GEOLOGIC MAP OF THE HOODSPORT 7.5-MINUTE QUADRANGLE, MASON COUNTY, WASHINGTON

by Michael Polenz,
Brendan A. Miller,
Nigel Davies,
Benjamin B. Perry,
Kenneth P. Clark,
Timothy J. Walsh,
Robert J. Carson, and
Jonathan F. Hughes

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Washington State Department of Natural Resources
Division of Geology and Earth Resources

Mailing Address:
MS 47007
Olympia, WA 98504-7007

Street Address:
Natural Resources Bldg, Rm 148
1111 Washington St SE
Olympia, WA 98501

Phone: 360-902-1450
Fax: 360-902-1785
E-mail: geology@dnr.wa.gov
Website: http://www.dnr.wa.gov/ResearchScience/GeologyEarthSciences/Pages/Home.aspx

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by Michael Polenz[1], Brendan A. Miller[2], Nigel Davies[1], Benjamin B. Perry[1], Kenneth P. Clark[3], Timothy J. Walsh[1], Robert J. Carson[4], Jonathan F. Hughes[5]

[1] Washington Division of
Geology and Earth Resources
MS Box 47007
Olympia, WA 98504-7007

[2] Department of Earth and Space Sciences
University of Washington
Johnson Hall, Rm 070, Box 351310
4000 15th Ave NE
Seattle, WA 98195-1310

[3] Geology Department
University of Puget Sound
1500 N Warner
Tacoma, WA 98416

[4] Department of Geology
Whitman College
345 Boyer Ave
Walla Walla, WA 99362

[5] Department of Geography
University of the Fraser Valley
33844 King Road
Abbotsford, BC V2S 7M8
Canada

INTRODUCTION

This mapping provides baseline geologic information for private and public land-use decisions and improves identification of geologic hazards, including landslides and active faults. It also provides information on stratigraphy and hydrology (needed, for example, by the Hood Canal Dissolved Oxygen Project). A supplemental report (Polenz and others, 2012) provides age control data, geochemical analyses, and other aspects of the geology that could not be fully presented within this map.

The map area surrounds Dow Mountain, west of Hood Canal. Bedrock is exposed in roughly one-fifth of the quadrangle and consists primarily of generally southeast-dipping Eocene Crescent Formation basalt with intervening sections of basaltic sedimentary rocks (units Ev_c and Em_{1c}) (see also bedrock characterization in Polenz and others, 2012). East and southeast of Dow Mountain, southeast-dipping, generally rhythmitic sandstone to mudstone (unit ΦEm) locally overlies and appears to be concordant with Crescent basalt. Owing to a lack of biostratigraphic or other age control, these rocks were not assigned to any formation. Published (Blakely and others, 2009; Lamb and others, 2009a,b) and unpublished (Richard Blakely, U.S. Geological Survey, written commun., 2010 and 2011) gravity and magnetic data and interpretations suggest that, at Hood Canal, basaltic bedrock ends or quickly drops to much deeper depths. Bedrock throughout the map area is unconformably overlain by Quaternary glacial sediment derived from the Olympic Mountains and geologic exposures north of the map area. This sediment covers most of the map area and ranges from a thin draping to several hundred feet in thickness. It likely reaches its maximum thickness in the southeast near Hood Canal.

Repeated Pleistocene glacial incursions into the map area deposited most of the sediment. The lithology of the sedimentary units was derived from glacial drift produced by alpine glaciers of the Olympic Mountains (Olympic-sourced) and the Cordilleran ice sheets (northern-sourced). Northern- and Olympic-sourced sediments resemble each other more in the map area than in most of the Puget Lowland because, on their way into the map area, Cordilleran ice sheets picked up sediment from the Olympics in addition to sediment from the Canadian Coast Range, San Juan Islands, and perhaps the Northwest Cascades. Northern-sourced rocks near the southeast corner of the map area were additionally supplemented by rocks from Green and Gold Mountains (about 14 mi east-northeast of the map area) that resemble Olympic-sourced rocks and were described by Reeve (1979), Clark (1989), Yount and Gower

