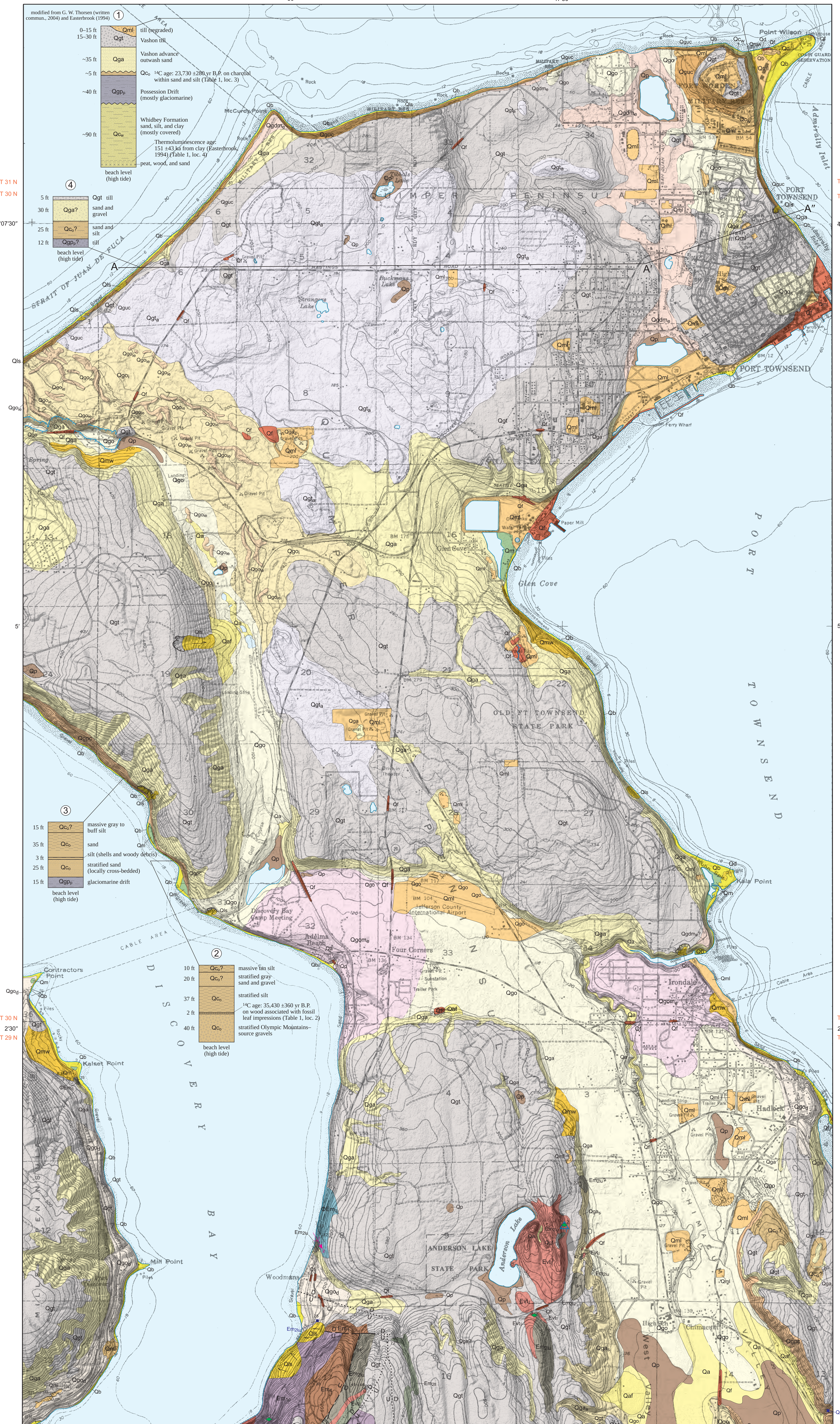
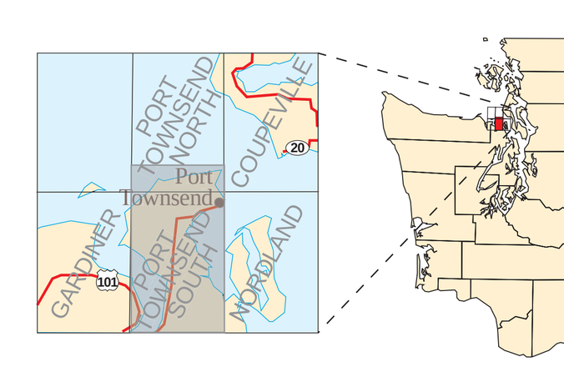


Lambert conformal conic projection
North American Datum of 1927; to place on North American Datum of 1983, move the projection lines 23 feet north and 95 feet east as shown by crosshair corner ticks
Base map from scanned and rectified U.S. Geological Survey 7.5-minute Port Townsend South quadrangle, 1973, and Port Townsend North quadrangle, 1981
Shaded relief generated from lidar; sun azimuth 315 degrees; sun angle 45 degrees; vertical exaggeration 6x
Digital cartography by Charles G. Caruthers
Editing and production by Karen D. Meyers

SCALE 1:24,000
contour interval 20 feet



Geologic Map of the Port Townsend South and Part of the Port Townsend North 7.5-minute Quadrangles, Jefferson County, Washington

by Henry W. Schasse and Stephen L. Slaughter

June 2005

GEOLOGIC SETTING

Lower to middle Eocene Crescent Formation basaltic rocks form the basement for the northeastern Olympic Peninsula and are the oldest rocks exposed in the map area (Tabor and Cady, 1978). They consist mostly of columnar to massive flows with oxidized tops and locally developed paleosols overlain by basaltic cobble to boulder conglomerate.

The rocks of the Crescent Formation are overlain by an unnamed sandstone and siltstone unit (Gower, 1980). This unit may be a correlative of the lower to middle Eocene sandstone of Scow Bay (Allison, 1959; Armentrout and Berta, 1977), which is exposed on Marrowstone and Indian Islands east of the map area where it consists of about 2,000 ft of turbidite sandstone and minor mudstone deposited in a submarine fan environment (Melim, 1984).

