

Mapping of the quadrangle has resulted in the following improvements to and understanding of the geology of the area:

- It provides the first geologic map of the area published at a scale of 1:24,000. • Lidar (laser swath mapping) has provided the means for improved geomorphologic interpretation of the landforms in the area, thus allowing more accurate mapping of surficial geologic units, especially those relating to the Everson interstadial period and the relative
- sea level high stand (sea level maximum) associated with that period. • New radiocarbon (14C) and optically stimulated luminescence (OSL) age estimates constrain the ages of some nonglacial sediments mapped in the sea cliffs of Whidbey and
- A summary of marine shell–based sedimentary age estimates from the shore along Admiralty Inlet on Whidbey Island includes previously published and new age estimates that highlight apparent conflicts between radiocarbon-based age estimates and aminostratigraphic correlation age assignments.
- The combination of lidar and shoreline oblique aerial photographs of the shoreline bluffs has allowed us to more accurately locate and map geologic units exposed in the bluffs. New geochemical analyses of pumiceous dacite clasts from the east shore of Whidbey Island provide the southernmost(?) identification to date of Glacier Peak–sourced lahar

GEOLOGIC SETTING AND DEVELOPMENT

runout deposits in the Puget Lowland.

Like most of the Puget Lowland, the map area is dominated by glacial sediment and lacks bedrock exposures. The map area is covered by 1500 to 3600 ft of glacial and nonglacial sediment (Jones, 1999; Mosher and others, 2000; Johnson and others, 2001) overlying Miocene(?) bedrock (Johnson and others, 1996). The Double Bluff Drift is the oldest sediment exposed in or near the map area. Booth and others (2004, fig. 2) correlate the drift to marine oxygen-isotope stage 6 (~185–125 ka). (Stage numbers and corresponding ages used in this report are as defined in Morrison, 1991.) Berger and Easterbrook (1993), Blunt and others (1987), and Easterbrook (1994a,b) report older ages for some exposures. We did not map any Double Bluff Drift, but unit Qguc may include this unit along Admiralty Inlet (Figs. 1 and 2; Table 1). In addition, OSL dates older than 150 ka on some nonglacial sediments south of the map area (Polenz and others, 2006) suggest that sediments that were deposited during or prior to stage 6 may be more widespread than previously recognized. We did not identify deposits of the interglacial Whidbey Formation (stage 5 or ~125–80 ka). We correlate glaciomarine and glacial drift along the lower west-facing bluffs on northern Camano Island with the Possession Glaciation (stage 4 or ~80–60 ka) (Booth and others, 2004). Based on a new OSL age estimate, we tentatively assign flood-plain or lacustrine sediments that crop out near beach level north of Rockaway Beach on Camano Island (base of Columnar Section 2) to the

Olympia nonglacial interval (stage 3 or ~60–20 ka). We mapped mostly Fraser Glaciation deposits (Armstrong and others, 1965) on upland surfaces and along some bluffs, and mass wasting features along the remaining bluffs. The Fraser Glaciation correlates to stage 2 (~28–10 ka) (Booth and others, 2004). Advance outwash of the Vashon Stade (within the Fraser Glaciation) began to bury the Puget Lowland no sooner than about 20 ka, if radiocarbon dates from north of the map area are accurate (Booth, 1994, Polenz and others, 2005a; Johnson and others, 2001). Radiocarbon dates on detrital samples and thermoluminescence (TL) and OSL dates from sediments exposed in sea cliffs south of the map area, east of Double Bluff in the north part of the Hansville quadrangle (Polenz and others, 2006), suggest that Fraser outwash of the Vashon (and preceding Evans Creek?) Stade(s) may have arrived earlier. The Puget lobe of the Cordilleran ice sheet apparently arrived about 18 ka (~15,000 14C yr B.P.) (Booth, 1991; Porter and Swanson, 1998; Booth and others, 2004; Polenz and others, 2005a) and covered the map area with about

4000 ft of ice (Thorson, 1980, 1981, 1989). The end of the glaciation is defined in the area by a succession of events that began with grounded ice retreat alongside calving basins that defined the northern margins of large proglacial lakes (Thorson, 1980; Porter and Swanson, 1998; Booth and others, 2004). Meltwater-driven incision of (typically relict) valleys that sharply dissect the fluted uplands of southern Whidbey Island and western Camano Island indicates that as ice retreated at the end of the Vashon Stade, part of Whidbey and most of western Camano Island were largely ice free, no longer submerged beneath ice-dammed lakes and not yet inundated by the Everson Interstade incursion of marine water. This seawater incursion raised base level for the meltwater streams to the glaciomarine limit (maximum relative seawater elevation), causing the lower portions of their valleys to be filled with fluvial and deltaic outwash before isostatic rebound began. Our interpretations of the local geomorphology place the glaciomarine limit at about 180 to 190 ft at the southern quadrangle boundary, between 196 and 229 ft at Smith Prairie on Whidbey Island, and between 225 and 240 ft at the north quadrangle boundary on Camano Island, which is consistent with Thorson (1980, 1981), Dethier and others (1995),

Easterbrook (2003), and Kovanen and Slaymaker (2004). Marine shells at Lake Carpenter (south of the map area) suggest that the Everson Interstade seawater incursion began before 14,610 14C yr B.P., and freshwater gyttja (organic-rich lake-bottom sediment) from the same site suggests that it ended before 13,600 14C yr B.P. (Anundsen and others, 1994), but that timeline conflicts with the apparent persistence of the Puget ice lobe in the central Puget Lowland through at least 13,800 14C yr B.P. (Booth and others, 2004; Porter and Swanson, 1998), and various workers have favored or implied other dates for the start and (or) end of the incursion (Easterbrook, 1966a,b; Swanson, 1994; Dethier and others, 1995; Blunt and others, 1987; Porter and Swanson, 1998; Booth and others, 2004; Kovanen and Slaymaker, 2004; Polenz and others, 2005a). The above age statements lack radiocarbon reservoir corrections, for which we refer interested readers to Hutchinson and others (2004).

Drumlins formed by southward ice flow are overprinted with marine landforms (Kovanen and Slaymaker, 2004), such as terraces (typically units Qgome and Qgomee), deltas (unit Qgom_e), and shorelines (typically unit Qgom_{ee}). Smith Prairie on Whidbey Island presents the most impressive example, with relict braided river channels atop the Partridge Gravel kame-delta deposit (included with unit Qgome). Above the marine limit, upland surfaces are commonly dissected by relict valleys (Kovanen and Slaymaker, 2004) that expose a discontinuous, diverse, and mostly thin (0–15 ft) cover of lodgment till above thick (?170 ft in a valley 5 mi south of the map area) sheets of apparent advance outwash sand. We agree with Polenz and others (2006) that the valleys were cut by meltwater because: 1) valley formation required surface runoff in excess of that in the modern environment; 2) the valleys terminate at the marine limit, below which they are infilled with recessional outwash sand and marine delta deposits; and 3) the valleys lack active stream channels and some include dry, closed depressions where mass wasting from valley sidewalls has locally elevated the valley floor.