(1991), and Haeussler and Clark (2000). In addition, lakes impounded by Puget lobe (northern-sourced) ice could in theory have floated northern-sourced sediment upvalley into the North Fork Skokomish basin, so that Olympic-sourced glaciers and rivers could also have picked up northern-sourced rocks en route to the map area. Bretz (1913), Long (1975, 1976), and Carson (1980) asserted, however, that at least during the most recent northern-sourced glaciation (the Vashon Stade of the Fraser Glaciation), northern-sourced ice did not extend upvalley beyond the map area and coeval Olympic ice prevented dropstones from rafting upvalley. (Hereinafter, we will use marine oxygen isotope stages [MIS] to identify glacial and nonglacial periods in the map area, as illustrated in Booth and others [2004] and Morrison [1991; Fig. 1 on plate]. Even stage numbers correspond to northern-sourced glacial advances, odd numbers to nonglacial intervals. Higher stage numbers identify older climatic intervals—the Fraser Glaciation spans Stage 2. Stades, such as the Vashon, identify shorter intervals within stages. The late Pleistocene spans MIS 5, 4, 3, and 2. Although Stage 3 was nonglacial in the Puget Lowland, it was marked by repeated Olympic ice advances [Thackray, 2001].)

We mapped all Olympic-sourced deposits as glacial. We lacked paleoclimatic data to support that pattern but reasoned that nonglacial times would be dominated by erosion, as is the case today, whereas large volumes of Olympic drift would enter the map area in response to Olympic ice advances, similar to the pattern found by Thackray (2001) on the west side of the Olympic Mountains. This assumption of near-exclusively glacial sedimentation is also supported by many exposures with sedimentary structures suggestive of a braid plain of Olympic sediment and other attributes consistent with rapid sedimentation, such as paucity of organic-rich deposits and paleosols.

While Long (1975, 1976), Carson (1980), and Logan (2003) noted that at least one earlier northern-sourced ice mass was more extensive, Vashon-age northern-sourced drift throughout the map area indicates that ice of the Vashon Stade Puget lobe covered the map area except for the tops of Dow Mountain and Cushman Hill and, apparently, the map area's northwest corner. We observed Vashon till with granitic erratics to 2,070 ft elevation on the northeast flank of Dow Mountain (significant site DMVT), slightly above the 1,900 ft limit previously noted by Long (1976) and roughly consistent with fig. 4 in Thorson (1980), which suggests about 450 to 650 m (1,500–2,100 ft) of Vashon ice over the map area. Along the east slope of Cushman Hill, our observation of till to at least 1,750 ft matches that of Long (1976). On the northwest tip of Cushman Hill, we observed till to 1,975 ft, but mapped it as MIS 2? (or MIS 3?) Olympic(?) drift, mainly because previous workers had done so (Carson, 1976; Long, 1976; Tabor and Cady, 1978). However, despite an apparent lack of granitic clasts, it remains unclear to us if anyone had compelling evidence to assign this till to Olympic rather than northern provenance.

Although we mapped many deposits as Olympic drift, we did so partly in deference to prior mappers who benefited from exposures we did not see and also cite a lack of granitic clasts as the distinguishing determinant of Olympic source (Carson, 1976; Long, 1976; Tabor and Cady, 1978). Lithologic distinctions do not require an Olympic-ice origin because deposits of demonstrable association with Vashon Puget lobe ice also lacked granitic or other diagnostically northern-sourced clasts in many exposures. With that caveat, we mapped late(?) Pleistocene Olympic drift at the northwest end of Cushman Hill, along segments of the Lake Cushman shoreline, and near the southern map boundary, where they are continuous with deposits previously identified as late Pleistocene Olympic drift south of the map area (Polenz and others, 2010b). All these deposits may date to MIS 3 or earlier, rather than to MIS2.

We saw stratigraphic or other field relations (such as fluting in till or striations in underlying bedrock) to support an Olympic ice presence only in the northwest corner of the map area, where we mapped unit Qgim (Vashon Puget lobe end moraine), but Bretz (1913), Long (1975, 1976), and Carson (1980) favored the notion that Vashon and MIS 2 Olympic ice joined and, according to Long (1976), Olympic ice "readvanced after the maximum of the most recent Puget Lobe and overlapped Vashon drift at mid-Lake Cushman." A valley-parallel fabric (apparently fluting) in the surface morphology of the west half of unit Qgim supports such a readvance (see ice limit line on map, and discussion and figure 5 in Polenz and others, 2012), but we found no evidence that this MIS 2 (or later?) Olympic ice left deposits of mappable thickness, although we saw few exposures in this area. Instead, we interpret the deposits within this lumpy hill as MIS 2 (Vashon) Puget lobe end moraine that seems to have been only surficially scratched by the apparent later readvance of Olympic ice.

