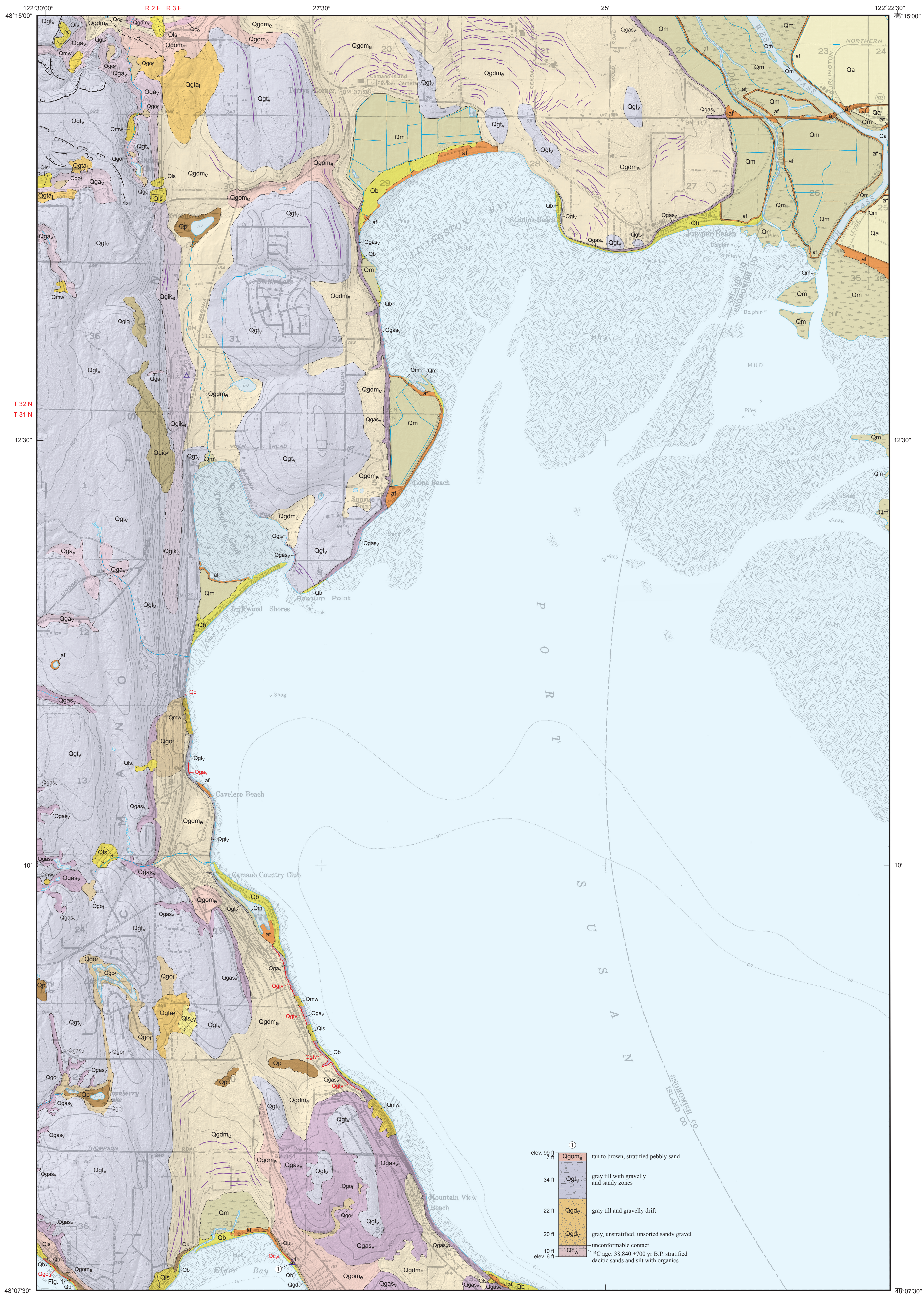
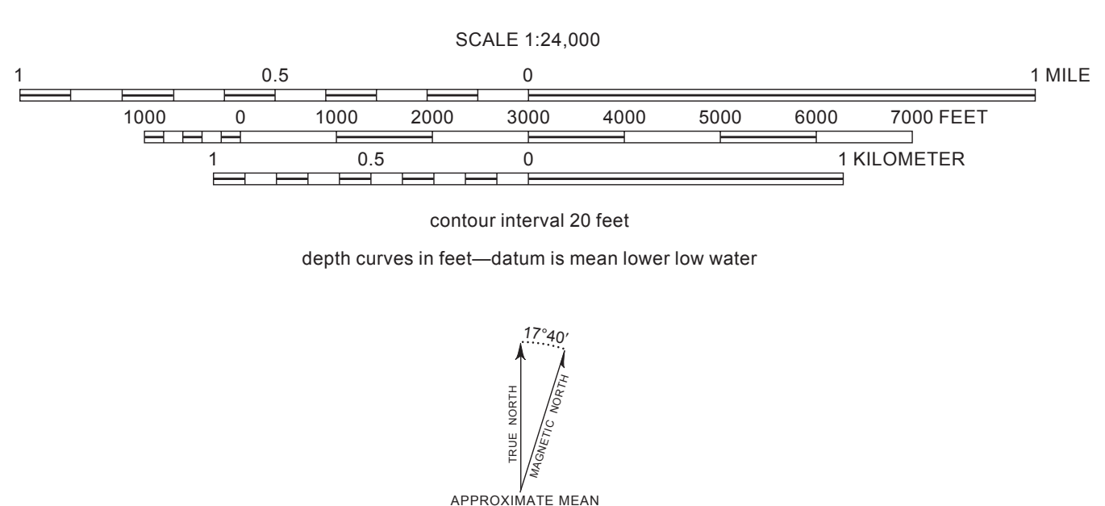
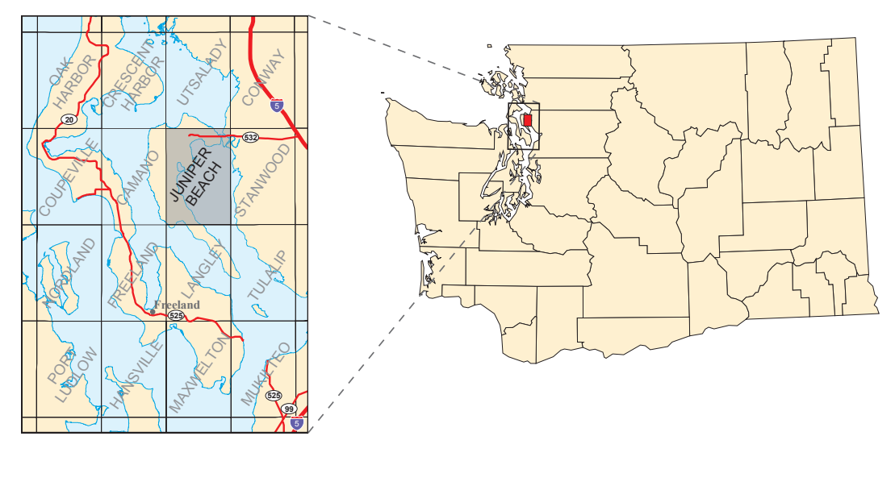
WASHINGTON STATE DEPARTMENT OF
Natural Resources
Peter Goldmark - Commissioner of Public Lands
Division of Geology and Earth Resources
David K. Norman - State Geologist

