

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science Directorate
Geologic Resources Division



Bainbridge Island Japanese American Exclusion Memorial

GRI Ancillary Map Information Document

Produced to accompany the Geologic Resources Inventory (GRI) Digital Geologic Data
for Bainbridge Island Japanese American Exclusion Memorial

bais_geology.pdf

Version: 3/22/2017

Geologic Resources Inventory Ancillary Map Information Document for Bainbridge Island Japanese American Exclusion Memorial

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Geologic Resources Inventory Map Document



Bainbridge Island Japanese American Exclusion Memorial, Washington

Document to Accompany Digital Geologic-GIS Data

[bais_geology.pdf](#)

Version: 3/22/2017

This document has been developed to accompany the digital geologic-GIS data developed by the Geologic Resources Inventory (GRI) program for Bainbridge Island Japanese American Exclusion Memorial, Washington.

Attempts have been made to reproduce all aspects of the original source products, including the geologic units and their descriptions, geologic cross sections, the geologic report, references and all other pertinent images and information contained in the original publication.

This document contains the following information:

- 1) **About the NPS Geologic Resources Inventory Program** – A brief summary of the Geologic Resources Inventory (GRI) Program and its products. Included are web links to the GRI GIS data model, and to the GRI products page where digital geologic-GIS datasets, scoping reports and geology reports are available for download. In addition, web links to the NPS Data Store and GRI program home page, as well as contact information for the GRI coordinator, are also present.
- 2) **GRI Digital Map and Source Citation** – The citation of the GRI digital geologic-GIS map produced for this project along with the source map used in its completion. In addition, an index map and a brief explanation of how the source map was used is provided.
- 3) **Map Unit Listing** – A listing of all geologic map units present on the map for this project, generally listed from youngest to oldest.
- 4) **Map Unit Descriptions** – Descriptions for all geologic map units.
- 5) **Ancillary Source Map Information** – Additional information present on the source map.
- 6) **GRI Digital Data Credits** – GRI digital geologic-GIS data and ancillary map information document production credits.

For information about using GRI digital geologic-GIS data contact:

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About the NPS Geologic Resources Inventory Program

Background

Recognizing the interrelationships between the physical (geology, air, and water) and biological (plants and animals) components of the earth is vital to understanding, managing, and protecting natural resources. The Geologic Resources Inventory (GRI) helps make this connection by providing information on the role of geology and geologic resource management in parks.

Geologic resources for management consideration include both the processes that act upon the Earth and the features formed as a result of these processes. Geologic processes include: erosion and sedimentation; seismic, volcanic, and geothermal activity; glaciation, rockfalls, landslides, and shoreline change. Geologic features include mountains, canyons, natural arches and bridges, minerals, rocks, fossils, cave and karst systems, beaches, dunes, glaciers, volcanoes, and faults.

The Geologic Resources Inventory aims to raise awareness of geology and the role it plays in the environment, and to provide natural resource managers and staff, park planners, interpreters, researchers, and other NPS personnel with information that can help them make informed management decisions.

The GRI team, working closely with the Colorado State University (CSU) Department of Geosciences and a variety of other partners, provides more than 270 parks with a geologic scoping meeting, digital geologic-GIS map data, and a park-specific geologic report.

Products

Scoping Meetings: These park-specific meetings bring together local geologic experts and park staff to inventory and review available geologic data and discuss geologic resource management issues. A summary document is prepared for each meeting that identifies a plan to provide digital map data for the park.

Digital Geologic Maps: Digital geologic maps reproduce all aspects of traditional paper maps, including notes, legend, and cross sections. Bedrock, surficial, and special purpose maps such as coastal or geologic hazard maps may be used by the GRI to create digital Geographic Information Systems (GIS) data and meet park needs. These digital GIS data allow geologic information to be easily viewed and analyzed in conjunction with a wide range of other resource management information data.

For detailed information regarding GIS parameters such as data attribute field definitions, attribute field codes, value definitions, and rules that govern relationships found in the data, refer to the NPS Geology-GIS Data Model document available at: <http://science.nature.nps.gov/im/inventory/geology/GeologyGISDataModel.cfm>

Geologic Reports: Park-specific geologic reports identify geologic resource management issues as well as features and processes that are important to park ecosystems. In addition, these reports present a brief geologic history of the park and address specific properties of geologic units present in the park.

For a complete listing of Geologic Resource Inventory products and direct links to the download site visit the GRI publications webpage http://www.nature.nps.gov/geology/inventory/gre_publications.cfm

GRI geologic-GIS data is also available online at the NPS Data Store Search Application: <http://irma.nps.gov/App/Reference/Search>. To find GRI data for a specific park or parks select the appropriate park

(s), enter "GRI" as a Search Text term, and then select the Search Button.

For more information about the Geologic Resources Inventory Program visit the GRI webpage: <http://www.nature.nps.gov/geology/inventory>, or contact:

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The Geologic Resources Inventory (GRI) program is funded by the National Park Service (NPS) Inventory and Monitoring (I&M) Division.

