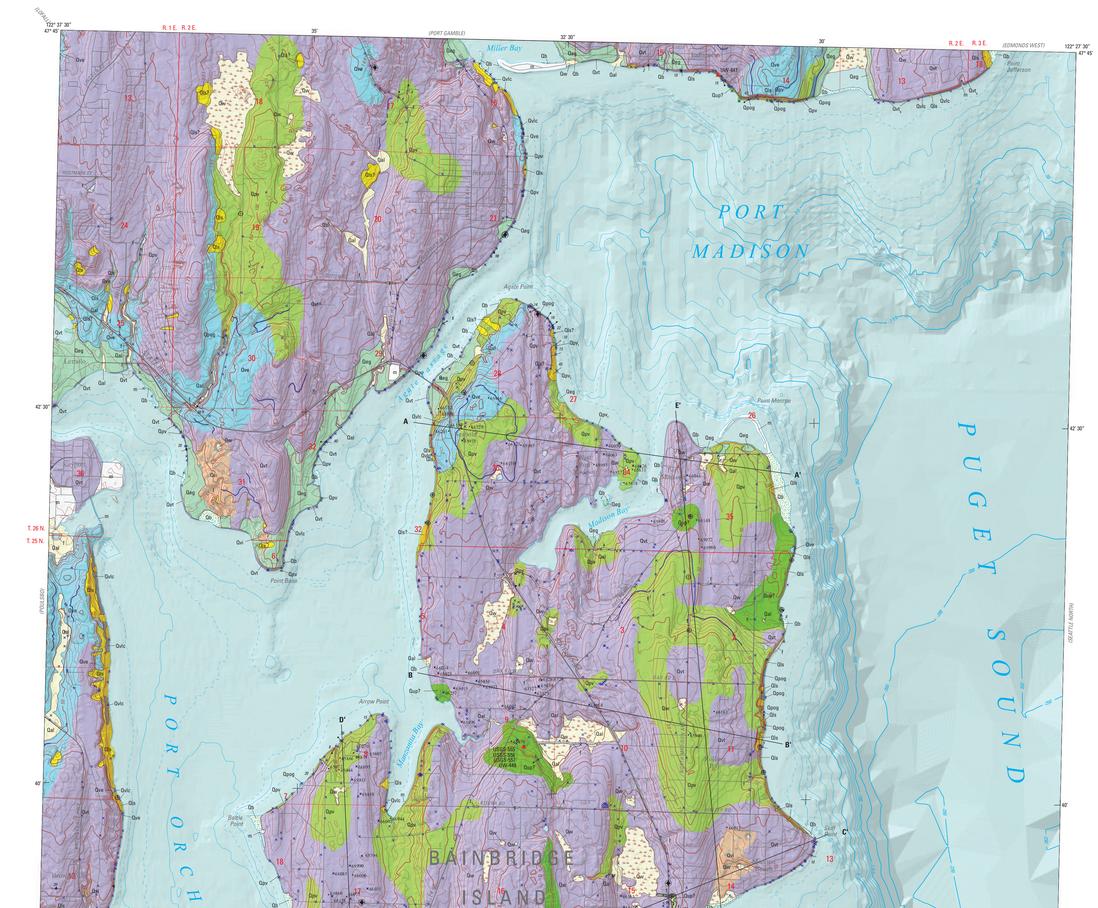

Geographic coordinates: North American Datum of 1927

Contours and shaded-relief base image calculated from 6-ft lidar DEM, Puget Sound Lidar Consortium, and 30-ft bathymetric DEM compiled by David Finlayson, http://www.ocean.washington.edu/data/pugetsound/psdem2005.html

Public Land Survey System from Washington Department of Natural Resources

Roads from Kitsap County

Place names modified from USGS Geographic Names Information System

Geology mapped by R.A. Haugerud, 1999-2005, E.A. Thorns, 2004, and Brett Cox, 2005

Database and digital cartography by R.A. Haugerud

Edited by _____

Manuscript approved for publication xxx xx, xxxx

INTRODUCTION

Suquamish 7.5-minute quadrangle is in the center of the Puget Lowland, Washington. The quadrangle contains the northern 2/3 of Bainbridge Island and adjacent parts of the Kitsap Peninsula. Puget Sound and contiguous waterways comprise 35% of the area; maximum elevation is 137 m in the northwest corner of the quadrangle, west of Suquamish. The modal elevation is 44 m. The center of the quadrangle is 20 km west-northwest of downtown Seattle. Winslow, in the southeast corner of the quadrangle, is a 35-minute ferry ride from Seattle.

At Bremerton, 10 km southwest of Winslow, mean annual precipitation for the period 1971–2000 was 137 cm (54 inches). Average January daily low temperature was 1.4°C (35°F); mean August daily high was 24°C (76°F). The temperate climate encourages dense vegetation. Second- and third-growth forest covers most of the land. Common tree species are Douglas fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), western red cedar (*Thuja plicata*), bigleaf maple (*Acer macrophyllla*), and alder (*Alnus rubra*). Undergrowth is lush: the cross-country pedestrian especially notices salmonberry (*Rubus spectabilis*), sword fern (*Polystichum andersonii*), salal (*Gaultheria shallon*), and—locally—exotic English ivy (*Hedera helix*). Open areas, unless grazed or mowed, are commonly filled with two exotic species of blackberry (*Rubus armeniacus* and *R. laciniatus* or scrub alder).