The middle Eocene Lyre Formation, overlying the unnamed unit in fault contact in the map area, consists of lower and upper conglomerate and sandstone facies separated by locally derived dacitic pyroclastic rocks (Hahn and others, 2004). The pyroclastic rocks are exposed in the Anderson Lake area, where we have dated them at 46.62 ±0.56 Ma (Table 1, loc. 1). An angular unconformity separates the Lyre Formation from the overlying Oligocene–Eocene Quimper Sandstone. The Tertiary rocks were folded and faulted in the map area by Oligocene or earlier tectonism.

During the Pleistocene, glacial and nonglacial deposits covered most of the map area, forming a thin veneer over bedrock in the south part of the map area but increasing in thickness to the north (from 900 at Irondale to 2,400 ft at Port Townsend, as suggested in Jones, 1999). Alternately, Mosher and others (2000), using geophysical data, suggested that the thickness ranges from about 500 ft (at Port Townsend) to about 800 ft along the west coast of the Quimper Peninsula. Sediments of Canadian Cordilleran provenance (Vancouver Island and the Coast Ranges, hereinafter termed 'northern') were deposited in the map area by the Vashon and earlier glaciations. The inclusion of high-grade metamorphic, granitic, and other crystalline rocks in these northern sediments distinguishes them from sediments of Olympic Mountains (Olympic) provenance, which consist of about 90 percent lithic sandstone with the remaining 10 percent including basalt, argillite, and low-grade metamorphic (mostly metasedimentary) rocks from the core of the Olympic Range.

The oldest Pleistocene sediment exposed at the surface in the map area is thought to be the Double Bluff Drift at the base of the bluff section (where its exposure is too small to show at map scale) on the Strait of Juan de Fuca 1500 to 3000 ft east of the western map boundary (Gayer, 1977; Wash. Dept. of Ecology, 1978). Based on stratigraphic position, Double Bluff Drift would likely date to marine oxygen-isotope stage (hereinafter 'stage') 6, about 185 to 125 ka (Morrison, 1991), although direct age estimates suggest that some exposures may be older (Berger and Easterbrook, 1993; Blunt and others, 1987; Easterbrook, 1994).

The oldest exposed interglacial unit is the Whidbey Formation, which forms the base of the bluff section west of Point Wilson. The Whidbey probably correlates with stage 5, about 125 to 80 ka (Morrison, 1991), which is corroborated by a thermoluminescence date of 151 ±43 ka (Easterbrook, 1994) (Table 1, loc. 4; columnar section 1).

Possession Drift overlies the Whidbey Formation, and field relations suggest an age correlated to stage 4 or about 80 to 60 ka (Morrison, 1991). Amino acid-based ages ranging from 50 to 80 ±22 ka were reported in Easterbrook (1994), Blunt and others (1987), and Easterbrook and Rutter (1981, 1982). In many locations, Possession Drift provides the only means of distinguishing Whidbey sediments from locally very similar, younger "deposits of the Olympia nonglacial interval" (Pessl and others, 1989).

Olympia deposits in the map area correlate with stage 3 or about 60 to 20 ka (Morrison, 1991). Two radiocarbon ages from Olympia deposits within the map area range from 36,430 to 23,730 ^{14}C yr B.P. (Table 1, loc. 2 and 3). Polenz and others (2005) reported radiocarbon ages for the Olympia deposits that range from 37,610 to 16,790 yr B.P. in the Coupeville area of Whidbey Island, northeast of our map area. Field relations indicate that the Olympia nonglacial interval endured as long in our map area as on Whidbey Island, such that the younger age control on the Olympia on Whidbey Island also applies to the area of the Quimper Peninsula.

The Olympia nonglacial interval ended when advance outwash sand and gravel of the Vashon Stade of the Fraser Glaciation (Armstrong and others, 1965) (stage 2) buried the Puget Lowland (Booth, 1994). Porter and Swanson (1998, Fig. 4) suggested that ice arrived and covered the map area approximately 18.16 ka (or ~15,200 ^{14}C yr B.P., Oxcal v. 3.9). That assessment is consistent with the above-mentioned and other nearby age control on Olympia deposits (Polenz and others, 2005). Modeling by Thorson (1981) indicates that ice thickness reached approximately 3,900 to 4,200 ft (1200-1300 m) in the map area, where it carved out drumlins and deposited till on most surfaces. Granitic clasts within the till attest to a source in the Coast Mountains of British Columbia.

As the climate warmed at the end of the Vashon Stade, the Puget lobe retreated northward depositing recessional outwash sands and gravels. The most prominent recessional outwash deposits in the map area occupy a broad flat-bottomed trough that merges with the mouths of West and Chimacum Valleys. Thorson (1981, p. 26-27) offered a possible deglaciation sequence for this area. The retreat of the Puget lobe was marked by ice stagnation and the accumulation of ice-contact stratified drift; associated landforms in the map area are eskers and kettles. Elsewhere the retreat was characterized by an active ice margin resulting in a thin layer of ablation till over the pre-existing lodgment till. Ablation till in the project area shows considerable evidence of reworking by meltwater, characterized by small-scale channel erosion resulting in a patchwork of lodgment till, ablation till, and outwash.

As the Puget lobe retreated northward, marine waters invaded the Puget Lowland, initiating the Everson Interstade (Armstrong and others, 1965). Ice collapse across Admiralty Inlet marks the beginning of deposition of Everson Glaciomarine Drift in the map area. The oldest nearby radiocarbon date from glaciomarine drift (at the Whidbey Island Naval Air Station, 14 mi north-northeast of Point Wilson) is 13,650 ±350 ^{14}C yr B.P. (Dethier and others, 1995), although Polenz and others (2005) believe that ice collapse across Admiralty Inlet may have occurred significantly earlier than Dethier's radiocarbon date suggests. The Everson Interstade ended locally when the rate of post-glacial crustal rebound exceeded global sea level rise, causing the land in the map area to emerge. We agree with Swanson (1994) that his radiocarbon date of 12,690 ^{14}C yr B.P. likely provides the best estimate for the end of the Everson Interstade in the map area, but others have favored other dates (Dethier and others, 1995; Easterbrook, 1966).