GRI Digital Map and Source Map Citation

The GRI digital geologic-GIS map for Bainbridge Island Japanese American Exclusion Memorial, Washington:

GRI Digital Geologic-GIS Map of Bainbridge Island, Washington (*GRI MapCode BAIS*)

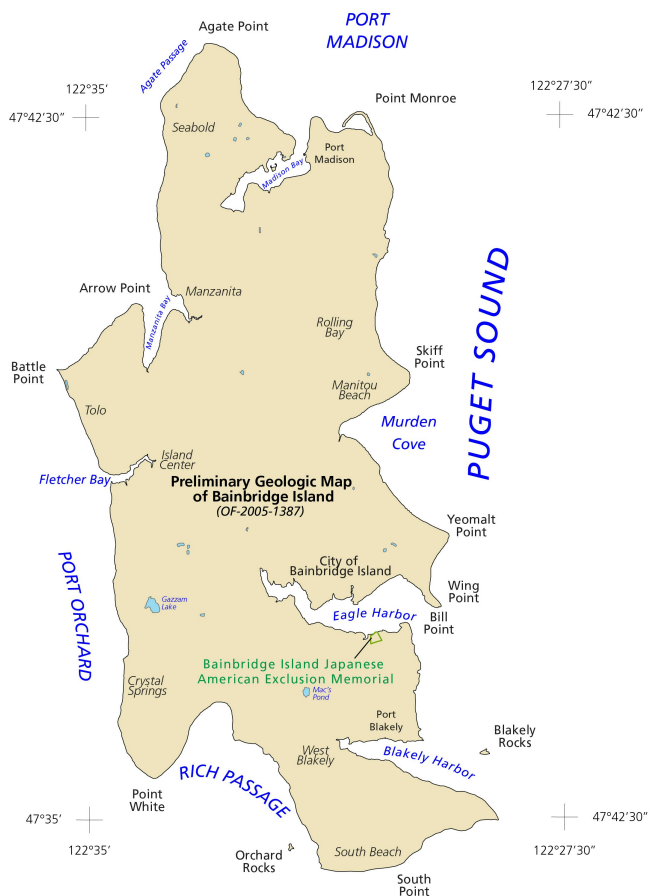
The map was produced using the following source map and digital data:

Haugerud, Ralph, 2005, Preliminary Geologic Map of Bainbridge Island, Washington, U.S. Geological Survey, Open-File Report OF-2005-1387, scale 1:24,000. (*GRI Source Map ID 74282*).

Additional information pertaining to the source map is also presented in the GRI Source Map Information (MIINMAP) table included with the GRI geologic-GIS data. As Bainbridge Island Japanese American Exclusion Memorial is presently administered by Minidoka National Historic Site (MIIN) this map is related to this historic site.

Index Map

The following index map displays the extent of GRI mapping, the National Park boundary for Bainbridge Island Japanese American Exclusion Memorial, Washington (in dark green, as of March, 2017), and the source map used with the series number in parenthesis. Graphic by James Winter.



Map Unit List

The geologic units present in the digital geologic-GIS data produced for Bainbridge Island Japanese American Exclusion Memorial, Washington are listed below. Units are listed with their assigned unit symbol and unit name (e.g., Qm - Modified land). Units are listed from youngest to oldest. No description for water is provided. Information about each geologic unit is also presented in the GRI Geologic Unit Information (BAISUNIT) table included with the GRI geologic-GIS data.

Cenozoic Era

Quaternary Period

Holocene Epoch

Post-Glacial Deposits

- [Qm](#) - Modified land
- [Qf](#) - Artificial fill
- [Qw](#) - Wetland deposits
- [Qal](#) - Alluvium
- [Qaf](#) - Alluvial fan deposits
- [Qb](#) - Beach deposits

Holocene and Pleistocene Epochs

- [Qls](#) - Landslide deposits

Holocene Epoch

- [Qtf](#) - Tide-flat deposits

Pleistocene Epoch

Glacial and Older Non-Glacial Deposits

- [Qeg](#) - Emergence gravels
- Vashon Drift
 - [Qvi](#) - Vashon Drift, ice-contact deposits
 - [Qvt](#) - Vashon Drift, Vashon till
 - [Qve](#) - Vashon Drift, Esperance Sand Member
 - [Qvc](#) - Vashon Drift, Lawton Clay Member
- Pre-Vashon deposits
 - [Qpv](#) - Pre-Vashon deposits
 - [Qpvf](#) - Pre-Vashon fine-grained deposits
 - [Qpvu](#) - Pre-Vashon deposits, University Point beds
 - [Qpog](#) - Pre-Vashon deposits, older glacial deposits
 - [Qpor](#) - Pre-Vashon deposits, Rockaway Beach unit

Tertiary Period

Miocene Epoch

Tertiary Sedimentary Rocks

- [Tbh](#) - Blakely Harbor Formation

Eocene and Oligocene Epochs

- [Tb](#) - Blakeley Formation
- [Tbt](#) - Blakeley Formation, tuff-rich beds

Map Unit Descriptions

Descriptions of all geologic map units, generally listed from youngest to oldest, are presented below.

Post-Glacial Deposits

Qm - 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: Artificial fill. (GRI Source Map ID 74282). ([Preliminary Geologic Map of Bainbridge Island](#)).

Qf - 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. (GRI Source Map ID 74282). ([Preliminary Geologic Map of Bainbridge Island](#)).

Qw - Wetland deposits (Holocene)

Silt, sand, muck, and peat deposited in wetlands. Mapped on basis of morphology or presence of surface water and wetland vegetation. (GRI Source Map ID 74282). ([Preliminary Geologic Map of Bainbridge Island](#)).

Qal - Alluvium (Holocene)

Well-sorted sand, gravel, and silt deposited by postglacial streams. Locally may contain intercalated poorly sorted debris flow deposits. (GRI Source Map ID 74282). ([Preliminary Geologic Map of Bainbridge Island](#)).

Qaf - Alluvial fan deposits (Holocene)

Stream-deposited sand and gravel deposited in low-angle conical fans. Locally may contain poorly sorted debris flow deposits. (GRI Source Map ID 74282). ([Preliminary Geologic Map of Bainbridge Island](#)).

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. (GRI Source Map ID 74282). ([Preliminary Geologic Map of Bainbridge Island](#)).

Qls - Landslide deposits (Holocene and latest Pleistocene?)

