advance, 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 1,500 m (Booth, 1987; Porter and Swanson, 1998). As the ice first advanced, it blocked northward lowland drainage out 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. We have tentatively assigned such lacustrine deposits flanking Olalla Valley and Colvos Passage to 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).

Advance outwash deposits (Qva), deposited by streams derived from the advancing ice sheet, marks the subsequent depositional interval. Sandy advance outwash deposits at least a few tens of meters thick (and locally as thick as 100 meters) underlies the broad uplands in the central part of the quadrangle. This deposit inundated the pre-Vashon topography of the lowland and resulted in a gently south-sloping landform (Booth, 1994), whose upper surface is as high as 120 m (400 ft) in the center of the quadrangle but locally has been scoured by the overriding ice down to as low as about 30 m (100 ft). The base of the unit is exposed along most of the deep valleys and coastal bluffs; its elevation varies between about 30 and 60 m (100-200 ft).

As ice covered the region, till (Qvt) was deposited by the melt-out of debris at the base of the glacier. This heterogeneous and generally compact sediment blankets the area to depths that are of, at most, a few tens of meters but, more typically, are only one or two meters. In the northwestern part of the quadrangle, the ground surface underlain by this deposit is strongly fluted to the south-southwest; elsewhere, it displays a modest grain that is recognizable but not nearly as pronounced.

Shortly after 17,000 (14,000 radiocarbon) years ago, the ice margin, which by this time had advanced about 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 more than one thousand meters of ice that still filled the Strait of Juan de Fuca. This water body, Glacial Lake Russell, drained out through the Black Hills into the Chehalis River many tens of kilometers to the south of the quadrangle (Thorson, 1980). Although the elevation of the Black Hills spillway was only about 40 m, the ancient level of Glacial Lake Russell is now higher because the land surface of the entire Puget Lowland has rebounded since the subsequent removal of the ice sheet. More rebounding occurred in the north than in the south because the ice was thicker to the north. Rebound in the Olalla quadrangle ranges from about 40 m (in the south) to 50 m (in the north), and so the level of Puget Sound during earliest deposition of recessional outwash deposits (Qvr) was at about 80 to 90 m (260-300 ft) elevation. 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, and on the upland areas of Vashon Island.

Other recessional outwash deposits, however, are present in valleys that have lower elevations than the level of Glacial Lake Russell, most notably in Olalla Valley, Crescent Valley, and the valley of Purdy Creek. These deposits must have been deposited either during drainage of Glacial Lake Russell or during the subsequent regional lake stage, that of Glacial Lake Bretz (Waitt and Thorson, 1983). Glacial Lake Bretz, which had a water-surface elevation of about 10 to 20 m across the quadrangle, 70 m lower than that of Glacial Lake Russell, was impounded by a spillway 50 km north of the quadrangle, at Leland Creek on the northeastern Olympic Peninsula. Continued ice retreat ultimately exposed sea-level channels that drained Glacial Lake Bretz, permitting the first postglacial access of Puget Sound drainages to the Strait of Juan de Fuca. With the ice margin so far north at the time, the area of the Olalla map must have been largely ice-free, and so fluvial activity could have consisted of only small creeks draining off of the local uplands, similar to that of the present day. Erosion of these large valleys, therefore, must be a result of subglacial activity, almost certainly subglacial fluvial erosion, because these landforms partly crosscut the upland indicators of ice-flow direction. 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).

GEOLOGIC SUMMARY

INTRODUCTION

The Olalla 7.5' quadrangle, which lies almost exactly 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. 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, the 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 meters 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 weighted down by one or more episodes of glaciation subsequent to their deposition. Some also are 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

In the Olalla quadrangle, the mapping shown on the Kitsap Peninsula was based entirely on original field work and published radiocarbon dates. On Vashon Island, however, preexisting map data of Booth (1991) largely was used. The locations of some geologic contacts were refined by reference to newly available LIDAR (**LI**ght **D**istance **A**nd **R**anging) topography from the Puget Sound LIDAR Consortium (see *http://pugetsoundlidar.org/*). 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 on this map, their data represent significant contributions for their time and have been valuable resources for establishing the general geologic context.