STRUCTURAL GEOLOGY

The paucity of good bedrock exposures within the map area makes it difficult to add to the current knowledge and understanding of the geologic structure. Gower (1980) has provided the most detailed geologic mapping and structural interpretation in the study area. We have adopted his mapping of the geology and structure for the area southwest of Anderson Lake on the Quimper Peninsula. However, we have not retained his mapped faults in the immediate area of the lake, because our field observations did not support their retention. Gower's mapping shows a series of closely spaced north- to northeast-trending normal faults with a cross fault inferred to account for discordance in bedding strike between the older Crescent Formation and the younger Lyre Formation and Quimper Sandstone.

Gower (1980) mapped a concealed north-trending, down-to-the-west fault through the central part of Discovery Bay, which he calls the Port Discovery fault. He doesn't discuss the fault in his report, but he apparently based his interpretation primarily on a high-amplitude aeromagnetic anomaly in MacLeod and others (1977).

Gower (1980) inferred two other structures (his structures C and F) from aeromagnetic data. MacLeod and others (1977) considered his structure C the offshore continuation of the Leech River fault of Vancouver Island, which Gower shows passing beneath the Quimper Peninsula at the northwest edge of our map and trending south-southeast. He shows structure C meeting with his east-trending structure F, where both structures die out in the vicinity of Adelma Beach. Wagner and Wiley (1980) presented seismic reflection survey data suggesting a large landslide offshore of Cape George (on the Strait of Juan de Fuca just west of the west boundary of our map) close to Gower's structure F. Wagner and Wiley (1980) suggested that a pre-Vashon seismic event generated the landslide. We were unable to find onshore evidence of the offshore structures during our study and do not show these structures on our map.

DESCRIPTIONS OF MAP UNITS

Quaternary Unconsolidated Deposits

HOLOCENE NONGLACIAL DEPOSITS

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

Qml — **Modified land**—Soil, sediment, or other geologic material locally reworked by excavation and (or) redistribution to modify topography; includes areas of commercial and industrial development, school yards, gravel pits converted to parks and sports fields, active gravel mines, building complexes, artillery bunkers at Fort Worden, and areas around landfills.

Qd — **Dune deposits**—Wind-blown sand and coarse silt; gray to tan; well sorted and stratified; loose. At Point Wilson, beach dunes are about 20 ft high; similar, but smaller dunes rest on beach deposits at Kala Point. Thin deposits (4 ft thick or less) of dark brown "dune" sand and silt rest on Vashon lodgment till (unit Qgt) above east-facing bluffs at Port Townsend (data are insufficient to establish that they are true dune deposits; not mapped because of map scale and poor exposure); gray, rounded pebbles and cobbles occur at the interface of the "dune" sand and underlying lodgment till, suggesting a period of post-glacial erosion before deposition of the "dune" sand.

Qb — **Beach deposits**—Sand and cobbles, may include silt, pebbles, and clay; pebble-sized and larger clasts typically well rounded; well sorted; loose; may be residual or transported. Large boulders up to 10 ft diameter rest on beach deposits or older in-place beach platform sediments, indicating a lag deposit derived from erosion and previous sliding.

Qa — **Alluvium**—Sand, gravel, silt, and clay; typically tan to gray, but dark grayish brown where stained by peat; variably sorted; loose to consolidated; stratified; deposited in stream beds and estuaries.

Qaf — **Alluvial fan**—Sand and gravel; gray to tan; moderately to well sorted; deposited by small streams flowing from highlands into lower-gradient valleys.

Qm — **Marsh deposits**—Organic-matter-rich sediments deposited in brackish or saltwater marsh (estuarine or lagoonal) environments.

Qmw — **Mass wasting deposits**—Boulders, gravel, sand, silt, and clay; generally unsorted but locally stratified; typically loose; consists of colluvium, colluvial soils, small landslides, and regolith; differentiated from mapped landslides by lack of obvious scarps or mappable individual slides.

Qls — **Landslide deposits**—Gravel, sand, silt, clay, and boulders; clasts angular to rounded; unsorted; generally loose, unstratified, broken, and chaotic, but may locally retain primary bedding structure; may include liquefaction features; deposited by mass wasting processes other than soil creep and frost heave; typically in unconformable contact with surrounding units. Scarps are shown where supported by lidar (light distance and ranging, based on airborne laser swath mapping) imagery. All shoreline bluffs in the map area are subject to episodic landsliding and resultant bluff retreat, but most slide deposits are removed (within months to years) by beach wave action.

Qp — **Peat deposits (late Pleistocene to Holocene)**—Organic-matter-rich sediment deposited in closed depressions; includes peat, muck, silt, and clay in and adjacent to wetlands. Two peat deposits up to 44 ft thick occur just south of the map area (Rigg, 1958) and contain a layer of Mazama tephra (Gayer, 1977), which has been dated at 6,730 ±40 ^{14}C yr B.P. (Hallet and others, 1997).

PLEISTOCENE GLACIAL AND NONGLACIAL DEPOSITS

Deposits of the Fraser Glaciation

EVERSON INTERSTADE

Qgdm$_e$ — **Everson Glaciomarine Drift**—Silt, clay, and clay-rich diamicton with highly variable amounts of gravel-sized clasts and lenses and layers of sandy or gravelly outwash; buff to olive- or light gray; well-developed columnar jointing with blocky fracture; fracture surfaces commonly stained dark brown; thickness where exposed in sea cliffs ranges from 3 to 10 ft; water well logs suggest that it is 20 ft thick west of Port Townsend (cross section A); widely distributed and found as high as about 135 ft elevation; deposited on the sea floor during the Everson Interstade sea-level high-stand preceding glacio-isostatic rebound; may contain marine fossils; generally overlies Vashon till (unit Qgt); overlies advance outwash (unit Qga) at McCurdy Point; we interpret the unit to overlie recessional outwash (unit Qgo) west of Port Townsend (cross section A). Deposition of the unit likely began when the ice sheet across Admiralty Inlet collapsed (see Geologic Setting), and its age is further defined by six radiocarbon dates in the Coupeville area (Polenz and others, 2005). The age of the unit spans the entire Everson Interstade (see Geologic Setting for age of the interstade).