The fault strands shown on the map are from Johnson and others (2000); some on Camano Island coincide with fault strands that appear on the adjoining Crescent Harbor quadrangle (Dragovich and others, 2005) and extend into the Camano quadrangle. Landslide scarps mapped from subtle northwest-trending landforms and several large arcuate landslide scarps that we have mapped with the aid of lidar in the northeast corner of the map on Camano Island appear to attest to tectonic activity near the north end of the map area. These features continue eastward into the adjoining Juniper Beach quadrangle (and arcuate landslide features continue northward into the Crescent Harbor and Utsalady quadrangles) and were first noticed by Johnson and others (2004). These large, older landslides were later cut by a northwest-trending drainage of Everson Interstade age, suggesting that the landslides occurred in late Pleistocene time. The associated landslide scarps are situated within an area bracketed by segments of the Utsalady Point fault zone, where offshore seismic-reflection data and geologic mapping suggest that deformation is distributed across a broad zone (Johnson and others, 2001, 2004; Dragovich and others, 2005). We speculate that a cluster of northwest-trending scarps and irregular topography about 0.5 mi further southwest may represent additional, seismically induced lateral spreading that was either not recognized or interpreted as fault scarps by Johnson and others (2004). We chose not to map the areas affected by any of these slides as landslides (except for some smaller, more recent, inset features) because we believe that the late glacial environment that prevailed when these slides occurred was more conducive to landsliding than the modern environment is. We see little reason to expect that even a strong shallow crustal earthquake on the Utsalady Point fault would result in similar landsliding in the modern environment. Nevertheless, we note that the slides disrupted the stratigraphic and hydrogeologic order of the area, and

onsequently, these areas may continue to be subject to an elevated slide hazard relative to unaffected but otherwise similar areas nearby. Dragovich and others (2005) and Johnson and others (2000, 2001) mapped the Utsalady Point fault to the north boundary of the Camano quadrangle on the northern end of Camano Island. We agree with Johnson and others (2001) in extending strands of the fault at least a short distance into the Camano quadrangle. Fault investigations, including trenching of the Utsalady Point fault on northern Whidbey Island, indicate a M ≥6.7 earthquake that caused surface offset between AD 1550 and 1850, and perhaps an additional event of similar size 1100 to 2200 years ago (Johnson and others, 2003, 2004). Johnson and others (2001) noted that, together with the Strawberry Point and Devils Mountain faults, the Utsalady Point fault composes a west-trending, active, "complex, distributed, transpressional deformation zone". Two other faults similarly approach or may reach into the northern part of the quadrangle:

1. Johnson and others (2000) used seismic lines in Saratoga Passage to infer an unnamed southwest of the Utsalady Point fault and extends at least a short distance onshore. The fault as mapped by Johnson and others and reproduced by us points toward a cluster of northwest-trending (fault-parallel) scarps and irregular topography approximately 0.5 to 1.5 mi southeast of the termination of the mapped fault extent that appear consistent with seismically induced lateral spreading.

between lidar data and map elevations.

¹⁴C vr B.P

-1.900" ¹⁴C vr B.P.

"~120–140" ka N/A

>45,000 ¹⁴C yr B.P. -10.6 AMS

5a 4.930 +40 ¹⁴C yr B.P. -26.8 AMS

5b | 4,940 ±40 ¹⁴C yr B.P. | -28.3 | AMS | organic material

107 "±9" ka N/A AA shells** (see Notes) Qguc**

(5.730-5.600 ka)

 $32.5 \pm 6.0 \text{ ka}$

36,200 "+2,600

Figure 3. Peat sample site on Saratoga Passage (see map

Suggested citation: Polenz, Michael; Schasse, Henry W.; Kalk, Michael L.; Petersen,

Bradley B., 2009, Geologic map of the Camano 7.5-minute quadrangle, Island County,

Dragovich and others (2005) used onshore data from the Oak Harbor area to infer a southeast-trending "Oak Harbor fault" that extends southeast into the waters of Saratoga Passage about 0.7 mi east of the northwestern corner of the quadrangle, where we have no further supporting data and so show it queried and terminating offshore.

marine shells

marine shell

marine shell(s?)

marine shells

Mytilus trossolus*

marine shell;

see Notes

wood from peat

organic material

AMS Saxidomus gigantea*

¹⁴C or AMS | Saxidomus gigantea

The Southern Whidbey Island fault zone traverses the southwestern map area (Johnson and others 2000). The "Southern Whidbey Island Fault", with possible Quaternary movement, was first inferred by Gower (1980). Johnson and others (1996) characterized the "southern Whidbey Island fault' as a long-lived transpressional zone that separates major crustal blocks. Brocher and others (2005) recently postulated that "the southern Whidbey Island fault...is a NW-SE oriented fold and thrust belt...[that accommodates] NE-directed crustal shortening". Sherrod and others (2005a,b) showed the fault zone extending about 95 mi from Vancouver Island to east of Seattle, with three to four main strands crossing southern Whidbey Island. Johnson and others (1996) noted that the Southern Whidbey Island fault zone has caused several historic shallow-crustal earthquakes and appears capable of generating earthquakes of surface-wave magnitude 7 or greater. Kelsey and others (2004) used Whidbey Island data to infer a moment-magnitude 6.5 to 7 earthquake on the fault zone about 3 ka. Sherrod and others (2005a,b) and Sherrod (2005) concluded that the Southern Whidbey Island fault zone has "produced at least four events since about 16,400 years ago, the most recent after 2,700 years

Our fieldwork revealed many possible tectonic fault strands along bluffs, but we felt that we could also interpret each as a product of landsliding or glaciotectonics. We note, however, that the above-mentioned faults north of the map area have been associated with uplift (Dragovich and others, 2005; Polenz and others, 2005a,b). Additionally, the most elevated uplands of southern Whidbey Island are bracketed by the mapped strands of the Southern Whidbey Island fault zone, and OSL age data suggest the presence of some very old (>150 ka) nonglacial sediments within the fault zone south of the map area (Polenz and others, 2006). Both observations are consistent with uplift in the fault zone and with interpretations of Johnson and others (1996) and Brocher and others (2005). The lack of recognized fault scarps on southern Whidbey Island does not necessarily reflect a lack of surface-deforming fault events, but could result from diffusion of fault deformation in the thick, sandy deposits that blanket much of the surface. We also note a large apparent landslide in bathymetry (as compiled by Finlayson, 2005) offshore of the west coast of Camano Island between Onamac Point and Woodland Beach. We were struck by a clustering(?) of subtle, northwest-trending surface lineaments (not shown on map) that were apparent in lidar data east to northeast of that slide, a coincidence of features reminiscent of the presence of large landslides in the vicinity of the southeastern end of the mapped strands of the Utsalady Point fault at the north end of the map area. However, Mosher and others (2000) do not show shallow-crustal earthquakes in or near central Camano Island.

DESCRIPTION OF MAP UNITS

We have attempted to match our geologic mapping to the prior mapping of Dragovich and others (2005) in the Crescent Harbor 7.5-minute quadrangle to the north. A scratch boundary occurs where we could not resolve differences in the geologic interpretations across the mutual boundary. These differences occur in areas of poor outcrops and also represent the mappers' biases based on their interpretations, which they developed in their respective map areas.

Fill—Clay, silt, sand, gravel, organic matter, rip-rap, and debris placed to elevate and reshape the land; includes engineered and nonengineered fills; shown where fill is readily verifiable, relatively extensive, and appears sufficiently thick to be geotechnically significant.

Modified land—Sediment, ranging from clay to gravel and diamict, mixed and reworked by excavation and (or) redistribution that notably modifies topography; shown where relatively extensive, masking underlying geology, and of geotechnical significance; generally excludes roads and abandoned pits where underlying units can be identified; includes aggregate pits active at time of mapping. **Beach deposits**—Sand and cobbles; may include boulders, silt, pebbles, and clay;

loose; derived from shore bluffs and underlying deposits and (or) carried in by Marsh deposits—Organic and organic-matter-rich mineral sediment (peat, muck, silt, and clay; may locally range to sand) deposited in a saltwater or brackish marsh estuarine or lagoonal) environment; not shown in wetland settings where field data

indicate fewer than 2 ft of marsh sediment. We found unit Qm only on the Whidbey

pebbles and larger clasts typically well rounded and oblate; mostly well sorted;

Holocene to Late Pleistocene

Island portion of the map area.

Peat—Organic and organic-rich sediment, typically in closed depressions; includes peat, muck, silt, and clay in and adjacent to wetlands; in some locations grades down to and comprises the freshwater equivalent of unit Qm; not shown where field data indicate a thickness of less than 2 ft. A new 5.6 to 5.7 ka date (Table 1, locs. 5a and 5b) from the base of a peat deposit on a till plain on Whidbey Island indicates a lack of peat deposition at the sample site prior to the mid-Holocene. We speculate that peat deposition prior to the mid-Holocene was limited to inferred lower-lying parts of this depression. In the Whidbey Island portion of the map area, the unit is queried where its interpretation was based largely on geologic setting and geomorphology with no supporting field data.

