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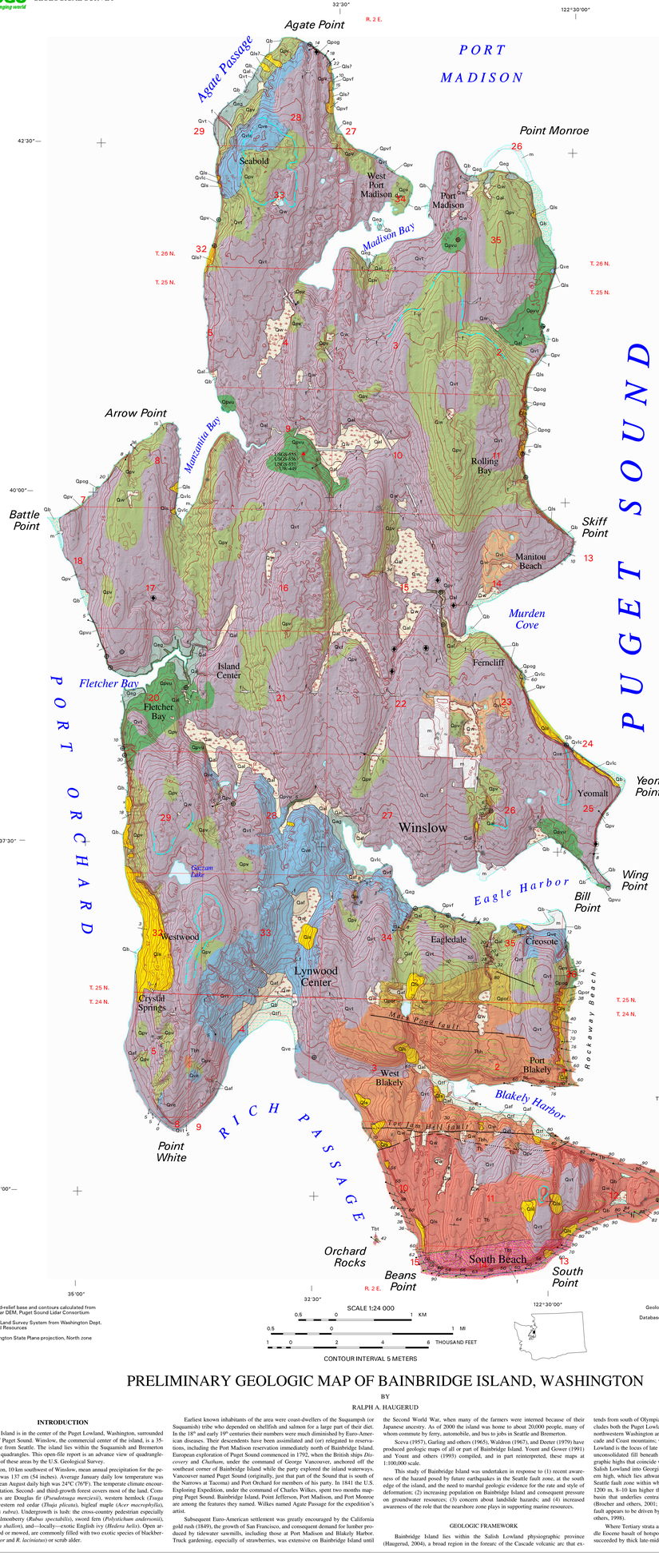
OPEN-FILE REPORT 2005-1387



Shaded-relief base and contours calculated from 6 ft lidar DEM, Puget Sound Lidar Consortium

Public Land Survey System from Washington Dept. Natural Resources

Washington State Plane projection, North zone

Geology mapped by R.A. Haugerud, 1999-2005, E.A. Thoms, 2004, and Brett Cox, 2005
Database and digital cartography by R.A. Haugerud

PRELIMINARY GEOLOGIC MAP OF BAINBRIDGE ISLAND, WASHINGTON

BY

RALPH A. HAUGERUD

INTRODUCTION

Bainbridge Island is in the center of the Puget Lowland, Washington, surrounded by the waters of Puget Sound. Winslow, the commercial center of the island, is a 35-minute ferry ride from Seattle. The island lies within the Suquamish and Bremerton East 7.5-minute quadrangles. This open-file report is an advance view of quadrangle-format mapping that covers the area by the U.S. Geological Survey.