Diamict, 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. (GRI Source Map ID 74282). ([Preliminary Geologic Map of Bainbridge Island](#)).

Of note, as the unit's description states "may be latest Pleistocene in age" the unit's age is recognized

to be "Holocene and latest Pleistocene?"

Qtf - Tide-flat deposits (Holocene)

Sand and gravel 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. (GRI Source Map ID 74282). ([Preliminary Geologic Map of Bainbridge Island](#)).

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 coextensive 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. (GRI Source Map ID 74282). ([Preliminary Geologic Map of Bainbridge Island](#)).

Vashon Drift

Qvi - Vashon Drift, ice-contact deposits (Pleistocene)

Gravel, sand, and diamict deposited against stationary ice. Commonly reworked by slumping. Mapped on basis of morphology. (GRI Source Map ID 74282). ([Preliminary Geologic Map of Bainbridge Island](#)).

Qvt - Vashon Drift, Vashon till (Pleistocene)

Dense sandy diamict. 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 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. (GRI Source Map ID 74282). ([Preliminary Geologic Map of Bainbridge Island](#)).

Qve - Vashon Drift, Esperance Sand Member (Pleistocene)

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 mostly loose sand. Local cross-beds and large foresets suggest deposition in fluvial or deltaic setting; elsewhere, pervasive decimeter-thick planar beds and lowangle cross-beds suggest deposition by prodelta turbidity currents. (GRI Source Map ID 74282). ([Preliminary Geologic Map of Bainbridge Island](#)).

Qvlc - Vashon Drift, Lawton Clay Member (Pleistocene)

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. (GRI Source Map ID 74282). ([Preliminary Geologic Map of Bainbridge Island](#)).

Pre-Vashon Deposits

Qpv - Pre-Vashon deposits (Pleistocene)

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: Fine-grained deposits (*GRI Source Map ID 74282*). ([Preliminary Geologic Map of Bainbridge Island](#)).

Qpvf - Pre-Vashon fine-grained deposits (Pleistocene)

Silt, clay, and local peat. (*GRI Source Map ID 74282*). ([Preliminary Geologic Map of Bainbridge Island](#)).

Qpvu - Pre-Vashon deposits, University Point beds (Pleistocene)

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 suggest an ultimate source in the Olympic Mountains. 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. (*GRI Source Map ID 74282*). ([Preliminary Geologic Map of Bainbridge Island](#)).

Qpog - Pre-Vashon deposits, older glacial deposits (Pleistocene)

Till, pebbly mud, and associated silt, sand, gravel, and conglomerate. On Rockaway Beach, till overlain by thin-bedded silt and fine sand, locally disrupted by subaqueous slumping. (*GRI Source Map ID 74282*). ([Preliminary Geologic Map of Bainbridge Island](#)).

Qpor - Pre-Vashon deposits, Rockaway Beach unit (Pleistocene)

Massive to disrupted silt, clay, and sand. Most disruption appears to be due to soft-sediment deformation. (*GRI Source Map ID 74282*). ([Preliminary Geologic Map of Bainbridge Island](#)).

Tertiary Sedimentary Rocks

Tbh - Blakely Harbor Formation (Miocene)

Volcanic-lithic sandstone, siltstone, conglomerate, and peat. Orange-brown weathering; pervasive clayey alteration. Conglomerate rich in basaltic clasts and without granitic clasts. Abundant wood and, locally, peat as thick as 3 m. Stream and flood-plain deposits. (*GRI Source Map ID 74282*). ([Preliminary Geologic Map of Bainbridge Island](#)).

Tb - Blakeley 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 marine shells and charcoal, locally extensive burrowing. Sandstones are rich in volcanic debris; trace white mica. In part mapped as: Tuff-rich beds. (*GRI Source Map ID 74282*). ([Preliminary Geologic Map of Bainbridge Island](#)).

Tbt - Blakeley Formation, tuff-rich beds (Eocene and Oligocene)

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. (*GRI Source Map ID 74282*). ([Preliminary Geologic Map of Bainbridge Island](#)).

Ancillary Source Map Information

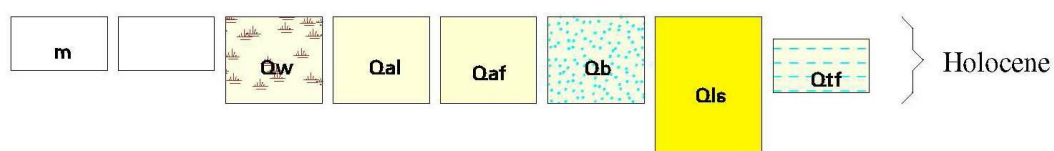
Open-File Report OF-2005-1387

Haugerud, Ralph, 2005, Preliminary Geologic Map of Bainbridge Island, Washington, U.S. Geological Survey, Open-File Report OF-2005-1387, scale 1:24,000. (*GRI Source Map ID 74282*).