Earliest known inhabitants of the area were coast-dwellers of the Suquamish (or Suquamish) tribe who depended on shellfish and salmon for a large part of their diet. In the 1810s and early 19th centuries their numbers were much diminished by Euro-American diseases. Their descendants have been assimilated and (or) relocated to near-native reservations, including the Port Madison reservation at the north edge of the quadrangle. European exploration of Puget Sound commenced in 1792, when the British ships Discovery and Chatham, under the command of George Vancouver, anchored off the southeast corner of Bainbridge Island while the party explored the inland waterways. Vancouver named Puget Sound (originally, just that part of the Sound south of the Narrows at Tacoma) and Port Orchard for members of his party. In 1841 the U.S. Exploring Expedition, under the command of Charles Wilkes, spent two months mapping Puget Sound. Bainbridge Island, Point Jefferson, Port Madison, and Point Monroe are among the features they named. Wilkes named Agate Passage for the expedition's ship.

Subsequent Euro-American settlement was greatly encouraged by the California gold rush (1849), the establishment of San Francisco, and consequent demand for lumber produced by tidewater sawmills, including one at Port Madison. Truck gardening, especially of strawberries, was extensive on Bainbridge Island until the Second World War, when many of the farmers were interned because of their Japanese ancestry. As of 2000 the quadrangle was home to about 30,000 people, many of whom commute by ferry, automobile, and bus to jobs in Seattle and Bremerton.

Sceva (1957), Garling and others (1965), and Dexter (1979) have produced geologic maps of all or part of Suquamish quadrangle. Yount and Gower (1991) and Yount and others (1993) compiled, and in part reinterpreted, these maps at 1:100,000 scale.

This study was undertaken in response to (1) awareness of the hazard posed by future earthquakes in the Seattle fault zone, at the south edge of the quadrangle, and the need to marshal geologic evidence for the rate and style of deformation; (2) increasing population on Bainbridge Island and consequent pressure on groundwater resources; (3) concern about landside hazards; and (4) awareness of the role that the nearshore zone plays in supporting marine resources.

GEOLOGIC FRAMEWORK

The Suquamish quadrangle lies within the Salish Lowland physiographic province (Haugerud, 2004), a broad region in the forearc of the Cascade volcanic arc that extends from south of Olympia, Washington to north of Campbell River, British Columbia and includes both the Puget Lowland of western Washington and the Georgia Depression of northwestern Washington and southwestern British Columbia. To the east are the Cascade Range and Coast Mountains; to the west is the outer-arc high of the Coast Ranges. The Salish Lowland is the locus of late Cenozoic subsidence: Jones (1996) indicates up to 1 km of unconsolidated fill beneath some parts. The Lowland is crossed by east–west topographic highs formed by bedrock uplift. A northern San Juan high divides the Salish Lowland into Georgia Depression and Puget Lowland sub-provinces. A southern high, which lies athwart the south end of Bainbridge Island immediately south of the map area, coincides with the Seattle fault zone along which uplift has brought Eocene rocks to elevations of 800–1200 m, 8–10 km higher than equivalent strata in the floor of the Seattle structural basin that underlies central and northern Bainbridge Island and areas to the east (Brocher and others, 2001; Blakely and others, 2002). Deformation along the Seattle fault appears to be driven by north-south shortening of the Cascade forearc (Wells and others, 1998).

Where Tertiary strata are exposed in uplifts of the Seattle fault zone, early to middle Eocene, largely submarine basalt (Crescent Formation) is overlain by thick late-middle and late Eocene fluvial to deltaic sandstone with intercalated andesitic volcanic rock (Puget Group), overlain by latest Eocene–Oligocene (Fulmer, 1975) continental shelf to nearshore tuffaceous marine strata of the Blakeley Formation. Locally, fluvial conglomerate, sandstone, siltstone, and peat of the mid-Miocene (Sherrod and others, 2002) Blakely Harbor Formation crop out. Ten Brink and others (2002; see also Brocher and others, 2004) infer that onset of deposition of the Blakely Harbor Formation corresponds to the beginning of offset on the Seattle fault.

Pleistocene glacial deposits that underlie most of the Puget Lowland have been studied for over a century (Table 1). The stratigraphy of the most recent glaciation is fairly well known. Older glaciations, interglacial periods, and the resulting stratigraphy are much less understood. Booth and others (2004) provide a useful summary and references. Willis (1898), after examining landforms and deposits in the Tacoma area, named two north-derived glacial drift sequences, a younger Vashon Drift and an older Admiralty Drift. Crandell and others (1958) recognized and named four glaciations in the southeastern Puget Lowland. From youngest to oldest, these were Vashon Glaciation, Olympia Interglaciation, Salmon Springs Glaciation, Puyallup Interglaciation, Stuck Glaciation, Alderton Interglaciation, Orting Glaciation. Only the deposits of the Vashon Drift and the preceding Olympia Interglaciation are young enough to be dated by radiocarbon means (i.e., younger than about 40,000 ^{14}C yr B.P.). On Whidbey Island, ~80 km north of the Tacoma area studied by Willis and Crandell and others, Easterbrook and others (1967) observed two drift layers beneath the Vashon Drift; they named these the Possession Drift and Double Bluff Drift, separated by non-glacial deposits of the Whidbey Formation.