Two new ^{14}C age estimates from glaciolacustrine deposits below Vashon till (localities SCVA and UFCVA; appendix A in Polenz and others, 2012) constrain the timing of Vashon (Puget lobe) ice arrival in the map area to between 17,000 and 15,700 calendar years B.P., somewhat later than suggested by the regional Puget lobe ice incursion timeline of Porter and Swanson (1998; see also improved timeline illustration, fig. 9, in Booth and others, 2004, and discussion of Vashon ice arrival in Polenz and others, 2012).

TECTONIC SETTING

The Hoodsport quadrangle is situated in the Cascadia subduction zone forearc, where active structures accommodate margin-parallel shortening due to oblique convergence at the subduction zone (Johnson and others, 2004). Several postglacially active, shallow crustal faults and a few more speculative structures either traverse or trend into the Hoodsport quadrangle, and the tectonic setting at the scale of the quadrangle appears complex and remains poorly understood. It is clear, however, that the Saddle Mountain fault zone crosses the map area from northeast to southwest, and multiple studies produced detailed evidence for postglacial ground rupture and coseismic land level changes along this fault zone, likely in association with M >6.0 earthquakes between 700 and 1000 A.D. (Carson, 1973; Wilson, 1975; Wilson and others, 1979; Hughes, 2005; Witter and Givler, 2005; Witter and others, 2008; Blakely and others, 2009; Czajkowski and others, 2009). Tectonic insights from this and prior studies are discussed in more detail by Polenz and others (2012).

Whereas Quaternary sediment in the map area is generally horizontally bedded, the underlying volcanic flows and sedimentary rocks typically strike northeast and dip 40 to 70 degrees southeast, consistent with regional trends apparent in Tabor and Cady (1978). Joints, folds, and shears typically permeate exposures of Crescent Formation basalt, and localized variations in bedding orientations are common. The overlying sedimentary rocks tend to be more orderly but still heavily jointed. The newly discovered Miller Creek syncline southeast of Dow Mountain is discussed in Polenz and others (2012).

DESCRIPTION OF MAP UNITS

Surficial deposits in the map area generally consist of (1) Olympic-sourced clast assemblages of basalt, sandstone, and metamorphic rocks, or (2) a mix of Olympic-sourced rocks and a broadly similar but more diverse northern-sourced assemblage that additionally incorporates 0 to 5 percent plutonic and metamorphic lithic clasts indicative of provenance from the Coast Ranges of British Columbia and (or) the San Juan Islands, and, perhaps, the North Cascades of Washington.

Along the Hood Canal shore, we found in both outcrop and petrographic examination of sedimentary thin sections that diagnostically northern-sourced clasts typically comprise at least 2 to 5 percent of clasts in drift of apparent northern source, similar to the findings of Polenz and others (2010a,b) in the Skokomish Valley quadrangle to the south. However, diagnostically northern-sourced clasts thin out to the west and are rare near the northwest corner of the map area. This systematic progression makes sense in light of the abundant supply of Olympic-sourced and similar sediment that Puget lobe ice and meltwater would encounter en route to and across the map area, especially along the Olympic range front, but also in the Green and Gold Mountains area. The farther west in the map area the ice or meltwater, the more likely it would incorporate Olympic-type lithologies.

Consequently, we mapped as Vashon and associated with northern-sourced ice some deposits that lack clasts of a diagnostically northern provenance. Conversely, the provenance of deposits that we mapped as Olympic source (of any age) is debatable, especially in the west half of the map area, because identification of provenance is fundamentally based on lithology, yet we know that this measure is insufficient. Fluting, striations, or field relations helped us identify many Vashon deposits as northern-sourced, but such pointers were generally not available for pre-Vashon deposits, regardless of provenance. We therefore assigned apparent provenance partly based on depositional location. Near the western map boundary, we generally mapped pre-Fraser deposits with much less than 1 percent diagnostically northern-sourced lithologies as Olympic-sourced, whereas near the east end of the map area we would still consider a possible Olympic source for deposits with 2 to 5 percent northern-sourced clasts. In addition, we used previous mappers' interpretations as tie breakers, but in the end, the provenance we assigned, especially for pre-Vashon deposits, rests on shaky legs.

