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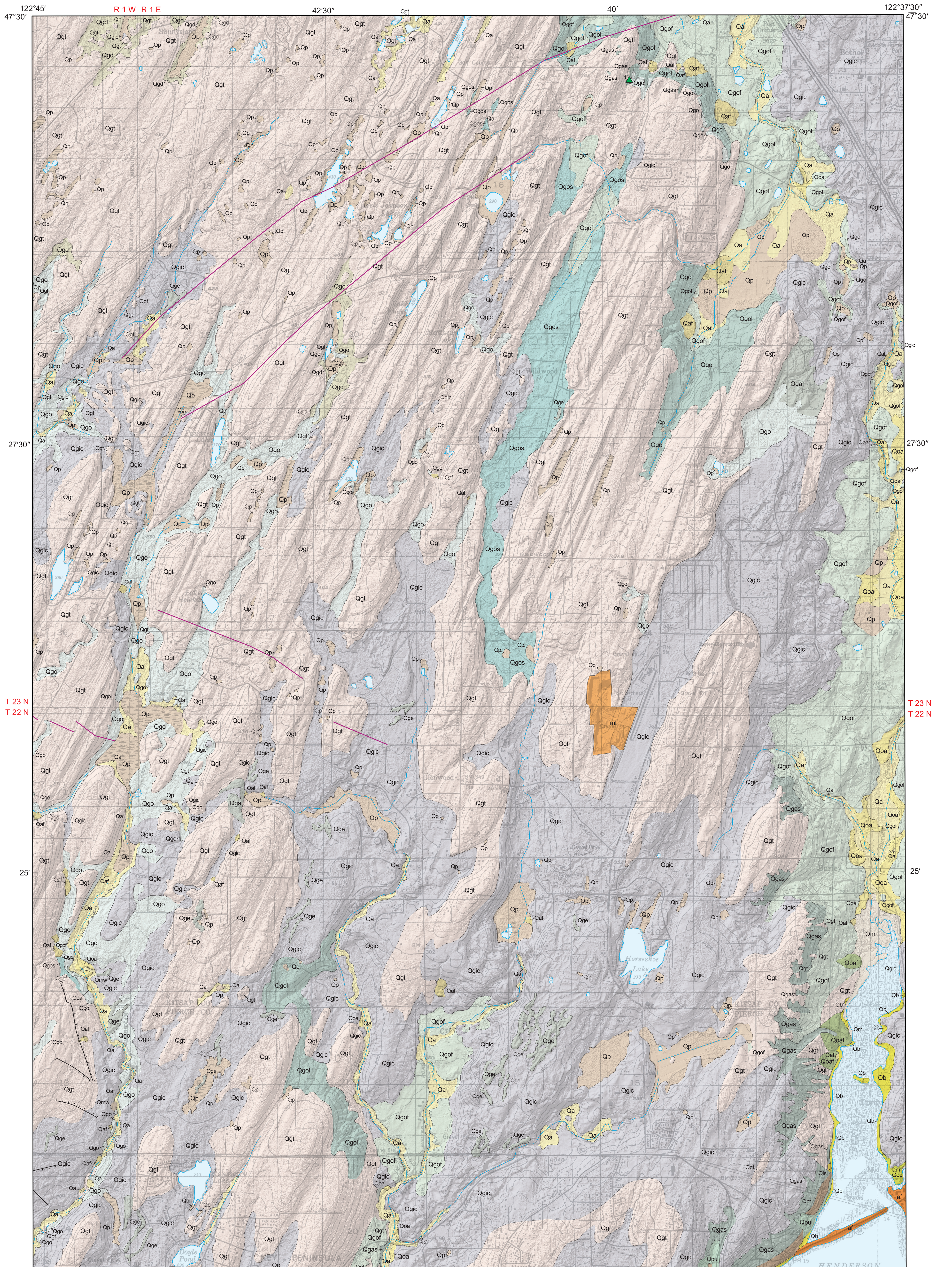

Lambert conformal conic projection
North American Datum of 1927; to place on North American Datum of 1983, move the projection lines approximately 20 meters north and 95 meters east as shown by crosshair corner ticks
Base map from scanned and rectified U.S. Geological Survey Burley 7.5-minute quadrangle, 1999
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 and J. Eric Schuster
Editing and production by Karen D. Meyers

SCALE 1:24,000
contour interval 20 feet

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APPROXIMATE MEAN DECLINATION, 2009

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Geologic Map of the Burley 7.5-minute Quadrangle, Kitsap and Pierce Counties, Washington

by Michael Polenz, Katelin Alldritt, Nicholas J. Hehemann, and Robert L. Logan

July 2009

MAJOR FINDINGS

- Faint scarps and lineaments and elevated relict beaches, stream terraces, and alluvial fans may be due to post-glacial tectonic activity.
- The Seattle uplift may be responsible for exposure of relatively old(?) sediment in the map area.
- Weathered bedrock exposures a few miles north of the map area may have contributed significantly to the polymictic sedimentary deposits in the map area.
- Ubiquitous subglacial channels and fluvial sediment are evidence that the Vashon Stade glacier stagnated at the end of the last glaciation.
- Deposits associated with late Wisconsinan ice-dammed lakes are widespread in the map area and record several late-glacial lake levels.
- Stagnant-ice deposits and subglacial erosion channels likely provide pathways for near-surface water drainage and groundwater infiltration.

