WASHINGTON STATE DEPARTMENT OF Natural Resources
Doug Sutherland - Commissioner of Public Lands
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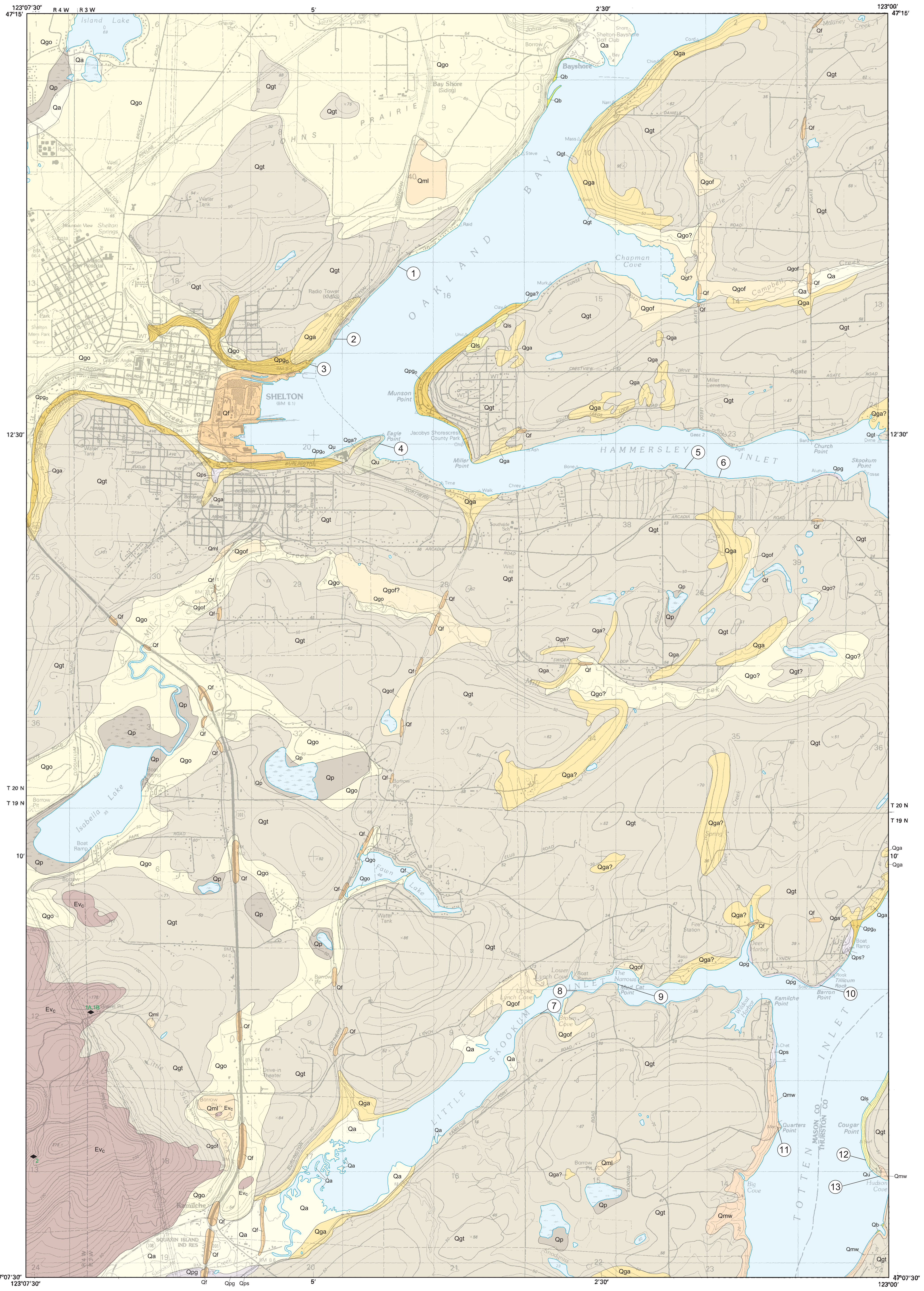
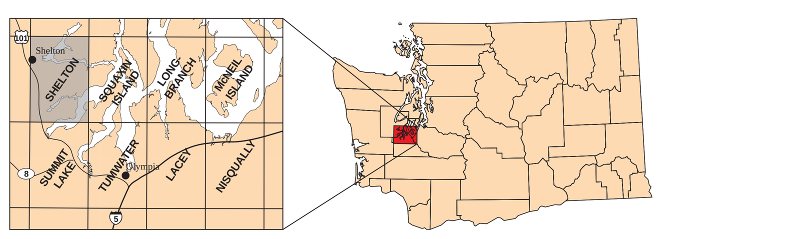