WASHINGTON DIVISION OF GEOLOGY AND EARTH RESOURCES
GEOLOGIC MAP GM-70
Juniper Beach 7.5-minute Quadrangle
February 2009



Lambert conformal conic projection
North American Datum of 1927; to place on North American Datum of 1983, move the projection lines approximately 17.7 meters north and 94.0 meters east as shown by crosshair corner ticks
Base map from scanned and rectified U.S. Geological Juniper Beach 7.5-minute quadrangle, 1956, photorevised 1968 and 1973
Shaded relief generated from a lidar bare-earth digital elevation model (available from Puget Sound Lidar Consortium, http://pugetsoundlidar.ess.washington.edu/); sun azimuth 315°; sun angle 45°; vertical exaggeration 6x
Digital cartography and GIS by Anne C. Heinitz, Elizabeth E. Thompson, J. Eric Schuster, Charles G. Caruthers, and Robert H. Berwick
Editing and production by Jaretta M. Roloff and Karen D. Meyers





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Geologic Map of the Juniper Beach 7.5-minute Quadrangle, Island and Snohomish Counties, Washington

by Henry W. Schasse, Michael L. Kalk, and Michael Polenz

February 2009

MAJOR FINDINGS

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.
- A new radiocarbon (^{14}C) age estimate constrains the age of nonglacial and overlying glacial sediments on the east side of Camano Island.
- The combination of lidar and shoreline oblique aerial photographs of the shoreline bluffs (provided by the Washington Department of Ecology) has allowed us to more accurately locate geologic units exposed in the bluffs.

GEOLOGIC SETTING AND DEVELOPMENT

The map area is covered by 1000 to 3100 ft of glacial and nonglacial sediment (Jones, 1999; Mosher and others, 2000; Johnson and others, 2001) above Miocene(?) bedrock (Johnson and others, 1996). The Whidbey Formation is the oldest named sedimentary unit exposed in the map area. Booth and others (2004, Fig. 2) correlate the Whidbey Formation to marine oxygen-isotope stage 5 (~125–80 ka). (Stage numbers and corresponding ages used in this report are as defined in Morrison, 1991.) We did not identify deposits of the Possession Glaciation (stage 4 or ~80–60 ka) (Booth and others, 2004). We mapped some deposits of the Olympia nonglacial interval (stage 3 or ~60–20 ka) where they are poorly exposed in the northern part of the map area, based primarily on mapping by Dragovich and others (2002, 2005), who mapped this unit in the adjoining Utsalady and Crescent Harbor quadrangles just north and northwest of the map area, where the Olympia nonglacial deposits are well exposed in north-facing bluffs at Utsalady Point.

We mapped mostly Fraser Glaciation deposits (Armstrong and others, 1965) on upland surfaces and along most 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, 2005; Johnson and others, 2001). Radiocarbon dates on detrital samples and optically stimulated luminescence (OSL) dates from southwest of the map area suggest that Vashon (and possibly Evans Creek alpine) outwash may have arrived earlier (Polenz and others, 2006). The Puget lobe of the Cordilleran ice sheet apparently arrived by about 18 ka (~15,000 ^{14}C yr B.P.) (Booth, 1991; Porter and Swanson, 1998; Booth and others, 2004; Polenz and others, 2005) 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 dissect the fluted uplands of western Camano Island and southern Whidbey Island (as previously noted southwest of the map area by Polenz and others, 2006) indicates that as ice retreated at the end of the Vashon Stade, parts of the islands were largely ice free, no longer submerged beneath ice-dammed lakes, and not yet inundated by the Everson Interstade incursion of marine water. We did not recognize a similar record of incision in the map area, however, and it is therefore not clear whether the Everson marine seawater incursion was also preceded by ice free conditions on the east side of Camano Island. Instead, ice may have persisted there until close to the time of the Everson marine high stand.

The Everson seawater incursion raised base level in the area to the glaciomarine limit (maximum relative seawater elevation), which caused strandlines, delta fans, and shore terraces to form at that elevation. These features are discontinuous and relatively subtle in the map area, but we feel that careful consideration of lidar-based hillshade images permits their recognition. Based on this and the similar but more strongly developed geomorphic record in nearby areas to the west and south (Polenz and others, 2005, 2006, 2009; Schasse and others, 2009), we place the glaciomarine limit at about 180 to 190 ft (at the southern quadrangle boundary) to between 225 and 240 ft at the north end of the quadrangle, 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 ^{14}C yr B.P., and freshwater gyttja (organic-rich lake-bottom sediment) from the same site suggests that it ended before 13,600 ^{14}C 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 ^{14}C 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, 2005). 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 unit Qgom$_e$), deltas (unit Qgom$_e$), and strandlines (characteristic but subtle benches that are paleo–beach berms at various elevations, which record successively lower elevations of the local sea level as glacial rebound took place (Carlstad, 1992; Easterbrook, 2003; Kovanen and Slaymaker, 2004). These strandlines were separately mapped as unit Qgom$_{ee}$ in the adjacent Crescent Harbor, Freeland, Camano, and Langley quadrangles (respectively, Dragovich and others, 2005; Polenz and others 2006, 2009; Schasse and others, 2009). One exposure of such deltas in the area may be in the southwest corner of the map area (Fig. 1), where gray, subhorizontally bedded gravels appear to unconformably overlie a thick section of northwest-dipping, iron-oxide-stained sand and gravel foreset beds. Age control is lacking at the exposure, and it is therefore unclear if the foreset beds date to the Everson Interstade (they could instead represent an older glaciation). If the entire exposure dates to the Everson Interstade, the deposit is consistent with the persistent presence of an ice sheet on the east side of Camano Island while the west side was ice free and submerged by Everson marine water. That scenario would provide a source of water and coarse sediment for the deposition of gravel in a proglacial marine delta at this location.

