GEOLOGIC MAP OF THE HOLLY 7.5-MINUTE QUADRANGLE, JEFFERSON, KITSAP, AND MASON COUNTIES, WASHINGTON

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INTRODUCTION

The Holly map area is located in the western Puget Lowland and straddles Hood Canal northeast of 'The Great Bend'. It is predominantly covered by glacial sediment from both the alpine glaciers of the Olympic Mountains and the Cordilleran ice sheet, which advanced south from Canada. This mapping was undertaken to delineate the glacial stratigraphy and hydrologic characteristics of the Hood Canal area for scientists working on the Hood Canal dissolved oxygen problem and to identify the geologic hazards of the area, including active faults and landslides.

Locating active faults in the western Puget Lowland was an important part of this mapping project. The Seattle, Tacoma, Hood Canal, Saddle Mountain, and Dow Mountain faults and the Lucky Dog structure (Polenz and others, 2010a,b) are in the area, but how these faults interact is not well understood. The Seattle fault zone has been mapped as far west as the east-adjacent Wildcat Lake quadrangle (Haeussler and Clark, 2000; Liberty, 2008; Rowland Tabor, USGS, unpub. data, 2011), and recent models by Andrew Lamb (Boise State Univ., written commun., 2011) suggest that the Tacoma fault merges with the Seattle fault and passes through the southeast corner of the map, creating a strain transfer zone across the area. Blakely and others (2009) suggest that the Seattle fault zone passes through the map area and merges with the Saddle Mountain fault zone to the west. Our mapping suggests that the Seattle fault zone passes through the map area and likely extends to the west across the Hood Canal.

Delineating unstable slopes is important because known massive landslides, such as the Alderwood landslide (Sarikhan and others, 2007), and smaller active slides continue to damage property and infrastructure in the area. Recent mapping (Contreras and others, 2010) suggests that ice-contact features, previously interpreted as landslides, are likely stable and more widely distributed along Hood Canal than previously mapped.

A supplemental report (Contreras and others, 2012) accompanies this map. It contains additional data, descriptions, and discussions pertaining to this map and includes a compilation of radiocarbon ages, geochemical data pertaining to a tephra correlated to Mount St. Helens and dacite clasts from Glacier Peak, a single optically stimulated luminescence (OSL) age estimate, and a grain-size analysis of Vashon-age till and ice-contact deposits.

GEOLOGIC OVERVIEW

Determining the type of bedrock and thickness of glacial sediments in the map area is difficult, due in part to the structural complexity caused by the intersection of the Seattle and Tacoma faults with the Olympic Mountains. Bedrock outcrops in the northwest corner and to the west of the map area are dominantly basalt of the Eocene Crescent Formation. Jones (1996) estimated unconsolidated sediment thickness above Tertiary bedrock at between 300 and 600 ft throughout most of the map area. Recent geophysical models (A. P. Lamb, written commun., 2011; Lamb and others, 2009; Blakely and others, 2009; Karel and Liberty, 2008; Brocher and others, 2004; Haug, 1998) help constrain depth to bedrock and provide insight into faulting in the area. Lamb (written commun., 2011) infers a strain transfer zone linking the Seattle, Tacoma, and Dow Mountain faults within the map area and indicates that sedimentary rocks near the south end of the map area may be covered by more than 3280 ft of sediment. Bedrock in the map area was mapped by Carson (1976a,b) and Tabor and Cady (1978) as basalts and sedimentary rocks of the Crescent Formation.

Previous mapping (Sceva, 1957; Garling and others, 1965; Deeter, 1979; Wash. Dept. of Ecology, 1978, 1979, 1980; Yount and others, 1993) provided Pleistocene stratigraphy in the map area and subsurface information relating to groundwater. This mapping documented repeated Pleistocene glacial incursions that deposited most of the unconsolidated sediment and attempted to classify and correlate these deposits within the Puget Lowland. Our map builds on previous work, but we tried to broadly categorize deposits without directly tying them to specific formations or type sections unless we had enough evidence (that is, age control) to confidently do so.

We broadly classify the various glacial drifts as 'northern-sourced' or 'Olympic-sourced'. Northern-sourced drift contains abundant clasts of granitic and metamorphic rock, indicating deposition by continental (Cordilleran) glaciers. Olympic-sourced drift contains basalt and sandstone (in addition to rare granitic and metamorphic clasts) deposited by alpine glaciers of the Olympic Mountains. There are several mechanisms by which the sediments from both sources have been mixed, making it difficult to interpret provenance with much confidence. The Cordilleran ice sheet overrode and incorporated sediment shed from the Olympics and deposited northern-sourced sediment in the Olympic foothills, resulting in deposits of northern-sourced granitic and metamorphic rocks mixed with the dominantly basalt- and sandstone-rich alpine drift. Green and Gold Mountains, 2.5 mi east of the map area, likely introduced additional basalt to the northern drift (Reeve, 1979; Clark, 1989; Yount and Gower, 1991; Haeussler and Clark, 2000), as inferred from the direction of glacial fluting.

Structure

SEATTLE AND TACOMA FAULTS AND ASSOCIATED BASINS

It is difficult to model the interaction of the Seattle, Tacoma, Hood Canal, and Dow Mountain fault zones in the map area due to the structural complexity and the fairly minor changes in geophysical potential fields, which are much less dramatic than magnetic and gravity anomalies elsewhere along the northern edge of the Seattle uplift. This map provides geological evidence for extending the Seattle fault zone southwest from its known location at the north end of Green and Gold mountains (Haeussler and Clark, 2000; Blakely and others, 2002; Rowland Tabor, USGS, unpub. data, 2011; Lamb, written commun., 2011). Consistent with Lamb's interpretation that the Seattle fault zone changes direction to the west-southwest and transfers strain across the area, we find stratigraphic evidence for deformation of Quaternary deposits continuing west-southwest to Hood Canal at Holly, extending the Seattle basin and uplift to this location.

The stratigraphic evidence shows much older glacial and nonglacial deposits in the south part of the map area; the oldest of these are likely magnetically reversed (Easterbrook and others, 1988) and are juxtaposed with younger Whidbey-age sediment to the north. The Whidbey-age deposits require the existence of a basin for deposition during nonglacial time (Marine Oxygen Isotope Stage [MIS] 5; Fig. 1 on plate). This accommodation space could have been eroded glacially or fluvially, but we suggest that this space was likely made by continued deformation along the Seattle fault zone. This continued deformation is seen in Lamb and others' (2009) seismic profiles, which show increasing dip (from 10 to 20 degrees) with depth in the Feather-Minnig profile. We interpret the upper reflector as Double Bluff–age glacial till (Easterbrook and other, 1967), stratigraphically below the Whidbey-age sediments. We tentatively correlate this reflector with a thick, northern-sourced glacial till south of Anderson Creek that is found directly under Vashon-age glacial deposits on the fluted uplands.