Lambert conformal conic projection
North American Datum of 1927; to place on North American Datum of 1983, move the projection lines 23 meters north and 95 meters east as shown by dashed corner ticks
Base map from scanned and rectified U.S. Geological Survey 7.5-minute Shelton quadrangle, 1981
Digital cartography by Charles G. Caruthers, Anne C. Heinitz, and J. Eric Schuster
Editing and production by Karen D. Meyers and Jaretta M. Roloff

SCALE 1:24 000

contour interval 10 meters



Geologic Map of the Shelton 7.5-minute Quadrangle, Mason and Thurston Counties, Washington

by Henry W. Schasse, Robert L. Logan, Michael Polenz, and Timothy J. Walsh

2003

INTRODUCTION

The Shelton quadrangle is located at the south end of Puget Sound and includes the city of Shelton, Oakland Bay, Little Skookum Inlet, and the western and southwestern parts of Hammersley and Totten Inlets respectively. Most of the quadrangle is rural residential or forestland. In the vicinity of the city of Shelton, the land is urban, industrial, or medium-density residential.

GEOLOGIC HISTORY

Late Wisconsinan–age Vashon Drift covers most of the quadrangle. Eocene-age Crescent Formation basalt and diabase are exposed in the southwest part of the quadrangle in the vicinity of Kamilche. Pre-Vashon Pleistocene units are generally exposed only along coastal bluffs or in shoreline outcrops, where mass wasting is common. Landslides and colluvium disrupt and obscure the continuity of exposures so that pre-Vashon geologic history is not easily deciphered. In the Puget Lowland south of Tacoma, all finite radiocarbon ages reported before 1966 are suspect due to laboratory contamination (Fairhall and others, 1966, p. 501). Stratigraphic assignments based on these radiocarbon ages are now questionable and need to be re-evaluated. We have systematically sampled all datable material from nonglacial sediments subjacent to the Vashon Drift and found them to be older than previously reported. With a few exceptions, these sediments have been beyond the range of radiocarbon dating.

The antiquity of the pre-Vashon units causes radiocarbon dating to be of little help for making correlations, and abrupt facies changes within glacial and nonglacial units also render correlations tenuous. Despite these difficulties, we have developed a conceptual model for the more recent pre-Vashon geologic history that is consistent with our observations but by no means compelling.

The oxygen-isotope stage 6 glaciation, called the Double Bluff Glaciation in northern Puget Sound, was probably as extensive as the stage 2 or Vashon Stade of the Fraser Glaciation (Mix, 1987, and Fig. 1). The end moraines of this glaciation lie a short distance beyond the inferred limit of the Vashon ice in the vicinity of Tenino, southeast of this quadrangle (Lea, 1984). Subglacial erosion was probably similar to the erosion that Booth (1994) documented beneath Vashon ice, and would have left accommodation space for deposition during the interglacial time of oxygen-isotope stage 5.