GEOLOGIC SETTING

The map area is located in the central Puget Lowland, where repeated glaciations have covered former rocks of the Cascadia subduction zone with allochthonous glacial sediment. No bedrock is exposed in the Burley quadrangle. Buchanan-Banks and Collins (1994) estimated sedimentary thickness above Tertiary bedrock in the map area at under 330 ft in the northwest, over 650 ft in the south, and between 1000 and 1,300 ft in the northeast. However, Haeussler and Clark (2000) estimated depth to bedrock in the Union River valley near the northwestern map edge at close to 950 ft. The record of the Hofert # 1 well 2600 ft west of the quadrangle and 1,600 ft north of the Pierce-Kitsap county line (well location per Washington Division of Geology and Earth Resources website, http://crpl.dnr.wa.gov/) noted basalt bedrock from 620 ft below the surface to the base of the well at 6,688 ft below the surface (Union Oil Company of California and Standard Oil Company of California, 1950; see also McFarland, 1983, p. 38-39). Surficial exposures of Tertiary volcanic and igneous intrusive rocks at Green and Gold Mountains two to six miles northwest of the map area were mapped by Reeve (1979), Clark (1989), and Yount and Gower (1991) as mostly basalt and diabase. Clark (1989) and Haeussler and Clark (2000) noted ophiolitic tendencies among the rocks, and Haeussler and Clark (2000) included basalt from this area with the Crescent Formation. East of Green and Gold Mountains, Fulmer (1975) described Tertiary volcaniclastic bedrock of the marine Blakeley and the overlying terrestrial Blakely Harbor Formations, and McLean (1977) characterized typical Blakeley Formation rocks as feldspathic-volcanolithic wacke. The mix of bedrock north of the map area and the 6,068 ft of volcanic (basalt) rock at Hofert # 1 well suggest that bedrock beneath the map area includes volcanic and volcaniclastic rocks.

Repeated Pleistocene incursions into the map area of northern-source ice sheets and nonglacial periods of erosion contributed to sediment older than the Vashon Stade of the Fraser Glaciation of Armstrong and others (1965); we were unable to subdivide this sediment by age. The pre-Vashon deposits in the map area are likely older than most others in exposures beneath Vashon till throughout the Puget Lowland, based on generally significant and locally intense weathering and the absence of any finite radiocarbon age estimates among these deposits. Furthermore, the Seattle uplift (see Structure) created a topographic barrier in the path of northern-sourced glaciers and thereby may have caused younger pre-Vashon sediment to be preferentially removed by erosion during successive glacial incursions.

Surficial geologic deposits in the map area are dominated by till, ice-contact deposits, lake sediments, and outwash of the upper Wisconsinan Fraser Drift. Landforms include both deposition and scour features from ice and meltwater. Booth and others (2004) associated the Fraser Glaciation with marine oxygen isotope stage 2, and Morrison (1991) assigned the glaciation to the period between 28 and 10 ka. Fraser Drift in the map area is herein associated exclusively with the Vashon Stade because no evidence encountered during this project would indicate deposits from other parts of the glaciation.

Surficial glacial deposits are mapped as Fraser Drift, except where stratigraphic field relations point to an older origin. The outwash unit Qgol was recognized as draping of proximal, generally subtle, relict, fluvio-deltaic terraces that mark a paleo-lake surface near the top of the unit. This unit is very likely more widespread than shown by our mapping, but most exposures form only a thin (less than 10 ft) draping of loose deposits. The pre-Vashon deposits in the map area are associated with unit Qgol at various elevations documents the transient existence during deglaciation of several regional lake levels (Haugerud, 2009, recognized five) and several more local ones.