The locations of the folds shown on the map and cross section on the east side of Hood Canal are poorly constrained by field exposures and seismic profiles, and we depict only large-scale features. We found few exposures that demonstrate shearing or faulting of sediments on the Kitsap Peninsula, and most of those found were pre-Fraser glacial and nonglacial deposits in the drainage of Anderson Creek. These features could be glaciotectonic in origin but are shown on the map as individual structural measurements and connected by a queried fault. This interpretation was primarily based on an apparent juxtaposition of older and younger units in Anderson Creek, depicted on the map as a significant site labeled 'fault?', but again, this feature could be glaciotectonic and not related to tectonic deformation.

Due to the multiple possible fault geometries responsible for the apparent deformation on Kitsap Peninsula, we have chosen not to depict the fault or faults responsible for the deformation. However, we suggest there is a major structural feature causing the apparent uplift of older sediments in the southern portion of the map and the down-dropping in the north—a continuation of the Seattle uplift and monocline to as far west as Holly.

Our interpretation of the low-amplitude magnetic anomaly that trends northwest across the canal and coincides with a 'fold' in the seismic profiles, while consistent with Lamb's model of a strain transfer zone, differs slightly. While this anomaly may be due to buried glacial deposits, it matches up with a small fault found in a drainage between seismic lines. The fault, found in a pebbly sand of unit Qgd_p, has a strike similar to that of the 'fold' and may project to the tip of the fold axis at depth. We speculate that unit Qgd_p is likely of Possession age (MIS 4) or younger. It is possible that this deformation has a glaciotectonic origin, but we choose to show the fold and fault on the map as a tectonic feature with its "identity or existence questionable, location concealed". This anomaly also corresponds to a minor topographic break and an unusual waterfall to the west.

In the extreme southwest corner of the map, we used measured shears and slickensides in an unnamed drainage, along with geophysical anomalies, to interpret a queried fault trending to the southeast.

CROSS SECTION

The cross section that accompanies this map used seismic data acquired by Liberty (2008) and subsequently used in the work of Karel and Liberty (2008) and Lamb and others (2009)(Lamb, Boise State Univ., written commun, 2011). We primarily used the Feather-Minnig section when constructing our cross section, but also referred to the SR101 seismic profile. The time-migrated seismic data image from Karel and Liberty (2008) was georeferenced and stretched to four times vertical exaggeration. We calculated or approximated differences in apparent dip due to differences in orientation between the cross section and seismic line. We interpret the dominant upper reflector as a thick till or diamict of the Double Bluff glaciation (MIS 6). We inferred the geometry of the units below this reflector and, because of the image quality and vertical exaggeration, these units appear to dip more steeply than they actually do.

We used well-location information from Kitsap Public Utility District No. 1 (Martin Sebren, Kitsap PUD, written commun., 2010) and matched it with well-log data from the Washington Department of Ecology's (DOE) online well-log database. Generally, the wells used penetrated the nonglacial clay, silt, and sands of the Whidbey-age unit Qc_w. The wells used are labeled on the map and cross section with the DOE unique well identification number.

HOOD CANAL FAULT

The Hood Canal fault (Gower and others, 1985) is shown on the map as "identity or existence questionable, location concealed". It was digitized from Lidke and others (2003). We found no convincing evidence for the existence of this fault, but we chose to include it based on the work of others, specifically Haug (1998). We suspect that Hood Canal was filled with sediment prior to the Vashon Stade because older units appear continuous across the canal, including alpine glacial drift (Contreras and others, 2010; Polenz and others 2010a). However, units as young as MIS 4 (Possession age) typically appear to be dipping to the southeast on the Kitsap Peninsula in both the Lilliwaup (Contreras and others, 2010) and Holly 7.5-minute quadrangles.

DESCRIPTION OF MAP UNITS

We sought to show deposits of geotechnical and hydrological significance, generally requiring a thickness of at least 5 ft, although where deposits were stiff, impermeable, or geotechnically challenging (for example, till or peat), we locally mapped thinner deposits. In most areas, we relied considerably on geomorphology, field relations, and subsurface records. We used the Udden-Wentworth scale (Pettijohn, 1957) to classify unconsolidated sediments and Dickinson's (1970) terminology for sandstones, and we estimated consistency and apparent density using the suggested guidelines of the American Association of State Highway and Transportation Officials (1988). We used the time scale of the U.S. Geological Survey (USGS Geological Names Committee, 2010). We used a U.S. Geological Survey 7.5-minute topographic map as a base map and refined contact locations by referring to lidar (light detection and ranging), aerial photos, and field observations.

Quaternary Unconsolidated Deposits

HOLOCENE NONGLACIAL DEPOSITS

ml **Modified land**—Locally derived sediment ranging from clay to boulder gravel and diamicton; mixed and reworked by excavation and (or) redistribution that notably modifies topography; shown where fairly extensive, masking underlying geology, and geotechnically significant (>5 ft thick); excludes roads (except where connected to a larger modified area).

Qa **Alluvium**—Sand to cobble gravel, locally includes silt, clay, and peat; typically gray and generally unweathered; loose; subrounded clasts; moderately to well-sorted; stratified to massively bedded; deposited in stream valleys and estuaries, includes some lacustrine and beach deposits, and may include unrecognized older glacial outwash; derived from reworked glacial and nonglacial deposits.

Qb **Beach deposits**—Sand to boulder gravel with shells and driftwood; gray to brown-gray; moderately to well-rounded clasts; may be well-sorted; loose; derived from shore bluffs, streams, and underlying deposits. Many exposures are too small to show at map scale and underrepresented in favor of mapping more geologically significant units.

HOLOCENE TO LATEST PLEISTOCENE NONGLACIAL DEPOSITS

Qp **Peat**—Organic-rich sediment, including peat, muck, silt, and clay; dark brown to black; very soft to medium soft; typically in closed depressions. Unit Qp includes upland wetland areas and flat surfaces in closed depressions, unless a different unit or standing water was specifically identified or the deposit was too small to show at map scale. Where field data were unavailable, peat was mapped on the basis of topography, aerial photos, or prior mapping (Washington State Department of Natural Resources, GIS soils data layer, 2010). Unit Qp overlies Vashon Drift and older glacial deposits and is Holocene but may include some late-Pleistocene deposits.