Most upland surficial deposits are only slightly weathered, but variations in weathering of clasts, both within and across units, are common and typically increase lower in the stratigraphic section. Weathering and interstitial secondary clay content also tend to increase in coarse-grained units with higher permeability, in sediment derived from the Olympics, and in paleosols. Weathered units range from red to brown and yellowish brown. Some drift exposures include a mix of unweathered and weathered sediment. Such mixing can result from in-place weathering but in some exposures appears to reflect the presence of relatively fresh, and in most places at least partly northern-sourced, particles alongside proximally sourced and at least partly pre-weathered particles (commonly saprolitized) of dominantly Olympic derivation. We found most such bimodal assemblages in the northwest part of the map area near the Vashon ice limit or where the ice was thin, such as near the top of Saddle Mountain, and infer that they developed where subglacial scour was minimized and the ice was nearly stagnant.

We sought to show as geologic units those deposits that form a sufficiently thick surficial cover to be of geotechnical significance, generally a thickness of 5 ft or more. Where stiff, impermeable, or geotechnically challenging units (for example, lodgment till or peat) were found or we sought to illustrate a geologic process, we locally mapped thinner deposits. In most areas, we relied on geomorphology, field relations, and, where available and helpful, subsurface records. We used the Udden-Wentworth scale (table 5 in Pettijohn, 1957) to classify unconsolidated sediments. U.S. Geologic Survey (USGS) 7.5-minute topographic maps were used as base maps, but contact locations other than marine shorelines were generally refined by reference to field observations, lidar, and aerial photos. We used the time scale of the USGS Geological Names Committee (2010); for subdivisions not shown there (for example, late Pleistocene), we referred to Wikipedia (http://en.wikipedia.org).

Quaternary Unconsolidated Deposits

HOLOCENE NONGLACIAL DEPOSITS

af **Artificial fill**—Sand, cobbles, pebbles, boulders, silt, clay, organic matter, rip-rap, and concrete placed to elevate the land; engineered or non-engineered; shown where readily verifiable, relatively extensive, and appearing thick enough to be geotechnically significant (>5 ft); excludes roads.

ml **Modified land**—Locally derived sand, pebbles, cobbles, boulders, silt, clay, and diamicton excavated and redistributed to modify topography; locally includes concrete and artificial fill; underlying units exposed in some cuts; shown where relatively extensive and apparently geotechnically significant (>5 ft thick); excludes roads and abandoned pits where underlying units can be identified; includes aggregate pits active at time of mapping. A map boundary mismatch resulted where Contreras and others (2010) mapped fill along the Hood Canal shore as part of unit ml.

Qb **Beach**—Sand, pebbles, pebbly sand, cobbles, silt, clay, shells, and isolated boulders; loose; clasts typically moderately to well-rounded and oblate; locally well-sorted; derived from shore bluffs, streams, and underlying deposits. Unit Qb is transient in the modern environment, with beach erosion at times exposing underlying units. The age of unit Qb is constrained to less than about 6,000 years because sea level was significantly lower prior to that time.

HOLOCENE TO POSTGLACIAL PLEISTOCENE NONGLACIAL DEPOSITS

Qp **Peat**—Organic and organic-rich sediment; includes peat, muck, silt, and clay; typically in closed depressions. Where field data were unavailable, unit Qp was mapped on the basis of prior mapping, topography, or aerial photos. Unit Qp was mapped in all recognized wetland areas and flat-bottomed closed depressions unless a different unit or standing water was specifically identified. The unit is predominantly Holocene but locally ranges to late Pleistocene.