Mass wasting deposits—Boulders, gravel, sand, silt, clay, and diamicton (generally nonstratified and unsorted mix of clay through boulder size material); generally unsorted, but locally stratified; typically loose; shown along mostly colluvium-covered or densely vegetated slopes that are demonstrably or appear potentially unstable; commonly mapped where field conditions suggest landsliding, but evidence for landslides is ambiguous or weak; locally contains landslides and underlying units that either we could not map confidently or are too small to show

Landslide deposits—Gravel, sand, silt, clay, and boulders in slide body and toe; includes exposure of underlying units in scarp areas; angular to rounded clasts; unsorted; generally loose, unstratified, broken, and chaotic, but may locally retain primary bedding; commonly includes liquefaction features; deposited by mass-wasting processes other than soil creep and frost heave; distinguished from unit Qmw by presence of unambiguous landslide features. Absence of a mapped slide does not imply absence of sliding or hazard. All shoreline bluffs in the map area are subject to episodic landsliding and bluff retreat, but many slides are too small to show at map scale, and most slide deposits are quickly removed by beach wave action. Unit is queried where its interpretation was based largely on geologic setting and geomorphology with no supporting field data.

Pleistocene Glacial and Nonglacial Deposits

We used stratigraphic position, organic content, radiocarbon and OSL dating, aminostratigraphic analyses, fossil content, and provenance data to separate glacial from nonglacial deposits. Provenance was inferred from stratigraphic relations, age data, and sand grain and gravel clast composition as observed petrographically and in the field. Glacial deposits are dominated by northern provenance materials and therefore contain little or no Glacier Peak detritus (0–5%) and include "significant" granitic and metamorphic lithic clasts (Dragovich and others, 2005). Nonglacial deposits are distinguished by eastern provenance materials. We found some petrographic and geochemical indications of possible ancestral Skagit and (or) Stillaguamish River provenance (hypersthene, hornblende, and possible Glacier Peak dacite) (Dragovich and others, 2005; Polenz and others, 2005a; Joe Dragovich, Wash. Div. of Geology and Earth Resources [DGER], oral commun., 2006; Table 2), but agree with Terry Swanson (Univ. of Wash., oral commun., 2005) in suspecting that some of the sediment may be from an ancestral Snohomish River. Speculations of Snohomish River source are based mostly on stratigraphic position and proximity to that basin.

DEPOSITS OF THE FRASER GLACIATION (PLEISTOCENE) **Undivided Fraser Glaciation**

Fraser drift, undivided—Composite of units deposited during the Fraser Glaciation; shown where map scale or exposure do not support stratigraphic division; queried where identification was uncertain.

Recessional outwash—Mostly sand, but includes lenses and beds of pebble-gravel, silt, sparse clasts of diamicton, and minor clay; gravelly facies tend to occur lower in the unit; loose; variably rounded; mostly moderately to well sorted; structureless to moderately stratified with medium to thick beds; forms either valley fill in relict, late glacial meltwater valleys or terraces above Everson Interstade marine shorelines; interfingers with adjoining Everson marine deltaic deposits (unit Qgome). This unit typically dates to Everson time but is assigned to the broader Fraser glacial period because some deposits are situated above Everson sea level and may date to the Vashon Stade.

Stratified, undifferentiated ice-contact deposits—Interbedded gravel, lodgment till, flow till, and sand; minor silt and clay beds; loose to compact; variably sorte moderately to well stratified; medium to very thickly bedded; some crossbeds, contorted beds, oversteepened beds and small-scale shears appear to be mostly collapse features but may include glacio- and seismo-tectonic deformation and (or) reflect sub-ice flow; shear fabric in tills tends to parallel bedding in nearby gravel and sand; most exposures unconformably overlain by unit Qgdme or Qgt_V (mostly <5 ft and thus not mapped); includes subaerial and some sub-ice deposits; distinguished from unit Qqt_V by more stratification, mostly low density materials, and inclusion of more sand and gravel.

110.8 g (several shells and fragments) reduced to 83 g by HCl acid etch

pretreatment. Of that, 47 g was analyzed (yielded 3 g final carbon). In

by AMS. Apparently same shell layer as I-2155 and 79-9.

Kyenvolden and others (1980): Source reported elevation of 15 m above beach. We added our estimate of

Kvenvolden and others (1980); Stratigraphic age assignment based on amino acid correlation to shells in

sample designation 79-9 Oregon and California, where nearby corals were dated by uranium-series

shell layer as Beta 211255, I-2155, and 79-9.

Hatfield, Beta Analytic Inc., oral commun., 2006).

fraction analyzed under blue light excitation.

sample designation 79-9 beach top elevation. Apparently the same shell layer as Beta 211255 and 79-9

addition, a single shell from sample split (already pre-treated) was re-analyzed

Location plotted per lat-long data of source and Kvenvolden, USGS, written

Age assignment based on aminostratigraphic correlation to corals in Oregon

and California, which were dated by uranium-series analysis. Apparently same

Sampled by Jerry Thorsen, Kitty Reed, and Deborah Mitchell from a silt layer

ntertidal to shallow subtidal marine shell environment (Liz Nesbitt, Univ.

Wash., written commun., 2006). In contrast, ¹³C/¹²C ratio of –10.6 suggests

freshwater setting (Ron Hatfield, Beta Analytic Inc., oral commun., 2006)

Sample from sandy, silty underclay with pebbles at base of peat bog. Intent

and re-analysis of sample split (pre-treated as part of original sample) render

lab error unlikely, suggesting that sample may not reflect the desired lowest

Sample from 3.5-in,-thick, fine-grained sand bed in a 10-ft-thick nonglacial

unit dominated by thin-bedded, rhythmically bedded silt/clay (lake beds?) at

the base of 200-ft-high sea cliff. Dated sediments underlie a 40-ft-thick gray till and gravelly drift unit of unknown age (unit Qgt_u; see Col. sec. 2). Quartz

Age estimate based on leucine (amino acid) content. Location described as miralty Bay and appears to refer to same layer as samples Beta 211255, I

Age estimate based on allo/iso (amino acid) content**. Location described as

Admiralty Bay. Appears to refer to same layer as samples Beta 211255, I-

Analysis initially reported as 42,480 ±2020 B.P., then adjusted to infinite (Ron

was to date onset of ice-free, post-Vashon conditions. Unexpectedly young age

just above samples Beta 211255, I-2155, and 79-9. Shell species indicates

analysis. Apparently same shell layer as Beta 211255 and I-2155.

Stratified, subglacial ice-contact deposits—Interbedded lodgment till, flow till, gravel, and sand, minor silt and clay beds; diverse; loose to compact; variably sorted, moderately to well stratified; medium to very thickly bedded; commonly contains crossbeds, contorted beds, oversteepened beds, and small-scale shears, all of which appear to be mostly collapse features but may include glacio- and seismo-tectonic deformation and (or) reflect sub-ice flow; exposures in which several till layers alternate with gravel, sand, and fines and where some layers gently dip south also appear consistent with sub-ice deposition; displays shear fabric that commonly occurs in till facies and tends to parallel bedding in nearby gravel and sand; typically more compact and contains more diamicton than unit Qgicf; in most exposures, unconformably overlain by unit Qgdme or Qgtv (mostly <5 ft and thus not mapped); distinguished from unit Qqt_V by more stratification, mostly lower density, and more distinct bedding in sand and gravel; preferentially exposed (deposited?) along side slopes to deep subglacial scour basins (now marine inlets); queried where uncertain of interpretation as a subglacial deposit.