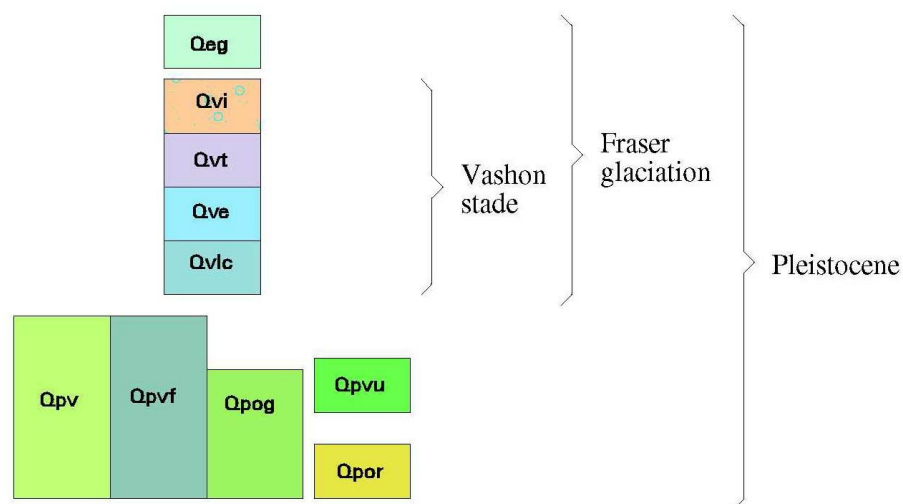
Correlation

CORRELATION OF MAP UNITS

POST-GLACIAL DEPOSITS



GLACIAL AND OLDER NON-GLACIAL DEPOSITS

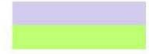


TERTIARY SEDIMENTARY ROCKS



Extracted from: ([Preliminary Geologic Map of Bainbridge Island](#)).

Map Legend

	contact		upright bedding
	approximately located contact		overturned bedding
	concealed contact		horizontal bedding
	scratch boundary at margins of till in upland areas		bedding, no facing direction observed
	fault		bedding, orientation approximate
	approximately located fault		foliation
	concealed fault		horizontal foliation
	trace of bedding		minor fold
	relict late-glacial shoreline		field or subsurface observation
			radiocarbon age sample

Extracted from: ([Preliminary Geologic Map of Bainbridge Island](#)).

Map Notes

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 of these areas 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 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 macrophylla*), 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 Sucumish) 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 tidewater 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 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 basalt of hotspot or forearc-basin-rift provenance (Crescent Formation) is succeeded by thick late-middle and late Eocene fluvial to deltaic sandstone with intercalated andesitic volcanic rock (Puget Group), overlain by latest Eocene-Oligocene continental shelf to nearshore tuffaceous marine strata of the Blakeley Formation. 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 infinite radiocarbon ages (i.e., older than ~40,000 ^{14}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 ^{14}C ybp). On Whidbey Island, well to the north of the Tacoma area studied by Willis 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 only by deposits of the Vashon stade. Thus "Fraser" and "Vashon" have been used almost synonymously, but in places "Fraser" explicitly includes events and deposits older (~24,000 ^{14}C ybp) and younger (~11,000 ^{14}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 foreset bedding, locally with silt and 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 basal member.

[Table 1](#) compares Pleistocene 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.

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 nonglacial (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 SEA 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, 4 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 Blakeley 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. Carbonized wood fragments are common, disarticulated shells are locally present, and McLean (1977) reports that hemipelagic shale beds usually contain abundant microfossils. Thick tuff beds locally show internal cross-bedding; associated thin beds of fine-grained detritus 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 here mapped as tuffaceous Blakeley 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 exposed 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 zeolite clinoptilolite as a common secondary mineral. Scattered grains of white mica are evident in many hand specimens.

McLean (1977) interpreted the Blakeley Formation as deposited for the most part by turbidity currents in a submarine-fan setting. He interpreted the coarser, thicker beds with local conglomerate layers in the tuffaceous unit as Submarine fan channel deposits. I note that more prevalent bioturbation in the upper part of the unit suggests that it was deposited in shallower water, or more slowly than the lower tuffaceous part of the Blakeley.

Fulmer (1975) reported Refugian and Zemorrian (late Eocene and Oligocene) foraminifera from the Blakeley Formation; all fossils from Bainbridge Island are Oligocene. Sherrod and others (2002) reported a 31.6 ± 2.1 Ma fission-track age from a pumiceous layer at Manchester State Park, on the Kitsap Peninsula west of Beans Point.

Blakely Harbor Formation

Fulmer (1975) named conglomerate-rich non-marine strata that crop out on the shores of Blakely Harbor and farther north the Blakely Harbor Formation. Most outcrops are massive to cross-bedded, basalt-pebble conglomerate and interbedded sandstone. Outcrops of sandstone, siltstone, and peat are less common, though these less resistant lithologies appear to comprise the bulk of the unit. Fossil wood--much of which can still be cut with a knife--is abundant. Sandstone of the Blakeley Harbor is rich in Volcanic rock fragments--many of them rounded--that are pervasively altered to clay. The extent of alteration does not appear to correlate with depth below the surface, thus I infer alteration to be diagenetic, not a consequence of recent weathering. Both conglomerates and sandstones weather to a yellowbrown to dark orange-brown color. Brett CoX (personal communication, 2005) suggests that conglomerate and interbedded sandstone were deposited in channels of a high-energy, non-glacial braided 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 (2002) 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 Sec4 and 5, T24N, R2E, and tentatively map this area as underlain by Blakely Harbor Formation.

¹ Fulmer (1975, p. 211) noted "this formational unit received its name from the nearby village of Port Blakely and its harbor. The more common geographic spelling was not retained by Weaver, possible because the name 'Blakely' had been previously used by Ulrich in 1911 for a sandstone unit of Lower Ordovician age." Ulrich's Blakely crops out in Arkansas.

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 waxy 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 intraclasts of waxy silt in a massive fine sand matrix. Perhaps the disruption records slumping 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 recognizable in stream exposures and roadcuts as far west as the intersection of Old Mill Road and McDonald Road in the SE 4 of Sec 34, T25N, R2E. Along Rockaway Beach this unit appears to be about 300 m thick, though structural repetition cannot be ruled out. The irregular trace of the basal contact west of Rockaway Beach suggests an unconformity with more than 100 m relief on the top of the underlying Blakely Harbor Formation. As these beds are pre-Vashon, and are probably glacial, they must be older than the Olympia interglaciation.