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 1.5°C (35°F); mean August daily high was 25.2°C (78°F). The temperate (Humid: mesic) ages 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 macrophyllum*), and alder (*Alnus rubra*). Undergrowth is lush: the cross-country pedestrian especially notices dense 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 discolor* and *R. laciniatus*) or scrub alder.

Earliest known inhabitants of the area were coast-dwellers of the Suquamish (or Squaxnish) tribe who depended on shellfish and salmon for a large part of their diet. In the 18th and early 19th centuries their numbers were much diminished by Euro-American diseases. Their descendants have been assimilated and (or) relegated to reservations, including the Port Madison reservation immediately north of Bainbridge Island. 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 that is 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 Port Monroe are among the features they named. Wilkes named Agate Passage for the expedition's artist.

Subsequent Euro-American settlement was greatly encouraged by the California gold rush (1849), the growth of San Francisco, and consequent demand for lumber produced by timberlot sawmills, including those at Port Madison and Blakely Harbor. 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 island was home to about 20,000 people, many of whom commute by ferry, automobile, and bus to jobs in Seattle and Bremerton.

Sceva (1957), Garling and others (1965), Waldron (1967), and Deeter (1979) have produced geologic maps of all or part of Bainbridge Island. Yount and Gower (1991) and Yount and others (1993) compiled, and in part reinterpreted, these maps at 1:100,000 scale.

This study of Bainbridge Island was undertaken in response to (1) recent awareness of the hazard posed by future earthquakes in the Seattle fault zone, at the south edge of the island, 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 landslide hazards; and (4) increased awareness of the role that the nearshore zone plays in supporting marine resources.

GEOLOGIC FRAMEWORK

Bainbridge Island 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, WA to north of Campbell River, BC on the north 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 and Coast mountains; 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 that coincide with bedrock uplifts. 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, coincides with the Seattle fault zone within which uplift has brought Eocene rocks to elevations of 800–1200 m, 8–10 km higher than adjacent basement and 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 basalt of hotspot or forearc-basin-rift provenance (Crescent Formation) is succeeded by thick late-middle and late Eocene fluvial to deltaic sandstone with interbedded volcanic rocks (Puget Group), overlain by latest Eocene–Oligocene continental sediment of northern Nisqually and Blakeley Formations. Locally, fluvial conglomerate, sandstone, siltstone, and peat of the mid-Miocene 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.

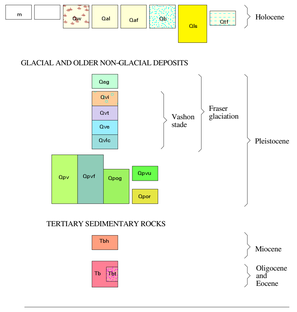
Pleistocene glacial deposits in the Puget Lowland have been studied for over a century. The stratigraphy of the most recent glaciation is fairly well known, while older glaciations, interglacial periods, and the resulting stratigraphy are much less understood. Booth and others (2004) provide a useful 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. The penultimate, Salmon Springs, glaciation gave the oldest radiocarbon ages (i.e., older than ~40,000 °C ybp). Only the deposits of the Vashon Drift and the preceding Olympia Interglaciation were young enough to be dated by radiocarbon means (i.e., younger than about 40,000 °C ybp). Crandell (1965) applied the Vashon drift sequence to the Puget Lowland, and Crandell and others, Easterbrook and others (1967) observed two pre-Vashon drift layers that they named the Possession Drift and Double Bluff Drift, separated by non-glacial deposits of the Whidbey Formation.

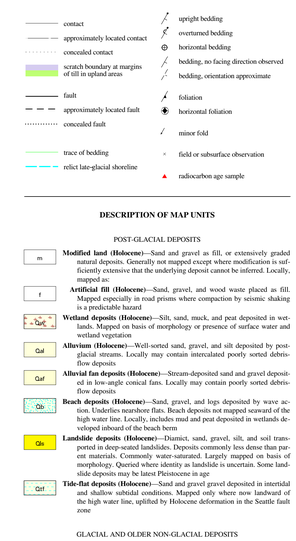
Armstrong and others (1965) noted that regionally the Vashon Drift is associated with three episodes of late Pleistocene ice growth, their Evans Creek, Vashon, and Sumas stades. These three stades constitute their Fraser glaciation. The base of the Fraser glaciation is strongly time-transgressive. In the central Puget Lowland, the Fraser glaciation is represented by deposits of the Vashon stade. Thus "Fraser" and "Vashon" are commonly used almost synonymously, but in places "Fraser" explicitly includes events and deposits older (~24,000 °C ybp) and younger (~11,000 °C ybp) than the Vashon stade and its associated Vashon Drift.