Qgom$_e$ — **Glaciomarine outwash**—Sand with silt and lenses of gravel; may be capped by silt and clay (Thorson, 1981); tan to gray; loose; best exposed in the Adelma Beach area in sea cliffs on Discovery Bay, where 5 ft of massive silt with rounded and angular dropstones of northern provenance overlies approximately 95 ft of flat bedded, laminated, and low-angle cross-bedded sand containing silt clasts and isolated lenses of gravel; at least 100 ft thick where exposed in the sea cliff, and analysis of water well records suggests a maximum thickness of 140 ft; interpreted by Thorson (1981) as being deposited by rapid subaqueous west-flowing currents near an active glacier terminus; also includes deltaic sediment; in the Irondale area, occurs as sandy drift forming a kettle topography suggesting that there was stagnant ice present during its deposition; contains marginal marine to intertidal fossils (mussels and barnacles) (Elizabeth Nesbitt, Univ. of Wash., written commun., 2004); overlies Vashon advance outwash (unit Qga) and is interpreted to be coeval with recessional outwash (unit Qgo) where two recessional outwash meltwater channels merge near Discovery Bay Camp Meeting.

VASHON STADE

Qgo — **Recessional outwash**—Pebble to cobble gravel and sand; gray to tan, generally unoxidized with little iron staining except in upper 3 to 4 ft; generally well rounded; unconsolidated; planar to cross-bedded; thickness ranges from 5 to 100 ft; clasts are of northern provenance; lies stratigraphically above Vashon till (unit Qgt) except where till had been removed by erosion. Locally divided into:

- **Qgo$_s$** — **Sand**—Sand with pebbles and silt; stratified; cross-bedded; at least 20 ft thick.
- **Qgo$_d$** — **Delta deposits**—Characterized by foreset beds; laid down by meltwaters flowing into Discovery Bay and Port Townsend Bay (Gayer, 1977; Thorson, 1981); an excellent source of aggregate.
- **Qgo$_i$**, **Qgo$_{ie}$** — **Ice-contact stratified drift**—Sand to coarse gravel deposited in contact with stagnant glacial ice; gray; tan where weathered; rounded to subrounded clasts; moderately well sorted; crudely stratified; highly permeable; characterized by deformation, including slumping, and collapse of sedimentary features; maximum thickness is about 50 ft; less desirable as a source of aggregate than unit Qgo$_d$ due to wide range of clast sizes. A group of eskers, identified by unit Qgo$_{ie}$, has a maximum relief in the map area of about 50 ft. The eskers lose their character to the north, where they grade into ablation till (unit Qgt$_a$). To the south a few of these features survived reworking by meltwater depositing unit Qgo.

Qgt — **Lodgment till**—Mix of clay, silt, sand, and gravel with isolated boulders deposited as diamicton directly by advancing glacier ice; gray where fresh, light yellowish brown where oxidized; cobbles and boulders commonly faceted and (or) striated and glacially polished; unsorted and highly compacted; permeability very low; most commonly matrix supported, but locally clast supported; matrix more angular than water-worked sediments; varies in thickness from 1 ft to about 80 ft and averages about 50 ft thick; may include loose ablation till (unit Qgt$_a$) too thin to map; commonly capped by 0.5 to 4 ft of dark brown wind-deposited sand (see unit Qd) with loose till-colored clasts near the till–sand interface; up to 10 ft diameter erratic boulders commonly associated with till and ablation till; typically forms a vertical face in coastal bluffs. Unit Qgt lies stratigraphically between recessional outwash (unit Qgo) above and advance outwash (unit Qga) below. Local and nearby age control constrains the age of the unit to between about 15,200 ^{14}C yr B.P. (see Geologic Setting and Swanson, 1994; Porter and Swanson, 1998; Booth, 1991) and 13,650 ±350 ^{14}C yr B.P. (see Geologic Setting).

Qgt$_a$ — **Ablation till**—Unsorted, unstratified, loose deposits of gravel, sand, silt and clay; gray to tan, usually oxidized; thickness generally ranges from 3 to 10 ft, but mapped only where sufficiently thick (5 ft or more) to mask underlying lodgment till (unit Qgt); thickest in northern part of the map area where it contains numerous kettles, in many cases filled with peat deposits (unit Qp); only overlies lodgment till (unit Qgt); a somewhat poor source of aggregate due to lack of sorting.

Qga, **Qga$_s$** — **Advance outwash**—Sand and pebble to cobble gravel with some bouldery facies; minor silts and clays; may contain till fragments; gray to grayish brown and grayish orange; clasts well rounded; well sorted; coarsens upward; compact, but in many exposures only minimally cohesive; parallel bedded, locally cross-bedded; approximately 130 ft of section is exposed near Glen Cove; crops out dominantly on fairly steep slopes where side streams have eroded through the overlying lodgment till; commonly forms angle-of-repose benches within coastal bluffs; advance lake beds (silts and clays) have been deformed due to overriding by Vashon ice; commonly overlain by unit Qgt along a sharp contact and stratigraphically above unit Qc$_o$. Subscript 's' denotes a sand-dominated deposit. The age of unit Qga is bracketed by local and nearby age control from the underlying unit Qc$_o$ (Table 1 and Geologic Setting) and an estimate of Vashon ice arrival by Porter and Swanson (1998) (see Geologic Setting).

Undivided Fraser and Pre-Fraser Deposits

Qguc — **Glacial and nonglacial deposits, undivided**—Sand, gravel, silt, clay, glaciomarine drift, and till; mapped where exposures are poor and (or) map scale does not allow detailed delineation; includes units Qga, Qc$_o$, Qgp$_p$, and Qc$_w$; may contain units Qmw and Qls; may contain Double Bluff Drift (Gayer 1977; Washington Department of Ecology, 1978).

Undivided Pre-Fraser Deposits

Qgpc — **Glacial and nonglacial deposits, undivided**—Believed to be Pre-Fraser in age, but may include some unit Qga because of uncertain identity of similar lithologies in units Qga and underlying unit Qc$_o$; includes some exposures too small to be differentiated and larger exposures with sediments whose age and origin could not be determined; in cross section A, consists of all unconsolidated deposits older than Vashon advance outwash. The largest exposures of unit Qgpc are confined to sea cliffs on the east shore of Discovery Bay, the southern parts of which consist mostly of unit Qc$_o$ (columnar sections 2 and 3) and the northern parts of which consist of well sorted, stratified, locally cross-bedded tan, brown, and gray sand and silt of uncertain origins exposed in vertical cliffs. This unit also occurs in the steeper walls of Chimacum Valley (in the southeast corner of the map), where it is poorly exposed and limited to a few outcrops consisting, in part, of till (Possession?) and underlying, gray, compact, laminated silt and clay (lake beds) of uncertain origin.