As noted by most workers, Pleistocene deposits of different ages in the Puget Lowland are compositionally similar. Observable distinctions are between north-derived (rich in volcanic, granitoid, and metamorphic rocks), east-derived (richer in volcanic debris derived from the Cascade arc, especially hypersthene of probable Mount Rainier origin), and west-derived (rich in basalt and graywacke from the Olympic Mountains) deposits, and between glacial (rapidly deposited, little or no organic material, dismict present) and non-glacial (slowly deposited, peat-bearing) deposits. With limited control, even these distinctions cannot always be made and most recent studies, including this one, have resorted to widespread lumping of pre-Vashon strata.

Armstrong and others (1965) noted that regionally the Vashon Drift is associated with three episodes of Late Pleistocene ice growth, their Evans Creek, Vashon, and Sumas stades. These three stades constitute their Fraser Glaciation. The base of their Fraser Glaciation is strongly time-transgressive. In the central Puget Lowland, the Fraser Glaciation is represented only by deposits of the Vashon stade. Thus "Fraser" and "Vashon" have been used almost synonymously, but outside the central Puget Lowland "Fraser" explicitly includes events and deposits older (Evans Creek stade, ~24,000 ^{14}C yr B.P.) and younger (Sumas stade, ~11,000 ^{14}C yr B.P.) than deposits of the Vashon stade, which in the central Puget Lowland were deposited between ~14,550 and ~13,600 ^{14}C yr B.P. (Porter and Swanson, 1998).

Immediately east of Bainbridge Island, at Fort Lawton in Seattle, Mullineaux and others (1965) formally subdivided the lower part of the Vashon Drift. They named the Lawton Clay Member (lacustrine silt and clay, commonly with varve-like layering, little or no organic debris) and the Esperance Sand Member (massive and plane-bedded sand, overlain by crossbedded sand, locally with forset bedding, silt and gravel, and coarsening upwards; commonly overlain by till). Their Esperance Sand Member was restricted from an earlier proposal by Newcomb (1952) that included silts and clays as a basal member.

Table 1 compares Pleistocene stratigraphies used on earlier geologic maps of Bainbridge Island with the stratigraphy used on recent geologic maps of areas in the central Puget Lowland and the stratigraphy used in this report.

ABOUT THIS REPORT

Haugerud (2009) mapped almost all post-glacial deposits, ice-contact deposits, most fault traces, and most bedding traces from detailed lidar topography collected in 1996-97 and 2000 on behalf of the Puget Sound Lidar Consortium (Harding and Berghoff, 2000; Haugerud and others, 2003). Haugerud, Evan Thorns, and Brett Cox walked almost all of the quadrangle's shoreline, traversed many stream gullies, and inspected road cuts and construction sites to observe deposit character and collect structural data.

Mapping the extent of Vashon-age till is challenging. Throughout the central Puget Lowland, the uppermost meter of unlithified deposits is marked by extensive bioturbation, minor addition of eolian material, clayey alteration, and variable oxidation. Many road- and streamcuts in this low-relief landscape are confined to this weathered zone. Even where the underlying material is fine-grained, the top meter is commonly pebbly. The genesis of such deposits is unclear: in some places the pebbles may be derived from up-slope exposures of pebbly deposits, but it is likely that upon deglaciation much of the landscape was littered with a thin skim of englacial and supraglacial debris that lacked the associated fine-grained material, comparction, and thickness necessary to make a mappable till. The tendency of Vashon-age till to reflect the composition of subjacent materials that lie within a few km in the ice-source direction compounds the difficulty: a sandy, brown subsoil with abundant small pebbles may be derived from underlying brown sand and gravel, or may be derived from a till derived from such a deposit. Earlier workers appear to have dealt with these difficulties by assuming that glacially-shaped uplands of the area are mantled with till unless good outcrops demonstrate otherwise. Along much of the shoreline, bluff exposures of older deposits that extend into the topmost strongly-weathered meter demonstrate that this is incorrect.

To delineate the extent of Vashon-age till, we supplemented outcrops in shoreline bluffs, stream banks, road cuts, ditches, and foundation excavations by digging or augering numerous shallow (0.5 m to 1.5 m) holes. We extracted subsurface data from the database compiled by Troost and colleagues (GeoMapNW, 2007), focusing on observations of the uppermost 10 feet (3 m) that included an interpreted stratigraphic unit (e.g., "Vashon till", "advance outwash"), or a distinctive lithology (e.g., "till"). Field identification of till in shallow exposures and identification of till from subsurface data are both prone to error; in the many places where interpretations from the subsurface database conflicted with our field observations, we gave precedence to field observations. Because of such uncertainties, contacts between till and older units in upland areas are shown as scratch boundaries (position very uncertain).