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 cross-bedded sand, locally with forset bedding, locally with silt and sand gravel, locally coarsening upwards, commonly overlain by till). Their Esperance was restricted from an earlier proposal by Newcomb (1952) that included silts and clays as a member.

Table 1 compares Holocene stratigraphies used on earlier geologic maps of Bainbridge Island with the current standard regional stratigraphy for the Puget Lowland and the stratigraphy used in this report.

CORRELATION OF MAP UNITS





DESCRIPTION OF MAP UNITS

POST-GLACIAL DEPOSITS

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

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

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

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

Qaf **Alluvial fan deposits (Holocene)**—Stream-deposited sand and gravel deposited in low-angle conical fans. Locally may contain poorly sorted debris-flow deposits

Qb **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

Qls **Landslide deposits (Holocene)**—Humici, 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. Queried where identity as landslide is uncertain. Some landslide deposits may be latest Pleistocene in age

Qtf **Tide-flat deposits (Holocene)**—Sand and gravel graded deposited in intertidal and shallow subtidal conditions. Mapped only where now landward of the high water line, uplifted by Holocene deformation in the Seattle fault zone

GLACIAL AND OLDER NON-GLACIAL DEPOSITS

Qeg **Emergence gravels (Pleistocene)**—Moderately sorted gravel and sand, 1–3 m thick, that mantles till and older deposits at low elevations. Beach and cosextensive stream deposits formed when late-glacial sea level was higher than at present. Mapped from exposures in shoreline bluffs, local artificial exposures (percolation test pits), and morphology

Vashon Drift (Pleistocene)—divided into:

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

Qvt **Vashon till**—Dense sandy diamict. Pebbles are matrix-supported; most are well-rounded. Rare clasts larger than 10 cm are commonly sub-angular to angular. Locally, bedded sand, silt, and gravel are entrained. Well-stretched exposures commonly show sub-horizontal foliation in diamict and isoclinal folding of silt and sand lenses. Most Vashon till exposed in shoreline bluffs appears to be subglacial lodgement till

In many upland locales, till is mapped on basis of silty, pebbly subsoil, commonly with gray to green-gray hue indicative of minimal oxidation

Qvse **Esperance Sand Member**—Quartzofeldspathic medium sand, locally with gravelly layers. Little cemented, though locally supports vertical faces. In deep exposures, commonly little oxidized. Sub-soils derived from this unit are mainly loose sand.

Local cross-beds and large forsets suggest deposition in fluvial or deltaic setting; elsewhere, pervasive decimeter-thick planar beds and low-angle cross-beds suggest deposition by prodelta turbidity currents

Qvlc **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

Qpv **Pre-Vashon deposits**—Sand, gravel, silt, peat, sandstone, mudstone, conglomerate, and diamict of fluvial, lacustrine, and glacial origin. May 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. In places, mapped as:

Qpvf **Fine-grained deposits**—Silt, clay, and local peat

Qpvu **University Point beds**—Fluvial gravel and sand, locally cross-bedded, with interbedded silt and peat. Gravels commonly oxidized. Lithification variable; local conglomerate and sandstone.

Gravel has high concentration of dark basaltic sandstone and basalt clasts that presumably originate in Cascades hinterland.

North of Fletcher Bay, shoreline bluff exposures display 2–3 m thick fining-upward sequences indicative of meandering stream deposits; silt and peat are overbank facies

Qpog **Older glacial deposits**—Till, pebbly mud, and associated silt, sand, gravel, and conglomerate. On Rockaway Beach, till overlain by thin-bedded silt and sand, locally disrupted by glacial shearing

Qpor **Rockaway Beach unit**—Massive to disrupted silt, clay, and sand. Most disruption appears to be due to soft-sediment deformation

TERTIARY SEDIMENTARY ROCKS

Tbh **Blakely Harbor Formation (Miocene)**—Volcanic-lithic sandstone, siltstone, conglomerate, and peat. Orange-brown weathering; pervasive clayey alteration. Cyclothemic: fluvial sandstone and conglomerate, overlain by paludal siltstone. Abundant wood and, locally, peat as thick as 3 m. Stream and flood-plain deposits

Tb **Blakely Formation (Eocene and Oligocene)**—Sandstone, siltstone and claystone, plane-bedded, locally calcareous. Thin to medium-bedded, mostly plane-bedded, local load casts and flutes at bases of beds. Moderately common wood and coal (charcoal), locally extensively burrowing. Sandstones are rich in volcanic debris; trace white mica. In part mapped as:

Tbt **Tuff-rich beds**—Similar to remainder of Blakeley Formation, but with 1- to 3-m thick beds of brown-weathering impure lapilli tuff and minor conglomerate. Tuff beds locally cross-bedded. Conglomerates polymict, including cobbles and boulders of distinctive black-and-gray welded silicic tuff

calated andesitic volcanic rock (Puget Group), overlain by latest Eocene–Oligocene continental sediment of northern Nisqually and Blakeley Formations. Locally, fluvial conglomerate, sandstone, siltstone, and peat of the mid-Miocene 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.