Older glacial deposits. Pre-Vashon, and thus pre-Olympia, glacial deposits (Qpog) crop out at several locales. Till crops out on the beach, beneath pre-Vashon bedded deposits, between Battle and Arrow Points (SWA Sec 8, T25N, R2E). Folded and locally faulted diamict, gravel, and thick-bedded sand crop out in the shoreline bluffs east of Agate Point (NEA Sec 28, T26N, R2E). Deformed massive silt with pebbles probable drop stones-crops out at the base of the bluff along Rolling Bay. Deeter (1979, p. 27) reported Snail, clam, and barnacle fossils in these outcrops. Till crops out along the bluff east of Ferincliff, where it underlies Lawton Clay(?).

On Rockaway Beach, above the Rockaway Beach unit, a single basal bed of indurated pebbly till (or conglomerate), with minor granitoid clasts, is succeeded by thin-bedded clay, silt, and fine sandstone that are approximately 150 meters thick. Undisturbed planar bedding, fine grain size, and lack of bioturbation all suggest deep-water deposition of the bulk of this unit. Ripple cross-lamination in the fine sands provides excellent evidence that these north-dipping beds are upright. These outcrops include several 1- to 2-m thick layers of complexly disrupted bedding that appear to record syndepositional slumping. Basal till and evidence of rapid deposition indicate a glacial and periglacial origin.

Landslide debris in the beach on the east shore of Port Orchard (Sec 29, T25N, R2E) suggests two pre-Vashon glaciations. The stratigraphy preserved in the debris is oxidized gravel above pebbly till above discontinuous peat above silt and clay with dropstones.

University Point beds. Well-sorted gravel and associated sand, silt, and peat crop out in several locales at and north of Eagle Harbor. Gravel beds are typically no more than 1-2 m thick and most pebbles are dark graywacke or basalt, suggesting derivation from the Olympic Mountains to the west. Pebbles are rarely larger than 6 cm in diameter. Pebble beds commonly display good imbrication. In good outcrops 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 similar character and relative proximity encourage me to consider these beds as one lithostratigraphic unit. Presence of granitoid pebbles and lack of clayey alteration distinguish these beds from the Blakely Harbor Formation, which is a similar depositional facies. Outcrops at University Point, on the shore of Port Orchard west of Fletcher Bay, are particularly good. Twenty-five meters of University Point strata 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.

Deeter (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 in Sec 4, T25N, R2E, at Fletcher Bay, and north of Rolling Bay (all of which I map as University Point beds). He reported the high concentration of dark greywacke clasts and poverty of granitoid clasts and reports that Crandell (in Levin and others, 1965) thus inferred an Olympic Mountains origin for the gravels. Nonetheless, Deeter interpreted these strata as glacial Sediments and tentatively assigned them to the Possession Drift of Easterbrook and others (1967) on the basis of infinite radiocarbon ages (W-1459, UW-449) and on account of "difficulties in explaining alpine glaciers advancing from the Olympic Mountain across Hood Canal during an interglaciation and also because the nature of coarse gravel deposits in the lowland on an interglacial floodplain is difficult to explain especially when present day streams do not carry anything as coarse as these deposits" (Deeter, 1979, P.55-56). I find these difficulties 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.

Infinite and not-quite-infinite that is, ^{14}C concentrations too low and almost too low to measure – radiocarbon ages ([Table 2](#)) suggest that the University Point beds were deposited during the Olympia interglacial interval.

Undifferentiated pre-Vashon deposits. Most of the area I mapped as undifferentiated pre-Vashon deposits (Gpv) 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 deposits (unit Gpfe) 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 Qpvu, Qpog, Qpor, and Qpwf. Some of the deposits mapped as Gpv are lithified and are best described as sandstone and conglomerate.

In the NE 1/4 of Sec 5, T24N, R2E, I found chunks of silt with shell fragments among the debris along a newly-bulldozed road. No shells were evident in nearby outcrops, where beds (covered by landscaping as of late 2005) dip at 35 degrees to the NW, suggesting that these deposits are substantially older than Vashon Drift.

Irregularly-bedded polymict conglomerate with thin layers of soft sandstone crops out at the north end of Rockaway Beach (NW 4 Sec 36, T25N, R2E). Abundant cut-and-fill structures and irregular bedding suggest fluvial deposition. Unlike most Quaternary deposits on Bainbridge Island, the sandstone, as well as underlying thin-bedded fine sandstone of glacial(?) origin, has a light-colored, probably diagenetic, matrix. Irregular bedding may in part reflect subsequent deformation. Sandstone and conglomerate here appear to be about 100 m thick, and are overlain by Esperance Sand exposed in the beach bluff and in a house excavation (as of late 2005) at the north end of Rockaway Beach. The base of the bluff exposes coarse cross-bedded (deltaic?) gravel that may be of pre-Vashon age (though bedding appears less deformed than bedding in pre-Vashon conglomerate that crops out in the beach), or of early Vashon age-agravelly facies-equivalent of the Esperance Sand.

Silt and clay with associated peat crop out along the south side of Eagle Harbor and southeast of Agate Point. These are mapped as fine-grained pre-Vashon deposits (Gpwf). Except for the occurrence of peat these beds appear similar to the Lawton Clay (described below).

The relation of the Rockaway Beach unit and overlying steeply to moderately dipping strata farther north on Rockaway Beach to pre-Vashon Quaternary strata elsewhere on Bainbridge Island is uncertain. If one supposes there is no fault or fold along the axis of Eagle Harbor, these beds project beneath, and thus are older than, the University Point beds exposed at Wing Point.