Deposits of the Olympia Nonglacial Interval

Qc$_o$ — **Nonglacial deposits of Olympia age**—Gravel, sand, silt, and clay; gravel yellowish brown where weathered, gray to dark gray where unweathered; sand, silt, and clay yellowish gray to tan; clasts are Olympic provenance; generally rounded to subrounded; well stratified; compact; typically horizontally bedded fluvial sand and gravel with sparse lenses of silty sand; at least 70 ft of sand and gravel are exposed in the uplands east of Chimacum Valley south of Hadlock and are correlated with similar gravels exposed in sea cliffs on Discovery Bay; overlies Possession Drift (unit Qgp$_p$) (columnar section 3) in a depositional setting similar to that in the exposures represented in columnar section 2. Other workers have mapped unit Qc$_o$ equivalents in bluff exposures on the west side of the Quimper Peninsula between McCurdy Point and Cape George, just west of the map boundary (Gayer, 1977; Wash. Dept. of Ecology, 1978), apparently based on outcrops that have since been partially destroyed by landsliding. Wood from silts just above the gravels at Discovery Bay were dated at 36,430 ±360 ^{14}C yr B.P. (Table 1 and columnar section 2). Silts above the dated wood (columnar section 2) contain fossil leaf impressions from a plant (*Salix planifolia*) known to grow in small swamps (Walter Buechler, written commun. to Rick Dillhoff of Burke Museum, Univ. of Wash., 2004). In bluffs west of Point Wilson, charcoal from sand and silt in erosional contact with overlying Vashon advance outwash sand was dated at 23,730 ± 280 ^{14}C yr B.P. (G. W. Thorsen, consulting geologist, written commun., 2004) (columnar section 1 and Table 1). The unit is queried where age assignment is uncertain.

Deposits of the Possession Glaciation

Qgp$_p$ — **Possession Drift (columnar sections and cross section only)**—Glaciomarine drift and underlying till; distinguished from equivalent Vashon facies by stratigraphic position. Glaciomarine drift facies variegated; typically clay and silt-rich diamicton; buff, gray, to dark gray; compact and commonly with vertical desiccation cracks and shells; locally indistinguishable from till. Till facies typically sandy diamict; gray to light gray; compact. At Point Wilson, approximately 40 ft of predominantly glaciomarine drift overlies the Whidbey Formation (unit Qc$_w$) (columnar section 1). Unit Qgp$_p$ is sporadically exposed near the base of sea cliffs along the Strait of Juan de Fuca southwest of McCurdy Point (Gayer, 1977; Wash. Dept. of Ecology, 1978), where we have included it in unit Qguc, and at another locality along the same stretch of sea cliffs (columnar section 4). Possession glaciomarine drift is also exposed at base of sea cliffs on east shore of Discovery Bay (columnar section 2).

Whidbey Formation

Qc$_w$ — **Whidbey Formation**—Layers of sand, silt, clay, and peat; most commonly weathered to varied shades of tan and light gray; dark gray where unweathered; well sorted and stratified; cross bedded in coarser fractions; typically forms base of sea-cliff exposures and most commonly consists of a basal 10 to 20 ft thick floodplain facies that is commonly slightly oxidized; basal floodplain facies forms prominent vertical bluffs and subhorizontal stratification with common, discontinuous peat beds; a 90 ft thick section is exposed in a landslide bluff section west of Point Wilson (columnar section 1). Gayer (1977) mapped Whidbey sediments in an area of landsliding southwest of McCurdy Point (unit Qls, southeast corner of sec. 1, T31N R2W).

Tertiary Sedimentary and Volcanic Rocks

ΦEm$_q$ — **Quimper Sandstone (Oligocene–Eocene)**—Feldspatholithic sandstone; gray to olive gray, weathers to yellowish tan; fine to coarse grained; typically massive to faintly bedded; locally thin bedded to laminated; locally cross bedded; contains siltstone beds up to 5 in. thick, spherical and elliptical calcareous concretions up to 9 in. in diameter, and calcareous lenses up to 13 ft long; contains rare isolated well-rounded chert pebbles; marine mollusks locally present; in unconformable contact with underlying Lyre Formation (unit Em$_{2lu}$); foraminifera from the unit have been assigned to the Refugian foraminifera stage (Armentrout and Berta, 1977).

Lyre Formation of Gower (1980) (middle Eocene)—Divided into:

- **Em$_{2lu}$** — **Upper sedimentary unit**—Conglomerate, sandstone, siltstone, and sandy siltstone; pebble to cobble conglomerate and sandstone are blue-gray in an unweathered exposure north of Woodmans, but more typically iron-stained to yellowish brown; conglomerate clasts mostly chert with some schist, argillite, metasandstones, and minor white to yellowish-gray dacite clasts (presumably from underlying unit Evt$_l$); conglomerate thick bedded; sandstone is very fine to medium grained and massive to thin bedded; siltstone and sandy siltstone are limonite stained and thin to very thin-bedded; locally includes thin beds of fine- to coarse-grained sandstone and granular sandstone; queried where unit assignment is uncertain; siltstone facies includes the Townsend Shale; foraminifera from siltstone interbeds farther west along the northern slope of the Olympic Peninsula have been assigned to the Narizian stage (V. S. Mallory in Ansfield, 1972). Armentrout and Berta (1977) agreed with Mallory's call for the age of the Lyre Formation and considered it to apply to the Quimper Peninsula.
- **Evt$_l$** — **Dacitic tuff and breccia**—Hornblende dacite tuff and breccia; previously described by others as andesitic (Gower, 1980; Tabor and Cady, 1978); light to medium gray; weathers tan; locally contains rare leaves and coalified wood; commonly massive, but some tuffs are thin bedded; broken zoned plagioclase and hornblende phenocrysts are observed in thin section. In a recent petrologic study of this unit Hahn and others (2004) estimated a 300 ft thick exposed section at Anderson Lake, which they suggest was deposited within topographic constraints such as a paleovalley. They describe the deposit as a subduction-related block and ash flow located in the Cascadia fore arc, which they suggest is unlikely to have traveled more than 6 mi from its source. Geochemical analyses of samples collected during this study have produced dacite chemistry (Table 2). A $^{40}Ar/^{39}Ar$ age of 46.62 ±0.56 Ma on plagioclase from tuff (Table 1) establishes the unit age as middle Eocene.
- **Em$_{2ll}$** — **Lower sedimentary unit**—Conglomerate, sandstone, and siltstone; iron-stained yellowish brown; conglomerate clasts are predominantly chert, with lesser metasedimentary and meta-igneous rocks, quartz, and feldspathic sandstone; sandstone is fine to very coarse grained and typically contains scattered pebbles; siltstone is sandy and thin to faintly bedded.