Qls **Landslide deposits**—Cobbles, pebbles, sand, silt, clay, boulders, and diamicton in slide body and toe; angular to rounded clasts and grains; unsorted; generally loose, jumbled, and unstratified, but may locally retain primary bedding and compaction; commonly includes liquefaction features. Absence of a mapped slide does not imply absence of sliding or hazard. Slides that were not recognized with confidence are typically shown as unit Qmw. Some polygons include exposures of underlying units. Larger slide polygons typically exclude head scarps, which may be separately identified by a hachured scarp symbol across upslope map units. The unit is predominantly Holocene but may include some late Pleistocene deposits.

Qmw **Mass-wasting deposits**—Cobbles, pebbles, sand, silt, clay, boulders, and diamicton; typically loose; generally unsorted, but locally stratified; shown along mostly colluvium-covered or densely vegetated slopes that are potentially or demonstrably unstable; locally includes alluvial fans, debris fans, landslides that are too small to show separately or could not be confidently mapped, or exposures of underlying units. Where fan shaped, unit Qmw generally covers steeper slopes than unit Qaf. Absence of a mapped mass-wasting deposit does not imply absence of slope instability or hazard. The unit is predominantly Holocene but locally includes late Pleistocene deposits.

Qa, Qoa **Alluvium**—Cobble- and pebble gravel and sand, with some silt, clay, peat, and isolated boulders; clasts and matrix generally gray and fresh, but some exposures iron-stained; loose; clasts typically well-rounded; typically moderately to well-sorted; stratified to massively bedded; deposited in streams and on flood plains and terraces. Shear-wave velocity profiles southeast of the map area confirm that unit Qa tends to form a more diverse deposit than at least some deposits of unit Qgic (Polenz and others, 2009). The unit may locally include some recessional outwash (unit Qgo) and other late Pleistocene deposits. Subunit Qoa resembles unit Qa but is older and forms elevated relict terraces. Along reaches of Clark and Miller Creeks, which are graded to modern sea level in the southeast part of the map area, no part of units Qa and Qoa should be older than about 6,000 years because, prior to that time, sea level was significantly lower and would not have supported build-up of this alluvium. East of Price Lake at ^{14}C age location QOA, two subunit Qoa terraces are dated to between 5.9 and 5.3 ka (appendix A in Polenz and others, 2012, ^{14}C age samples Qoa3, Qoa1, and Qoa2). Preservation of these terraces coupled with abundance of charcoal and apparent equivalence of the age estimates from both terraces suggest an interval of rapid terrace building, possibly due to a pulse of sediment mobilization in the aftermath of a wildland fire, followed by little geomorphic modification since that time.

Qaf, Qoaf **Alluvial fan**—Cobble- and pebble gravel with sand, silt, and boulders; loose; moderately to poorly sorted; stratified; forms concentric lobes where streams emerge from confining valleys,and where reduced gradients, channel morphology changes, and (or) increased substrate permeability cause sediment load to be deposited. Especially along the base of smaller, steep drainages, deposition is commonly sudden, hazardous, and associated with significant storm events, such as the "Great Coastal Gale" of December 1–3, 2007 (Read, 2007). The unit is predominantly Holocene but locally ranges to Pleistocene. Relict fan deposits that have stopped accumulating are identified as subunit Qoaf. Their surface is typically dissected by a modern stream channel that is deep and steep enough to pre-empt addition of modern sediment to the fan. Unit Qgoaf is distinguished from unit Qoaf because field relations suggest or require deposition of unit Qgoaf coeval with Vashon recessional outwash. A map edge mismatch at Potlatch resulted where Polenz and others (2010b) did not recognize the relict nature of the fan, demonstrated by the entrenched, incised drainage in the Hoodsport quadrangle. A map edge mismatch with unit Qmw in the Skokomish Valley quadrangle resulted where logging that postdated the field work of Polenz and others (2010b) revealed morphology that favors alluvial fan deposition over other mass-wasting processes.