Haugerud (2009) noted that deglaciation in the southern Puget Lowland probably began with stagnation of the ice sheet, which resulted in preservation of subglacial drainage features. Within the map area, these features include eskers (unit Qge; see also fig. 1 in Polenz and others, 2009), subglacial channels eroded into the till plain (locally marked on our map by elongate polygons of units Qgic and Qgo; see fig. 2 in Polenz and others, 2009), and locally voluminous stagnant ice deposits (unit Qgic). In some areas that generally slope south toward larger basins, locally permeable and relatively loose till that is typically 2 to 10 ft thick and commonly overlies angular sand was found below 350 ft in elevation. These deposits appear to be the "subglacially reworked till" noted by Laprade (2003) and were included with unit Qgic. These sediments likely formed in response to the presence to the south of proglacial or subglacial lakes that caused the overlying ice to float.

Subglacial drainage features in the map area are commonly laterally continuous with and appear to grade into clearly subaerial outwash terraces (unit Qgo) that in turn appear to be graded to a glaciolacustrine base level. While various different base levels are locally apparent, the most prominent one points to a lake surface at roughly 300 ft, apparently associated with glacial Lake Russell (Bretz, 1910; Thorson, 1981). Some lower-elevation outwash terraces that post-date glacial Lake Russell proved difficult to separate from and may locally be included with more recent alluvium (units Qa, Qoa). The combination of abundant stagnant ice deposits, till plain surface irregularities (subglacial channels, "ripples on flutes"; see fig. 3 in Polenz and others, 2009), and subglacially reworked and/or otherwise poorly developed till in the map area suggests that the ice mass stagnated against the shores of the large proglacial lakes that filled Carr Inlet south of the map area late in the Vashon Stade, perhaps because, in the words of Haugerud (2009), the ice mass was "decapitated by collapse of the Juan de Fuca lobe".

STRUCTURE

Tectonic Setting

Broadly situated in the forearc of the Cascadia subduction zone, the map area is located in the south half of the tectonically active Seattle uplift, a west-trending structural high between the Seattle fault to the north and the Tacoma fault zone to the south. Post-glacial uplift along what is now known as the Seattle fault was first noted by Kimball (1897). Raisz (1945) suggested a major fault along a topographically prominent, regional lineament that he termed the Olympic-Wallowa lineament, which coincides with what is now considered the Seattle fault in and near Seattle. Heiskanen (1951) used Puget Lowland seismicity and a gravitational low at Seattle to call for detailed gravitational analysis of the region. Geophysical evidence for the Seattle uplift and the faults that bound it has since been summarized by Daneš and others (1965), Rogers (1970), Gower and others (1985), and Brocher and others (2001). Interpretations of the exact character and activity level of the Seattle uplift and the faults that bound it continue to develop (for example, Bucknam and others, 1992; Bucknam and Biasi, 1994; Blakely and others, 2002; Sherrod and others, 2003a,b; Sherrod and others, 2004; Johnson and others, 2004; Kelsey and Sherrod, 2005; Liberty, 2005; Martin and others, 2007; Logan and Walsh, 2007; Karel and Liberty, 2008; Mitchell and others, 2008; Liberty and Pratt, 2008; Kelsey and others, 2008; Pratt and Troost, 2009). These and many other studies from recent years together indicate that the faults are active, with kilometers of post-Eocene reverse offset that has led to exposure of bedrock north of the map area and elevated the map area against the Tacoma basin to the south. Earthquake focal mechanisms summarized by Ma and others (1996) suggest north-south compressive stress and a possible strike-slip component to offset in the area. Evidence of coseismic land level changes and at least one fault scarp are located within the map area (see map and Evidence for Post-glacial Tectonic Effects). These are attributable to either the Tacoma fault zone or other faulting within the Seattle uplift. Sherrod and others (2003a) have suggested that earthquake effects in and near the map area may represent a Tacoma fault earthquake up to magnitude 7 between A.D. 770 and 1160, but separating such an event from an A.D. 900-930 earthquake on the Seattle fault or late Holocene activity on other nearby structures (for example, Witter and others, 2008; Walsh and Logan, 2007) has proven elusive (Sherrod and others, 2004; Nelson and others, 2009). Confident assignment of specific earthquake effects to specific events on particular faults in the area will require further study, as will delineation of the Tacoma fault where it may extend into the map area (see Liberty, 2005, for one discussion of possible locations and uncertainty about those locations). Owing to that enduring uncertainty, we have chosen not to show the Tacoma fault on this map, though it may be present.

Evidence for Post-glacial Tectonic Effects

Two scarps whose eastern ends extend into the map area cross each other in the adjacent Belfair quadrangle 4,600 ft north of the southwest corner of the map area (144[th] Street and Wright Bliss Road scarps in Polenz and others, 2009, after Sherrod and others, 2003b, and Nelson and others, 2009). Trenching failed to reveal evidence of faulting on the Wright Bliss Road scarp but suggested an earthquake on the southeast-trending 144[th] Street scarp between 1.1 and 1.5 ka (Nelson and others, 2009). Liberty (2005) used seismic profiles to suggest several fault strands with south-directed reverse offset between this area and about 4000 ft farther north, where we noted additional, faint scarps and lineaments on lidar-based images of the map area and the Belfair quadrangle (Polenz and others, 2009). We caution that we did not systematically survey the map area for such lineaments and may have missed others of equal subtlety.