Em$_1$ — **Unnamed sedimentary rocks of Gower (1980) (middle to lower Eocene)**—Sandstone interbedded with massive to faintly bedded, dark gray to black siltstone; weathered dark yellowish brown; sandstone fine to medium grained, thin to thick bedded, and locally contains rounded shale clasts up to 4 in. long; common convolute bedding; groove casts at the base of many beds; cavernous weathering in thick sandstone beds; overlies unit Em$_{1c}$; contains foraminiferal assemblages referable to the Ulatisian and possibly Penutian stages (Thoms, 1959; W. W. Rau in Gower, 1980).

Crescent Formation (middle to lower Eocene)—Divided into:

- **Em$_{1c}$** — **Conglomerate**—Rounded boulder and cobble conglomerate; basaltic (Table 2); dark gray to black weathering to dark brown; commonly deeply weathered; overlies unit Ev$_c$. Gower (1980) states that the unit overlies a red saprolite about 20 ft thick exposed in a highway road cut along the east side of Discovery Bay. Thoms (1959) called this unit his "Upper Crescent member".
- **Ev$_c$** — **Basalt**—Massive tholeiitic flows and breccia with very rare pillow lavas; grayish black; weathers to dark greenish gray, brown, and grayish yellow to white; common red-oxidized zones at tops of flows; columnar jointed south of map area indicating that most of the exposed part of the unit is subareal; contains foraminiferal assemblages referable to the Penutian to Ulatisian Stages (Rau 1981). Babcock and others (1992, 1994) dated subareal basalts, correlative with those in the map area, in and near the Dosewallips River valley, 20 mi to the south, using $^{40}Ar/^{39}Ar$ geochronometry; their ages range (from top to bottom of the section) from 50.5 ±1.6 Ma to 51.0 ±4.6 Ma.

ACKNOWLEDGMENTS

This map was produced in cooperation with the U.S. Geological Survey National Cooperative Geologic Mapping Program, Agreement Number 04HQAG0069, which partially supported our mapping project. We thank Gerald W. Thorsen for extensive geologic advice, site-specific and general expertise, field trips, radiocarbon age data, and review of map and text; Katherine Reed for delivery of fossil specimens and acting as an intermediary to the staff at the Burke Museum and their associates (Rick Dillhoff and Walter Buechler) for identification of leaf fossils and Elizabeth Nesbitt (also of the Burke Museum) for identification of the depositional environment of marine fossils; Tom Mumford and Helen Berry for their help with fossil identification; F. William Simonds (U.S. Geological Survey Water Resources Division, Tacoma) for providing location information for water well records; Brian Lynn (Wash. Dept. of Ecology) for facilitating delivery of digital shoreline photos; Danielle Priest (Olympic Resource Management) for providing keys to access Pope Resources timberlands; and last, but not least, the uncounted people who permitted us to study geologic exposures on their land and provided local knowledge.

REFERENCES CITED

Allison, R. C., 1959, The geology and Eocene megafaunal paleontology of the Quimper Peninsula area, Washington: University of Washington Master of Science thesis, 121 p., 1 plate.

Ansfield, V. J., 1972, The stratigraphy and sedimentology of the Lyre Formation, northwestern Olympic Peninsula, Washington: University of Washington Doctor of Philosophy thesis, 131 p., 1 plate.

Armentrout, J. M.; Berta, Annalisa, 1977, Eocene–Oligocene foraminiferal sequence from the northeast Olympic Peninsula, Washington: Journal of Foraminiferal Research, v. 7, no. 3, p. 216-233

Armstrong, J. E.; Crandell, D. R.; Easterbrook, D. J.; Noble, J. B., 1965, Late Pleistocene stratigraphy and chronology in southwestern British Columbia and northwestern Washington: Geological Society of America Bulletin, v. 76, no. 3, p. 321-330.

Babcock, R. S.; Burmester, R. F.; Engebretson, D. C.; Warnock, A. C.; Clark, K. P., 1992, A rifted margin origin for the Crescent basalts and related rocks in the northern Coast Range volcanic province, Washington and British Columbia: Journal of Geophysical Research, v. 97, no. B5, p. 6799-6821.

Babcock, R. S.; Suczek, C. A.; Engebretson, D. C., 1994, The Crescent "terrane", Olympic Peninsula and southern Vancouver Island. *In* Lasmanis, Raymond; Cheney, E. S., convenors, Regional geology of Washington State: Washington Division of Geology and Earth Resources Bulletin 80, p. 141-157.

Berger, G. W.; Easterbrook, D. J., 1993, Thermoluminescence dating tests for lacustrine, glaciomarine, and floodplain sediments from western Washington and British Columbia: Canadian Journal of Earth Sciences, v. 30, no. 9, p. 1815-1828.

Blunt, D. J.; Easterbrook, D. J.; Rutter, N. W., 1987, Chronology of Pleistocene sediments in the Puget Lowland, Washington. *In* Schuster, J. E., editor, Selected papers on the geology of Washington: Washington Division of Geology and Earth Resources Bulletin 77, p. 321-353.

Booth, D. B., 1991, Glacier physics of the Puget lobe, southwest Cordilleran ice sheet: Geographie physique et quaternaire, v. 45, no. 3, p. 301-315.

Booth, D. B., 1994, Glaciofluvial infilling and scour of the Puget Lowland, Washington, during ice-sheet glaciation: Geology, v. 22, no. 8, p. 695-698.