Qls **Landslide and mass-wasting deposits**—Unsorted mixture of clay, silt, sand, and gravels (diamicton); angular to rounded clasts; loose or soft; unsorted to poorly sorted and nonstratified, but locally retains primary bedding; includes exposures of underlying units in scarp areas. Some landslides, such as that just south of Tekiu Point on Hood Canal, are large rotational slumps. This slide initiated in unit Qc_w and threatened the historic Willcox House mansion (http://www.willcoxhouse.com/). Absence of a mapped slide does not imply absence of sliding or hazard, as some slides are too small to show at map scale. Many previously mapped slides were not included in order to show underlying geology or because of lack of evidence of movement or different interpretation of landforms. It is difficult to distinguish landslides from slump features in ice-contact deposits (unit Qgic). Also not shown are the numerous debris flow chutes evident in the lidar elevation model. Several large landslides appear to be lateral spreads and may have been seismically induced. These landslides are typically restricted to areas north of Holly on the east side of the Hood Canal, where unit Qgd_p consists of well-sorted sand layers and sits upon unit Qc_w. Unit Qc_w also appears to fail in large rotational slumps. This unit is mostly Holocene but may include some late Pleistocene deposits.

Qaf **Alluvial fan**—Debris-flow diamicton and alluvial sand and gravel; gray, weathering to brownish-orange; loose; subrounded to rounded clasts; typically poorly to moderately sorted and massive to weakly stratified; forms concentric lobes where streams emerge from confining valleys and reduced gradient causes sediment to be deposited. Unit Qaf is predominantly Holocene but likely includes some late Pleistocene deposits. Debris flows and debris torrents may be a geologic hazard on some alluvial fans—the December 2007 storms added material to most fans in the map area. These deposits damaged homes and infrastructure and covered beaches and shellfish beds.

Qafo **Older alluvial fan**—Cobble and pebble gravel, sand, and rare boulders; gray to brown-gray; loose; subrounded to rounded clasts; mostly poorly sorted and stratified; forms concentric lobes where streams emerge from confining valleys. These fans are found primarily in the Dewatto River drainage, where undersized streams cannot effectively erode the fans. Most of these older fans likely developed as glacial ice melted, but some fans continue to build during extreme climatic events.

Qoa **Older alluvium**—Sand and silt with lesser gravelly sand, sandy pebble gravel, peat, and organic detritus; gray to brown-gray and blue-gray; loose; subrounded to rounded clasts; well-stratified and well-sorted. This alluvium makes terraces above modern stream channels in every drainage in the north half of the map area on the Kitsap Peninsula. These terraces commonly have wood and organic material just above modern stream level. ^{14}C ages indicate that these deposits filled outwash channels at various times throughout the Holocene. Three samples dated from these deposits provided age estimates of 1400 ±40, 3020 ±50, and 5680 ±40 yr B.P. and may provide clues to the dates of earthquakes in the area. See the supplement (Contreras and others, 2012) for additional information on Holocene terraces. This unit is also mapped along the Dewatto River in the southwest corner of the map area, but does not appear to form terraces; this may be due to the stream being underfit.

PLEISTOCENE GLACIAL AND NONGLACIAL DEPOSITS

Recessional Deposits of the Fraser Glaciation (Northern and Olympic Sources)

Mapped recessional deposits of the Fraser Glaciation consist of units Qao, Qgo, Qgog and Qgic. Unit Qao is included in the recessional deposits, because it appears on top of Vashon Stade glacial deposits of northern source, but it is the result of alpine glacial and likely nonglacial, a result of transport of glacially derived material from the Olympics.

Haugerud (2009a,b) and Porter and Carson (1971) noted that deglaciation at the end of the Vashon Stade in the southern Puget Lowland probably began with stagnation of the Puget lobe, where the ice thinned, stopped moving, and melted in place, resulting in preservation of subglacial drainage and other ice-contact features. This is consistent with our observations in the map area and with recent mapping by Polenz and others (2009a,b), Derkey and others (2009), and Contreras and others (2010) in adjacent and nearby quadrangles.

Qao **Vashon-age recessional Olympic-sourced outwash (late Pleistocene and Holocene)**—Fluvial cobble to pebble gravel and pebbly sand and minor silt beds; brown-gray, weathering to red-brown; subangular to subrounded clasts; loose; moderately to well-sorted; crudely stratified beds typical; clasts predominantly basalt; makes large fans on the west side of Hood Canal.

Qgo **Vashon recessional outwash (late Pleistocene)**—Fluvial cobble to pebble gravel and pebbly sand and minor silt beds; gray, weathering to tan; subangular to rounded clasts; loose and generally less compact than advance outwash (unit Qga); moderately to well-sorted; crudely stratified beds typical; derived from both northern and local sources; a few feet to tens of feet thick. Unit Qgo was deposited by glacial meltwater in outwash channels (supraglacially or subglacially) and isolated basins on the fluted upland surface as the Vashon glacial ice melted. Some deposits are ice-proximal and difficult to separate from unit Qgic, resulting in gradational boundaries between units Qgic and Qgo. Locally divided into:

Qgog **Vashon recessional outwash gravels (late Pleistocene)**—Fluvial cobble to pebble gravel: gray; subangular to subrounded clasts; loose and generally less compact than advance outwash (unit Qga); moderately to well-sorted; horizontally stratified beds typical; derived from both northern and local sources; tens of feet thick. Unit Qgog is exposed east of Anderson Cove and is used as an aggregate source. It was deposited by glacial meltwater, possibly subglacially as with unit $Qgog_e$ on Whidbey Island (Polenz and others, 2005).

Qgic **Vashon ice-contact deposits**—Diamicton, cobbly pebble gravel, silty sandy till, silty pebble gravel, and pebbly sand, with lesser sand and silt; yellow-tan to gray; loose to very dense; subangular to rounded clasts; variously sorted; massive to well-stratified; accompanied by stagnant-ice features, such as kettles, hummocky topography, eskers (separately mapped as unit Qge where distinct), and subglacial or subaerial outwash channels; formed in the presence of meltwater alongside, in, on, or above ice. Where mapped on fluted uplands that lack more recognizable stagnant-ice features, unit Qgic is commonly a friable but compact, subglacial melt-out till that appears permeable. Unit Qgic ranges in thickness from a few feet to tens of feet and is mapped over a large extent of the fluted upland surface. It crudely corresponds to areas mapped by Haugerud (2009b) as rippled fluted glaciated surface (unit gfr). Unit Qgic was also found in outcrops too small to depict at map scale near Holly in what appear to be ice-contact slump features. As Haugerud (2005) noted on Bainbridge Island, unit Qgic appears directly on top of older material or locally on advance glacial deposits, and does not have Vashon-age lodgment till beneath. In the southern portion of this map area, unit Qgic appears to be in contact with older northern-sourced glacial till, speculated to be as old or older than MIS 6 (Double Bluff age). Though found in fluted drumlins (indicating subglacial emplacement and likely the same age as unit Qgt), unit Qgic is typically a diamict, without subhorizontal foliation, and is permeable and less competent than a 'standard' subglacial lodgment till. It may be related to tills found by Laprade (2003) around Seattle. See additional discussion in the supplement (Contreras and others, 2012). Locally divided into:

Qge **Vashon eskers**—Pebble to cobble gravel and sand; tan to brown; moderately to well-rounded clasts; loose; typically well-sorted; high porosity and permeability; forms low, elongate, sinuous hills; deposited subglacially or englacially by Vashon meltwater in areas occupied by stagnant ice; mapped in nearby quadrangles as well (Polenz and others, 2009a,b; Derkey and others, 2009).