The oxygen-isotope stage 4 glaciation, called the Possession Glaciation in northern Puget Sound, was mild relative to stages 2 and 6 (Mix, 1987, and Fig. 1), represented by the Vashon and Double Bluff Drifts respectively in the Puget Lowland. The Possession ice sheet probably did not extend far south of Seattle (Lea, 1984; Troost, 1999). Because the ice sheet blocked drainage out of Puget Sound to the Strait of Juan de Fuca, a proglacial lake was impounded covering most of the southern Puget Lowland. Streams flowing into this lake, such as the Nisqually, Puyallup, and Skokomish Rivers, formed alluvial plains and deltas grading to lake level. These nonglacial sediments, deposited during stage 4, are all radiocarbon-infinite and overlie and interfinger with Possession glacial outwash deposits. Once Possession ice no longer impounded the lake (but sea level was still significantly below modern sea level), existing drainages, such as the Skokomish, Nisqually and Puyallup Rivers, deeply and rapidly incised into their former alluvial plains and became entrenched. At least initially, stage 3, called the Olympia nonglacial interval locally (Armstrong and others, 1965), was characterized by downcutting and erosion. As sea level began to rise, most deposition was confined to these entrenched channels. Because stage 3 sea level was probably about 100 feet lower than modern sea level (Ludwig and others, 1996 and references therein), stage 3 deposits were areally restricted. As Vashon ice advanced and sea level fell again at the beginning of stage 2, these rivers preferentially downcut in the same channels, thereby eroding much of the late Olympia deposits, so that finite-aged Olympia deposits are rare above sea level. For pre-Vashon nonglacial deposits that are radiocarbon-infinite, it is difficult to distinguish deposits of stage 3 from deposits of stages 4 and 5, and we have not attempted to do so in the present mapping. In some outcrops, however, tephras are present that provide a tool for geochemical correlation to known eruptions on nearby Cascade stratovolcanoes. Tephra correlations appear promising but will require more data.

As Vashon ice moved southward and grounded across the Strait of Juan de Fuca during stage 2, it dammed the northern outlet of the Puget Sound basin. Proglacial streams carried fluvial sediments southward into the Puget Lowland, filling proglacial lakes and eventually the Puget Sound basin, first with silts then sands and gravels. These sediments, referred to as advance outwash, form the 'great lowland fill' of Booth (1994). Ice overrode these sediments, covering most of them with till, or scoured them away to deposit till directly onto pre-Vashon sediments or Crescent Formation basalt. Subglacial channels were subsequently eroded into the fill. Proglacial lakes became impounded in these channels at different elevations above today's sea level as ice impinged on divides. The former lakebeds are presently the southernmost inlets of Puget Sound. (For a more thorough discussion of the subglacial channel network, see Booth, 1994, and Booth and Goldstein, 1994.) As these proglacial lakes spilled into lower-elevation basins and channels near the end of the Pleistocene, they deposited coarse, steeply dipping deltaic gravels along the margins of the channels and basins, such as in much of the area near Shelton as well as near Steilacoom and Fort Lewis (east of this quadrangle). Some of the gravel is an important aggregate resource, especially along the west bank of Oakland Bay north of Shelton.

Much of the drainage originating from the ice sheet flowed southward and southwestward toward the Chehalis River. Some of the drainage probably occurred as glacial-lake outburst floods when valley-blocking ice dams in the Cascade and Olympic Range foothills were breached during ice retreat. Deep troughs were carved out of the fill and extensive and complex terraces and braided channels were formed. As the ice receded, streams near Olympia (southeast of this quadrangle) filled the deep troughs with sandy sediments characterized by northward-directed paleocurrent indicators. These sediments provide evidence that drainage reorganized to flow northward through the recently formed outwash plain. The thickness of these sediments (not exposed in this quadrangle; see unit Qgos in Walsh and others, 2003b) varies substantially throughout the area, reaching more than 400 ft in a geotechnical borehole at the Port of Olympia, southeast of the map area (Washington Public Power Supply System, 1974). Unit Qgos is important because it is widespread throughout the populous South Sound area and appears to behave differently from the rest of the Vashon Drift during earthquakes (Palmer and others, 1999a,b; Bodle, 1992; King and others, 1990).

In the waning stages of the Fraser Glaciation, glacial Lake Russell covered a large area of the southern Puget Lowland and deposited a relatively thin layer (1–10 ft) of fine-grained varved sediments (unit Qgof) to an elevation of about 140 ft. These lacustrine silts (and rare clays and peats) commonly overlie unit Qgos sands and Vashon till (unit Qgt).