Cross-sections were interpreted by Troost from borehole logs in the GeoMapNW (2007) subsurface database and subsequently revised on the basis of additional map data. In general, data from boreholes within 2,200 feet (670 m) of the section line were considered when interpreting sections. Borehole collar elevations were obtained by intersecting the reported map location with the lidar elevation model. Borehole logs shown on the cross sections depict the material class assigned by compilers of the GeoMapNW (2007) database.

One of the consequences of mapping on an accurate lidar base is that neither this topography nor the interpreted geology matches available base maps. We thus present this geologic map on a greyscale topographic hillshade using contours calculated from the lidar elevation model, Public Land Survey System land lines, some roads and road names, and some place names, but without streams or municipal boundaries.

This report supercedes U.S. Geological Survey Open-file Report 2005-1387 (Haugerud, 2005).

STRATIGRAPHY

GLACIAL AND NON-GLACIAL DEPOSITS

DEPOSITS OLDER THAN OLYMPIA INTERGLACIATION OF ARMSTRONG AND OTHERS (1965)

Similar physical characteristics of deposits of different ages and limited outcrops make correlation of Quaternary deposits older than the Vashon Drift uncertain. On this map we have not subdivided these older deposits, except where distinctive physical characteristics or structural position suggest correlation from outcrop to outcrop.

CORRELATION OF MAP UNITS

Note: Units Qpog, Qpogs, Qpogg, Qpogl, Qpo1, Qpo2, Qpo3, Qpo4, Qpo5, Qpo, and Qpor are present in subsurface only

EXPLANATION OF MAP SYMBOLS

Shoreline

Fossil shoreline

Contact—Continuous where estimated location uncertainty less than 30 meters; long dash where estimated location uncertainty 30 to 100 meters; short dash where estimated location uncertainty greater than 100 meters

Strike and dip of bedding

Inclined—Facing direction observed in outcrop, upright

Inclined—Facing direction not observed

Inclined—Facing direction not observed, approximate orientation

Horizontal

Strike and dip of foliation

Inclined

Horizontal

Minor fold axis, with plunge

LOW-440 ^{14}C **age locality** with sample number

Borehole—From GeomapNW database, used in construction of cross sections. Adjacent number is borehole identifier EXPLOID

Observation point—Outcrop, dug or augured hole, or record from GeoMapNW database

DESCRIPTION OF MAP UNITS

POST-GLACIAL DEPOSITS

Modified land (Holocene)—Sand and gravel as fill, or extensively graded natural deposits. Mapped only where modification is sufficiently extensive that the underlying deposit cannot be inferred. Locally mapped as:

Artificial fill—Sand, gravel, and wood waste placed as fill. Mapped especially in road prisms where compaction by seismic shaking is a predictable hazard

Wetland deposits (Holocene)—Silt, sand, muck, and peat deposited in wetlands. Mapped on basis of surface morphology or presence of surface water and wetland vegetation

Alluvium (Holocene)—Well-sorted, unconsolidated sand, gravel, and silt deposited by post-glacial streams. Locally may contain intercalated poorly-sorted debris-flow deposits

Beach deposits (Holocene)—Sand, gravel, and logs deposited by wave action. Underlies nearshore flats. Beach deposits not mapped seaward of the high water line. Locally includes mud and peat deposited in wetlands developed inboard of the beach berm

Landslide deposits (Holocene and Pleistocene?)—Dismict, sand, gravel, silt, and soil transported in deep-seated landslides. Deposits commonly less dense than parent materials. Commonly water-saturated. Largely mapped on basis of morphology. Some landslide deposits may be latest Pleistocene in age

LATE-GLACIAL DEPOSITS

Emergence gravels (Pleistocene)—Moderately sorted gravel and sand, 1–3 m thick, that mantles till and older deposits at low elevations. Beach and stream deposits formed when late-glacial sea level was higher than at present, or along shores of late-glacial ice-marginal lakes. Mapped from exposures in shoreline bluffs, local artificial exposures, and surface morphology

GLACIAL AND OLDER NON-GLACIAL DEPOSITS

Vashon Drift (Pleistocene)—Divided into:

Ice-contact deposits—Gravel, sand, and dismict deposited against stationary ice. Commonly reworked by slumping. Mapped on basis of surface morphology

Till—Mostly dense sandy dismict. Pebbles are matrix supported; most are well-rounded. Rare clasts larger than 10 cm are commonly sub-angular to angular. Lenses of bedded sand, silt, and gravel are common. Wave-etched exposures commonly show sub-horizontal foliation in dismict and isaclinal folding of silt and sand lenses. In many upland locales, till is mapped on basis of clayey, pebbly subsoil, commonly with gray to green-gray hue indicative of minimal oxidation. Good shoreline bluff exposures indicate that most till of the Vashon Drift is subglacial lodgement till. Locally mapped as:

Gravel—Coarse, cross-bedded gravel that grades into overlying till

Esperance Sand Member—Quartzofeldspathic medium-fine to medium sand, locally pebbly or with small amounts of gravel or silt. Little cemented, though locally supports vertical faces. In deep exposures, commonly little oxidized. Sub-units derived from this unit are mostly loose sand, light-colored when dry. Advance outwash deposits. Local cross-beds and large foresets suggest deposition in fluvial or deltaic setting; elsewhere, pervasive decimeter-thick planar beds and low-angle cross-beds suggest deposition by prodelta turbidity currents

Lawton Clay Member—Thin-bedded (5 mm to 15 cm) dark gray silt and clay, locally with dropstones and (or) lenses of ice-rafted sand and gravel. Lacustrine advance outwash deposits

DEPOSITS OLDER THAN VASHON STADE OF ARMSTRONG AND OTHERS (1965)

Pre-Vashon-age deposits (Pleistocene)—Sand, gravel, silt, peat, sandstone, mudstone, conglomerate, and dismict of fluvial, lacustrine, and glacial origin. Mny include marine deposits. Where outcrop is good, it is evident that much of material mapped as Qpv is interbedded sand and gravel of fluvial origin or thin-bedded fine sand and silt of indeterminate origin.

Mostly mapped where poor outcrop—typically, brown, sandy, pebbly subsoil—does not permit a more detailed classification. Probably includes deposits elsewhere mapped as Qpvf, Qpg, and Qpog. May include minor Qpo and Qpfe. Locally mapped as:

Fine-grained deposits

DEPOSITS OLDER THAN OLYMPIA INTERGLACIATION OF ARMSTRONG AND OTHERS (1965)

Glacial deposits (Pleistocene)—Till, pebbly mud, and tillite and associated silt, sand, gravel, and conglomerate. Subsurface deposits recognized as glacial on the basis of identifiable till fragments and (or) predominance of clasts suggestive of northern provenance: granitic and (or) metamorphic clasts in gravel; garnet, epidote, magnetite, and (or) metamorphic rock fragments in sand. In subsurface, locally divided into:

Fine-grained glacial deposits—Silt, clay, sandy silt, gravelly silt, gravelly sandy silt, clayey silt, and silty clay. Present in subsurface only

Coarse-grained glacial deposits—Dismict, gravel, sand, sandy gravel, silty gravel, clayey gravel, gravelly sand, gravelly silty sand, silty sand, gravelly clayey sand, and clayey sand. Present in subsurface only

Glaciomarine deposits—Fine-grained (silt, clay) deposits with minor sand and gravel and associated marine shells. Present in subsurface only

Non-glacial deposits (Pleistocene)—Present in subsurface only. Sand, gravel, silt, clay, and peat. Identified as non-glacial by the presence of in-situ peat, paleosols, plant fragments, plant-fragment impressions, and (or) in-situ volcanic deposits (ash, pumice, mud-flow). Locally, predominance of volcanic clasts suggests central Cascade Range provenance. Present in subsurface only. Locally divided into:

Fine-grained non-glacial deposits—Silt, clay, sandy silt, clayey silt, silty clay, and peat. Present in subsurface only

Coarse-grained non-glacial deposits—Sand, gravel, sandy gravel, gravelly sand, gravelly silty sand, silty sand, clayey sand, and peat. Present in subsurface only

Fine-grained deposits (Pleistocene)—Clay, silt, fine sand, and shale of indeterminate origin. Present in subsurface only

Coarse-grained deposits (Pleistocene)—Sand and gravel, minor silt and clay, of indeterminate origin. Present in subsurface only

Beds of University Point (Pleistocene)—Variably lithified fluvial gravel and sand, locally cross-bedded, with interbedded silt and peat. Gravel commonly oxidized. Gravel has high concentration of dark basaltic sandstone and basalt clasts that suggest an ultimate source in the Olympic Mountains. Gravel beaches below bluffs of University Point beds are noticeably darker than typical central Puget Sound beaches. Presence of a small fraction of grainfilled pebbles in conglomerate and absence of pervasive bedding-parallel sand-stone distinguish University Point beds from the Blakely Harbor Formation (exposed 3 km south of map area), which they otherwise resemble.

At University Point and north of Fletcher Bay, shoreline bluff exposures display 2–3 m thick fining-upward sequences indicative of meandering stream and point bar deposits

Unit of Rockaway Beach (Pleistocene)—Massive to disrupted silt, clay, and sand. Some silt is wavy-structured. Most disruption appears to be non-tectonic. Present in subsurface only

Unit of Rockaway Beach. A massive, fine-grained unit is interpreted to occur in the subsurface in the south end of section E. Extensive core-hole suggests correlation with distinctive, disrupted, grey, wavy silt, clay, and fine sand that crop out about 2 km south of the quadrangle on Rockaway Beach, where it overlies the Miocene Blakely Harbor Formation (Haugerud, 2005). Disruption of the beds suggests slumping of sediments shortly after they were deposited on a subaqueous slope. The facies suggests ice-proximal deposition, thus the weak inference of a Quaternary age. As the unit is older than Vashon Drift, and is probably glacial, it is likely older than Olympia interglaciation.