Proglacial and Subglacial Deposits of the Vashon Stade of the Fraser Glaciation

Qgt **Vashon lodgment till**—Mixture of sand, pebbles, cobbles, silt, and clay (diamicton); gray, weathering to yellow-orange; subangular to rounded clasts, from both northern and Olympic sources; striated and faceted clasts common; very compact; unsorted and unstratified; may contain angular clasts where directly overlying local bedrock. Lodgment till is typically supported by a sandy-silty matrix and is unweathered, but near the surface it is slightly oxidized and jointed as a result of weathering and desiccation. It is typically covered by 1 to 6 ft of loose ablation till or rounded outwash gravel. Some exposures include beds and lenses of sand and gravel, locally with an ice-shear foliation. Unit Qgt thickness ranges from 1 to 20 ft, but it is commonly less than 5 ft thick. Till is typically found on the fluted upland surfaces where the drumlins appear smooth, wide, and well defined. Unit Qgt is typically in sharp, unconformable contact with underlying units, most commonly advance outwash gravels (unit Qga). Unit Qgt may include unrecognized exposures of older till.

Qga **Vashon advance outwash**—Sandy gravel, sand, and sandy pebble to cobble gravel; gray to tan, with some light orange oxidized zones; dense; subrounded to well-rounded clasts, northern-sourced; mainly well-sorted and well-stratified, with ice-proximal deposits that are poorly sorted; thinly to very thickly bedded; contains planar, graded beds, cut-and-fill structures, crossbeds, and foresets; up to 200 ft thick. Unit Qga is restricted to the northeast corner of the map area where it appears to be in unconformable contact with units Qc_w or Qgd_p and is prone to mass wasting. Near Holly, this unit is assumed to be of Vashon age, but it could be older and may be as old as MIS 4 (Possession age). The unit appears to have been deposited in a proglacial fluvial, deltaic, and lacustrine environment during the Vashon glacial advance. Due to limited exposures and stratigraphic constraints, this unit may be more extensive than mapped. Unit Qga is typically overlain by unit Qgic.

Pre-Fraser Glacial and Nonglacial Deposits

Prior to the Vashon Stade of the Fraser Glaciation, both Cordilleran and Olympic glaciers deposited sediment in the map area. Previous mapping suggests that stratigraphic relations are important; it is difficult to determine age using weathering alone (Deeter, 1979). We relied on the optically stimulated luminescence (OSL) age estimate in the extensive nonglacial unit Qc_w to interpret stratigraphy in the northern portion of the map area. It supported our assertion that overlying, poorly exposed glacial drift that appeared more oxidized than Fraser-age deposits is likely Possession in age.

Unit Qc_w is generally absent south of Anderson Creek; instead, a well-developed, slightly weathered, brown northern-sourced glacial diamict, 40 to 70 ft thick, appears directly under Fraser age deposits. We tentatively assign this diamict to MIS 6 (Double Bluff age), but we have no age control for this assertion. This unit could be much older. We relied on the seismic data from Karel and Liberty (2008) to trace a prominent reflector under unit Qc_w and inferred that it reaches the surface where this unit is mapped.

We analyzed thin sections of various samples to determine the sediment source, but we ended up lumping many of the older units south of Anderson Creek as “pre-Fraser glacial and nonglacial deposits, undivided” due to the complex mix of sediment sources, glacial and nonglacial deposits, and multiple well-developed paleosols and deep weathering. Where we were able to consistently differentiate northern-sourced material, we did so with unit Qgpc.

We tentatively correlate the oldest glacial deposits within unit $Qguc_1$ with the Annas Bay and Clark Creek Drifts (Easterbrook and others, 1988; Birdseye and Carson, 1989) at Capstan Rock, approximately 1 mi southwest of the southwest map corner.

Pre-Fraser glacial deposits tentatively correlated with Marine Isotope Stage (MIS) 4 (Possession age)

Qgd_p **Glacial drift of MIS 4 (Possession age), undivided**—Sand, sandy pebble gravel, and diamicton; brown to gray and red-brown; compact; coarsens upward from sand to pebble gravel and diamicton; subrounded to rounded clasts; moderately to well-sorted and well-stratified; medium- to thickly bedded. Deposits include metamorphic and granitic clasts, indicating a northern source. Unit Qgd_p is up to approximately 150 ft thick and is found in exposures north of Anderson Creek on the Kitsap Peninsula, above the nonglacial unit Qc_w where it may be prone to landslides and liquefaction and may fail in large lateral spreads during large earthquakes. Exposures of lodgment till are rare and are typically found directly under Vashon till, so without age control it is difficult to discern younger or older sands and silts of MIS 3 and 5 (Olympia- and Whidbey-age); therefore this unit may inadvertently include deposits of these ages. It is possible that this unit is exposed on the west side of Hood Canal, but it is not exposed well enough to confidently discern this. At rare locations where we were able to satisfactorily constrain stratigraphy, Possession-age till is shown as line or point unit and divided into:

Qgt_p **Glacial till of MIS 4 (Possession age)(line unit)—**Sand, pebbles, cobbles, silt, and clay (diamicton); light brown to gray with some oxide staining; subangular to rounded clasts; very dense; unsorted and unstratified; includes polycrystalline quartz and metamorphic and granitic clasts, implying a northern source. This thin (<5 ft thick) till is found north of Anderson Creek beneath Vashon-age deposits on the Kitsap Peninsula and is depicted on the map only where we can confidently constrain stratigraphy.

$Qguc_2$ **Pre-Fraser glacial and nonglacial deposits, undivided**—Predominantly sandy pebble to cobble gravels and diamicton; brown-gray and red-brown; subrounded to rounded clasts of both Olympic and northern glacial sources and minor nonglacial silts and sands; stratified; dense and stiff. Unit $Qguc_2$ was scoured and fluted by Fraser-age glaciation and is restricted to the west side of Hood Canal. It is typically above unit Qgd_d, but it may also include small exposures of unit Qgd_d. Unit $Qguc_2$ is tentatively mapped as younger than MIS 6 (Double Bluff age), but no age control is available.