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Table 1. Quaternary stratigraphies used on earlier maps of Bainbridge Island, current standard Quaternary stratigraphy for Puget Lowland, and Quaternary stratigraphy of this report

Sceva (1957)	Molenaar (in Garling and others, 1965)	Deeter (1979)	Current usage (e.g. 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	Recessional outwash	Recessional outwash	Recessional outwash	Ice-contact deposits
Vashon Drift: Gorst Creek outwash	Vashon Drift: Till	Vashon Drift: Till	Vashon Drift: Till	Till
Vashon Drift: Till	Vashon Drift: Advance outwash (gravel and coarse sand)	Vashon Drift: Esperance Sand (*separated into sandy and gravelly phases*)	Vashon Drift: Advance outwash	Esperance Sand
Puyallup Sand (*as mapped includes advance outwash of the Vashon Drift*)	Colvos Sand (bedded to massive sand, some clay and gravel, basal blue clay)	Vashon Drift: Lacustrine deposits	Vashon Drift: Lawton Clay	Lawton Clay
Orting Gravel: Kitsap Clay member	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	
Orting Gravel: Lower member (*sand and gravel, slightly cemented, rusty colored*)	Salmon Springs (?) Drift (*gravel and coarse sand, local till*)	Possession Drift (*oxidized sand and gravel, local peat, silt, and clay*)	Possession Drift	University Point beds
Admiralty Drift (*blue-gray clay, sand, gravel, lignite, volcanic ash, minor lenses of glacial till*)		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	

As noted by most workers, Pleistocene deposits of different ages in the central 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, diamict present) and non-glacial (slowly deposited, peat-bearing) deposits. With limited outcrop, even these distinctions cannot always be made and most recent studies, including this one, have resorted to widespread lumping of pre-Vashon strata.

ABOUT THIS MAP

I mapped almost all post-glacial deposits, ice-contact deposits, most fault traces, and most bedding traces from detailed lidar topography (Harding and Berghoff, 2000; Haugerud and others, 2003). Evan Thoms, Brett Cox, and I walked almost all of the island's shoreline, traversed many stream gullies, inspected roadcuts and construction sites, and dug or augered numerous shallow (0.5m to 1.5m) holes to delineate Vashon till and older strata and collect structural data. I extracted subsurface observations from the database compiled by GeoMapNW at the University of Washington (GeoMapNW, 2004) for the City of Bainbridge Island, concentrating 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 within the subsurface database conflicted with my field interpretations, I gave field interpretations precedence. Because of such uncertainties, contacts of till with older units are shown as scratch boundaries (position very uncertain) in upland areas.

In small pits dug into the forest floor or, more commonly, through the vegetation that mantles shallow road cuts, I found difficulty distinguishing Vashon till from older Pleistocene deposits. 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. Even where the parent material is fine-grained, the top meter is commonly pebbly. In some places the pebbles may be derived from up-slope exposures of pebbly deposits, but I think it 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, compaction, and thickness to make a mappable till. The tendency of Vashon till to reflect the composition of subglacial 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 a deposit of brown sand and gravel, or may be derived from a till derived from that deposit. On the evidence of their maps, earlier workers appear to have dealt with this difficulty by assuming that uplands of Bainbridge Island are mantled with till unless good outcrops demonstrated otherwise. Along much of the shoreline, bluff exposures of older deposits that extend into the topmost strongly-weathered meter demonstrate that this is not the case.

Where the landscape has changed since the lidar topography was acquired in winter 1996-97, the map follows the lidar topography. In particular, a borrow pit in Esperance Sand in the SE ¼ of Sec 28, T25N, R3E has since been filled but I have not mapped it as artificial fill. A wetland has been constructed amidst tide-flat deposits north of the Point White Road, ¼ km SW of Lynwood Center, but is not mapped.