Above the marine limit, upland surfaces (especially in nearby quadrangles to the south and west) (Polenz and others, 2006, 2009; Schasse and others, 2009) 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 sheets of apparent advance outwash sand (≤170 ft in a valley on southern Whidbey Island, 6 mi southwest of the map area). 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, and 3) the valleys lack active stream channels. On southern Whidbey Island, Polenz and others (2006) noted, in addition, that some of these valleys include dry, closed depressions where mass wasting from valley sidewalls has locally elevated the valley floor.

STRUCTURE

Landslide scarps mapped from subtle northwest-trending landforms, and several large, arcuate landslide scarps, which we have mapped with the aid of lidar, appear to attest to tectonic activity in the northwest corner of the map. These features continue westward into the adjoining Camano quadrangle (and northward into the Utsalady and Crescent Harbor 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 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 . 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 consequently, these areas may continue to be subject to an elevated slide hazard relative to unaffected but otherwise similar areas nearby.

Johnson and others (2000, 2001) mapped an unnamed apparent strand of the Utsalady Point fault in the northwestern end of the map area. Although the Utsalady quadrangle geologic map of Dragovich and others (2002) did not show the extension of the same fault strand across the Utsalady quadrangle to the northern map boundary of our map area, Dragovich agrees that the fault is present in the area and appears to extend across the Utsalady quadrangle into our map area (Joe Dragovich, Wash. Divn. of Geology and Earth Resources [DGER], year 2001 field notes and oral commun., 2007). We therefore extend the strand into the Camano quadrangle as shown by Johnson and others. Data gathered during trenching of the Utsalady Point fault (on northern Whidbey Island), indicated an earthquake (M ≤6.7) 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".

With the possible exception of the above mentioned landslide scarps, our fieldwork did not reveal specific tectonic fault strands. We note, however, that the lack of recognized fault scarps does not necessarily reflect a lack of surface-deforming fault events, but could result from diffusion of fault deformation in extensive, thick deposits that appear to dominate the uplands in the map area.

DESCRIPTION OF MAP UNITS

We have attempted to match our geologic mapping to the prior mapping of Dragovich and others (2002) in the Utsalady 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.

Holocene

af **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.

Qb **Beach deposits**—Sand and cobbles; may include boulders, silt, pebbles, and clay; pebbles and larger clasts typically well rounded and oblate; mostly well sorted; loose; derived from shore bluffs and underlying deposits and (or) carried in by longshore drift.

Qa **Alluvium and estuarine deposits**—Sand, silty sand, silt, silty clay, and clay; loose and soft; sand is fine to very fine grained; sand and silt are gray to olive gray; clay is bluish gray with various admixtures of organic materials; levees have converted parts of the map area underlain by these deposits to agricultural use; unit consists of deltaic deposits near the mouth of the Stillaguamish River in the northeast corner of the map area.

Qm **Marsh deposits**—Mostly soft to stiff, olive gray to gray silt and silty clay and bluish gray clay, commonly with lenses and layers of peat, muck, and other organic material; deposited in a saltwater or brackish marsh (estuarine or lagoonal) environment; deposits occur near highest tide levels and are covered with salt-tolerant vegetation or floated logs (particularly at Elger Bay). Many of these deposits (at the north end of Port Susan) have been converted to agricultural use by construction of levees. Contacts between marsh and Stillaguamish River deltaic deposits (unit Qa) are commonly gradational or masked by agricultural modifications.