Pre-Fraser nonglacial deposits of MIS 5 (Whidbey age)

Qc_w **Nonglacial prodelta deposits**—Sand, silt, and clay with rare pebble gravel; light brown to gray; some strata contain disseminated detrital wood, tephra, dacite lithics, a dacite-rich diamicton, and rare Olympic-sourced sandy pebble to cobble gravel; subangular to subrounded clasts typical, with rare subangular (very fine) pebble gravel of volcanic lithics; dense and stiff; mostly well-stratified and well-sorted; thinly laminated to very thickly bedded. Some portions of this unit are rhythmically bedded sands, silts, and clays. Some sands have ripple cross bedding indicating a transport direction to the southwest, and some beds show soft sediment deformation (flame structures). Unit Qc_w appears to have an average thickness of 250 ft and extends to approximately 100 ft below sea level in the northern portion of the map area, but on Tekiu Point it may be more than 400 ft thick. This unit is found in the bottom of drainages in the map area north of Anderson Creek. It appears to represent a distal prodelta that received sand, silt, and a few layers of very fine pebbles and dacite-rich diamicton from drainages near Glacier Peak, suggesting extensive delta building from the North Cascades during MIS 5. These exposures are 25 to 30 mi farther southwest than previously mapped Whidbey Formation (Peterson, 2007). Rare contact relations suggest that thin, discontinuous oxidized glacial till and drift (predominantly advance sand) exist above this unit and are of MIS 4 (Possession) age. The base of this unit is not exposed in the map area; well reports and seismic data suggest glacial drift of MIS 6 (Double Bluff age) may be present below it. The laminated clay within unit Qc_w appears to make it a hydrologic barrier, causing springs to appear at the top of the unit. Franklin Foit (Wash. State Univ., written commun., 2011) analysed the tephra from this study and concluded that there is a good correlation with an older Mount St. Helens C–like tephra from Carp Lake (Whitlock and others, 2000), which has an age of approximately 100 ka. A single luminescence age from this study of 82.5 ±3.89 ka coincides with Berger and Easterbrook's (1993) ages for the Whidbey Formation of Easterbrook and others (1967). Locally divided into:

Qvc **Volcaniclastic deposit from Glacier Peak**—Diamicton and layers of dacite clasts (sand to cobble and rare small boulder) in laminated sand, silt, and clay; tan to light gray; subangular to moderately rounded clasts; stiff; poorly sorted with lenses of dacite sand to cobble gravel. Diamicton is a massive unit with chaotic lenses of sandy pebble to cobble gravel consisting primarily of hornblende dacite but also rare granitic rocks and basalt. The diamicton is clay rich. Laterally adjacent to the diamicton are laminated silts and sands that include dropstones and iceberg dumps of dacite debris. Geochemical data from glass, bulk rock, and bulk pumice samples indicate a Glacier Peak source and are very similar to those reported by Dragovich and others (2005) for Whidbey Island. The diamicton is up to 90 ft thick, and adjacent laminated sands and silts with dacite clasts are more than 30 ft thick. Unit Qvc is found between Anderson Creek and Nellita and in an isolated landslide deposit approximately 3000 ft northeast of Nellita along the shore of Hood Canal. We speculate that the depositional environment may be a prodelta. Currently we are unsure what this diamicton may represent; hypotheses include glacial marine drift as MIS 4 (Possession age) glaciation begins, a submarine debris flow, or a lahar runout over Puget lobe ice. This unit is deposited on interbedded sands, silts, and clay of MIS 5 (Whidbey age) deposits; above, it may grade into deposits of MIS 4 (Possession age). The dropstones within this deposit may indicate the presence of Cascade alpine glacial icebergs, either due to an advance of glacial ice or a jökulhlaup (catastrophic glacial outburst flood). This deposit is approximately 150 ft above the OSL sample dated at 82.5 ±3.89 ka taken at Anderson Creek. See additional data and interpretation in the supplement (Contreras and others, 2012).

Pre-Fraser glacial deposits tentatively correlated with MIS 6 (Double Bluff age)

Qgo_d **Northern-sourced drift (cross section only)**—Outwash gravels below nonglacial unit Qc_w; found in water wells and interpreted from seismic data (Lamb, written commun., 2011). Unit Qgo_d is tentatively correlated with MIS 6 (Double Bluff age) recessional outwash, but could be older or part of the nonglacial unit Qc_w above.

Qgt_d **Northern-sourced lodgment till**—Sand, pebbles, cobbles, silt, and clay (diamicton); brown-gray; subangular to rounded clasts; very dense; unsorted and unstratified; includes polycrystalline quartz and metamorphic and granitic clasts, implying a northern source. This 20- to 70-ft-thick glacial diamicton is found on the Kitsap Peninsula. It is in unconformable contact under Vashon-age glacial deposits south of Seabeck-Holly Road, but it is absent at the surface north of an inferred strand of the Seattle fault on the Kitsap Peninsula. In the cross section, unit Qgt_d is inferred from seismic surveys by Liberty (2008), Karel and Liberty (2008), and Lamb (written commun., 2011). Below this unit are northern-sourced glacial advance pebble gravel, sand, and silt that are likely related to this glacial deposit, but due to the difficulty in mapping these thin layers of advance material, they have been grouped in unit Qgpc below. Unit Qgt_d is tentatively correlated with MIS 6 (Double Bluff age), but it could be older. It is also shown as a point unit in the southeast corner of the map.

Qgd_d **Glacial drift of MIS 6 (Double Bluff age), undivided**—Sand, sandy pebble gravel, and diamicton; brown to gray; subrounded to rounded metamorphic and granitic clasts, indicating a northern source; compact; moderately to well-sorted and well-stratified; medium- to thickly bedded; coarsens from sand to pebble gravel and diamicton. Unit Qgdd is approximately 30 to 60 ft thick and is found in exposures along and south of Anderson Creek on the east side of Hood Canal and in the Fulton Creek drainage on the west side of the canal. On the Kitsap Peninsula, it is found above unit Qgpc where a paleosol exists, separating glacial advances or glaciations. In the Fulton Creek drainage, it includes advance outwash deposits and a lodgment till and is deposited on top of unit Qapd. It is likely MIS 6 in age, but the only age control is an infinite ^{14}C age estimate.