Beds of University Point. Well-sorted dark gravel and associated sand, silt, and peat crop out in several localities. Gravel beds are typically no more than 1-2 m thick and most pebbles are greywacke or basalt, suggesting derivation from the Olympic Mountains to the west. Pebbles are rarely larger than 6 cm in diameter. Gravel beds commonly display good imbrication. Good outcrops show that strata are commonly organized into repeated 2- to 3-meter-thick fining-upward sequences that indicate relatively slow fluvial deposition, with channel gravels overlain by sands and succeeded by overbank silt and peat. Bluffs of this unit have a pinkish-to orange-brown hue when seen from a distance. Some beds are lithified: strata at some outcrops are best described as mudstone, sandstone, and conglomerate. These deposits may have formed during several non-glacial intervals, but their similar character and relative proximity encourage us to map these beds as one lithostratigraphic unit. Presence of grainsized pebbles and lack of clayey alteration distinguish these beds from similar depositional facies in the Blakely Harbor Formation of the Bremerton East quadrangle directly south of the map area. Outcrops at University Point, on the shore of Port Orchard west of Fletcher Bay, are particularly good. Twenty-five meters of beds of University Point crop out in the bluff north of Fletcher Bay. Poor outcrop suggests as much as 65 m of section may be present on the south side of Fletcher Bay. Interpretation of subsurface dat indicates a maximum thickness as great as 160 m (section D).

Dexter (1979, p. 47-58) recognized the similarity of gravel and interbedded sand, silt, and peat at University Point, at a gravel pit on Miller Road on Bainbridge Island, at a gravel pit near Hwy 305 at the base of Agate Pass, at Fletcher Bay, and north of Rolling Bay (all of which we map as University Point beds). He noted the high concentration of dark greywacke clasts and scarcity of granitoid clasts and reports that Crandell (in Levin and others, 1965) thus inferred an Olympic Mountains origin for the gravels. Nonetheless, Dexter interpreted these strata as glacial sediments and tentatively assigned them to the Possession Drift of Easterbrook and others (1967) on the basis of inferred glacial origin. UW-440 (Table 2) and on account of "difficulties in explaining slope glaciers advancing from the Olympic Mountains across Hood Canal during an interglaciation and also because the nature of course gravel deposits in the lowland on an interglacial floodplain is difficult to explain especially when present dry streams do not carry anything as coarse as these deposits" (Dexter, 1979, p. 55-56). These supposed difficulties are unconvincing: the beds were deposited by slowly-aggrading streams as evidenced by their good organization and common peat, they are not dominated by north-derived debris, modern streams do carry pebbles as large as 6 cm, and Hood Canal may not have existed during an earlier interglacial period.

Near Fernciff, along the shoreline north of Rolling Bay, and between Fletcher and Manzanita Bay, University Point beds appear to stratigraphically underlie pre-Vashon deposits of fluvial position, though dismict superposition was not observed. This relation suggests that the beds of University Point are older than Vashon drift, but better outcrop, could be assigned to units Qup, Qpog, Qpor, and Qpv. Some of the deposits mapped as Qpv are lithified and are best described as sandstone and conglomerate.

Silt and clay with associated peat crop out southeast of Agate Point. These are mapped as fine-grained pre-Vashon age deposits (Qpv). Except for the occurrence of peat these beds resemble the Lawton Clay (Qvlc); they could have been deposited during Olympia interglaciation.

Beds of mud, clay, and silt—locally with dropstones—exposed in the bluffs and beach at and southwest of Arrow Point are overlain by fine sand. Together the fine-grained beds and sand beds are similar to the Lawton Clay and Esperance Sand of the Vashon Drift. However, these beds are probably older than Vashon Drift, as they appear to lie beneath an older till that crops out on the beach farther southwest.

VASHON DRIFT

The Vashon stade Cordilleran ice sheet gathered in the mountains of British Columbia and flowed south, reaching its maximum southern extent near Olympia at about 16,900 calibrated yr B.P. (Porter and Swanson, 1998). Ice here reached a thickness of about 1 km (Thorson, 1980).

The geomorphic effects of the ice sheet are impressive. Meltwater issuing from the advancing ice deposited clay, and silt sand, and gravel of the Lawton Clay and the Esperance Sand and Arrow Points (SW¼ Sec 8, T27N, R2E). Folded and locally flattened (Qvlc) and thick-bedded sand crop out in the shoreline bluffs east of Agate Point (NE¼ Sec 28, T26N, R2E). Deformed massive silt with pebbles—probable dropstones—exposed at the south end of the bluff along Rolling Bay. Dexter (1979, p. 27) reported small, clam, and barnacle fossils in these outcrops; these may be evidence for glaciomarine deposition. Till crops out along the bluff east of Fernciff, where it underlies Lawton Clay. Along the north shore of Port Madison, till and gravel are exposed at the base of the bluff a kilometer east of Indianola (Sec 14, T26N R2E). Dexter (1979, p. 21-24) described these outcrops and reported an infinite radiocarbon age (Table 2, sample UW-447).

The stratigraphy preserved in landslide debris in the beach on the east shore of Port Orchard (Sec. 29, T27N, R2E) suggests two pre-Vashon age glaciations. The debris contains oxidized gravel above pebbly till above discontinuous peat above silt and clay with dropstones.