Ablation till—Unsorted, unstratified, and heterogeneous melt-out deposit of sand, silt, clay, gravel, diamicton, and patchy stratified proximal outwash deposits, ice-dammed lake sediment, and peat; loose to compact; typically forms geomorphically complex patchwork of melt-out deposits (material formerly carried by an ice mass, then left in place after the ice mass has melted away), outwash, closed depressions, erosional exposures of older (Fraser?) units, and incipient and

Everson Glaciomarine Drift—Clayey to silty diamicton with variable content of gravel clasts; also includes silt, clay, and sand; contains sparse shells, generally marine; dark gray where unweathered; mostly weathers to buff, but ranges to olive gray, ash gray, or white; commonly forms dry vertical face with failure-prone, vertical desiccation cracks with dark brown staining; massive to rhythmically bedded, commonly with sharp upper and lower, unit-bounding unconformities (Domack, 1984); mostly loose and soft but locally hard and compact; may resemble till (Domack, 1982, 1984; Domack and Lawson, 1985), but till generally lacks fossils and glaciomarine drift has a finer-grained, smoother-feeling matrix and is less compact and more likely to be stratified. The unit is sea-floor sediment and consists mostly of glacial flour. Its textural diversity reflects proximity of the ice front (Domack, 1983; Dethier and others, 1995). Locally divided into:

> Glaciomarine drift, emergence (beach) facies—Sand and gravel, locally silty; loose; mostly structureless, but may be stratified, laminated, or ripple crossbedded with rare boulder lag deposits; typically only a few feet thick; occurs below the glaciomarine limit; underlain by units Qgdme, Qgome, or older sediments; represents emergence deposits that cap glaciomarine drift and may include terrestrial deposits (Domack, 1983; Dethier and others, 1995); includes characteristic but subtle benches that are paleo–beach berms at various elevations (Carlstad, 1992; Easterbrook, 2003; Kovanen and Slaymaker, 2004); queried where identification was uncertain due to poor exposures.

Glaciomarine deltaic outwash deposits—Sand, and sand-gravel mixtures with minor interlayered silt and silty sand; generally loose; includes Partridge Gravel in the northwest part of the map area (Easterbrook, 1968; Carlstad, 1992; Polenz and others, 2005a); except in the Partridge Gravel, unit generally dominated by sand, at least in the uppermost several feet; Partridge Gravel coarsens upsection and includes bouldery gravel; maximum clast size elsewhere limited to pebbles and small cobbles; most deposits are at least a few tens of feet thick; may locally exceed 200 ft in the Partridge Gravel; forms a marine delta–turbidite complex (Carlstad, 1992; Polenz and others, 2005a) with: 1) a horizontally bedded, sand-dominated, detrital peat, charred wood, charcoal, coal, pumice, and dacite; 2) an overlying delta front foreset-bedded sand, and locally gravel facies; and 3) a capping deltaic top-set, channelized sand, and locally gravel facies.

Landslide deposits—Mix of till and outwash sand and gravel; identified as landslide based on surface morphology; queried because assigned to the Everson Interstade based only on field relations, low slope angle (~10% average), and subdued morphology.

Till—Typically unweathered, unsorted mix of clay through boulder size material (diamicton) deposited directly by ice; includes extensive areas of compact (advance outwash?) sand; compact, well-developed facies resemble concrete; locally ranges to loose in ablation till (also separately mapped as unit Qgta_f) and well-sorted in some sand-dominated areas; erratic boulders common on the surface; gray where fresh; oxidizes yellowish brown; permeability very low in compact diamicton but locally high in sandy or loose facies; most commonly matrix supported; cobbles and boulders commonly faceted and (or) striated; may include flow banding:

typically forms vertical faces in coastal bluffs; locally resembles unit Qgdme; lies stratigraphically between overlying units Qgdme and Qgome and underlying units Qga_V and Qgas_V; may include unrecognized exposures of older till. Most till deposits have had their surface fluted by overriding ice and form a patchy and seemingly randomly distributed cover that varies from 0 to at least 200 ft thick, with 2 to 30 ft thickness most common. Cliff exposures along the west shore of Whidbey Island, about 5.6 mi south of the map area, reveal that even where well developed and thick, lodgment till may locally pinch out across short distances, even in the center of a well-formed drumlin. Regional age data appear to constrain the age of the unit to between about 18 ka and the onset of the Everson Interstade. Unit is queried where identification was uncertain because of poor exposures.

Advance outwash—Locally bouldery pebble to cobble gravel, sand, and some layers and lenses of silt and clay; may contain till fragments; gray to grayish brown and grayish orange; clasts typically well rounded, well sorted, and clean, except in ice-proximal deposits; compact; mostly well stratified; very thinly to very thickly bedded; contains planar and graded beds, cut-and-fill structures, trough and ripple crossbeds, and foresets; maximum thickness on Whidbey Island exceeds 35 ft but is poorly defined and may exceed 100 ft in landslide exposures along Admiralty Inlet; thickness may exceed 200 ft on Camano Island; deposited as proglacial fluvial (and deltaic) sediment; complete sections tend to coarsen upward; commonly overlain by unit Qgt_V along a sharp contact, and stratigraphically above units Qc and Qc₀?. Estimated age of the unit is \sim 18 to \geq 20 ka. Locally divided into:

> Advance outwash sand—Mostly lacustrine sand with layers of silt; locally grades upward into gravel; thickness may exceed 80 ft on Whidbey Island, but this estimate is unreliable due to poor exposure; thickness may exceed 150 ft on Camano Island; commonly forms angle-of-repose slopes along drainages and coastal bluffs. Unit includes Lawton Clay (not recognized in surface exposures, but may exist in the subsurface) and Esperance Sand. Relict valleys are common on southern Whidbey Island (Polenz and others, 2006) and morphologically resemble many Camano Island valleys, suggesting that, like their Whidbey Island equivalent, these valleys on Camano Island are incised into unit Qgas_V. They also typically lack modern streams, due to the high permeability in

Vashon Drift, undivided—Composite of units Qgt_V and Qga_V (or Qgas_V); shown where map scale or exposure does not support stratigraphic division. Bluffs on Camano Island north and south of Indian Beach expose gray to tan lodgment till (unit Qgt_V) overlying compact, tan sand and silty sand and silt with gravel lenses (unit Qgas_V). The latter unit may include some older sediment.

GLACIAL DEPOSITS OF UNKNOWN AGE (PLEISTOCENE)

Exposed in lower beach bluffs (at two separate areas on Camano Island) as a second till where an upper till (unit Qgt_V) is exposed near the top of the bluffs. At Rockaway Beach (Columnar Section 2), the lower till consists of 20 to 40 ft of gray lodgment till and gravelly drift that grades both north and south to poorly to well-stratified sand and gravel; unit at this location overlies 1 to 15 ft of medium to dark gray, thin, rhythmically bedded lake sediments (unit Qc₀?), which are locally deformed by the overriding till. Five miles to the south, between Indian and Cama Beaches, 1800 ft of discontinuous cliff exposures at beach level reveal a similar sedimentary package that we believe to be the same unit. At this location, unit Qgtu consists of gray (locally weathered

Till of unknown age (columnar section and line units only)—

tan) lodgment till, ranging widely in thickness from 1 to 40 ft with flow(?) stratification dipping both south (Columnar Section 3) and north. Unit age is unresolved because on the one hand, the exposures are low in the section and are overlain by more recent till that is exposed near the top of the section, suggesting a pre-Fraser age for the lower till; on the other hand, north of Rockaway Beach an OSL age estimate of 32.5 ±6 ka (Columnar Section 2; Table 1, loc. 6) for deposits exposed beneath unit Qgt_u suggests a Fraser age for the lower till.

DEPOSITS OF THE OLYMPIA NONGLACIAL INTERVAL (PLEISTOCENE)

Armstrong and others (1965) defined the "Olympia Interglaciation" as the "climatic episode immediately preceding the last major glaciation" and associated it with "nonglacial strata lying beneath Vashon Drift". We associate those strata with stage 3 (~60–20 ka) but avoid the label "Olympia Interglaciation" because stage 3 is not a true interglacial period (as defined in fig. 4 of Morrison, 1991).