Between two and five miles farther north, we show a set of conjugate(?), northeast- and northwest-trending, faint and questionable scarps and lineaments. The northeast-trending scarps and lineaments appear to be the extension into the map area of the northeast-trending line of Sunset Beach scarps (Haugerud and others, 2003; Polenz and others, 2009; Nelson and others, 2009), which is located three miles west of the map area and has a record of activity about 1.1 to 1.3 ka (Sarikhan and others, 2007; Polenz and others, 2009; Nelson and others, 2009).

Mud-flat sediment at Burley Lagoon was coseismically uplifted about 1,100 ^{14}C yr B.P. (Bucknam and others, 1992; Bucknam, 1998) and is capped by peat. The peat represents an upland setting and includes two separate, discontinuous sand layers that Bucknam (1998) and Bourgeois (2008) and her collaborator M. Elizabeth Martin (Univ. of Wash.) have interpreted as liquefaction features. Bucknam (1998) attributes the liquefaction that produced the older of the two sand layers to the above-mentioned 1,100 ^{14}C yr B.P. coseismic uplift event and suggests liquefaction during another event "310 to 720 years ago" as cause of the younger sand layer. Assuming that we correctly located all exposures referred to by Bucknam and Bourgeois, we mapped these exposures and adjacent mudflat areas at the north end of Burley Lagoon as unit Qm. Based on morphology, we also included with unit Qm some adjacent coastal flatland at the north end of Burley Lagoon that is elevated about 10 ft above the modern mud flat. At the southeast end of Burley Lagoon, we mapped a terrace that appears to be elevated by a few feet above the modern beach as older, apparently uplifted beach. Additional, similarly elevated surfaces that we interpret as uplifted beach elsewhere at Burley Lagoon were too narrow to show separately from the modern beach but appear to confirm late Holocene net uplift, despite the suggestion by Garrison-Laney (2003) that the 1,100 ^{14}C yr B.P. uplift event at Burley Lagoon was followed by subsidence, the timing and rate of which remain unconstrained. Two miles north of the map area, Martin and others (2007) and Bourgeois (2008) similarly noted uplifted mud-flat deposits capped by sand and upland deposits. Sherrod and others (2003a, 2004) suggested that more distinctly uplifted shorelines at North Bay three miles west of the map area (see also Polenz and others, 2009) may have resulted from a large Tacoma fault earthquake between A.D. 770 and 1160.

On the north shore of Hood Canal, about 4 miles west of the map area, elevated terraces that Polenz and others (2009) interpreted as probable relict marine terraces (mostly mapped as unit Qob) are about 25 to 35 ft above the top of the modern beach terrace surface. In all cases, the elevation of emergent coastal terraces appears to be at grade with relict fluvial terraces (included with unit Qoa) and alluvial fans (unit Qoaf) in the lower portions of nearby drainages, thus providing another indirect (and largely unexplored) record of the tectonic activity in the area. That record can be difficult to separate from glaciolacustrine terracing and the potentially complex incision history of the post-glacial streams.

DESCRIPTION OF MAP UNITS

Surficial deposits in the map area generally consist of a diverse mix of glacially derived, plutonic, volcanic, and metamorphic lithic fragments, indicative of sediment contribution from a northern source (including the North Cascades of Washington and/or Coast Ranges of British Columbia). Most deposits are relatively unweathered, but deep weathering of some exposures is confirmed by their petrography and suggests that these are quite old. At least in the Belfair quadrangle west of the map area, Polenz and others (2009) also noted exposures that include unweathered particles alongside significant quantities of weathered ones. This weathering contrast within individual exposures suggests a mix of allochthonous, unweathered and proximally sourced, previously weathered particles and causes some apparent advance outwash to look less "fresh" than deposits of comparable age elsewhere in the Puget Lowland. To what extent this pattern extends into the map area remains largely undocumented, but we attribute the mixing to entrainment of deeply weathered sediment and bedrock from between the Seattle fault and the map area. The bedrock is exposed around Bremerton about four miles north of the map area and consists of terrestrial volcaniclastic rocks assigned by Fulmer (1975) to the Miocene Blakely Harbor Formation and underlying marine, feldspathic-volcanolithic rocks assigned to the Blakeley Formation by Fulmer (1975) and McLean (1977). We speculate that the deeply weathered sediment in the map area resulted from reworking of this bedrock.