Two radiocarbon ages in the quadrangle (see units Qpf and Qps and ^{14}C ages shown in stratigraphic columns 5 and 12) fit a pattern established in several nearby quadrangles from which many more radiocarbon samples have been analyzed in recent years (Walsh and others, 2003c). Preliminary, unpublished tephra correlation evidence from adjacent quadrangles also suggests that the sediments directly below the Vashon Drift are considerably older than Olympia beds (Walsh and others, 2003c) identified in the same stratigraphic position farther north in the Puget Sound.

PREVIOUS GEOLOGIC MAPPING

The glacial history and geology of south Puget Sound are well summarized by Bretz (1913), who mapped the entire Puget Sound basin in reconnaissance. Molenaar and Noble (1970) and Noble and Wallace (1966) produced small-scale water resource studies. The Coastal Zone Atlas (Washington Department of Ecology, 1980a,b) provides mapping of a 2000 ft wide strip along the shoreline at a scale of 1:24,000. Logan (1987) compiled and augmented previous mapping for the Shelton 1:100,000-scale quadrangle, which was used in the construction of the southwest quadrant of the 1:250,000-scale geologic map of Washington (Walsh and others, 1987).

MAPPING METHODS

For the present map, we inspected available construction site excavations, gravel pits, rock quarries, and roadcuts. We surveyed the shorelines by boat and collected samples and measured sections at bluff and low shoreline exposures. Contacts between map units are commonly not exposed and are only approximately located on this map. They are generally located by outcrop mapping, air photo interpretation, and interpretations of water well logs from Washington Department of Ecology files. Light Detection and Ranging (LIDAR) imagery became available to us after field work was completed, but we were able to use it with some follow-up field checking to augment our interpretation of the geology. Location accuracy of contacts is judged to be about 200 ft in general. In addition, the contacts between some units are gradational. We have tried to consider geotechnical significance in mapping geological units and have attempted to show units only where they are thicker than 5 to 10 ft or mask the underlying lithology.

DESCRIPTION OF MAP UNITS

Quaternary Unconsolidated Deposits

HOLOCENE NONGLACIAL DEPOSITS

Qf — **Fill**—Clay, silt, sand, gravel, organic matter, shells, rip-rap, and debris emplaced to elevate the land surface and reshape surface morphology; includes engineered and non-engineered fills; shown only where fill placement is extensive, sufficiently thick to be of geotechnical significance, and readily verifiable.

Qml — **Modified land**—Soil, sediment, or other geologic material that has been locally reworked to modify the topography by excavation or redistribution.

Qa — **Alluvium**—Silt, sand, gravel, and peat deposited in stream beds and estuaries; may include some lacustrine deposits.

Qb — **Beach deposits**—Unvegetated mud, sand, and gravel residual on a wave-cut platform or deposited in the intertidal zone.

Qp — **Peat and marsh deposits**—Organic and organic-matter-rich mineral sediments deposited in closed depressions; includes peat, muck, silt, and clay in and adjacent to wetlands.

Qmw — **Mass wasting deposits**—Colluvium consisting of loose soil and glacial sand and gravel deposited by soil creep and shallow ravelling on hillslopes, some of which occurred during the waning stages of the Vashon Stade of the Fraser Glaciation; shown where colluvium is of sufficient thickness to mask underlying geologic strata.

Qls — **Landslide deposits**—Rock, soil, and organic matter deposited by mass wasting; depending on degree of activity, location within the slide mass, type of slide, cohesiveness, and competence of materials, may be unstratified, broken, chaotic, and poorly sorted or may retain primary bedding structure; may be cut by clastic dikes or normal or reverse shear planes; surface is commonly hummocky in lower reaches of deep-seated landslides or 'stepped' with forward- or back-tilted blocks in headward areas; deep-seated slides tend to be relatively large. Slow-moving slumps (Varnes, 1978) commonly transform into slump–earth flows, can commonly be recognized by bowed or randomly tilted trees, and most commonly occur at the interface between poorly compacted, poorly cohesive, permeable sands overlying relatively impermeable silt or clay layers; shallow, more rapid debris flows commonly occur at the interface between impermeable substrate, such as till, and shallow, loose, permeable soils that are rich in organic matter. Unit Qls is shown only where landslides are large or obscure the underlying geology.