Dethier, D. P.; Pessl, Fred, Jr.; Keuler, R. F.; Balzarini, M. A.; Pevear, D. R., 1995, Late Wisconsinan glaciomarine deposition and isostatic rebound, northern Puget Lowland, Washington: Geological Society of America Bulletin, v. 107, no. 11, p. 1288-1303.

Easterbrook, D. J., 1966, Radiocarbon chronology of late Pleistocene deposits in northwest Washington: Science, v. 152, no. 3723, p. 764-767.

Easterbrook, D. J., 1994, Chronology of pre-late Wisconsin Pleistocene sediments in the Puget Lowland, Washington. *In* Lasmanis, Raymond; Cheney, E. S., convenors, Regional geology of Washington State: Washington Division of Geology and Earth Resources Bulletin 80, p. 191-206.

Easterbrook, D. J.; Rutter, N. W., 1981, Amino acid ages of Pleistocene glacial and interglacial sediments in western Washington [abstract]: Geological Society of America Abstracts with Programs, v. 13, no. 7, p. 444.

Easterbrook, D. J.; Rutter, N. W., 1982, Amino acid analyses of wood and shells in development of chronology and correlation of Pleistocene sediments in the Puget Lowland, Washington [abstract]: Geological Society of America Abstracts with Programs, v. 14, no. 7, p. 480.

Gayer, M. J., 1977, Quaternary and environmental geology of northeastern Jefferson County, Washington: North Carolina State University Master of Science thesis, 140 p.

Gower, H. D., 1980, Bedrock geologic and Quaternary tectonic map of the Port Townsend area, Washington: U.S. Geological Survey Open-File Report 80-1174, 1 sheet, scale 1:100,000, with 19 p. text.

Hahn, M.; Graettinger, A.; Gustafson, J.; Ponzini, C.; Wolfe, M.; Peters, R.; Stein, K.; Tepper, J., 2004, Eocene pyroclastic deposits at Chimacum, Washington—Adakite magmatism in the Cascadia forearc [abstract]: Geological Society of America Abstracts with Programs, v. 36, no. 4, p. 69.

Hallet, D. J.; Hills, L. V.; Clague, J. J., 1997, New accelerator mass spectrometry radiocarbon ages for the Mazama tephra layer from Kootenay National Park, British Columbia, Canada: Canadian Journal of Earth Sciences, v. 34, no. 9, p. 1202-1209.

Jones, M. A., 1999, Geologic framework for the Puget Sound aquifer system, Washington and British Columbia: U.S. Geological Survey Professional Paper 1424-C, 31 p., 18 plates.

Johnson, D. M.; Hooper, P. R.; Conrey, R. M., 1999, XRF analysis of rocks and minerals for major and trace elements on a single low dilution Li-tetraborate fused bead: Advances in X-ray Analysis, v. 41, p. 843-867.

MacLeod, N. S.; Tiffin, D. L.; Snavely, P. D., Jr.; Currie, R. G., 1977, Geologic interpretation of magnetic and gravity anomalies in the Strait of Juan de Fuca, U.S.–Canada: Canadian Journal of Earth Sciences, v. 14, no. 2, p. 223-238.

Melim, L. A., 1984, The sedimentary petrology and sedimentology of the unnamed middle Eocene sandstones of Scow Bay, Indian and Marrowstone Islands, northwest Washington: Western Washington University Master of Science thesis, 123 p., 1 plate.

Morrison, R. B., 1991, Introduction. *In* Morrison, R. B., editor, Quaternary nonglacial geology—Conterminous U.S.: Geological Society of America DNAG Geology of North America, v. K-2, 672 p., 8 plates in accompanying case.

Mosher, D. C.; Johnson, S. Y., editors; Rathwell, G. J.; Kung, R. B.; Rhea, S. B., compilers, 2000, Neotectonics of the eastern Juan de Fuca Strait—A digital geological and geophysical atlas: Geological Survey of Canada Open File Report 3931, 1 CD-ROM disk.

Pessl, Fred, Jr.; Dethier, D. P.; Booth, D. B.; Minard, J. P., 1989, Surficial geologic map of the Port Townsend 30- by 60-minute quadrangle, Puget Sound region, Washington: U.S. Geological Survey Miscellaneous Investigations Series Map I-1198-F, 1 sheet, scale 1:100,000, with 13 p. text.

Polenz, Michael; Slaughter, S. L.; Thorsen, G. W., 2005, Geologic map of the Coupeville and part of the Port Townsend North 7.5-minute quadrangles, Island County, Washington: Washington Division of Geology and Earth Resources Geologic Map GM-58, 1 sheet, scale 1:24,000.

Porter, S. C.; Swanson, T. W., 1998, Radiocarbon age constraints on rates of advance and retreat of the Puget lobe of the Cordilleran ice sheet during the last glaciation: Quaternary Research, v. 50, no. 3, p. 205-213.

Rau, W. W., 1981, Pacific Northwest Tertiary benthonic foraminiferal biostratigraphic framework—An overview: Geological Society of America Special Paper 184, p. 67-84.

Rigg, G. B., 1958, Peat resources of Washington: Washington Division of Mines and Geology Bulletin 44, 272 p.

Swanson, T. W., 1994, Determination of ^{36}Cl production rates from the deglaciation history of Whidbey Island, Washington: University of Washington Doctor of Philosophy thesis, 121 p.

Tabor, R. W.; Cady, W. M., 1978, Geologic map of the Olympic Peninsula, Washington: U.S. Geological Survey Miscellaneous Investigations Series Map I-994, 2 sheets, scale 1:125,000.

Thoms, R. E., 1959, The geology and Eocene biostratigraphy of the southern Quimper Peninsula area, Washington: University of Washington Master of Science thesis, 102 p.

Thorson, R. M., 1981, Isostatic effects of the last glaciation in the Puget Lowland, Washington: U.S. Geological Survey Open-File Report 81-370, 100 p., 1 plate.

Wagner, H. C.; Wiley, M. C., 1980, Preliminary map of offshore geology in the Protection Island–Point Partridge area, northern Puget Sound, Washington: U.S. Geological Survey Open-File Report 80-548, 4 p., 2 plates.