We sought to show as geologic units those deposits that form a sufficiently thick surficial cover to be of geotechnical significance, generally requiring a thickness of 5 ft, although where stiff, impermeable, or geotechnically challenging units (for example, till or peat) were encountered or we sought to illustrate a geologic process, we locally mapped thinner deposits. In most areas, exposure or access was too limited to determine unit thickness, and we relied considerably on geomorphology, field relations, or, where available and helpful, subsurface records. A U.S. Geologic Survey 7.5-minute topographic map was used as the base map, but contact locations were generally refined by reference to lidar, aerial photos, and field observations.

Quaternary Unconsolidated Deposits

HOLOCENE NONGLACIAL DEPOSITS

af — **Artificial fill**—Clay, silt, sand, gravel, organic matter, and rip-rap; placed to elevate and reshape the land; may be engineered or non-engineered; shown where fill is readily verifiable and relatively extensive and appears sufficiently thick to be geotechnically significant (greater than 5 ft); excludes roads, except across water basins.

ml — **Modified land**—Local sediment ranging from clay to gravel and diamicton; mixed and reworked by excavation and (or) redistribution that notably modifies topography; shown where relatively extensive, masking underlying geology, and geotechnically significant (greater than 5 ft); excludes roads and abandoned pits where underlying units can be identified; includes aggregate pits active at time of mapping.

Qb, Qob — **Beach deposits**—Sand, pebbles, pebbly sand, cobbles, silt, clay, and shells; clasts typically moderately to well rounded and oblate; locally well sorted; loose; derived from shore bluffs, streams, and underlying deposits. Uplifted (relict) beach terraces are apparent in parts of the map area and, where map scale permits, are separately shown as subunit Qob.

Qm — **Marsh deposits**—Organic sediment and (or) loose clay, silt, and sand in tidal flats and coastal wetlands; saltwater to brackish equivalent of unit Qp; includes layers of freshwater peat in some areas, due to relative sea-level changes. We excluded from unit Qm mudflat areas identified as water on the USGS topographic base map.

HOLOCENE AND LATE PLEISTOCENE NONGLACIAL DEPOSITS

Qp — **Peat**—Organic and organic-rich sediment; includes peat, muck, silt, and clay; typically in closed depressions; includes all recognized upland wetland areas and flat surfaces in closed depressions, unless a different unit or standing water was specifically identified (identification of some polygons is therefore tentative); freshwater equivalent of unit Qm; where field data were unavailable, mapped on the basis of topography, aerial photos, or prior mapping such as soil maps (U.S. Bureau of Chemistry and Soils, 1934; McMurphy, 1980 ; Zulauf, 1979). The unit post-dates Vashon ice and is predominantly Holocene but locally includes some late Pleistocene deposits.

Qls — **Landslide deposit**—Clean sand; gray; medium- to fine-grained; moderately to well sorted; loose; structureless, except for inclusions of compact, bedded sand blocks derived from outwash sand that served as sediment source for the single slide documented in the map area. This outwash is mapped as Vashon advance outwash sand (unit Qgas) south and north of the slide, which is located on the west shore of Burley Lagoon, where additional slides were also observed but are too small to show at map scale. Absence of a mapped slide does not imply absence of sliding or hazard, and the single mapped slide is unlikely to leave a persistent deposit because shore erosion may quickly remove slide debris. A mid-slide bench and boulders on the beach below the slide suggest that the pre-Vashon drift we mapped south of the slide is also present in the slide area, and it is unclear if the gray sand exposed by the slide is Vashon advance or from an earlier glaciation.

Qmw — **Mass wasting deposits**—Boulders, gravel, sand, silt, clay, and diamicton; generally unsorted, but locally stratified; typically loose; shown along mostly colluvium-covered or densely vegetated slopes that are potentially or demonstrably unstable; may locally include exposures of underlying units that either we could not map confidently or are too small to show, as well as debris fans, alluvial fans, and landslides. Absence of a mapped mass-wasting deposit does not imply absence of slope instability or hazard. The unit post-dates Vashon ice and is predominantly Holocene but locally may include some late Pleistocene deposits.