Nonglacial deposits (columnar section only)—Clay, silt, and very fine-grained sand; medium to dark gray; very thin, rhythmically bedded (lake beds?); upper contact with overlying till and gravelly drift (unit Qgt_u) (Columnar Section 2) very irregular; locally deformed by folding (ostensibly by the overriding till); crops out between Sunset and Rockaway Beaches, where it ranges from 0 to 30 ft thick. We dated a sand layer in the undeformed, rhythmically bedded part of the unit, which yielded an OSL age date of 32.5 ± 6.0 ka (Table 1, loc. 6; Columnar Section 2). We query the unit because it lies stratigraphically beneath a second till, which if older than Vashon age, would suggest a pre-Olympia age for this unit, whereas our single OSL date suggests a late Olympia origin (*see also* descriptions for units Qgt_u and Qguc).

UNDIVIDED PRE-FRASER NONGLACIAL DEPOSITS (PLEISTOCENE) **Pre-Fraser nonglacial deposits, undivided**—Sand, silt, clay, peat, and some fine and rare medium gravel; compact; well stratified to massive; mapped on Whidbey Island; resembles unit Qco?; reflects flood plain and channel settings; may include unrecognized glacial material; locally includes clast-rich channel sands that we interpret as probable lahar

runout deposits of Skagit or Stillaguamish River provenance (Table 2; Columnar Section 1; geochemical locations 05-10 and 05-17). Unit Qc also includes a beach-level exposure of peat along the east shore of Whidbey Island approximately 9000 ft south of Race Lagoon (Fig. 3; Table 1, loc. 4) that yielded a new radiocarbon date of >40,400 ¹⁴C yr B.P. The peat dips about 11 degrees (apparent) north and is underlain by at least 10 ft of compact blue clay. Due to limited exposure, it is unclear if the deposit was tilted by landsliding or tectonics, but additional beach-level exposures of unit Qc occur to the north and south. Unit Qc is stratigraphically below Fraser glacial deposits, but its age and association are otherwise unresolved. It likely includes stages 3 and (or) 5 but may also contain older deposits (Polenz and others, 2006). It is

queried where identification was uncertain. DEPOSITS OF THE POSSESSION GLACIATION (PLEISTOCENE)

Glaciomarine drift— Gray silt and clay with sparse to locally abundant pebble dropstones; minor laminated silt and fine sand and rare gravel lenses; contains scattered shell fragments; some weathered exposures contain numerous desiccation cracks; poorly exposed in lower parts of Camano Island shoreline bluffs that are marked by mass wasting; believed to correlate with similar sediments assigned to the Possession

glaciomarine drift in adjoining Crescent Harbor 7.5-minute quadrangle (Dragovich and others, 2005). Calculations based on amino-acid analyses of marine shells in the Oak Harbor 7.5-minute quadrangle (Dragovich and others, 2005) and elsewhere in the northern Puget Lowland suggest a mean age of 80 ±22 ka (Blunt and others, 1987; Easterbrook, 1994a). Unit is queried because of uncertain correlation with the Possession Drift.

Drift, undivided—Gray nonbedded silt and clay with pods of cobble gravel and stratified sand, locally contains fractured diamicton and contorted sand and silt beds; contains some glaciomarine sediments; queried because of uncertain correlation with the Possession Drift.

UNDIVIDED GLACIAL AND NONGLACIAL DEPOSITS OLDER THAN VASHON TILL (PLEISTOCENE)

Undifferentiated deposits older than Vashon till—Various mixtures of sand, gravel, diamicton, silt, clay, and peat; compact; well stratified to massive; composite of glacial and nonglacial deposits; pre-dates Vashon till; may include Vashon advance outwash. Bluff exposures near the southwest corner of the map area along the west shore of Whidbey Island (Figs. 1 and 2) include a highly fossiliferous, stony diamicton from which three ¹⁴C analyses on two *Saxidomus* gigantea (marine clam) shell samples yielded dates between ~36,000 and 37,000

¹⁴C yr B.P. (Figs. 1 and 2; Table 1, locs. 1a, 1b, and 2a). However, an immediately overlying layer contained a *Mytilus trossolus* (marine mussel) shell that yielded a ¹⁴C date of >45,000 (Fig. 1; Table 1, loc. 3), and two aminostratigraphic correlation age estimates for the Saxidomus gigantea shells yielded age estimates of \sim 77 \pm 6 ka and ~120 to 140 ka (Fig. 1; Table 1, locs. 2b and 2c). Petrographic analysis of the diamicton revealed conditions and deposits consistent with a glaciomarine setting. We therefore favor a glaciomarine origin dating to the end of the Double Bluff Glaciation (stage 6 [185–125 ka] or older) (Berger and Easterbrook, 1993; Blunt and others, 1987; Easterbrook, 1994a,b) or the end of the Possession Glaciation (stage 4) and note that the more recent aminostratigraphic analysis appears to favor

the Double Bluff Glaciation (Dan Muhs, U.S. Geological Survey, written commun., 2006). We map the deposit as unit **Qguc** because the age control data, while suggestive of a Double Bluff origin, are conflicted, and the layers above and below the fossiliferous diamicton are not necessarily of the same age and association. On Camano Island, we associate unit **Qguc** with deposits that we tentatively classified as nonglacial unit Qc₀? and a second glacial till (unit Qgt_u) that overrides unit Qc₀? in the lower bluffs between Rockaway and Sunset Beaches (Columnar Section 2). We also show unit Qgtu at the base of unit Qguc farther south (Columnar Section 3). The lower parts of unit Qguc on Camano Island may be Olympia age (stage 3) as implied by a single OSL age (Table 1, loc. 6; Columnar

Undivided Quaternary Deposits

Pleistocene deposits, undivided—May include sand, gravel, diamicton, silt, clay, and peat; may range from loose to compact; well stratified to massive; composite of glacial and (or) nonglacial deposits; shown along coastal bluff areas in the southeast corner of the map where dense forest cover and poor geologic exposures do not allow for more detailed subdivision.

Section 2) or could be older (*see also* descriptions for units Qc₀? and Qgt_u).

GEOLOGIC SYMBOLS

where inferred — – – Contact, scratch boundary

--- Fault, unknown offset—dashed where inferred; dotted where $-\frac{1}{10}$ Fault, left-lateral oblique slip—dashed where inferred; dotted where concealed; queried where uncertain

Landslide scarp—hachures point downslope Arrow showing direction of landslide movement

Geologic unit too narrow to show as a polygon at map scale

 Geochemistry sample site △ Age-date sample, radiocarbon

* Age-date sample, optically stimulated luminescence (OSL) ★ Age-date sample, amino acid (AA)

Fig. 1 — Figure location

This geologic map was funded in part by the U.S. Geological Survey (USGS) National Cooperative Geologic Mapping Program, agreement nos. 05HQAG0085 for 2005–2006 (south Whidbey Island) and 06HQAG0035 for 2006–2007 (Camano Island). We thank Doug Kelly (Island Co. Health Dept.) and other Island County staff for geologic, hydrogeologic, geotechnical, and other assistance and records; Terry Swanson (Univ. of Wash.), Liz Nesbitt (Univ. of Wash. Burke Museum), Gerald Thorsen and Katherine Reed (both DGER, retired), Deborah Mitchell, and Yvonne Dettlaff for assistance with field work and interpretation of cliff exposures; Liz Nesbitt (Univ. of Wash. Burke Museum) for identification of fossils and their paleoenvironmental implications; Dan Muhs (USGS) for technical and interpretive assistance and permission to include his unpublished age-control data; Keith Kvenvolden for technical and interpretive assistance with some age estimates; Sam Johnson and Brian Sherrod (both USGS) for consultations and technical reviews on the tectonic setting; Joe Dragovich (DGER) for assistance with thin-section petrography and geochemical analyses; Jon Peterson (M.S. candidate at Western Wash. Univ.) for assistance with our petrographic characterization and interpretation of sand samples, which attempted to match his systematic approach to distinguishing nonglacial from glacial deposits on Camano Island; and Joe Dragovich, Tim Walsh, and Josh Logan (DGER) for technical reviews and interpretive assistance. Thanks also to the Washington State Department of Ecology for permission to use proprietary shoreline

aerial photos for our fieldwork. Last, but not least, thanks to the many people who permitted

us to study and sample geologic exposures on their land and provided site-specific records and

local expertise.