Washington Department of Ecology, 1978, Coastal zone atlas of Washington; volume 11, Jefferson County: Washington Department of Ecology, 1 v., maps, scale 1:24,000.

Table 1. Age control data from the study area. CS, columnar section (see map); TL, thermoluminescence; – – –, no data

Loc. no.	Map loc.	Analytical method	Age	Material dated	Geologic unit	Sample no.	Reference	Notes
1	1	$^{40}Ar/^{39}Ar$	46.62 ±0.56 Ma	plagioclase	Evt$_l$	– – –	this study	Analysis performed at Oregon State University
2	CS 2	^{14}C	36,430 ±360 yr B.P.	wood	Qc$_o$	Beta 197624	this study	Accelerator mass spectrometry—standard delivery; analysis performed by Beta Analytic, Inc. (Miami, Fla.)
3	CS 1	^{14}C	23,730 ±280 yr B.P.	charcoal	Qc$_o$	– – –	G. W. Thorsen (consulting geologist, written commun., 2004)	
4	CS 1	TL	151 ±43 ka	clay	Qc$_w$	– – –	Easterbrook (1994)	From base of bluff section

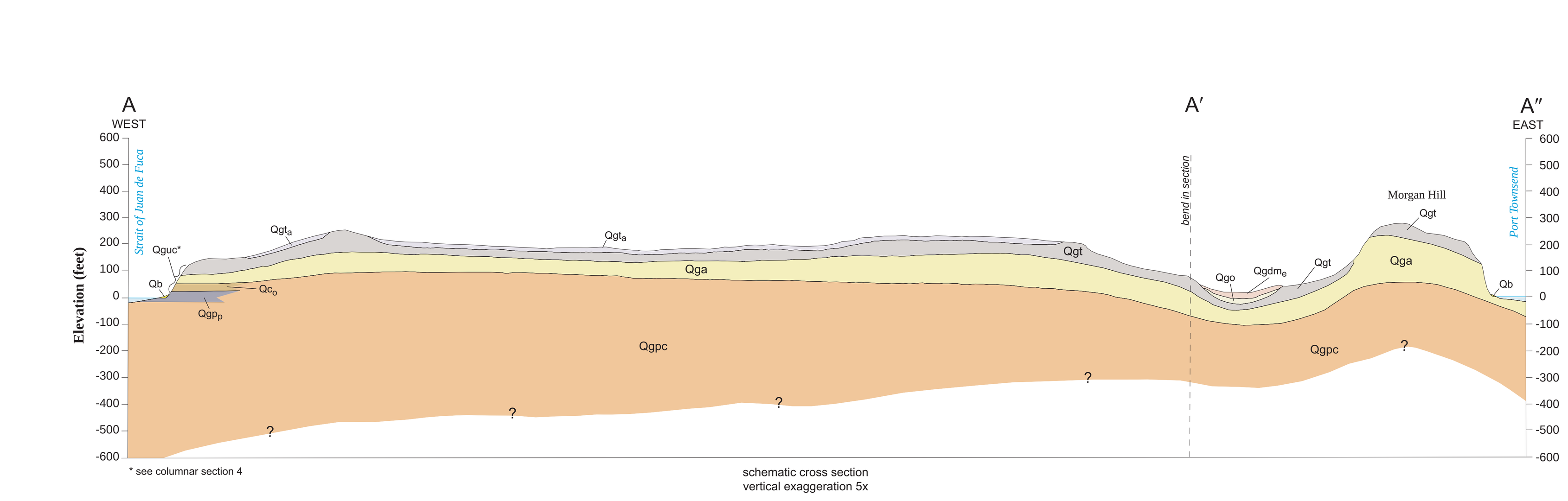
Table 2. Geochemical analyses for the Port Townsend South quadrangle. Performed by x-ray fluorescence at the Washington State University GeoAnalytical Laboratory (Pullman, Wash.). Instrumental precision is described in Johnson and others (1999). Major elements are normalized to 100 on a volatile-free basis, with total Fe expressed as FeO

MAJOR ELEMENTS—NORMALIZED (in weight percent)

Loc. no.	Sample no.	Geologic unit	Rock type	Chem. analysis	SiO_2	TiO_2	Al_2O_3	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Total	Original total
1	HS-14	Em$_{1c}$	basalt (cobble)	basalt	48.57	1.615	15.69	11.62	0.305	6.73	12.75	2.51	0.08	0.139	100.00	98.75
2	HS-25	Evt$_l$	hornblende dacite tuff	dacite	64.33	0.566	17.82	5.08	0.043	1.61	4.91	4.30	1.20	0.142	100.00	98.74
3	HS-35	Evt$_l$	hornblende dacite tuff	dacite	67.40	0.498	17.90	2.60	0.017	0.72	5.42	4.35	0.96	0.119	100.00	99.23

TRACE ELEMENTS (in parts per million)

Loc. no.	Sample no.	Geologic unit	Rock type	Chem. analysis	Ni	Cr	Sc	V	Ba	Rb	Sr	Zr	Y	Nb	Ga	Cu	Zn	Pb	La	Ce	Th	Nd
1	HS-14	Em$_{1c}$	basalt (cobble)	basalt	68	231	50	358	28	1	160	85	27	8.1	22	271	87	1	3	14	1	11
2	HS-25	Evt$_l$	hornblende dacite tuff	dacite	28	28	10	57	331	18	410	140	9	7.8	19	34	51	4	18	27	4	9
3	HS-35	Evt$_l$	hornblende dacite tuff	dacite	18	25	6	61	313	8	439	109	6	6.2	20	40	30	2	10	21	5	9



schematic cross section
vertical exaggeration 5x

GEOLOGIC SYMBOLS

- Contact—Long dashed where approximately located, short dashed where inferred
- High-angle dip-slip fault—Dashed where approximately located, dotted where concealed, queried where uncertain; U on upthrown block; D on downthrown block
- Terrace—Hachures on downslope side
- Landslide scarp—Hachures on downslope side
- Direction of landslide movement
- Inclined bedding—Showing strike and dip
- Minor anticline—Showing bearing and plunge
- Geologic unit too small to show as a polygon at map scale
- Geochemistry sample location
- $^{40}Ar/^{39}Ar$ date sample location