The presence of a landslide at a particular location need not imply degree of instability. The absence of a recognized landslide at a particular location on the map should not be construed as absence of slide hazards or of an unrecognized or new slide. Where local conditions are potentially conducive to landsliding, this map should not be used as a substitute for a site-specific slope-stability assessment.

PLEISTOCENE GLACIAL DEPOSITS

Deposits of Continental Glaciers—Cordilleran Ice Sheet

Vashon Stade of Fraser Glaciation

Glacial sediments described in this section consist mostly of rock types of northern provenance, most from the Canadian Coast Range. A wide variety of metamorphic and intrusive igneous rocks not indigenous to the Puget Lowland and generally southerly directed current indicators help distinguish these materials from the volcanic-lithic-rich sediments of the eastern Puget Lowland and the Crescent Basalt– and Olympic core–rich sediments of the western Puget Lowland.

Age of maximum Vashon ice advance in the map area was previously estimated to be approximately 14,000 radiocarbon yr B.P., based on apparent post-glacial deposits in the central Puget Lowland that were radiocarbon dated at about 13,600 radiocarbon yr B.P. (Porter and Swanson, 1998). However, five more-recently obtained radiocarbon dates from deposits that directly underlie Vashon till in the southern Puget Lowland indicate a maximum ice advance after about 13,400 radiocarbon yr B.P. (Borden and Troost, 2001; Walsh and others 2003a), which leaves only about 200 years for the glacial advance into and recession from the southern Puget Lowland. Most exposures mapped as Vashon till lack geochronologic data and are identified based on occurrence at or near the top of the stratigraphic section.

Qgof — **Latest Vashon fine-grained sediments**—Lacustrine clayey and (or) fine sandy silt with sparse, disseminated dropstones; laminated and commonly vertically jointed; medium gray where fresh to pale yellow where dry and oxidized; distinguished by relatively darker (chocolate brown in oxidized exposures) horizontal bands about 1 in. thick that may represent annual winter depositional layers in a varve sequence; no more than about 20 apparent varves were counted in any exposure, suggesting a short life for the glacial lake(s) in which unit Qgof was deposited; present in deposits up to 10 ft thick over much of southern Puget Lowland and most commonly found at elevations below about 140 ft; mapped where it is thought to be at least about 5 ft thick or where it masks the underlying geomorphology; includes deposits of glacial Lake Russell and other lakes of the Vashon glacial recession.

Qgo — **Vashon recessional outwash**—Recessional and proglacial stratified, moderately to well-rounded, poorly to moderately sorted outwash sand and gravel of northern or mixed northern and Olympic source, locally containing silt and clay; may contain ice-contact stratified drift and lacustrine deposits. Some areas mapped as unit Qgo may instead be advance outwash (unit Qga) because it is difficult to distinguish between the two without the presence of an intervening till.

Qgt — **Vashon till**—Unsorted and generally highly compacted mixture of clay, silt, sand, and gravel deposited directly by glacier ice; gray where fresh and light yellowish brown where oxidized; generally of very low permeability; most commonly matrix-supported but may be clast-supported; matrix generally feels more gritty than outwash sands when rubbed between fingers, due to being more angular than water-worked sediments; cobbles and boulders commonly faceted and (or) striated; ranges in thickness from wispy, discontinuous layers less than 1 in. to more than 30 ft thick; thicknesses of 2 to 10 ft are most common; mapped till commonly includes outwash clay, silt, sand, gravel, or ablation till that is too thin to substantially mask the underlying, rolling till plain; erratic boulders are commonly associated with till plains but may also occur as lag deposits where the underlying deposits have been modified by meltwater; typically, weakly developed modern soil has formed on the cap of loose gravel, but the underlying till is unweathered; local textural features in thick till exposed along Hammersley Inlet in the adjacent Squaxin Island quadrangle (Logan and others, 2003a) include flow banding and apophyses commonly extending 10 to 15 ft downward into underlying sand and gravel and that are oriented transverse to ice flow direction.