Vashon Drift

The Vashon-age Cordilleran ice sheet gathered in the mountains of British Columbia and flowed south, reaching its maximum southern extent near Olympia at about 16,900 ybp; it covered Bainbridge Island for about 1000 years, from 17,600 to 16,600 calibrated ybp (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 carried clay, silt, sand, and gravel deposited first as the Lawton Clay and then as the Esperance Sand, as described below. The net effect was to fill low spots throughout the Lowland and produce a broad, south-sloping alluvial plain (Crandell and others, 1965; Booth, 1994). This surface is preserved, with modification, as an upland surface that is the dominant landform of the Puget Lowland. At the latitude of the Bainbridge Island this surface is at an elevation of about 140 m. The overriding glacier then eroded, shaped, and smoothed its outwash plain. The broad, anastomosing, sinuous troughs filled by Puget Sound, Port Orchard, Port Madison, and Rich Passage were eroded beneath the glacier (Crandell and others, 1965; Booth, 1994), as demonstrated by widespread blanketing by lodgement till, pervasive smoothing by south-directed flow, and the inability of post-glacial streams to erode hollows that extend far beneath any post-glacial base level. Booth (1994) suggested that erosion of the troughs was primarily by flowing subglacial water. The glacier also formed pervasive north-south flutes (elongate drumlins) with heights of 10s of meters, widths of 100s of meters, and lengths of several kilometers. These may reasonably be attributed to direct shaping by moving ice, by virtue of their parallel orientation and lack of sinuosity.

Lawton Clay. Once Vashon ice reached the northeast corner of the Olympic Peninsula, near Port Townsend, it dammed the Puget Lowland and turned low-elevation parts of the Lowland into one or more large lakes with an outlet at Black Lake, south of Olympia (Mullineaux and others, 1965; Waitt and Thorson, 1983; Booth and others, 2004). The Lawton Clay Member of the Vashon Drift was deposited in this lake. Clay and silt were transported by suspension in glacial meltwater that fed the lake. Coarser debris was probably ice-rafted. Lawton sedimentation at any particular locale ended when Vashon ice approached close enough that the supplied sediment was dominantly sand. The present elevation of the Black Lake outlet is circa 42 m (Thorson, 1989; Bretz, 1913). Allowing for some Vashon-age incision of the outlet and some local isostatic depression by the advancing ice sheet, the likely level of this lake on

Bainbridge Island is somewhat higher than 42 m. Barring tectonism, Lawton Clay should not be present at elevations greater than the lake level. At near-lake-level elevations, the Lawton should be very thin. Fittingly, most recognized Lawton Clay occurs near sea level.

Gray to blue-gray, thinly (cm) to thickly (10s of cm) bedded silt, clay, and fine sand, locally with dropstones and lenses of sand and gravel, are here mapped as the Lawton Clay Member of the Vashon Drift where evidence indicates that such beds are part of a continuous coarsening-upwards succession that culminated in Vashon till. Such evidence comprises (a) gradational contact with overlying uncemented fine to medium sand sand, or (b) occurrence at the base of laterally extensive landslide complexes that suggest the silt and clay beds and overlying sand deposits are equally extensive. Lawton silt and clay are common as landslide debris embedded in the modern beach. The highest Lawton Clay recognized on Bainbridge Island is at about 40 m elevation.

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

Esperance Sand. Thick, commonly homogeneous, fine to medium sand, usually poorly consolidated, locally pebbly, locally with gravel layers, in places coarsening upwards, is here mapped as the Esperance Sand Member of the Vashon Drift. Recently published maps of the central Puget Lowland (e.g. Booth and Waldron, 2004; Troost and others, 2005) have mapped equivalent strata as “Vashon advance outwash deposits (Qva). I have revived Mullineaux and others' (1965) nomenclature to emphasize that (1) on Bainbridge Island this unit is predominantly sandy, and (2) I have mapped a lithostratigraphic unit with its attendant uncertainties, not a time-process unit.

Subsoil developed on this unit is loose sand. These beds are advance outwash, deposited in front of the advancing Vashon glacier. At lower elevations much of the unit is massive to plane-bedded, and probably was deposited by mass sediment gravity flows avalanching off advancing delta faces. At higher elevations, some of this unit is strongly cross-bedded and clearly fluvial. Our present understanding of Vashon glaciation (e.g. Booth, 1994) requires that at the latitude of Bainbridge Island, advance outwash deposits at lower elevations (below 42+ m) cannot be fluvial; conversely, fluvial deposits beneath Vashon till at low elevations must be older than Vashon glaciation.

Esperance Sand fills a paleovalley that extends from the head of Eagle Harbor south to Lynwood Center and Rich Passage and, perhaps, a paleovalley that extended NW-SE along the present-day low that extends from Fletcher Bay to Eagle Harbor. Similarly, Esperance 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 4 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 periglacial 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 late-glacial lake elevations of about 110 meters (Lake Russell) and 50 meters (Lake Bretz) and a post-ice marine limit at an elevation of 20 to 30 meters. High-resolution topography suggests that shorelines developed along the late-glacial lakes are locally preserved as geomorphic features, but any corresponding shoreline deposits must have been no thicker than a meter or so and are indistinguishable from other weathered and bioturbated deposits of sand and gravel.

In contrast, deposits related to late-glacial marine inundation and subsequent emergence are locally preserved. On the north side of Fletcher Bay, shoreline bluff exposures show 1 to 2 m of sorted sand, gravel, and silt. These are mapped as emergence gravels (Qeg). Elsewhere, the presence of similar deposits is inferred from subtle smoothing of the glacial land surface. These deposits are probably former beach sands and gravels, though they may include some nearshore stream deposits. Emergence gravels were not deposited by streams flowing from melting Vashon-age ice, as Bainbridge Island appears to have been ice-free even earlier, at the time of glacial Lake Bretz, when shoreline knicks were developed on the north part of the island near Seabold (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.