Pre-Fraser glacial and nonglacial deposits older than MIS 6 (Double Bluff age)

Qguc1 **Pre-Fraser glacial and nonglacial deposits, undivided**—Sandy pebble gravel and cobble gravel with interstitial alteration clay and minor beds of diamicton, sand, silt, and paleosols; orange-brown with buff interstitial clay and gray nonglacial silt; mostly subrounded clasts; dense and very stiff; poorly to moderately sorted; poorly stratified to massive; predominantly glacial deposits (outwash and diamicts) of both Olympic and northern sources with minor nonglacial deposits. This unit includes at least two Olympic- and northern-sourced glacial tills and four or more saprolitized paleosols. Where they are extensive and can be field verified, these paleosols are shown as line units. As mapped, unit Qguc1 has an exposed thickness of more than 450 ft on the Kitsap Peninsula, but its total thickness is unknown. Unit Qguc1 is exposed in the drainages of Anderson Creek and creeks to the south on the Kitsap Peninsula and on the west side of Hood Canal in the Fulton Creek drainage, but some exposures allowed us to separate units. Lower sediments in this unit are likely magnetically reversed, like those found at the Capstan Rock section of Easterbrook and others (1988) approximately 1 mi southwest of the southwest map corner. Where we were able to differentiate these deposits, divided into:

Qgpc **Pre-Fraser northern-sourced glacial drift, undivided**—Predominantly glacial, outwash sands and pebble gravels with diamicton; slightly brown-gray to gray; metamorphic and granitic clasts, indicating a northern source; dense to very dense; moderately to well-sorted and well-stratified; medium- to thickly bedded with beds of diamicton. Unit Qgpc is about 120 ft thick and is found in exposures at Anderson Creek on the Kitsap Peninsula, where it is below unit Qgtd. This unit includes minor nonglacial silt and peat and at least one paleosol, implying multiple glacial advances. Unit Qgpc is likely older than MIS 6, but we have no age estimates.

paleosol **Pre-Fraser paleosol (line unit)**—Buried soil horizon and (or) deeply weathered surface indicating prolonged subaerial exposure; identity and existence certain, location accurate.

Qgpt **Pre-Fraser northern-sourced glacial till (line unit)**—Lodgment till or diamict; brown-gray; very dense; subangular to rounded clasts; unsorted and unstratified; includes polycrystalline quartz, metamorphic and granitic clasts, implying a northern source. This till is approximately 3 ft thick in its limited exposures. Unit Qgpt is found within unit Qguc1 along the bluffs above Hood Canal south of Holly. Unit Qgpt is tentatively correlated with the Annas Bay Drift—part of the Capstan Rock section of Easterbrook and others (1988) approximately 1 mi southwest of the southwest map corner. This unit appears to interfinger with the Clark Creek Drift, but may be younger than the Annas Bay Drift at Capstan Rock because it appears to be stratigraphically above the Capstan Rock section and paleosols suggest that multiple glacial episodes are responsible for these deposits.

Qapt **Pre-Fraser Olympic-sourced glacial till (line unit)**—Alpine till; brown-gray; very dense; subangular clasts, primarily of basalt and feldspathic sandstone, implying an Olympic source; unsorted and unstratified. This till is approximately 2 to 5 ft thick in the limited exposures. Unit Qapt is found within unit Qguc1 along the bluffs of Hood Canal south of Holly. We correlate the lower portions of unit Qapt with the Clark Creek Drift of Easterbrook and others (1988) and postulate that these sediments are magnetically reversed. This unit appears to interfinger with the northern-sourced drift in the area, but paleosols (recognized or unrecognized) suggest that multiple glacial episodes are responsible for these deposits.

Qp_{pf} **Pre-Fraser peat (line unit)**—Organic-rich sediment, including peat, muck, silt, and clay; dark gray to black; very stiff to hard; well-bedded and well-stratified; typically laminated and in compressed beds up to 0.8 ft thick. This unit is found near the lower exposures of unit $Qguc_1$ along the eastern shore of Hood Canal near Holly. Plant material is well preserved and appears to represent a nonglacial environment. Unit Qp_{pf} is tentatively correlated with peats found by Birdseye and Carson (1989) above the Clark Creek Drift of Easterbrook and others (1988). While we did not find a tephra associated with these peats, on the basis of their geographic relation to Birdseye and Carson's stratigraphic column 4, we suggest they are likely magnetically reversed.

Qapd **Pre-Fraser Olympic-sourced glacial drift, undivided**—Sandy pebble to cobble gravel and diamict; orange-brown to gray; subrounded to subangular clasts; dense; predominantly poorly stratified to massive; poorly to moderately sorted. Clasts are dominantly basalt and sandstone with minor polycrystalline quartz and are very weathered. Unit Qapd is as much as 110 ft thick in the Fulton Creek drainage and lies on saprolitized basalts of the Crescent Formation. This unit appears to represent alpine glacial outwash and till and is likely older than MIS 6, but we have no age control.

Tertiary Sedimentary and Volcanic Rocks

Em_{1c} **Siltstone and sandstone (lower to middle Eocene)**—Marine siltstone and feldspathic sandstone; dark gray to green-gray; fine- to coarse-grained; angular to subrounded grains; moderately to well-sorted and well-bedded; thin to massive. Grains are dominantly quartz with some feldspars and are altered to chlorite and other clay minerals. The unit is 600 to 800 ft thick and is found in drainages within a mile north and south of Triton Head. Unit Em_{1c} appears to be an interbed of the Crescent Formation (unit Ev_c), is bounded on the top and bottom by basalts, and dips approximately 40 degrees east. However, faulting may have placed these units in contact; some siltstones are highly deformed into chevron folds and locally faulted with fault gouge up to 5 ft thick. The unit is locally fossiliferous and includes serpulid and echinoid fossils.

Ev_c **Crescent Formation (lower to middle Eocene)**—Basalt; black to greenish black in unweathered exposures, gray and medium yellow-brown in weathered exposures; commonly occurs as fine-grained blocky sills and pillows; commonly includes amygdules of zeolite- and chlorite-group minerals. Flows are locally pillowed and include palagonitized breccias. Mineralogy typically includes plagioclase with intergrowths of pyroxenes and disseminated opaque minerals. Replacement of interstitial glass by chlorite and oxidation products is also common. Unit Ev_c crops out in gorges in the northwest corner of the map area and is likely part of the upper Crescent Formation. It contains rare faulted thin interbeds of siltstone.

SIGNIFICANT SITES

See the discussion of significant sites in the supplement (Contreras and others, 2012).

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REFERENCES CITED

American Association of State Highway and Transportation Officials, 1988, Manual on subsurface investigations, 1988: American Association of State Highway and Transportation Officials, Inc., 391 p. [http://www.sil.ucdavis.edu/downloads/NHI_SI_Manual.pdf]

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.