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); neither, however, had any numerical age determinations with which to guide their judgment. 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. As a result, this name is abandoned 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.

STRUCTURE

The Olalla quadrangle occupies a region of known Holocene seismicity and surface faulting (Bucknam and others, 1992; Johnson and others, 1996; Brocher and others, 2001). Most apparent displacements and truncations, however, likely are the result of Holocene landsliding, depositional unconformities, or glacial overriding, instead of tectonic movement. One fault of likely tectonic origin is mapped in the beach cliff near Sandford Point, where pre-Fraser-age silt abuts sand along a vertical, extensively sheared (presumably faulted) contact. Bedding is strongly distorted along this (presumed) 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 long-term crustal deformation during the Quaternary period. Pre-Vashon-age deposits in and around the map area define a regional pattern of fold axes striking west to west-northwest (Booth and others, 2004b); the axis of an anticline is expressed by opposing dips just north of Sandford Point on Vashon Island, and a synclinal axis is suggested by dips just south of Fragaria Creek. No deformation has been observed in sediments of Vashon age, but deposits of Olympia age and older exhibit deformation here and throughout the southern Puget Sound region.

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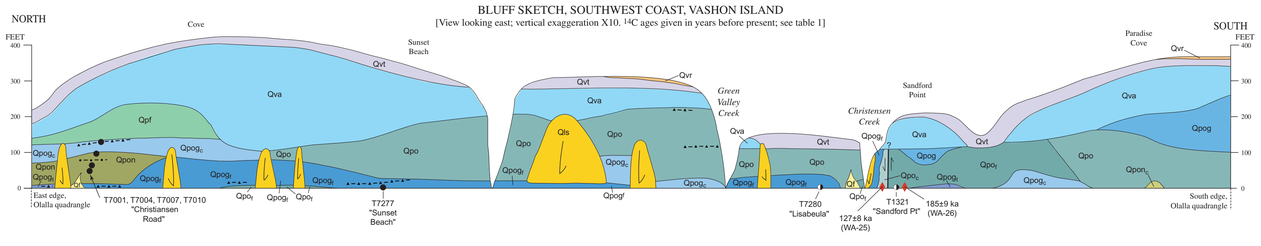
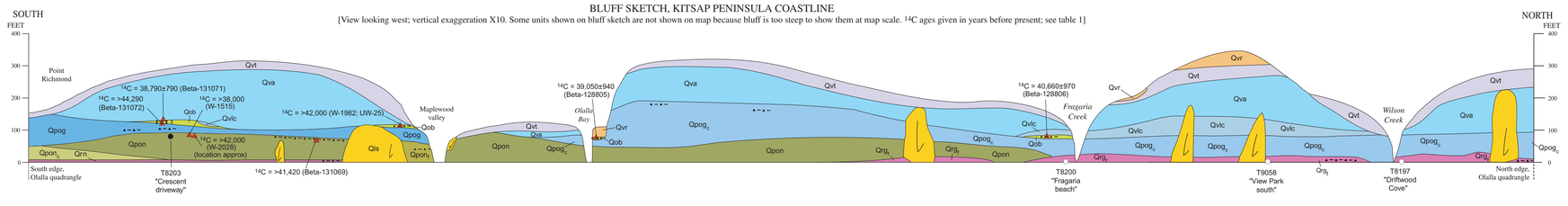
BLUFF SKETCH, SOUTHWEST COAST, VASHON ISLAND

[View looking east; vertical exaggeration X10. ^{14}C ages given in years before present; see table 1]



BLUFF SKETCH, KITSAP PENINSULA COASTLINE

[View looking west; vertical exaggeration X10. Some units shown on bluff sketch are not shown on map because bluff is too steep to show them at map scale. ^{14}C ages given in years before present; see table 1]



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

By
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