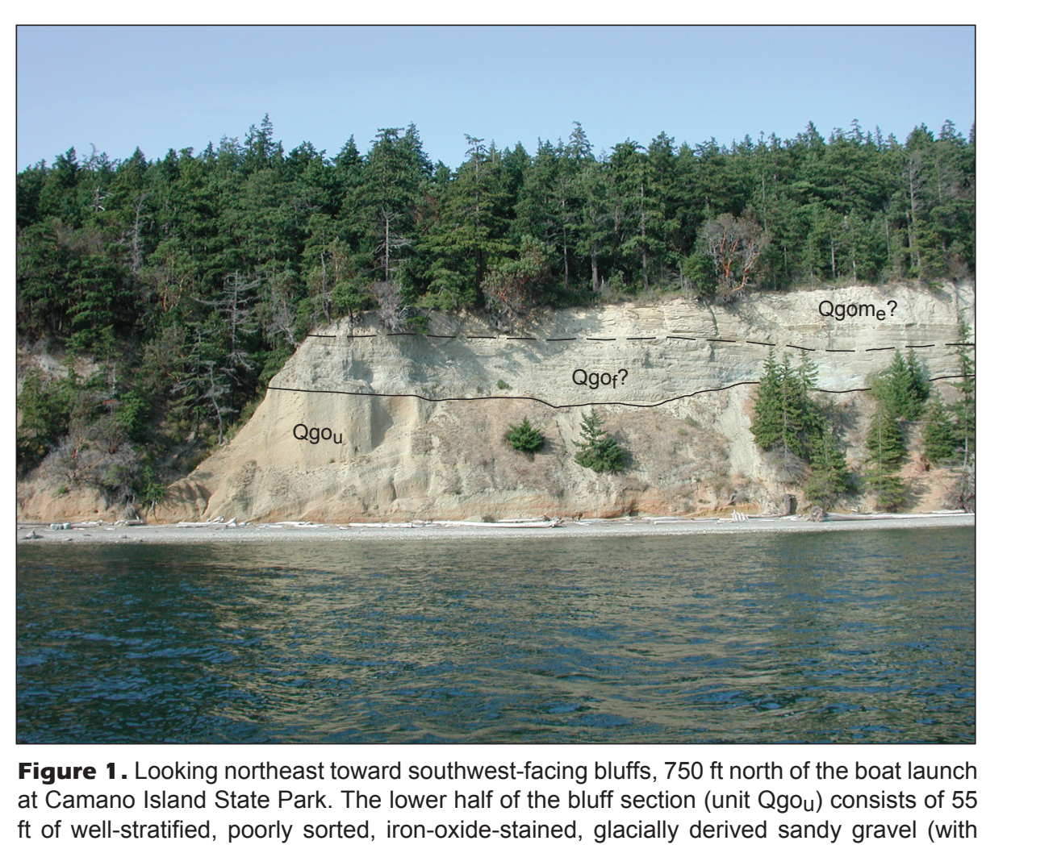

Figure 1. Looking northeast toward southwest-facing bluffs, 750 ft north of the boat launch at Camano Island State Park. The lower half of the bluff section (unit Qgo$_u$) consists of 55 ft of well-stratified, poorly sorted, iron-oxide-stained, glacially derived sandy gravel (with northwest-dipping foreset beds), which conformably overlies irregularly iron-oxide-stained sand. Gray, subhorizontally cross-stratified pebble to cobble gravels (postulated unit Qgo$_f$), 35 feet thick, appear to unconformably overlie unit Qgo$_u$. Postulated unit Qgo$_f$ grades upward to similarly oriented, tan, thin-bedded sand and silt (postulated unit Qgom$_e$, which we also encountered and mapped as unit Qgom$_e$ nearby on the upland surface) with exposed thickness of 15 ft.

Holocene to Late Pleistocene

Qp **Peat**—Organic and organic-rich sediment, typically in closed depressions; includes peat, muck, silt, and clay in and adjacent to wetlands; may locally grade down to and include the freshwater equivalent of unit Qm; not shown where field data indicate fewer than 2 ft of peat.