Qga — **Vashon advance outwash**—Sand and gravel and lacustrine clay, silt, and sand deposited during glacial advance; dominated by northern-source rock, generally of granitoid or metamorphic or volcanic affinity and with abundant polycrystalline quartz; gray where fresh, light yellowish gray where stained; sands generally well sorted and fine-grained, with lenses of coarser sand and gravel; locally contains nonglacial sediments, typified by silt rip-ups, cobbles, and peat rip-ups as lag along channel sides and bottoms; commonly exposed where topography is steep and the overlying unit Qgt has been removed by erosion.

PLEISTOCENE DEPOSITS OLDER THAN VASHON DRIFT

Qpf — **Pre-Vashon glaciolacustrine deposits (stratigraphic columns only)**—Parallel-laminated clayey and (or) fine sandy silt with rare dropstones; clasts of glacially comminuted (crushed) northern provenance rock characterized by abundant polycrystalline quartz; medium gray where fresh to light tan where dry and oxidized to olive tan where moist and oxidized; very low permeablility and porosity cause this unit to readily perch groundwater; soft-sediment deformation common; a 1 to 2 ft thick peaty silt exposed along the south shore of Hammersley Inlet produced a ^{14}C age of >42,810 yr B.P. (see stratigraphic column 5).

Qps — **Pre-Vashon sandy deposits**—Thin- to thick-bedded to cross-bedded low-energy fluvial sand and interbedded laminated silt and minor peat and gravel; commonly in upward-fining sequences; older than Vashon Drift and generally overlying or interbedded with unit Qpg; interpreted as nonglacial, but may include glacial-stage deposits, particularly from oxygen-isotope stage 4.

These sediments have previously been referred to the Kitsap Formation and were interpreted to have been deposited during the Olympia nonglacial interval (Garling and others, 1965). Deeter (1979), however, has shown the type locality of the Kitsap Formation to include radiocarbon-infinite sediments of both glacial and nonglacial origin, and we follow his suggestion that the name be abandoned.

Logan and others (2003b) and Walsh and others (2003a) found both normal and reversed paleomagnetic layers within unit Qps and interpret the reversed layers as having been deposited during the Blake reversed subchron in the Bruhnes chron (Morrison, 1991). We obtained a ^{14}C age of >43,350 yr B.P. within the study area from a peat at Cougar Point on the east shore of Totten Inlet (see stratigraphic column 12).

Sediments mapped as unit Qps in the south Puget Lowland may have been deposited during oxygen-isotope stages 3, 5, 7, or 9 (Walsh and others, 2003c), that is, during the Olympia nonglacial interval and much older nonglacial intervals. Because we can establish that not all pre-Vashon nonglacial sediments are correlative, we have chosen not to assign them a stratigraphic name.

Qpg, Qpg_o — **Pre-Vashon gravel**—Gravel and sand deposits that are thought to stratigraphically underlie Vashon till (unit Qgt); may include some Vashon advance outwash; typically iron-oxide stained to an orange tint and cemented and (or) compacted to such a degree that clast lithology and sediment source area is commonly not readily apparent in outcrop; most commonly exposed immediately beneath unit Qps; gravelly portions are relatively resistant to erosion; moderately to poorly sorted; commonly cross bedded but may lack primary sedimentary structures; inferred to be of glacial origin because interglacial conditions do not appear conducive to streams with sufficient competency to deposit widespread gravels in most of the Puget Lowland and because the majority of the exposures include northern-source metamorphic rock clasts. Exposures dominated by Olympic-source basalt and sandstone clasts, including those previously mapped as alpine glacial outwash (Skokomish Gravel; Molenaar and Noble, 1970) are designated as unit Qpg_o.