Birdseye, R. U.; Carson, R. J., 1989, Tephra of Salmon Springs age from the southeastern Olympic Peninsula, Washington: Washington Division of Geology and Earth Resources Open File Report 74-1 (revised), 23 p. [http://www.dnr.wa.gov/publications/ger_ofr74-1_tephra_olympic_peninsula.pdf]

Blakely, R. J.; Sherrod, B. L.; Hughes, J. F.; Anderson, M. L.; Wells, R. E.; Weaver, C. S., 2009, Saddle Mountain fault deformation zone, Olympic Peninsula, Washington—Western boundary of the Seattle uplift: Geosphere, v. 5, no. 2, p. 105-125.

Blakely, R. J.; Wells, R. E.; Weaver, C. S.; Johnson, S. Y., 2002, Location, structure, and seismicity of the Seattle fault zone, Washington—Evidence from aeromagnetic anomalies, geologic mapping, and seismic-reflection data: Geological Society of America Bulletin, v. 14, no. 2, p. 169-177.

Brocher, T. M.; Blakely, R. J.; Wells, R. E., 2004, Interpretation of the Seattle uplift, Washington, as a passive-roof duplex: Seismological Society of America Bulletin, v. 94, no. 4, p. 1379-1401.

Carson, R. J., 1976a, Geologic map of north-central Mason County, Washington: Washington Division of Geology and Earth Resources Open File Report 76-2, 1 sheet, scale 1:62,500. [http://www.dnr.wa.gov/publications/ger_ofr76-2_geol_map_mason_co_62k.pdf]

Carson, R. J., 1976b, Preliminary geologic map of the Brinnon area, Jefferson County, Washington: Washington Division of Geology and Earth Resources Open File Report 76-3, 1 sheet, scale 1:24,000. [http://www.dnr.wa.gov/publications/ger_ofr76-3_geol_map_ brinnon_24k.pdf]

Clark, K. P., 1989, The stratigraphy and geochemistry of the Crescent Formation basalts and the bedrock geology of associated igneous rocks near Bremerton, Washington: Western Washington University Master of Science thesis, 171 p., 1 plate.

Contreras, T. A.; Legorreta Paulin, Gabriel; Czajkowski, J. L.; Polenz, Michael; Logan, R. L.; Carson, R. J.; Mahan, S. A.; Walsh, T. J.; Johnson, C. N.; Skov, R. H., 2010, Geologic map of the Lilliwaup 7.5-minute quadrangle, Mason County, Washington: Washington Division of Geology and Earth Resources Open File Report 2010-4, 13 p., 1 plate, scale 1:24,000. [http://www.dnr.wa.gov/ Publications/ger_ofr2010-4_geol_map_lilliwaup_24k.zip]

Contreras, T. A.; Weeks, S. A.; Perry, B. B., 2012, Analytical data from the Holly 7.5-minute quadrangle, Jefferson, Kitsap, and Mason Counties, Washington—Supplement to Open File Report 2011-5: Washington Division of Geology and Earth Resources Open File Report 2011-6, 16 p. [http://www.dnr.wa.gov/Publications/ger_ofr2011-6_holly_supplement_24k.pdf]

Deeter, J. D., 1979, Quaternary geology and stratigraphy of Kitsap County, Washington: Western Washington University Master of Science thesis, 175 p., 2 plates.

Derkey, R. E.; Heheman, N. J.; Alldritt, Katelin, 2009, Geologic map of the Lake Wooten 7.5-minute quadrangle, Mason County, Washington: Washington Division of Geology and Earth Resources Open File Report 2009-5, 1 sheet, scale 1:24,000. [http://www.dnr.wa.gov/Publications/ger_ofr2009-5_geol_map_lakewooten_24k.pdf]

Dickinson, W. R., 1970, Interpreting detrital modes of greywacke and arkose: Journal of Sedimentary Petrology, v. 40, no. 2, p. 695-707.

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. [http://www.dnr.wa.gov/Publications/ger_gm59_geol_map_oakharbor_ crescentharbor_24k.zip]

Easterbrook, D. J.; Crandell, D. R.; Leopold, E. B., 1967, Pre-Olympia Pleistocene stratigraphy and chronology in the central Puget Lowland, Washington: Geological Society of America Bulletin, v. 78, no. 1, p. 13-20.

Easterbrook, D. J.; Roland, J. L.; Carson, R. J.; Naeser, N. D., 1988, Application of paleomagnetism, fission-track dating, and tephra correlation to lower Pleistocene sediments in the Puget Lowland, Washington. *In* Easterbrook, D. J., editor, Dating Quaternary sediments: Geological Society of America Special Paper 227, p. 139-165.

Garling, M. E.; Molenaar, Dee; and others, 1965, Water resources and geology of the Kitsap Peninsula and certain adjacent islands: Washington Division of Water Resources Water-Supply Bulletin 18, 309 p., 5 plates. [http://www.ecy.wa.gov/programs/eap/wsb/wsb_All.html]

Gower, H. D.; Yount, J. C.; Crosson, R. S., 1985, Seismotectonic map of the Puget Sound region, Washington: U.S. Geological Survey Miscellaneous Investigations Series Map I-1613, 1 sheet, scale 1:250,000, with 15 p. text.

Haeussler, P. J.; Clark, K. P., 2000, Preliminary geologic map of the Wildcat Lake 7.5′ quadrangle, Kitsap and Mason Counties, Washington: U.S. Geological Survey Open-File Report 00-356, 1 sheet, scale 1:24,000. [http://pubs.er.usgs.gov/usgspubs/ofr/ofr00356]

Haug, B. J., 1998, High resolution seismic reflection interpretations of the Hood Canal–Discovery Bay fault zone; Puget Sound, Washington: Portland State University Master of Science thesis, 1 v.

Haugerud, R. A., 2005, Preliminary geologic map of Bainbridge Island, Washington: U.S. Geological Survey Open-File Report 2005-1387, version 1.0, 1 sheet, scale 1:24,000. [http://pubs.usgs.gov/of/2005/1387]

Haugerud, R. A., 2009a, Deglaciation of the southern Salish lowland [abstract]. *In* Northwest Scientific Association, The Pacific Northwest in a changing environment—Northwest Scientific Association 81st annual meeting; Program with abstracts: Northwest Scientific Association, p. 27-28.

Haugerud, R. A., 2009b, Preliminary geomorphic map of the Kitsap Peninsula, Washington; version 1.0: U.S. Geological Survey Open-File Report 2009-1033, 2 sheets, scale 1:36,000. [http://pubs.usgs.gov/of/2009/1033/]

Jones, M. A., 1996, Thickness of unconsolidated deposits in the Puget Sound lowland, Washington and British Columbia: U.S. Geological Survey Water-Resources Investigations Report 94-4133, 1 sheet.