Qmw **Mass wasting deposits**—Boulders, gravel, sand, silt, clay, and diamicton; generally an unsorted mix, but locally stratified; typically loose; shown along mostly colluvium-covered or densely vegetated slopes that are demonstrably unstable or appear potentially unstable; locally contains landslides and underlying units that either we could not map confidently or are too small to show at map scale.

Qls **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, and most slide deposits are quickly removed by beach wave action.

Pleistocene Glacial and Nonglacial Deposits

We used stratigraphic position, organic content, radiocarbon dating, 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. We found some petrographic indications of possible ancestral Skagit and (or) Stillaguamish River provenance (hypersthene, hornblende, and possible Glacier Peak dacite) (Dragovich and others, 2005; Polenz and others, 2005; Joe Dragovich, DGER, oral commun., 2006; Peterson, 2007).

DEPOSITS OF THE FRASER GLACIATION (PLEISTOCENE)

Undivided Fraser Glaciation

Qgo$_f$ **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; poorly to well sorted in most exposures; 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 Qgom$_e$; Fig. 1); queried where assignment to this unit is uncertain due to limited exposures or inaccessibility. This unit typically dates to Everson time but is assigned to the broader Fraser glacial period because some deposits (notably where above Everson sea level) may date to the Vashon Stade.

Qgic$_f$ **Recessional, stratified ice-contact deposits**—Sandy gravel, sand, and cobble gravel; silty in places; yellowish brown to gray; poorly sorted, variably stratified, loose to compact; poorly exposed in a few road cuts. Characteristic morphology includes hummocky topography and elevated terraces interpreted from lidar imagery. Lateral ice buttressing is required to produce these elevated deposits.

Qgta$_f$ **Ablation till**—Unsorted, unstratified, and heterogeneous melt-out deposit of sand, silt, clay, gravel, and diamicton and patchy stratified proximal outwash deposits; loose to compact; typically marked by diverse and locally irregular geomorphology.

Everson Interstade

Qgdm$_e$ **Everson Glaciomarine Drift, undivided**—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; best exposures along east shores of Triangle Cove and Livingston Bay; 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 in general, till lacks fossils and glaciomarine drift has a finer-grained, smoother-feeling matrix, is less compact, and more likely to be stratified. 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).

Qgom$_e$ **Glaciomarine deltaic outwash deposits**—Sand, and sand-gravel mixtures with minor interlayered silt and silty sand; generally loose; most deposits are at least a few tens of feet thick; forms a marine delta–turbidite complex (Carlstad, 1992; Polenz and others, 2005) with a horizontally bedded, sandy sea-floor facies, an overlying delta-front foreset-bedded facies, and a capping deltaic top-set, channelized facies.

Qgik$_e$ **Ice-contact kame deposits**—Sand, gravel, and silty sand; loose to medium dense; gray to tan; locally reddish brown; gravel clasts up to 3 in. diameter; shape of unit suggests a kame terrace deposit approximately 10 to 15 ft thick. A blue-gray sandy silt containing scattered clam shells and organic debris directly underlies this unit. An atomic mass spectrometry (AMS) radiocarbon analysis of a marine shell from the underlying unit yielded a date of 13, 380 ± 40 yr B.P. (Table 1; loc. 2) suggesting an Everson age for this unit.

Qls$_{e?}$ **Landslide deposits**—Till and outwash sand and gravel; identified as landslide based on surface morphology; field relations, a low slope angle (≤5%), and apparently advanced age of feature (subdued morphology) cause us to suspect an Everson Interstade slide event that need not imply an elevated modern slide hazard.

Vashon Stade

Qgt$_v$ **Till**—Typically unweathered, unsorted mixture 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 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 Qgdm$_e$ (see that unit). 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 100 ft thick (as reflected in some water well records), with 2 to 30 ft most common. Cliff exposures along the west shore of Whidbey Island about 7 mi southwest 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 Unit Qgt$_v$ lies stratigraphically between overlying units Qgdm$_e$ and Qgom$_e$ and underlying units Qga$_v$ and Qgas$_v$. Regional age data appear to constrain the age of the unit to between ~18 ka and the onset of the Everson Interstade. Unit Qgt$_v$ may include unrecognized exposures of older till.