Qa, Qoa — **Alluvium**—Silt, sand, and gravel; clasts typically well rounded; typically well sorted and loose; stratified to massively bedded; deposited in streams and adjacent banks. The sediment source is most commonly reworked recessional outwash, ablation till, advance outwash, and (or) glaciolacustrine deposits, but may include lodgment till and nonglacial deposits. Exposures locally resemble the unit's sediment source units, a particularly notable feature in the lowlands around Burley and Blackjack Creeks, where the unit is mostly derived from glaciolacustrine and (or) ice-contact deposits (units Qgof and Qgic). Shear-wave velocity profiles confirm, however, that unit Qa forms a more diverse deposit than unit Qgof and at least some deposits of unit Qgic (fig. 4 of Polenz and others, 2009). Subunit Qoa is older alluvium that resembles unit Qa in every way but forms elevated, relict terraces. Most appear to be tied to an elevated base level that prevailed prior to a local base-level lowering event(s) (see discussion of elevated terraces under Structure). Such elevated former base levels are more clearly apparent in the Belfair quadrangle west of the map area (Polenz and others, 2009). Where unit Qoa is correctly identified along the lower reaches of streams that are graded to sea level, the age of unit Qoa should not exceed about 6,000 years because prior to that, sea level was significantly lower, which likely resulted in an erosional setting that precluded deposition of alluvium. As mapped, the unit is generally Holocene but may locally include some unrecognized recessional outwash terraces (unit Qgo) and other late Pleistocene deposits.

Qaf, Qoaf — **Alluvial fan**—Silt, sand, gravel, and boulders; typically poorly sorted and stratified; forms concentric lobes where streams emerge from confining valleys and reduced gradients cause sediment load to be deposited. Subunit Qoaf identifies relict late Holocene alluvial fans that resemble unit Qaf in every way but form relict fans that are tied to an elevated, former base level (see discussion of elevated terraces and fans under Structure). Such older fans typically are dissected by a distinctly incised modern stream channel. The unit post-dates Vashon ice and is predominantly Holocene but locally probably includes some late Pleistocene deposits.

PLEISTOCENE GLACIAL AND NONGLACIAL DEPOSITS

Deposits of the Fraser Glaciation, Vashon Stade

Qgo — **Vashon recessional outwash**—Gravel and sand; locally includes silt or clay; tan to gray; rounding and sorting diverse, but most commonly subrounded and moderately sorted; stratified and loose; ranges from a few feet to a few tens of feet thick; deposited by Vashon meltwater in outwash channels or isolated basins; generally less compact than advance outwash (unit Qga), but in some exposures difficult to distinguish from unit Qga where not separated by till; stratigraphically overlies till. Most deposits of this unit are ice-proximal and difficult to separate from unit Qgic, locally resulting in gradational boundaries and poor distinction between units Qgic and Qgo (and subunits). This difficulty is illustrated, for instance, by a "leaping" outwash channel documented in figure 2 of Polenz and others (2009) slightly west of the map area. Locally divided into:

Qgos — **Vashon recessional outwash sand**—Mostly sand, but locally includes lenses and beds of pebble gravel and silt; mostly matrix-free; gray to tan; loose; moderately to well sorted; moderately to well rounded; generally less compact than but in some exposures difficult to distinguish from advance outwash sand (unit Qgas).

Qgof — **Vashon recessional outwash fines**—Mostly silt, commonly ranges to fine sand or locally clay; may contain dropstones, but very few were observed during mapping; gray to brown; generally angular to subangular, well-sorted, and loose; may be locally stiff, but not usually compact (see fig. 4 of Polenz and others, 2009); laminated to structureless; deposited in ice-dammed lakes near the end of the Fraser Glaciation; locally grades laterally into units Qgol and Qgos; in the Burley Creek watershed, includes many terraces that suggest significant reworking fluvially and (or) by step-wise lowering of lake levels and episodes of extensive lakeshore terrace erosion. These terraces were included with unit Qgof because their deposits resemble undisturbed glaciolacustrine deposits and the multitude of terraces does not permit straightforward recognition of a fluvial landscape development pattern. Some of these terrace distinctions are reflected in the soil map of McMurphy (1980), however.

Qgol — **Vashon recessional lake marginal outwash**—Gravel, sand, and locally fines; gray to brown; formed by proximal reworking of upslope units (usually ablation till) into a systematic lake-marginal deltaic assemblage of fluvial beds near the top, foreset beds in the center, and quiet-water lake-bottom beds at the base; fines typically limited to the bottomset beds, where the unit grades laterally into unit Qgof. See Geologic Setting for notes on unit thickness and distribution.