Qpd — **Pre-Vashon drift (stratigraphic columns only)**—Blue-gray glaciolacustrine beds occurring as rhythmites, generally near the top of unit, non-stratified silt and clay, and locally till; occurs along several hundred feet of the eastern shoreline of Totten Inlet, south of Cougar Point (see stratigraphic column 13); may be near-terminal till, flow till, or ice-contact stratified drift; gravel clasts are of northern provenance.

Qpt — **Pre-Vashon till (stratigraphic columns only)**—Compact, brown, oxidized, unsorted, unstratified mixture of clay, silt, and gravel; recognized separately from undifferentiated pre-Vashon drift (unit Qpd) in only one location on south shore of Hammersley Inlet (see stratigraphic column 6), where it underlies oxidized pre-Vashon gravel with clayey matrix (unit Qpg); unit is of mixed provenance.

Qu — **Pre-Vashon sediments, undifferentiated**—Glacial and nonglacial sediments beneath Vashon Drift that are not separable at map scale; may include some Vashon advance outwash; stratigraphic columns illustrate detailed geology within unit Qu.

Tertiary Rocks

Ev_c — **Crescent Formation (lower to middle Eocene)**—Basalt and diabase; basalt commonly occurs as fine- to coarse-grained, blocky sills and submarine flows or possibly subaerial flows that commonly include amygdules of zeolite and chlorite-group minerals; flows are locally pillowed and very fine grained; plagioclase-phyric and aphyric; black to greenish black in unweathered exposures; gray and moderate yellow-brown in weathered exposures; contains minor thin beds of dark gray siltstone; diabase is coarse-grained and occurs as sills; basalt and diabase both contain intergrowths of augite and plagioclase, with disseminated opaque minerals and ubiquitous replacement of interstitial glass by chlorite and oxidation products; basalt and diabase have uniform basalt chemistry (Table 1).

Contact—Approximately located

Geochemistry sample location

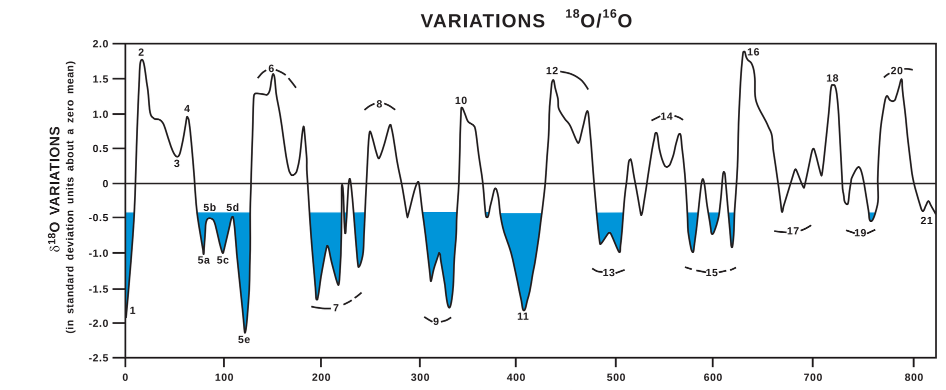


Figure 1. Marine oxygen-isotope stages (from Morrison, 1991). The numbers within the graph are stage numbers; the even-numbered peaks (at top) are glacial maxima and the odd-numbered troughs (at bottom) are interglacial minima. The blue areas indicate interglacial episodes, based on a cutoff at -0.5 $\delta^{18}O$ oxygen-isotope values (equivalent to Holocene interglacial values).