Qga$_v$ **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 plane and graded beds, cut-and-fill structures, trough and ripple crossbeds, and foresets; maximum thickness may exceed 200 ft in the map area (as reflected in some water well records); 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 Qc$_o$. Estimated age of the unit is ~18 to at least 20 ka. Locally divided into:

> Qgas$_v$ **Advance outwash sand**—Mostly lacustrine sand with layers of silt; well-stratified; gray; thick exposures display well-developed crossbedding and cut-and-fill structures that are typical of this unit; locally coarsens upward into gravel; thickness is typically 80 ft; thick and extensive in subsurface, with maximum estimated thickness of approximately 200 ft; commonly forms angle-of-repose slopes along drainages and coastal bluffs. Unit is the most widespread lithology of advance outwash in the map area and includes the Esperance Sand and possibly the Lawton Clay, but the latter was not recognized by us in our mapping.

Qgd$_v$ **Vashon Drift, undivided**—Composite of units Qgt$_v$ and Qga$_v$ (or Qgas$_v$). Unit consists of gray till and gravelly drift overlying gray, unstratified, unsorted sandy gravel exposed in bluffs east of Elger Bay (Columnar Section 1) where map scale or exposure does not support stratigraphic division into the above listed constituent units.

GLACIAL DEPOSITS OF UNKNOWN AGE (PLEISTOCENE)

Qgo$_u$ **Outwash of unknown age (line unit and Fig. 1 only)**—Iron-oxide-stained sand and gravel with prominent northwest-dipping foreset beds in bluff exposures at Camano Island State Park, northeast of the boat launch (Fig. 1); unconformably overlain by unit Qgo$_f$?; age unknown. Unit is exposed for approximately 0.3 mi—disappearing to the north in a landslide and obscured to the south by dense forest cover. It may be a glacial outwash deltaic deposit of Everson Interstade (late Fraser) age, or may represent outwash from an earlier glaciation, later eroded, then covered by glaciofluvial outwash deposits.

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).

Qc$_o$ **Nonglacial deposits**—Sand, silt, laminated silty clay, pebbly sand, organic sand, and minor lenses and layers of pebble gravel; light gray to brown. The unit is poorly exposed in the map area but well-exposed just outside the map area in coastal bluffs at Utsalady Point, just northwest of the northwest corner of the quadrangle, where geometry and a mix of the above lithologies suggest variable depositional environments within fluvial channels, flood plains, and possibly lakes of an alluvial plain (Johnson and others, 2001; Dragovich and others, 2005); sparse, fine-grained organic matter disseminated within sandy silt beds at Utsalady Point yielded radiocarbon dates of 21,100 ±150 and 15,190 ±220 ^{14}C yr B.P. (Johnson and others, 2001), although Johnson and others questioned the validity of one or both of these age estimates.

INTERGLACIAL DEPOSITS OF THE WHIDBEY FORMATION (PLEISTOCENE)

Qc$_w$ **Whidbey Formation (columnar section and line unit only)**—Sand, silt, and clay with minor peat layers and lenses of fine gravel; mostly weathered to a muted light yellowish gray in exposed faces; includes flood plain and channel-sand facies; flood plain facies typically well stratified with silt and clay beds; slightly oxidized; channel-sand facies typically clean, gray, coarse grained, and cross- to nonbedded. Dacite clasts are a common component of sand and gravel facies and reflect an eastern provenance. The unit is mapped only at the base of bluffs on the east side of Elger Bay, where a 10-ft-thick section is exposed for about 700 ft. Vashon Drift (unit Qgd$_v$) lies in unconformable contact with this unit (Columnar Section 1), which has yielded two radiocarbon age dates (Table 1; locs. 1 and 3). A peat from this unit yielded an infinite ^{14}C date of >35,700 yr B.P. (Easterbrook, 1968), and more recently wood from this unit yielded a finite AMS date of 38,840 ±700 ^{14}C yr B.P. (Kathy Troost, Univ. of Wash., written commun., 2006). Although these ages suggest that the nonglacial beds at east Elger Bay could belong to the Olympia nonglacial period, we believe that they belong to the Whidbey Formation because nonglacial sediments at Lowell Point (on the west side of Elger Bay in the adjoining Langley quadrangle) yielded an infinite ^{14}C age of >45,210 ^{14}C yr B.P. and an optically stimulated luminescence (OSL) age of 124.8 ±4.2 ka. The sediments at these two localities are only a mile apart and each hosts dacitic, nonglacial sand unconformably overlain by glacial diamicton. On the basis of their close geographic proximity, their similar petrology, and similar geologic setting, and considering that the finite radiocarbon age is close to the upper detection limit of the radiocarbon dating method and that this single, ostensibly finite ^{14}C age estimate stands in contrast with two infinite radiocarbon age estimates and the 124 ka OSL age, we believe the data favor a Whidbey age for the nonglacial sediments at these two localities.