Karel, Patrick; Liberty, L. M., 2008, The western extension of the Seattle fault—New insights from seismic reflection data [poster]: American Geophysical Union Fall Meeting 2008, poster T21B-1951.

Lamb, A. P.; Liberty, L. M.; Blakely, R. J.; van Wijk, Kasper, 2009, The Tahuya lineament—Southwestern extension of the Seattle fault? [abstract]: Geological Society of America Abstracts with Programs, v. 41, no. 7, p. 479.

Laprade, W. T., 2003, Subglacially reworked till in the Puget Lowland [abstract]: Geological Society of America Abstracts with Programs, v. 35, no. 6, p. 216.

Liberty, L. M., 2008, The western extension of the Seattle fault—New insights from seismic reflection data: U.S. Geological Survey, External research support—Final technical reports—Funded research, Pacific Northwest: 14 p. [http://earthquake.usgs.gov/research/ external/reports/08HQGR0075.pdf]

Lidke, D. J.; Johnson, S. Y.; McCrory, P. A.; Personius, S. F.; Nelson, A. R.; Dart, R. L.; Bradley, Lee-Ann; Haller, K. M.; Machette, M. N., 2003, Map and data for Quaternary faults and folds in Washington State: U.S. Geological Survey Open-File Report 03-428, 1 sheet, scale 1:750,000, with 15 p. text. [http://pubs.usgs.gov/of/2003/428]

Morrison, R. B., editor, 1991, 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.

Peterson, Jonathan, 2007, Petrographic signature for the Whidbey Formation: Western Washington University Master of Science thesis, 157 p.

Pettijohn, F. J., 1957, Sedimentary rocks; 2nd ed.: Harper & Brothers, 718 p.

Polenz, Michael; Alldritt, Katelin; Heheman, N. J.; Logan, R. L., 2009a, Geologic map of the Burley 7.5-minute quadrangle, Kitsap and Pierce Counties, Washington: Washington Division of Geology and Earth Resources Open File Report 2009-8, 1 sheet, scale 1:24,000. [http://www.dnr.wa.gov/Publications/ger_ofr2009-8_geol_map_burley_24k.pdf]

Polenz, Michael; Alldritt, Katelin; Heheman, N. J.; Sarikhan, I. Y.; Logan, R. L., 2009b, Geologic map of the Belfair 7.5-minute quadrangle, Mason, Kitsap, and Pierce Counties, Washington: Washington Division of Geology and Earth Resources Open File Report 2009-7, 1 sheet, scale 1:24,000. [http://www.dnr.wa.gov/Publications/ger_ofr2009-7_geol_map_belfair_24k.pdf]

Polenz, Michael; Czajkowski, J. L.; Legorreta Paulin, Gabriel; Contreras, T. A.; Miller, B. A.; Martin, M. E.; Walsh, T. J.; Logan, R. L.; Carson, R. J.; Johnson, C. N.; Skov, R. H.; Mahan, S. A.; Cohan, C. R., 2010a, Geologic map of the Skokomish Valley and Union 7.5-minute quadrangles, Mason County, Washington: Washington Division of Geology and Earth Resources Open File Report 2010-3, 1 sheet, scale 1:24,000, with 21 p. text. [http://www.dnr.wa.gov/Publications/ger_ofr2010-3_geol_map_skokomish_valley_union_24k.zip]

Polenz, Michael; Miller, B. A.; Contreras, T. A.; Czajkowski, J. L.; Legorreta Paulin, Gabriel; Martin, M. E.; Logan, R. L.; Carson, R. J.; Johnson, C. N.; Skov, R. H.; Mahan, S. A.; Cohan, C. R., 2010b, Supplement to the geologic maps of the Lilliwaup, Skokomish Valley, and Union 7.5-minute quadrangles, Mason County, Washington—Geologic setting and development around the Great Bend of Hood Canal: Washington Division of Geology and Earth Resources Open File Report 2010-5, 27 p. [http://www.dnr.wa.gov/Publications/ger_ofr2010-5_lilliwaup_skokomish_valley_union_suppl_24k.pdf]

Polenz, Michael; Slaughter, S. L.; Dragovich, J. D.; Thorsen, G. W., 2005, 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. [http://www.dnr.wa.gov/Publications/ger_ofr2005-2_geol_map_ebeyslanding_24k.zip]

Porter, S. C.; Carson, R. J., 1971, Problems of interpreting radiocarbon dates from dead-ice terrain, with an example from the Puget Lowland of Washington: Quaternary Research, v. 1, no. 3, p. 410-414.

Reeve, William, 1979, Bedrock geology of the Blue Hills, Kitsap County, Washington: Colorado School of Mines Master of Science thesis, 58 p., 1 plate.

Sarikhan, I. Y.; Walsh, T. J.; Cakir, Recep, 2007, Morphology of the Alderwood landslide—A probable origin for tsunami in Lynch Cove, Puget Sound, Washington [abstract]: Geological Society of America Abstracts with Programs, v. 39, no. 4, p. 31.

Sceva, J. E., 1957, Geology and ground-water resources of Kitsap County, Washington: U.S. Geological Survey Water-Supply Paper 1413, 178 p., 3 plates. [http://pubs.er.usgs.gov/usgspubs/wsp/wsp1413]

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

U.S. Geological Survey Geologic Names Committee, 2010, Divisions of geologic time—Major chronostratigraphic and geochronologic units: U.S. Geological Survey Fact Sheet 2010-3059, 2 p. [http://pubs.usgs.gov/fs/2010/3059/]

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

Washington Department of Ecology, 1979, Coastal zone atlas of Washington; volume 10, Kitsap County: Washington Department of Ecology, 1 v., maps, scale 1:24,000.

Washington Department of Ecology, 1980, Coastal zone atlas of Washington; volume 9, Mason County: Washington Department of Ecology, 1 v., maps, scale 1:24,000.

Whitlock, C.; Sarna-Wojcicki, A. M.; Bartlein, P. J.; Nickmann, R. J., 2000, Environmental history and tephrostratigraphy at Carp Lake, southwestern Columbia Basin, Washington, USA: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 155, no. 1-2, p. 7-29.

Yount, J. C.; Gower, H. D., 1991, Bedrock geologic map of the Seattle 30′ by 60′ quadrangle, Washington: U.S. Geological Survey Open-File Report 91-147, 37 p., 4 plates.

Yount, J. C.; Minard, J. P.; Dembroff, G. R., 1993, Geologic map of surficial deposits in the Seattle 30' x 60' quadrangle, Washington: U.S. Geological Survey Open-File Report 93-233, 2 sheets, scale 1:100,000.