Holocene Deposits

Beach and tide-flat deposits

Mapping beach deposits along Puget Sound presents an unresolved set of problems. First and

foremost 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 pebble to cobble 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-see, for example, the beach west and east of Point White-or a thicker deposit of recently accreted material. For this study, surface materials are mapped landward of the break in slope at the high-water line, either the crest of the beach berm or the toe of the bluff. Thus the only beach deposits mapped are the sand, gravel, and logs of accreted back-beach platforms (unit Qb) and the associated silt, muck, and peat deposited in lagoons occluded behind beach berms and spits. Deposits farther seaward are mapped only in certain locales where older material pokes through a veneer of modern beach sediment.

On a geologic time scale it is clear that the beaches and their associated deposits are ephemeral. A good example is at the south side of Skiff Point, where soft, probable Holocene peat that was probably deposited in a marsh behind a beach berm is exposed in the upper intertidal zone in front of the present berm, suggesting that the berm here has migrated to the north. Extensive bulkheads along the shoreline demonstrate that many property owners are concerned that the beaches are ephemeral on a human time scale, as are the bulkheads; bulkheads are commonly deformed by landslides, or the fill behind the bulkhead is sapped by wave action, or, ironically, new beach is accreted in front of a bulkhead.

The large, once-natural spit at Point Monroe has been extensively modified for residential construction and is mapped as modified land.

A large earthquake on the Seattle fault about 1,100 years ago (Bucknam and others, 1992; Nelson and others, 2003) uplifted the south end of Bainbridge Island and stranded a mid-Holocene beach. This fossil beach extends from the large landslide at Crystal Springs on the west to Rockaway Beach on the east. Most of the beach is veneered by thin deposits of gravel and sand that are not mapped. Thicker, and shown on the map, are fossil beach berms 1/2 km west of Restoration Point and at Lynwood Center, and tide-flat deposits (Qt_f) along the south shore of Blakely Harbor and southwest of Lynwood Center.

Landslide deposits

Coastal landslides are particularly abundant where Esperance Sand overlies Lawton Clay with a contact at or above mean high water line. The correlation is so strong that with moderate accuracy one could infer the distribution of Esperance Sand and Lawton Clay on the basis of extensive coastal landslides. Landsliding is episodic. Regionally, extensive failures occurred following heavy rainfall on Saturated soils in early 1972 and early 1997. Tubbs (1974) is an excellent reference on landsliding in this region.

Changes in details of bluff morphology between collection of lidar data in 1997 and 2000 and final field work in 2003-2004 reinforce the conclusion that landsliding is an ongoing process. Evidence for ongoing activity includes sub-angular clasts of fragile bedded silt and clay in the beach at the toe of the large slide at Yeomalt (Sec 23, T25N, R2E). Some coastal bluffs, particularly those cut entirely in the University Point beds, appear to be relatively stable.

I used high-resolution topographic data to map large deep-seated landslide deposits. Because the lidar data do not image the shallow debris flows, commonly no more than a meter thick, that are the most common and frequent slope failures, I did not map the deposits of these events. Neither did I map the colluvial debris that mantles many hillslopes.

Of note, as the unit's description states "may be latest Pleistocene in age" the unit's age is recognized to be "Holocene and latest Pleistocene?"

Wetland deposits and alluvium

The rolling glaciated upland of the Puget Lowland, with numerous closed depressions commonly underlain by low-permeability Vashon till or older silt and clay, has numerous upland wetlands. Other wetlands are coastal, occluded behind beach berms and spits. In places streams have aggraded across such lows and deposited mappable amounts of alluvium. Less commonly, alluvial flats wide enough to map fringe streams that have incised into the upland surface.

I mapped Wetland deposits and alluvium largely on the basis of surface morphology, supplemented by field observations and reference to the U.S. Fish and Wildlife Service's National Wetlands Inventory.

Modified land and fill

Mostly I have not mapped modified land. Significant exceptions are the spit at Point Monroe, where bulkheads and fill have disguised the berm crest and probably raised the average level of the ground surface, and the extensive paved area around the shopping mall and high school north of Winslow. Mapped fill at the site of the former Port Madison sawmill includes anthropogenic peat, recognizable from fragments of dimension lumber. Because of their potential for failure during severe seismic shaking if they were not adequately compacted during construction, I have mapped road fills wherever they are evident in high-resolution lidar topography.

Structure

I recorded the attitude of bedding wherever it was evident. In a few places these observations have been reduced in number for the purposes of presentation at map scale. Symbols with open centers (for example, "approximate bedding") denote observations with a low degree of confidence in the reported measurement, because of poor exposure, suspected slumping, or strong cross-bedding. Such observations, while not accurate to within a few degrees, are commonly useful to define facing direction or approximate strike. If I suspected that beds are sufficiently disturbed that this is not possible, I did not measure them. Measurements that are not "approximate" describe the orientation of structures to within a few degrees.

With poor exposure, unconsolidated deposits, and interest in small amounts of deformation, it is of some concern whether observed deformation is tectonic or due to landsliding, ice push, or syndepositional failure of sediment deposited on a slope. I have attempted to omit all observations of bedding that may have been deformed by landsliding. In general, mild deformation of deposits older than Vashon Drift is common. Locales where deformation is evident are discussed below.