Anundsen, Karl; Abella, S. E. B.; Leopold, E. B.; Stuiver, Minze; Turner, Sheila, 1994, Late-glacial and early Holocene sea-level fluctuations in the central Puget Lowland, Washington, inferred from lake sediments: Quaternary Research, v. 42, no. 2, p. 149-161.

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. 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.

005a). Elevations are estimated in feet above mean sea level (see Table 1 caption for methods).

Loc. 1: Saratoga Passage shore bluff, ~1.3 mi (beach distance) south of Race Lagoon

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.

Booth, D. B.; Troost, K. G.; Clague, J. J.; Waitt, R. B., 2004, The Cordilleran ice sheet. In Gillespie, A. R.; Porter, S. C.; Atwater, B. F., 2004, The Quaternary period in the United States: Elsevier

Brocher, T. M.; Blakely, R. J.; Wells, R. E.; Sherrod, B. L.; Ramachandran, Kumar, 2005, The transition between N-S and NE-SW directed crustal shortening in the central and northern Puget Lowland—New thoughts on the southern Whidbey Island fault [abstract]: Eos (American Geophysical Union Transactions), v. 86, no. 52, p. F1459. Carlstad, C. A., 1992, Late Pleistocene deglaciation history at Point Partridge, central Whidbey Island,

Washington: Western Washington University Master of Science thesis, 1 v. 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.

Domack, E. W., 1982, Facies of late Pleistocene glacial marine sediments on Whidbey Island, Washington: Rice University Doctor of Philosophy thesis, 312 p., 11 plates. Domack, E. W., 1983, Facies of late Pleistocene glacial-marine sediments on Whidbey Island, Washington—An isostatic glacial-marine sequence. In Molnia, B. F., editor, Glacial-marine

sedimentation: Plenum Press, p. 535-570. Domack, E. W., 1984, Rhythmically bedded glaciomarine sediments on Whidbey Island, Washington: Journal of Sedimentary Petrology, v. 54, no. 2, p. 589-602. Domack, E. W.; Lawson, D. E., 1985, Pebble fabric in an ice-rafted diamicton: Journal of Geology, v. 93, no. 5, p. 577-591.

Dragovich, J. D.; Petro, G. T.; Thorsen, G. W.; Larson, S. L.; Foster, G. R.; Norman, D. K., 2005, Geologic map of the Oak Harbor, Crescent Harbor, and part of the Smith Island 7.5-minute quadrangles, Island County, Washington: Washington Division of Geology and Earth Resources Geologic Map GM-59, 2 sheets, scale 1:24,000. Easterbrook, D. J., 1966a, Glaciomarine environments and the Fraser glaciation in northwest

Washington—Guidebook for first Annual Field Conference, Pacific Coast Section, Friends of the Pleistocene, September 24–25, 1966: [Privately published by the author], 52 p. Easterbrook, D. J., 1966b, Radiocarbon chronology of late Pleistocene deposits in northwest

Washington: Science, v. 152, no. 3723, p. 764-767. Easterbrook, D. J., 1968, Pleistocene stratigraphy of Island County: Washington Department of Water Resources Water-Supply Bulletin 25, part 1, 34 p., 1 plate (in 4 parts). Easterbrook, D. J., 1994a, 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., 1994b, Stratigraphy and chronology of early to late Pleistocene glacial and interglacial sediments in the Puget Lowland, Washington. In Swanson, D. A.; Haugerud, R. A., editors, Geologic field trips in the Pacific Northwest: University of Washington Department of Geological Sciences, v. 1, p. 1J 1 - 1J 38.

Easterbrook, D. J., 2003, Cordilleran ice sheet glaciation of the Puget Lowland and Columbia Plateau and alpine glaciation of the North Cascade Range, Washington. In Swanson, T. W., editor, Western Cordillera and adjacent areas: Geological Society of America Field Guide 4, p. 137-157. Finlayson, D. P., 2005, Combined bathymetry and topography of the Puget Lowland, Washington State (January 2005): University of Washington School of Oceanography, [accessed 6/30/2006 at

psdem_2005.zip at http://www.ocean.washington.edu/data/pugetsound/psdem2005.html]. 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.

Hutchinson, Ian; James, T. S.; Reimer, P. J.; Bornhold, B. D.; Clague, J. J., 2004, Marine and limnic radiocarbon reservoir corrections for studies of late- and postglacial environments in Georgia Basin and Puget Lowland, British Columbia, Canada and Washington, USA: Quaternary Research 61, v. 2,

Johnson, S. Y.; Dadisman, S. V.; Mosher, D. C.; Blakely, R. J.; Childs, J. R., 2001, Active tectonics of the Devils Mountain fault and related structures, northern Puget Lowland and eastern Strait of Juan de Fuca region, Pacific Northwest: U.S. Geological Survey Professional Paper 1643, 45 p., 2 plates. Johnson, S. Y.; Mosher, D. C.; Dadisman, S. V.; Childs, J. R.; Rhea, S. B., 2000, Tertiary and

Quaternary structures of the eastern Juan de Fuca Strait—Interpreted map. In Mosher, D. C.; Johnson, S. Y., editors; and others, 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

Johnson, S. Y.; Nelson, A. R.; Personius, S. F.; Wells, R. E.; Kelsey, H. M.; Sherrod, B. L.; Okumura, Koji; Koehler, Rich; Witter, Robert; Bradley, Lee-Ann; Harding, D. J., 2003, Maps and data from a

trench investigation of the Utsalady Point fault, Whidbey Island, Washington; version 1.0: U.S. Geological Survey Miscellaneous Field Studies Map MF-2420, 1 sheet, [with 7 p. text]. Johnson, S. Y.; Nelson, A. R.; Personius, S. F.; Wells, R. E.; Kelsey, H. M.; Sherrod, B. L.; Okumura, Koji; Koehler, Rich, III; Witter, R. C.; Bradley, Lee-Ann; Harding, D. J., 2004, Evidence for late Holocene earthquakes on the Utsalady Point fault, northern Puget Lowland, Washington:

Seismological Society of America Bulletin, v. 94, no. 6, p. 2299-2316. Johnson, S. Y.; Potter, C. J.; Armentrout, J. M.; Miller, J. J.; Finn, C. A.; Weaver, C. S., 1996, The southern Whidbey Island fault—An active structure in the Puget Lowland, Washington: Geological Society of America Bulletin, v. 108, no. 3, p. 334-354, 1 plate.