STRATIGRAPHY

TERTIARY SEDIMENTARY ROCKS

Blakeley Formation

Weaver (1912) discussed fossiliferous marine strata that crop out on the south end of Bainbridge Island as the Blakeley Formation, with a type section at Restoration Point. In later papers, Weaver (1916a, b, c, d; 1937) discussed molluscan biostratigraphy and physical stratigraphy of these rocks. Subsequently, Fulmer (1954), Waldron (1967), and McLean (1968) described these strata. Fulmer's hard-to-access 1975 report is invaluable for its observations on physical stratigraphy, detailed biostratigraphy, and definition of the Blakely Harbor Formation. McLean (1977) documents sedimentary structures and questions earlier interpretations of the physical stratigraphy of the Blakeley.

On Bainbridge Island the strata of the Blakeley Formation strike roughly east-west and dip moderately to steeply to the north. From Beans Point to South Point (Sec 13, 14, and 15, T24N, R2E), the unit comprises abundant thick (1 to 3 m) beds of water-lain impure lapilli tuff, with associated thin-bedded siltstone, fine-grained sandstone, and rare conglomerate. Thick tuff beds locally show internal cross-bedding; associated thin beds of fine-grained debrite are commonly plane-laminated The thick tuff beds weather to a yellow-brown color and rounded, massive shapes. Planar bedding and lack of bioturbation in the thin-bedded part of the unit suggests deposition in deep water. Strewn upon the beach in this region are angular to rounded boulders as large 2 m in diameter of distinctive welded silicic tuff with cm-thick flattened lenses of black glass in a gray matrix of flattened pumice shards, crystals, and lithic fragments. Cobbles of the same tuff are present in conglomerate beds, indicating that the large tuff boulders were also clasts within this unit. These beds belong to the Orchard Point Member of Fulmer (1975) and lithofacies B of McLean (1977), and they are correlated with the Blakely Harbor Formation (Tbt).

Interbedded fine-grained sandstone, siltstone, and claystone gradationally overly the tuffaceous beds. Much of this part of the unit is thin-bedded. These upper beds crop out at Restoration Point (Sec 7, T24N, R3E and most of Sec 12, T24N, R2E) and also for about a mile along the northeast shore of Rich Passage (in Sec 10, T24N, R2E). Strata are uniformly plane-bedded and locally massive. Not all bed margins are planar: incomplete bioturbation has commonly rendered the tops of sand beds irregular. Shell fragments and fossil burrows are common, as are carbonized wood fragments; these beds belong to the Restoration Point Member of Fulmer (1975) and lithofacies C of McLean (1977).

Neither the base nor the top of the Blakeley is preserved in the vicinity of Bainbridge Island. Fulmer (1975, p. 218, 222) measured 800 ft (250 m) of lower tuffaceous strata and 5400 ft (1650 m) of overlying fine-grained strata. A tight fold about 150 m east of Beans Point may be associated with an unmapped fault that repeats strata, but lack of offset of the upper contact of the lower, tuffaceous unit limits any duplication to this unit. McLean (1977) states that the original thickness of the unit in this region is about 2.5 km, but the possibility that this thickness includes significant repetition by faulting has yet to be evaluated.

Sandstones of the Blakeley Formation are rich in feldspar and volcanic rock fragments. Cements are siliceous and locally calcareous. McLean (1968, quoted in Fulmer, 1975) identified the presence of recent weathering. Both conglomerates and sandstones weather to a yellow-brown to dark orange-brown color. Brett Cox (personal communication, 2005) suggests that conglomerate and interbedded sandstone were deposited in channels of a high-energy, sand-dominated stream system, and that recessive sandstone and siltstone are slack-water deposits of the stream's floodplain.

The base of the Blakely Harbor Formation is not exposed. About 750 meters of north-dipping and north-facing Blakeley Harbor strata are present along the southern end of Rockaway Beach, though some repetition by thrusting is likely. The preserved top of the formation is at this point closely defined, though the actual contact was not observed; overlying strata are of probable Pleistocene age. Farther south, limited outcrop along the shore of Blakely Harbor indicates folding of at least local extent.

Sherrod and others (2000) report a 13.3 ± 1.3 Ma fission-track age from the south side of Blakely Harbor, as well as late middle Miocene pollen.

I encountered orange-brown weathering sand and mafic pebbles in an auger-hole north of Point White, on the boundary between Sec 4 and 5, T24N, R2E, and tentatively map this area as underlain by Blakely Harbor Formation.