Seattle Fault zone

The Seattle fault zone (Gower and others, 1985; Blakely and others, 2002) crosses southern Bainbridge Island. Map relations and topography suggest at least two episodes of movement. The Toe Jam Hill and Macs Pond fault strands have been active in the Holocene (Nelson and others, 2003; Brian Sherrod, USGS, personal communication 2003). A subtle WNW-trending topographic scarp farther north, near Creosote, is similar in character to the scarp along the Macs Pond fault and I map it also as a Holocene fault. Another fault separates the Blakeley and Blakely Harbor formations in Sec 10, 11, and 12, T24N, R2E. Although Fulmer (1975) thought it was a conformable contact, it truncates bedding in both units. Unlike the Toe Jam Hill and Macs Pond fault strands, this fault is sinuous, thus probably folded, and lacks topographic expression. I infer it to be older than Vashon glaciation. Sharp folds in the

Blakeley Formation immediately east of Beans Point suggest the presence of a nearby older fault.

From Rockaway Beach to the east shore of Port Orchard south of Fletcher Bay, bedding in Esperance and older strata dips to the north. Older beds (Blakely Harbor Formation, Rockaway Beach unit) dip steeply, whereas younger units (older glacial deposits, undifferentiated pre-Vashon deposits, University Point beds, Esperance Sand) have moderate to shallow dips. The northern limit of dipping beds runs from Wing Point to Fletcher Bay. Variation of dip with age and position probably reflects a combination of continuing deformation, with younger beds rotated less, and progressive deformation, with beds farther south having been incorporated earlier into the north-migrating Seattle fault zone.

Minor N-S faults cut the Blakeley Formation along the south shore of Bainbridge Island at and west of Restoration Point. Horizontal, dextral, separations on these faults range from 1 to 3 meters. Given the near vertical dip of beds at this point, about 5-1/2 meters of dextral strike slip is required.

Agate Point

Pre-Vashon sediments, including some of glacial provenance, that crop out on the bluff within 4 km southeast of Agate Point are folded and faulted. A small fault strikes NE, dips steeply, and has an observed dip separation of less than a meter. Bedding attitudes define a northeast-trending fold as well.

Clay, silt and peat that crop out in the intertidal zone farther southeast of Agate Point, beneath a landslide on the bluff, are deformed. The deformation pattern is sufficiently consistent that landslide-related deformation seems unlikely. A small NE-trending fold is evident in outcrop. Bedding strike is parallel to the fold axis and to the axis of the fold defined by bedding farther northwest, closer to Agate Point. Several small NW-trending faults cut the section with an aggregate left-lateral separation of 1.5 meters.

To the southwest of Agate Point, at Seabold, on strike with these dipping beds, topographically higher pre-Vashon deposits are horizontal. Perhaps these higher deposits are younger, deposited after the folding recorded on the beach southeast of Agate Point.

Arrow Point

Fine sand, silt, and clay exposed in shoreline bluffs 2/3 km southwest of Arrow Point are strongly folded, with dips locally in excess of 45°. This section shows local intrastratal deformation that is probably syndepositional; the longer-wavelength folding of the section as a whole is probably younger. Bedding attitudes suggest folding about a northwest trend.

West of Manitou Beach

West of Manitou Beach, in the interior of the island, center of Sec 15, T25N, R2E, an isolated Outcrop of thin-bedded fine sand and silt evinces an east dip of 34°. There is no indication that this is landslide-related deformation. I could not find other outcrops nearby to verify this attitude.

Acknowledgements

I thank Kitsap Public Utility District for contracting the 1996-1997 lidar survey of Bainbridge Island, and Greg Berghoff (KPUD) for bringing this Survey to the attention of the geologic community. Without these data, this map would be very different.

Evan Thoms provided significant help by writing computer code for a digital geologic field map notebook. Brett Cox provided a most useful description of the Blakely Harbor Formation. Scott Morse

(City of Bainbridge Island) supplied useful GIS base data. I thank Kathy Troost (University of Washington, GeoMapNW) for making available the City of Bainbridge Island subsurface database.

Reviews by Derek Booth and Rowland Tabor led to significant improvements of this report.

Table 1: Quaternary Stratigraphies

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

Seeva (1957)	Molenaar (in Garling and others, 1965)	Deeter (1979)	Current usage (e.g. Booth and Waldron, 2004; Booth and others, 2004)	This report																																																																																
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Extracted from: ([Preliminary Geologic Map of Bainbridge Island](#)).

Table 2: Carbon-14 ages from Bainbridge Island

Table 2. ¹⁴C ages from Bainbridge Island

Sample ID	Location	Material analyzed	Age (¹⁴ C ybp)	Reference
USGS-555	47° 40.3' 122° 32.7'	Peat	>48,000	S.W. Robinson <i>in</i> Yount and others (1993)
USGS-556	47° 40.3' 122° 32.7'	Wood	40,000 ± 2,100	SW Robinson <i>in</i> Yount and others (1993)
USGS-557	47° 40.3' 122° 32.7'	Peat	45,500 ± 2,800	SW Robinson <i>in</i> Yount and others (1993)
UW-449	47° 40.3' 122° 32.8' ¹	Peat	>40,000	Deeter (1979)

¹ Latitude and longitude as reported by Yount and others (1993). Location on map and in database as figured by Deeter (1979).

Extracted from: ([Preliminary Geologic Map of Bainbridge Island](#)).

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Map Note

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version 1.0

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This document was developed and completed by James Winter (Colorado State University) for the NPS Geologic Resources Division (GRD) Geologic Resources Inventory(GRI) Program. Quality control of this document by Stephanie O'Meara (Colorado State University).

The information in this document was compiled from the GRI source map, and intended to accompany the digital geologic-GIS map and other digital data for Bainbridge Island Japanese American Exclusion Memorial, Washington developed by James Winter (see the [GRI Digital Map and Source Map Citation](#) section of this document for all sources used by the GRI in the completion of this document and related GRI digital geologic-GIS map.

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