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. Kelsey, H. M.; Sherrod, Brian; Johnson, S. Y.; Dadisman, S. V., 2004, Land-level changes from a late Holocene earthquake in the northern Puget Lowland, Washington: Geology, v. 32, no. 6, p. 469-472. Kovanen, D. J.; Slaymaker, Olav, 2004, Relict shorelines and ice flow patterns of the northern Puget Lowland from lidar data and digital terrain modelling: Geografiska Annaler, Series A, Physical

Geography, v. 86, no. 4, p. 385-400. Kvenvolden, K. A.; Blunt, D. J.; McMenamin, M. A.; Straham, S. E., 1980, Geochemistry of amino acids in shells of the clam Saxidomus. In Douglas, A. G.; Maxwell, J. R., editors, Advances in organic chemistry 1979: Pergamon Press Physics and Chemistry of the Earth, v. 12, p. 321-332. 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. Polenz, Michael; Schasse, H. W.; Petersen, B. B., 2006, Geologic map of the Freeland and northern part of the Hansville 7.5-minute quadrangles, Island County, Washington: Washington Division of Geology and Earth Resources Geologic Map GM-64, 1 sheet, scale 1:24,000. Polenz, Michael; Slaughter, S. L.; Dragovich, J. D.; Thorsen, G. W., 2005b, Geologic map of the Ebey's Landing National Historical Reserve, Island County, Washington: Washington Division of Geology and Earth Resources Open File Report 2005-2, 1 sheet, scale 1:24,000. Polenz, Michael; Slaughter, S. L.; Thorsen, G. W., 2005a, 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,

Sherrod, B. L., 2005, Prehistoric earthquakes in the Puget Lowland, Washington [abstract]: Eos (American Geophysical Union Transactions), v. 86, no. 52, p. F1458-1459.

Sherrod, Brian; Blakely, R. J.; Weaver, Craig; Kelsey, H. M.; Barnett, Elizabeth; Wells, Ray, 2005a, Holocene fault scarps and shallow magnetic anomalies along the southern Whidbey Island fault zone near Woodinville, Washington [abstract]: Eos (American Geophysical Union Transactions), v. 86, no. 52, p. F1438. Sherrod, B. L.; Blakely, R. J.; Weaver, Craig; Kelsey, Harvey; Barnett, Elizabeth; Wells, Ray, 2005b,

Holocene fault scarps and shallow magnetic anomalies along the southern Whidbey Island fault zone near Woodinville, Washington: U.S. Geological Survey Open-File Report 2005-1136, 35 p. Swanson, T. W., 1994, Determination of ³⁶Cl production rates from the deglaciation history of Whidbey Island, Washington: University of Washington Doctor of Philosophy thesis, 121 p. Thorson, R. M., 1980, Ice-sheet glaciation of the Puget Lowland, Washington, during the Vashon Stade (late Pleistocene): Quaternary Research, v. 13, no. 3, p. 303-321. 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. Thorson, R. M., 1989, Glacio-isostatic response of the Puget Sound area, Washington: Geological Society of America Bulletin, v. 101, no. 9, p. 1163-1174.

Disclaimer: This product is provided 'as is' without warranty of any kind, either expressed or implied, including, but not limited to, the implied warranties of merchantability and fitness for a particular use. The Washington Department of Natural Resources and the authors of this product will not be liable to the user of this product for any activity involving the product with respect to the following: (a) lost profits, lost savings, or any other consequential damages; (b) the fitness of the product for a particular purpose; or (c) use of the product or results obtained from use of the product. This product is considered to be exempt from the Geologist Licensing Act IRCW 18.220.190 (4)] because it is geological research conducted by the State of Washington, Department of Natural Resources, Division of Geology and Earth Resources

64.64 | 66.61 | 67.12 | 65.96 | 66.29 | 63.75 | 67.04 | 61.59 | 65.94 | 66.64 | 64.32 | 66.78 | 65.78 | 66.71 | 63.76 | 66.18 | 64.82 | 65.65 | 1.42 | 65.57 | 0.88 | 65.09 | 1.30 | 65.09 | 1.30 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65.09 | 65. 66.51 | 66.22 | 66.18 | 66.43 87 | 16.29 | 16.36 | 16.83 | 16.39 | 16.44 | 16.34 | 17.25 | 16.12 | 16.68 | 16.53 | 0.48 | 16.52 | 0.30 | 16.62 | 0.47 0.081 0.065 0.068 0.083 0.080 0.083 0.080 0.083 0.080 0.083 0.095 0.077 0.075 0.084 0.069 0.080 0.070 0.081 0.082 0.081 0.08 0.01 0.08 0.02 0.083 0.007 0.075 | 0.079 | 0.078 | 0.075 4.32 | 4.40 | 4.37 | 4.34 | $4.04 \quad \begin{vmatrix} 4.30 & 4.20 & 4.17 & 4.15 & 4.14 & 4.28 & 3.96 & 4.16 & 4.20 & 4.03 & 4.20 & 4.23 & 4.29 & 4.07 & 4.19 & 4.11 & 4.16 & 0.09 & 4.07 & 0.09 & 4.12 & 0.12$ 4.16 | 4.16 | 4.16 | 4.23 100 00 | 100 00 | 100 00 | 100 00 |100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00|100.00Unnorm. 99 32 98 97 99 17 99 89 99.34 | 99.11 | 98.92 | 100.17 | 98.71 | 99.30 | 99.09 | 98.92 | 98.72 | 98.27 | 99.14 | 99.42 | 98.88 | 100.10 | 99.98 | 99.32 | 99.34 | race Elements, Unnormalized, by X-ray Fluorescence (expressed in weight percen 24 | 17 | 19 | 21 | 21 | 29 | 17 | 36 | 19 | 27 | 26 | 31 | 25 | 21 | 22 | 19 | 19 | 23.21 | 4.92 | 19.44 | 3.35 | 18 | 5 535 | 547 | 550 | 538 | 528 | 482 | 559 | 446 | 554 | 573 | 516 | 571 | 553 | 581 | 509 | 563 | 526 | 538.58 | 31.99 | 552 543 542 548 17 | 17 | 17 | 17 | 17 | 20 | 17 | 20 | 17 | 17 | 18 | 17 | 16 | 18 | 17 | 17 | 19 | 17.41 | 1.07 | 17.42 | 0.76 | 17 | 16 | 17 | 18 | 18 56 48 50 57 55 61 46 67 56 53 59 50 58 54 56 59 57 55.42 4.84 57.42 3.01 57 6 ace Elements, Unnormalized, by inductively coupled plasma mass spectrometry (expressed in parts per million)
 17.89
 17.60
 18.14
 17.45
 17.87
 17.94
 18.37
 15.28
 17.44
 14.82
 17.95
 18.88
 16.68
 17.43
 18.05
 19.18
 16.35
 17.53
 17.44
 17.54
 1.07
 18.15
 0.79
 16.02
 1.23
 34.62 | 34.24 | 35.71 | 33.56 | 34.13 | 35.04 | 35.60 | 29.63 | 33.15 | 29.40 | 34.77 | 36.32 | 32.38 | 33.91 | 35.35 | 37.56 | 32.24 | 34.52 | 34.27 | 34.10 | 2.02 | 35.33 | 1.41 | 31.23 | 2 3.94 | 3.88 | 4.19 | 3.81 | 3.90 | 4.05 | 4.14 | 3.51 | 3.73 | 3.58 | 4.00 | 4.10 | 3.76 | 3.85 | 4.08 | 4.32 | 3.69 | 3.94 | 3.98 | 3.93 | 0.21 | 4.04 | 0.15 | 3.47 | 0.53 3.15 | 3.07 | 3.09 | 2.91 | 2.96 | 3.22 | 3.21 | 2.97 | 2.70 | 3.18 | 3.04 | 3.03 | 3.13 | 2.95 | 3.28 | 3.30 | 2.93 | 3.09 | 3.15 | 3.08 | 0.15 | 3.09 | 0.11 | 2.64 | 0.44 $\begin{vmatrix} 0.63 & 0.63 & 0.62 & 0.59 & 0.60 & 0.65 & 0.66 & 0.66 & 0.60 & 0.56 & 0.65 & 0.61 & 0.62 & 0.63 & 0.61 & 0.65 & 0.67 & 0.59 & 0.63 & 0.63 & 0.62 & 0.03 & 0.63 & 0.03 & 0.54 & 0.09 \\ \end{vmatrix}$ 1.72 | 1.63 | 1.68 | 1.82 | 1.80 | 1.66 | 1.54 | 1.77 | 1.72 | 1.70 | 1.76 | 1.67 | 1.79 | 1.86 | 1.64 | 1.78 | 1.76 | 1.72 | 0.08 | 1.76 | 0.07 | 1.48 | 0.24 $\begin{vmatrix} 0.26 & 0.27 & 0.26 & 0.25 & 0.26 & 0.27 & 0.26 & 0.27 & 0.27 & 0.24 & 0.23 & 0.26 & 0.27 & 0.27 & 0.26 & 0.25 & 0.28 & 0.27 & 0.25 & 0.27 & 0.27 & 0.26 & 0.01 & 0.26 & 0.01 & 0.22 & 0.04 \end{vmatrix}$ 1.65 | 1.68 | 1.68 | 1.61 | 1.65 | 1.74 | 1.73 | 1.58 | 1.52 | 1.66 | 1.68 | 1.71 | 1.70 | 1.66 | 1.77 | 1.82 | 1.57 | 1.69 | 1.68 | 1.68 | 0.07 | 1.69 | 0.06 | 1.43 | 0.23 6.11 | 6.21 | 5.66 | 5.91 | 6.34 | 5.84 | 6.20 | 4.94 | 6.15 | 4.48 | 6.17 | 6.62 | 5.41 | 6.22 | 6.00 | 6.50 | 5.39 | 6.12 | 5.76 | 5.91 | 0.52 | 6.39 | 0.38 | 5.39 | 0.58 5.26 | 5.08 | 5.04 | 5.12 | 5.19 | 5.55 | 5.63 | 4.61 | 5.03 | 4.36 | 5.29 | 5.57 | 4.91 | 5.21 | 5.43 | 5.58 | 4.45 | 5.19 | 4.82 | 5.15 | 0.38 | 5.22 | 0.29 | 4.94 | 0.40 4.13 | 4.07 | 3.84 | 3.92 | 4.08 | 4.21 | 4.05 | 3.47 | 3.95 | 3.58 | 4.04 | 4.08 | 3.73 | 4.07 | 4.27 | 4.33 | 3.67 | 4.11 | 3.88 | 3.97 | 0.22 | 4.11 | 0.18 | 3.44 | 0.51 $\begin{vmatrix} 10.12 & | & 10.22 & | & 9.03 & | & 9.97 & | & 10.14 & | & 9.88 & | & 9.93 & | & 8.62 & | & 9.91 & | & 7.97 & | & 9.85 & | & 10.75 & | & 8.64 & | & 9.96 & | & 9.80 & | & 10.12 & | & 8.92 & | & 9.93 & | & 12.30 & | & 9.79 & | & 0.89 & | & 10.17 & | & 0.77 & | & 9.38 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | & 1.14 & | &$