Other pre-Olympia age deposits. Older deposits in the subsurface are assigned on stratigraphic units Qpog, Qpogg, Qpogs, Qpogl, Qpo1, Qpo2, Qpo3, Qpo4, Qpo5, and Qpo, on the basis of inferred depositional facies and predominant grain size: glacial, glacial-marine, and nonglacial, coarse and fine.

DEPOSITS OLDER THAN VASHON STADE OF FRASER GLACIATION OF ARMSTRONG AND OTHERS (1965)

Most of the area mapped as undifferentiated pre-Vashon age deposits (Qpv) appears to be underlain by fine quartzofeldspathic sand, pebbly sand, and gravel with lesser peat and silt, of probable fluvial and lacustrine origin. This unit is largely equivalent to coarse-grained pre-Fraser age deposits (unit Qpvf) mapped on recent maps of nearby areas (e.g., Booth and Waldron, 2004). It is likely that unit Qpv locally includes sand, silt, and clay of early Vashon age as well as beds that, with better outcrop, could be assigned to units Qup, Qpog, Qpor, and Qpg. Some of the deposits mapped as Qpv are lithified and are best described as sandstone and conglomerate.

Silt and clay with associated peat crop out southeast of Agate Point. These are mapped as fine-grained pre-Vashon age deposits (Qpv). Except for the occurrence of peat these beds resemble the Lawton Clay (Qvlc); they could have been deposited during Olympia interglaciation.

Beds of mud, clay, and silt—locally with dropstones—exposed in the bluffs and beach at and southwest of Arrow Point are overlain by fine sand. Together the fine-grained beds and sand beds are similar to the Lawton Clay and Esperance Sand of the Vashon Drift. However, these beds are probably older than Vashon Drift, as they appear to lie beneath an older till that crops out on the beach farther southwest.

VASHON DRIFT

The Vashon stade Cordilleran ice sheet gathered in the mountains of British Columbia and flowed south, reaching its maximum southern extent near Olympia at about 16,900 calibrated yr B.P. (Porter and Swanson, 1998). Ice here reached a thickness of about 1 km (Thorson, 1980).

The geomorphic effects of the ice sheet are impressive. Meltwater issuing from the advancing ice deposited clay, and silt sand, and gravel of the Lawton Clay and the Esperance Sand and Arrow Points (SW¼ Sec 8, T27N, R2E). Folded and locally flattened (Qvlc) and thick-bedded sand crop out in the shoreline bluffs east of Agate Point (NE¼ Sec 28, T26N, R2E). Deformed massive silt with pebbles—probable dropstones—exposed at the south end of the bluff along Rolling Bay. Dexter (1979, p. 27) reported small, clam, and barnacle fossils in these outcrops; these may be evidence for glaciomarine deposition. Till crops out along the bluff east of Fernciff, where it underlies Lawton Clay. Along the north shore of Port Madison, till and gravel are exposed at the base of the bluff a kilometer east of Indianola (Sec 14, T26N R2E). Dexter (1979, p. 21-24) described these outcrops and reported an infinite radiocarbon age (Table 2, sample UW-447).

The stratigraphy preserved in landslide debris in the beach on the east shore of Port Orchard (Sec. 29, T27N, R2E) suggests two pre-Vashon age glaciations. The debris contains oxidized gravel above pebbly till above discontinuous peat above silt and clay with dropstones.

Other pre-Olympia age deposits. Older deposits in the subsurface are assigned on stratigraphic units Qpog, Qpogg, Qpogs, Qpogl, Qpo1, Qpo2, Qpo3, Qpo4, Qpo5, and Qpo, on the basis of inferred depositional facies and predominant grain size: glacial, glacial-marine, and nonglacial, coarse and fine.

DEPOSITS OLDER THAN VASHON STADE OF FRASER GLACIATION OF ARMSTRONG AND OTHERS (1965)

Most of the area mapped as undifferentiated pre-Vashon age deposits (Qpv) appears to be underlain by fine quartzofeldspathic sand, pebbly sand, and gravel with lesser peat and silt, of probable fluvial and lacustrine origin. This unit is largely equivalent to coarse-grained pre-Fraser age deposits (unit Qpvf) mapped on recent maps of nearby areas (e.g., Booth and Waldron, 2004). It is likely that unit Qpv locally includes sand, silt, and clay of early Vashon

Table 1. Quaternary stratigraphies used on earlier maps of Suquamish quadrangle, recent standard Quaternary stratigraphy for Puget Lowland, and Quaternary stratigraphy of this report