Qgic — **Vashon glacial ice-contact deposits**—Sand, gravel, lodgment till, and flow till; minor silt and clay beds; tan to gray; variably sorted; loose to compact; massive to well stratified; locally includes over-steepened beds that typically reflect sub-ice flow, but their dip may, along with small-scale shears, also have developed as collapse features or due to glaciotectonic and tectonic deformation; formed in the presence of meltwater alongside ice, generally toward the end of the glaciation, and is thus commonly accompanied by stagnant-ice features, such as kettles and less-orderly hummocky topography, eskers (also separately mapped as subunit Qge), and subglacial or subaerial outwash channels. Deposits and morphologies that support conceptual association with both ice and meltwater are common in the map area and suggest that where unit Qgic is mapped in the presence of fluted topography, it is commonly only a few feet thick and locally could have been mapped as undifferentiated drift (unit Qgd). Elsewhere, the unit may be over 100 ft thick. Unit Qgic also includes poorly consolidated till commonly accompanied by underlying, angular sand and noted as "sub-glacially reworked till" by Laprade (2003) (see Geologic Setting), especially in fluted areas that lack dead-ice features. See unit Qgo and fig. 4 of Polenz and others (2009) for discussion of similarities between units Qgic and Qgo (and its subunits Qgos, Qgof, and Qgol). A discrepancy between this map and the Fox Island quadrangle to the south resulted where dead-ice topography north of the boundary reveals sandy deposits mapped as unit Qgos by Logan and others (2006) to be a facies within unit Qgic. Several additional discrepancies resulted where subglacially reworked till was included with unit Qgic on this map but mapped as till (unit Qgt) by Logan and others. Locally divided into:

Qge — **Vashon glacial eskers**—Sand and gravel; tan to brown; loose; moderately to well sorted; moderately to well rounded with good porosity and permeability; deposited subglacially by Vashon melt-water in areas occupied by stagnant ice; forms low, elongate, sinuous hills that seem to rest like slugs on fluted uplands or subglacial outwash channels and locally can be seen to merge into channel incisions (fig. 1 in Polenz and others, 2009).

Qgt — **Vashon till**—Unsorted, unstratified (but locally banded) mix of clay, silt, sand, and gravel; typically supported by a sandy matrix; gray but locally ranging to tan, light brown, or orange; typically unweathered; lodgment till compact, with well-developed facies resembling concrete, but near the surface commonly hackly and (or) looser and covered by 1 to 6 ft of loose ablation till; deposited directly by glacial ice and commonly includes clasts or clumps plucked from underlying units. Clasts are commonly striated and faceted, with angular or rounded edges. Boulders are generally sparse within the till but large (erratic) boulders of plutonic or metamorphic rock are common on till surfaces. Some exposures include interbands and lenses of sand and gravel, locally with shears and joints. Till forms a locally patchy and seemingly randomly distributed cover up to a several tens of feet thick, with a thickness of 5 to 20 ft most common. It typically dominates, but is also locally discontinuous on, fluted surfaces, with individual drumlins measuring 0.1 to 0.3 mi wide by 0.8 to 1.3 mi long and the long axis aligned with the direction of ice flow. Till typically is in sharp, unconformable contact with underlying units, most commonly advance outwash (unit Qga and subunit). Unit Qgt lies stratigraphically below unit Qgo. It may include unrecognized exposures of older till.

Qga — **Vashon advance outwash**—Pebble to cobble gravel, sand, and layers and lenses of silt and clay; gray to tan; typically stratified, well rounded, well sorted, and clean (<5% silt or clay in matrix), except in less-sorted and more angular ice-proximal deposits; compact (see fig. 4 of Polenz and others, 2009) and resistant to erosion, except where well sorted and well rounded; very thinly to very thickly bedded; contains planar and graded beds, cut-and-fill structures, trough and ripple cross-beds, and foresets; thickness not well constrained by this mapping but ranges from a few feet to more than (?) 100 ft; deposited as proglacial fluvial and deltaic sediment during Vashon glacial advance and typically overlain by unit Qgt along a sharp, unconformable contact. Locally divided into:

Qgas — **Vashon advance outwash sand**—Sand; fluvial facies may include minor layers and lenses of gravel; lacustrine facies may include lenses and layers of silt; gray to tan; typically well rounded, well sorted, and clean (<5% silt or clay in matrix); generally compact but due to lack of cohesion locally appears loose where well sorted and well rounded; generally porous and permeable; deposited during Vashon glacial advance; prone to rapid landslides where resting on impermeable substrate.

Qgd — **Undifferentiated glacial drift**—Heterogeneous patchwork of stratified and unstratified sand, silt, clay, gravel, and diamicton; may locally include till, subglacial outwash, advance outwash, proximal recessional outwash, and ice-dammed-lake sediment; gray to tan; loose to compact; typically forms geomorphologically complex patchwork of mounds, terraces, incipient to fully developed channels, closed depressions, and erosional exposures of older units; predominantly Vashon Drift but may also include older drift; shown where map scale or exposure do not support stratigraphic division.