GLACIAL AND OLDER NON-GLACIAL DEPOSITS

Pre-Vashon deposits

Similar physical characteristics of deposits of different ages and limited outcrops on Bainbridge Island make correlation of Quaternary deposits older than the Vashon Drift uncertain. I have chosen not to subdivide these older deposits, except for a few instances where distinctive physical characteristics or structural position suggest that correlation from outcrop to outcrop is likely correct.

Rockaway Beach unit. On the central part of Rockaway Beach, directly overlying orange-brown weathering clay-altered sandstone and conglomerate of the Blakely Harbor Formation, are distinctive, disrupted, gray wavy silt, clay, and fine sand of the Rockaway Beach unit (Qpor). Disruption of these beds ranges from irregular plastic folding—in places giving the impression that the unit was stirred with a spoon—to angular intracastes of wavy silt in a massive fine sand matrix. Perhaps the divergent records stumping of sediments shortly after they were rapidly deposited on a subaqueous slope. The facies suggests ice-proximal deposition, and thus the weak inference of a Quaternary age. This unit is recognized only on the north part of the island near Scabold (Sec 28 and 33, T26N, R2E) and south of the community of Port Madison (Sec 2 and 3, T25N, R2E). By the time marine conditions prevailed on Bainbridge Island the ice margin was almost certainly at least 20 km farther north, no closer than the northern tip of the Kitsap Peninsula.

That mappable marine shoreline deposits are present, whereas late-glacial lake shoreline deposits are not, could reflect longer inundation at lower elevations—the areas submerged by salt water after the ice melted were earlier submerged by ice-marginal lakes and the rate of isostatic rebound slowed with time. But more likely marine tides kept a significant vertical extent of the shoreline free of armoring vegetation and thus subject to wave erosion and more extensive reworking of underlying deposits.

Sand near Agate Passage appears to be buttressed against older deposits (mapped as Qpv) to the east. West of Lynwood Center, Esperance Sand appears to be as much as 105 m thick.

A single outcrop of Esperance-like sand west of the Toe Jam Hill Road in NE ¼ Sec 11, T24N, R2E is lumped with adjacent gravelly deposits as Qpv.

Vashon till. The Vashon glacier covered much of the Puget Lowland with a thin layer of lodgement till. On Bainbridge Island, Vashon till varies from less than a meter (at which point it is unmappable) to more than 35 m thick. There is some suggestion that the till is thicker on south-facing (down-ice) slopes than on north-facing slopes. Vashon till is mostly compact diamict rich in sand and well-rounded pebbles. Most pebbles are less than 10 cm in diameter. Only rarely are clasts larger or angular. Meltwater streams carried the majority of the sediment moved (albeit indirectly) by the glacier and deposited this sediment as outwash. Most debris in the till was reworked from underlying outwash; only a minor amount was carried within, or on top of, the ice sheet.

Lenses of sorted, layered material (silt, sand, gravel) are common in the till, no doubt reflecting the near-pervasive presence of flowing water beneath the Vashon glacier.

Good outcrops of Vashon till are common in shoreline bluffs. Particularly accessible and instructive are outcrops on the west side of Point White and south of Battle Point. Wave-etched outcrops commonly show foliation that is rarely evident in upland outcrops. Presumably, foliation records simple shear induced by traction from the overlying ice. Minor folds in the till, where evident, commonly have north-south axes: the rotation of folds into the transport direction indicates large shear strain. Rare clastic dikes thread some outcrops.

Ice-contact deposits. North of Winslow and near Manitou Beach, surface morphology suggests that buried ice fragments have melted and the adjacent deposits have collapsed. These areas are mapped as ice-contact deposits.

Late-glacial deposits

The weight of the Vashon ice sheet induced significant isostatic subsidence at the time of glaciation. As the Vashon ice sheet retreated it dammed extensive ice-marginal lakes in the Puget Lowland (e.g. Bretz, 1913). As the mass of the waning ice sheet decreased, isostatic uplift lagged, as recorded by now-elevated peripheral shorelines and marine deposits. Thorson (1989) further described and analyzed these features, and interpreted post-glacial rebound with an up-to-the north tilt of about 1 meter per kilometer. Most rebound occurred within a few thousand years of deglaciation (Thorson, 1989; Dethier and others, 1995; Clague and James, 2002). In the vicinity of Bainbridge Island, Thorson's analysis suggests —Results from the 1998 Seismic Hazards Investigations in Puget Sound: Journal of Geophysical Research, v. 106, no. B7, p. 13,541-13,564.

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