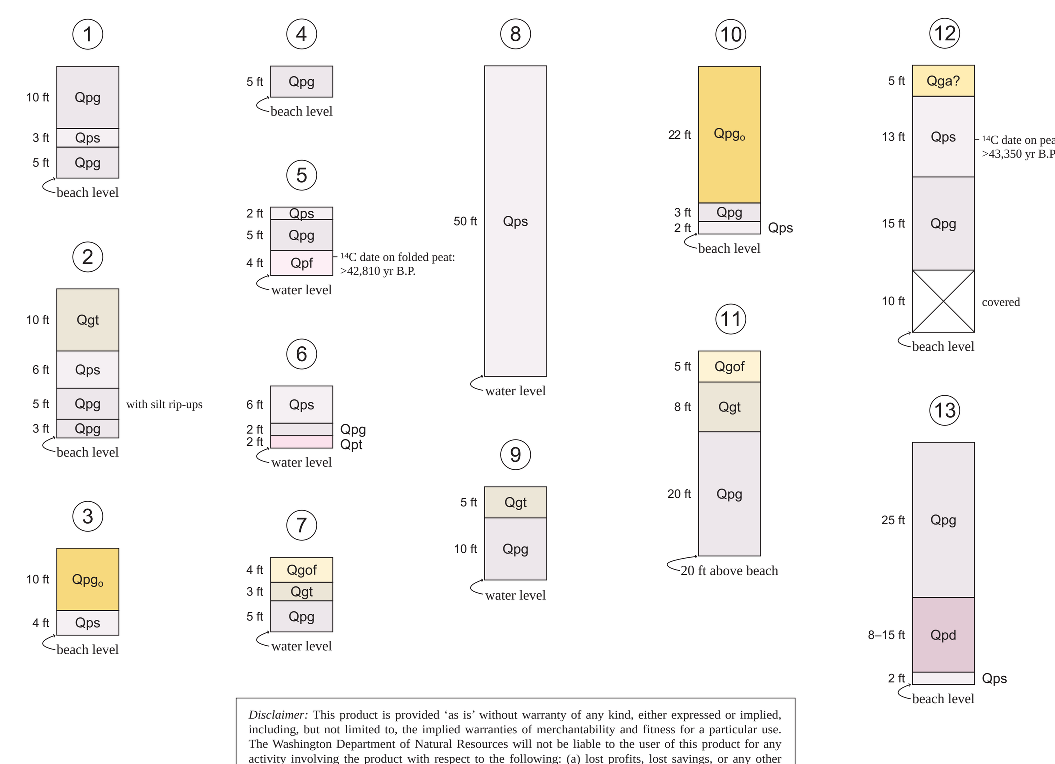
Table 1. Geochemical analyses of Crescent Formation basalt performed by x-ray fluorescence at the Washington State University GeoAnalytical Lab. Instrumental precision is described in detail in Johnson and others (1999). Major elements are normalized on a volatile-free basis, with total Fe expressed as FeO. †, values greater than 120 percent of the laboratory's highest standard

MAJOR ELEMENTS—NORMALIZED (in weight percent)

Loc.	Sample no.	SiO_2	Al_2O_3	TiO_2	FeO	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5	Original Total
1A	SCH1011011A	48.36	15.16	2.345	12.36	0.207	12.47	6.37	0.11	2.37	0.244	98.24
1B	SCH1011011B	49.00	13.48	2.619	13.12	†0.28	10.99	6.51	0.35	3.36	0.282	98.24
2	SCH1015011	48.65	14.17	2.799	13.24	0.215	12.10	5.86	0.16	2.52	0.287	98.82

TRACE ELEMENTS (in parts per million)

Loc.	Sample no.	Ni	Cr	Sc	V	Ba	Rb	Sr	Zr	Y	Nb	Ga	Cu	Zn	Pb	La	Ce	Th
1A	SCH1011011A	67	115	38	349	52	0	254	146	31	14.5	19	†183	102	0	21	34	1
1B	SCH1011011B	48	110	36	370	80	2	182	167	36	16.1	20	†203	104	2	8	23	0
2	SCH1015011	56	67	35	377	63	0	295	178	32	18.3	24	†200	109	2	13	53	0



ACKNOWLEDGMENTS

We have benefited greatly from discussions with Derek Booth and Kathy Troost (Univ. of Wash.) and Ray Wells and Brian Sherrod (U.S. Geological Survey). This map is supported by the National Geologic Mapping Program under Cooperative Agreement No. 01HQAG0105.

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