Pre-Vashon Glacial Deposits

Qpd — **Pre-Vashon drift, undivided**—Till and compact clay, silt, sand, and gravel deposited prior to the Vashon Stade; shown where map scale or exposures do not support distinction among subunits of drift. This unit is clearly identified in the drainage above Henderson Bay 1.3 mi west of the southeast corner of the map, where it consists of compact glaciolacustrine clay underlain by lodgment till and appears to be stratigraphically below exposures of deeply weathered sand. Identification of this unit is more speculative farther east but supported by its apparent presence in nearby well records, where compatible deposits are noted at similar elevations beneath weathered sand and gravel. It is also supported by reported presence of a well-developed lodgment till near beach level along the Henderson Bay shore that contrasts with the typically thin and softer diamicton mapped as unit Qgic on nearby upland surfaces. Compact clay on the west shore of Burley Lagoon is also included with this unit based on the above-mentioned well records and pre-Vashon lodgment till.

Undifferentiated Deposits Older than Vashon Till

Qpu — **Undifferentiated sediment older than Vashon till**—Gravel, sand, fines, and diamicton older than Vashon till; compact; may include any pre-Vashon unit and units Qga and Qgas where those could not be differentiated from pre-Vashon outwash. A map boundary mismatch with the Fox Island quadrangle to the south resulted where Logan and others (2006) included narrow exposures of pre-Vashon deposits along steep valley walls with Vashon till (unit Qgt).

Qps — **Pre-Vashon sand**—Compact sand, locally with layers and lenses of silt, clay, peat, and minor gravel; moderately oxidized; poorly to well bedded; locally iron-oxide cemented; assumed to be nonglacial based on the grain size, common presence of organic-rich layers, and sedimentary characteristics (suggestive of slower sedimentation rates and relative paucity of lacustrine settings when compared to sandy glacial deposits), but could locally include glacial deposits. This unit is shown on the map only as a single polygon along the west shore of Henderson Bay but is also locally exposed in deeply incised valleys such as an intermittent stream, informally known as "Dry Rocky Creek"; this creek exits the southwest corner of the map area about 1 mi west of Doyle Pond. The unit is also exposed along the bluffs in Henderson Bay, where we radiocarbon dated detrital wood from a silt bed at the base of the exposure (>43,000 14C yr B.P.; see Table 1, Beta 253253). A map boundary mismatch with the Fox Island quadrangle to the south resulted where Logan and others (2006) included narrow exposures of pre-Vashon deposits along steep valley walls within unit Qgt.

GEOLOGIC SYMBOLS

Contact—long dashed where approximately located, short dashed where inferred.

Fault—unknown offset

Fault—reverse offset, R on upthrown side

Scarp—hachures point downslope

Lineament

Age-date sample site, 14C

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Table 1. Age control data from the map area. Lab uncertainty values are one standard deviation (68% confidence interval) and include random errors that can be estimated by the lab but exclude uncertainties that cannot be detected by the laboratory's analytical procedures. Analyses were performed by Beta Analytic, Inc. (Miami, FL). "14C yr B.P." signifies radiocarbon years before A.D. 1950. Radiocarbon ages are 'conventional' (that is, adjusted for measured 13C/12C ratio). 14C, radiocarbon analysis by liquid scintillation counting. 14C AMS, radiocarbon analysis by atomic mass spectrometry. The geologic unit shown in this table is the unit from which the sample was extracted. Where that differs from the unit shown for the sample location on the map, either the sample was collected from the subsurface or map scale prohibited display of the sampled unit on the map. Elevations are in feet above mean sea level, as estimated in this study using lidar data (supplemented by visual elevation estimates on outcrops) and referring to VERTCON (http://www.ngs.noaa.gov/TOOLS/Vertcon/vertcon.html) for vertical datum shifts between lidar data and map elevations. Elevations in quotation marks are reported by referenced source.

Loc no.	Age estimate (^{14}C yr B.P.)	$\delta^{13}C$ (‰)	Analytical method	Material dated	Geologic unit	Lab no.	Elev (ft)	Reference	Notes
1	>48,000	-28.4	14C AMS	organic sediment	Qps*	Beta 218750	"305"	Stetson EP-8 exploration boring (Jenny Saltonstall, AESI, Inc., written commun., Apr. 1, 2009)	Lidar data for site confirm 305 ft sample elevation, and VERTCON suggests that elevation estimate for NAD 27 map projection is 302 ft. AESI interpreted sample site as pre-Vashon nonglacial deposits (unit Qps) beneath ~8 ft Vashon advance sand (unit Qga).
2	>43,400	-26.5	14C	wood	Qps	Beta 253253	7	this report	Sampled from flattened wood in stiff clay exposed by erosion at top of beach; overlain by sand.

*Sample collected from exposure of unit Qps 15 ft below surface in an exploration pit. Surface at site consists of sand mapped as unit Qga, thus resulting in mismatch between sampled unit and surface unit on map.

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