UNDIVIDED PRE-FRASER NONGLACIAL DEPOSITS (PLEISTOCENE)

Qc **Pre-Fraser nonglacial deposits, undivided (line unit only)**—Sand, silt, and clay, compact; well stratified; resembles units Qc$_o$ and Qc$_w$; reflects flood plain setting; poorly exposed near beach level for about 150 ft (0.5 mi south of Driftwood Shores) in an area of mass-wasting bluffs. Unit Qc lies stratigraphically below Fraser glacial deposits, but its age and association are otherwise unresolved. It is most likely to be stage 3 (Olympia nonglacial) on the basis of its geologic setting.

UNDIVIDED QUATERNARY DEPOSITS

Qu **Pleistocene deposits, undivided**—Locally includes sand, gravel, diamicton, silt, clay, and peat; loose to compact; well stratified to massive; composite of glacial and (or) nonglacial deposits; ranges in age (in coastal bluff exposures east of Elger Bay) from Everson glaciomarine outwash deltaic deposits (unit Qgom$_e$) that are exposed in the upper bluffs to Whidbey Formation (unit Qc$_w$) exposed near base of the bluffs (Columnar Section 1); shown along coastal bluffs where map scale does not allow for more detailed subdivision (Fig. 1).

GEOLOGIC SYMBOLS

——— — — – –?– –	Contact—long dashed where approximately located, short dashed where inferred; queried where uncertain
– – –?– – –	Fault, unknown offset, inferred—queried where uncertain
Qgt$_v$	Geologic unit too narrow to show as a polygon at map scale
⊥⊥⊥⊥	Landslide scarp—hachures point downslope
→	Arrow showing direction of landslide movement
———	Strand line (former shoreline)
1△	Age-date sample site, radiocarbon
Fig. 1	Figure location
①	Columnar section location

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Table 1. Age control data from the map area. Lab uncertainty values include random errors and are one standard deviation (68% confidence interval). ^{14}C, 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 ^{13}C/^{12}C ratio); other entries may be 'measured' or 'conventional'. Age estimates are in radiocarbon years before 1950 (^{14}C yr. B.P.) or as reported by lab or prior publication. 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 between lidar data and map elevations.

Loc. no.	Age estimate (^{14}C yr B.P.)	^{13}C/^{12}C (‰)	Analytical method	Material dated	Geologic unit	Lab no.	Elev. (ft)	Reference	Notes
1	38,840 ±700	-27.7	AMS	wood	Qc$_w$	Beta 162219	~20	Kathy Troost (Univ. of Wash., written commun., 2006; collected by Ralph Isaacs)	Wood from nonglacial sediments collected by Ralph Isaacs and dated by Kathy Troost (age is close to upper detection limit for ^{14}C and may not accurately represent true age of unit; unit believed to be correlative of unit Qc$_w$ (OSL age date of 124.8 ±14.2 ka), which crops out on west side of Elger Bay (Langley quadrangle).
2	13,380 ±40	-1.2	AMS	shell	Qgik$_e$	Beta 151593	97	Curtis J. Koger (Associated Earth Sciences, Inc., written commun., 2007)	Shell collected by Tim Peter, Associated Earth Sciences, Inc., from 4-ft-thick, blue-gray sandy silt; underlies 9-ft-thick gravel with sand (unit Qgik$_e$).
Location not understood well enough to plot (see notes)									
3	>35,700		^{14}C	peat	Qc$_w$			Easterbrook (1968); Trautman and Willis (1966)	Peat from bed overlain by Vashon till at Elger Bay (48°08'N 122°28'W), Camano Island, Washington

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