Sceva (1957)	Molenaar (in Garling and others, 1965)	Dexter (1979)	Booth and Waldron (2004) Booth and others (2004)	This report
Alluvium	Holocene alluvium	Holocene alluvium, beach deposits	Holocene (*many facies*)	Holocene (*many facies*)
Vashon Drift: Recessional outwash, Gorst Creek outwash, Till	Vashon Drift: Recessional outwash, Till, Advance outwash (*gravel and coarse sand*), Colvos Sand (*bedded to massive sand, some clay and gravel, basal blue clay*)	Vashon Drift: Recessional outwash, Till, Esperance Sand (*separated into sandy and gravelly phases*), Lacustrine deposits	Vashon Drift: Recessional outwash, Till, Advance outwash, Lawton Clay	Vashon Drift: Ice-contact deposits, Till, Esperance Sand, Lawton Clay
Puyallup Sand (*as mapped includes advance outwash of the Vashon Drift*)				
Orting Gravel: Kitsap Clay member, Lower member (*sand and gravel, slightly cemented, rusty colored*)	Kitsap Formation (*bedded silt and clay, minor sand and gravel, peat*)	Kitsap Formation (*fine-grained nonglacial sediment deposited between 15,000 and 35,000 ybp*)	Olympia beds	Qpv Qpo (*many facies*) Beds of University Point
Admiralty Drift (*blue-gray clay, sand, gravel, lignite, volcanic ash, minor knees of glacial till*)	Salmon Springs (?) Drift (*gravel and coarse sand, local till*)	Possession Drift (*stratified sand and gravel, local peat, till, and clay*)	Possession Drift	Unit of Rockaway Beach
		Whidbey Fm. (*sand, silt, clay, and peat; local coarser sand and gravel*)	Whidbey Formation	
		Double Bluff Drift (*till, glaciomarine drift*)	Double Bluff Drift	
			—*unknown interval*—	
			Salmon Springs Drift	
			Deposits of Puyallup interglaciation	
			Stuck Drift	
			Deposits of Alderton interglaciation	
			Orting Drift	

[1] Latitude and longitude as reported by Yount and others (1993). Locations on map and in database are adjusted by Dexter (1979)

Point are at least as old as the Whidbey Formation. Infinite and near-infinite radiocarbon ages (Table 2) are consistent with this interpretation.

Pre-Olympia glacial deposits. Pre-Vashon, and thus pre-Olympia, glacial deposits (Qpo$_x$) crop out at several locales. Isolated outcrops of till and bedded silt occur northeast of Lemolo in the streambed in the center of Sec 19, T26N R2E where they underlie the extensive sand of pre-Vashon till age. Till crops out beneath pre-Vashon deposits on the beach between Battle Point and Arrow Points (SW¼ Sec 8, T27N, R2E). Folded and locally flattened (Qvlc) and thick-bedded sand crop out in the shoreline bluffs east of Agate Point (NE¼ Sec 28, T26N, R2E). Deformed massive silt with pebbles—probable dropstones—exposed at the south end of the bluff along Rolling Bay. Dexter (1979, p. 27) reported small, clam, and barnacle fossils in these outcrops; these may be evidence for glaciomarine deposition. Till crops out along the bluff east of Fernciff, where it underlies Lawton Clay. Along the north shore of Port Madison, till and gravel are exposed at the base of the bluff a kilometer east of Indianola (Sec 14, T26N R2E). Dexter (1979, p. 21-24) described these outcrops and reported an infinite radiocarbon age (Table 2, sample UW-447).

Sample ID	Location	Material analyzed	Age (^{14}C ybp)	Reference
USGS-555	47° 40.3' 122° 32.7'	Peat	>48,000	S.W. Robinson (r Yount and others, 1993
USGS-556	47° 40.3' 122° 32.7'	Wood	40,000 ± 2,100	S.W. Robinson (r Yount and others, 1993
USGS-557	47° 40.3' 122° 32.7'	Peat	45,500 ± 2,800	S.W. Robinson (r Yount and others, 1993
UW-447	47° 48.8' 122° 31.2' [1]	Wood	>40,000	Dexter, 1979
UW-449	47° 40.3' 122° 32.8' [1]	Peat	>40,000	Dexter, 1979
W-1459	47° 38.4' 122° 35.5' [1]	Peat	>38,000	Yount and others, 1965

LEGEND FOR BORING LOGS

Peat, Cobbles, Gravel, Silty Gravel, Clayey Gravel, Sand, Gravelly Sand, Gravelly Silty Sand, Silty Sand, Gravelly Clayey Sand, Clayey Sand, Silt, Gravelly Silt, Gravelly Sandy Silt, Sandy Silt, Clayey Silt, Sandy Clay/Silt, Clay, Gravelly Clay, Gravelly Sandy Clay, Sandy Clay, Silty Clay, Sedimentary Bedrock, Undifferentiated Rock

5x VERTICAL EXAGGERATION ON ALL SECTIONS

HOLOCENE DEPOSITS

BEACH AND TIDE-FLAT DEPOSITS

Mapping beach deposits along Puget Sound presents an unresolved set of problems. Although beaches are commonly well-developed and extensive, they are commonly narrow and foreshore is lack of an adequate base map. At present, medium- and high-resolution topography for most of the Puget Lowland extends down only to the high-water line. Second, many Puget Sound beaches are underlain by pebbles or cobbles gravel. We do not have an efficient technique to routinely ascertain whether this sediment is a thin veneer over a beach platform eroded into older material or a thicker deposit of recently sorted material. For this study surface materials are mapped landward of the break in slope at the high-water line, either crest of the beach berm or the toe of the bluff. Thus the only beach deposits mapped (Db) are the sand, gravel, and