42.4 41.0 38.1 41.2 43.2 40.9 42.8 31.9 42.7 28.8 42.7 45.6 37.2 42.3 40.7 44.1 35.7 40.3 38.5 40.18 4.16 41.76 3.57 36.9 4.3

 10.0
 11.7
 10.0
 8.9
 12.7
 9.8
 9.9
 11.9
 12.2
 12.7
 9.3
 17.5
 12.3
 10.6
 14.3
 11.4
 13.1
 12.6
 11.0
 9.5
 9.1
 11.56
 2.04
 12.12
 1.39
 11.7
 1.4

 148
 152
 153
 145
 142
 146
 149
 159
 148
 128
 143
 129
 146
 149
 135
 148
 158
 158
 132
 149
 137
 145.29
 9.04
 150.11
 7.46
 130
 8

Table 2. Geochemical analyses of 20 dacite clasts from two shoreline bluff exposures along Saratoga Passage, and average geochemical values for 20 dacite clasts from central to northern Whidbey Island (Polenz and others, 2005a; Dragovich

and others, 2005) and 107 Glacier Peak-sourced clasts from east of Whidbey Island (Dragovich and others, 2005). Each analysis represents a single clast of vesicular dacite or dacitic pumice. All analyses were performed by Washington State

University GeoAnalytical Laboratory (Pullman, Wash.). Major elements are normalized on a volatile-free basis, with total Fe expressed as FeO. Loss on ignition (LOI) was computed on a wet basis to permit comparison of data from XRF and ICP-MS.

/alues for samples 05-10BR and 05-10C®fb represent repeat analyses of samples 05-10B and 05-10C, respectively; these repeat analyses are pooled with their respective initial analyses into single entries for computation of averages. Analytical

hemically altered by weathering. The chemical values we present and petrographic characteristics of our clasts and the surrounding sand matrix resemble those of the lahar runout of Oak Harbor (Whidbey Formation; Dragovich and others, 2005)

Loc. 2: Saratoga Passage shore bluff, ~1.4 mi (beach dist.) south of Race Lagoon

results with shaded background differ by at least two standard deviations from the average of 107 Glacier Peak-sourced clasts of Dragovich and others (2005), suggesting to us that sample 05-17A and perhaps samples 05-10E and 05-10J are

perhaps with an inclusion of alluvium from the Skagit and (or) Stillaguamish River(s). Deposits mapped as Olympia nonglacial sediments near Coupeville (~4 mi northwest of our samples) likewise consist of similar sediments (Polenz and others

Sample ID | 05-10A | 05-10B | 5-10BR | 05-10C | 05-10C | 05-10C | 05-10C | 05-10D | 05-10D | 05-10D | 05-10F | 05-10G | 05-10H | 05-10H | 05-10I | 05-10J | 05-17A | 05-17B | 05-17B | 05-17C | 05-17D | 05-17E | 05-17F | 05-17F | 05-17F | 05-17J | 05-17J | 05-17J | 05-17J | 05-17D |

designations for layers are the same as those in Figure 1. The stratigraphic Washington: Washington Division of Geology and Earth Resources Geologic Map GM-68, position of layer C3 (Fig. 1) relative to layers C1 and C2 (this fig.) is unresolved. 1 sheet, scale 1:24,000.

Figure 2. Shell sample site on Admiralty Inlet (see map for location). Letter

by Michael Polenz, Henry W. Schasse, Michael L. Kalk, and Bradley B. Petersen

Geologic Map of the Camano 7.5-minute Quadrangle, Island County, Washington

E. Sandy, silty gravel with boulder-size

Figure 1. Shell sample site on Admiralty Inlet (see map for

in Figure 2. The stratigraphic position of layer C3 (this fig.)

relative to layers C1 and C2 (Fig. 2) is unresolved.

location). Letter designations for layers are the same as those

blocks of silt, clay, and diamicton

http://www.dnr.wa.gov/AboutDNR/Divisions/GER/

February 2009

*, shells identified by Liz Nesbitt (University of Washington **, referenced source lists six analyses of marine shells (Saxidomus gigantea, one Mya truncata, and two Macoma), but does not spell out which samples are reflected in the age estimate; may include sample 79-9 of Kvenvolden and others

Beta 211260 263

Beta 211260 | 263

UIC 1892 ~13.5

Table 1. Age control data from the map area. Lab uncertainty values include random errors; uncertainty values preceded by '±' are one standard deviation (68% confidence interval), whereas age ranges reported as

number-to-number' span two standard deviations (95% confidence interval). Where uncertainty statements are shown in quotation marks, we do not know how many standard deviations are included. AA, amino acid content

analysis; OSL, optically stimulated luminescence; 14C, radiocarbon analysis by liquid scintillation counting; AMS, radiocarbon analysis by atomic mass spectrometry. New radiocarbon analyses from this study were performed

by Beta Analytic, Inc. (Miami, Fla.) and are 'conventional' (that is, adjusted for measured 13C/12C ratio) if a 13C/12C ratio is shown; other entries may be 'measured' or 'conventional'. Radiocarbon age estimates are in

adiocarbon years before 1950 (14C yr B.P.) or as reported by lab or prior publication; ages stated in 'ka' are in thousands of calendar years before 1950. Elevations are in feet above mean sea level, as estimated in this study

using lidar data (supplemented by visual elevation estimates on bluffs) and referring to the North American Datum Conversion Utility (NADCON; http://geodesy.noaa.gov/TOOLS/Nadcon/Nadcon.html) for vertical datum shifts