PLEISTOCENE GLACIAL AND NONGLACIAL DEPOSITS

Deposits of the Vashon Stade of the Fraser Glaciation (Northern Source)

Qgo **Vashon recessional outwash**—Cobble- and pebble gravel with mostly clean, sandy matrix but commonly containing some silt and clay and some sand interbeds; observed to be sand-dominated only at significant site DCSO (near the mouth of Dow Creek and only in upper 10 ft and overlying 5 ft of pebbly cobble gravel with boulders); clasts and matrix generally fresh, but some exposures iron-stained to red and yellow; loose, but where not separated by till, difficult to distinguish from the typically more compact unit Qga; clast rounding and sorting diverse, but most commonly subrounded and moderately sorted. Unit Qgo is stratified, and its exposures are typically 5 to 15 ft thick, with 50 ft maximum observed thickness. Unit Qgo was deposited by Vashon meltwater in outwash channels or isolated basins. Deposits are commonly ice-proximal, as illustrated by gradational contacts with unit Qgic south of Lake Cushman. The unit stratigraphically overlies till and postdates Vashon ice. It typically covers perched terraces along valleys. Locally divided into:

Qgoaf **Vashon recessional alluvial fan**—Cobble- and pebble gravel, sand, silt, and boulders; loose; moderately to poorly sorted and stratified; forms concentric lobes where outwash streams once emerged from confining valleys and reduced gradients, channel morphology changes, and (or) increased substrate permeability caused sediment to be deposited. The relict fans of unit Qgoaf no longer receive fresh deposits and resemble those of unit Qoaf but appear to be constrained by cross-cutting or other field relations to a Vashon recessional setting. The apparent depositional agent was meltwater. Compaction in a single polygon of clean, unweathered sandy gravel to gravelly sand at significant site PVAF (1,600 ft south and 4,000 ft east of the northwestern quadrangle border) indicates that this particular alluvial fan was glacially overridden. Lack of weathering, paucity of matrix clay, and exposure amid Vashon and Holocene sediment suggest that the deposit dates to late MIS 3 or early MIS 2. Bedding structure, sorting, and location suggest an alluvial fan setting.

Qgol **Vashon recessional glacial lake–deltaic outwash**—Pebble- and cobble gravel, sand, and locally fines; gray to brown; loose; moderately to well-sorted and clean; formed by glaciofluvial reworking of upslope units into a systematic, ice-dammed-lake-marginal deltaic assemblage of pebbly to cobbly glaciofluvial topset beds near the top, pebbly, cobbly or sandy foreset beds in the center, and sand-dominated quiet-water lake-bottom (bottomset) beds at the base. Unit Qgol was mapped in three locations along the east-facing slope above Hood Canal: south of Miller Creek, south of Finch Creek, and northwest of Potlatch. Implications of this distribution are discussed in Polenz and others (2012).

Qgl_s **Vashon recessional glacial-lake beach**—Sand, pebbly sand, cobbly sand, silt, and clay; loose; clasts typically moderately to well-rounded and oblate; locally well-sorted; derived from glaciolacustrine shore slopes, outwash streams, and underlying deposits. Unit Qgl_s was recognized in apparent glaciolacustrine shoreline segments along the east-facing slope above Hood Canal between about 230 and 250 ft, suggesting a lake in that part of the modern Hood Canal basin. Implications of the distribution of this shoreline are discussed by Polenz and others (2012).

Qgic **Vashon ice-contact deposits**—Sand, cobble- and pebble gravel, ablation till, flow till, lodgment till (commonly patchy and (or) less well developed than in unit Qgt), isolated boulders, and minor silt and clay beds; tan to gray; loose to compact; variously sorted; massive to well-stratified; locally includes oversteepened beds that either reflect sub-ice flow or developed as collapse features or due to glaciotectonic (or tectonic?) deformation; ranges in thickness from a few feet to more than 100 ft. Unit Qgic was deposited by meltwater or ice or both, generally late in the glaciation, and is commonly accompanied by stagnant-ice features, such as kettles and hummocky topography, ripples on flutes, disrupted surfaces on and between flutes, eskers (subunit Qge), and subglacial or subaerial outwash channels. Mapping of unit Qgic where morphologic evidence for stagnant ice is weak or absent relied on observation of poor development or absence of lodgment till. Where stagnant-ice features are found, lodgment till, if present, is commonly only a few feet thick, locally ranges to “sub-glacially reworked till” (Laprade, 2003), and is generally more permeable than a well-developed blanket of lodgment till. (See also discussions in Polenz and others (2009, 2010a) of the Fraser Glaciation, leaky till, and similarities between units Qgic, Qgo, and subunits Qgos, Qgof, and Qgol east and south of the map area.) A map boundary mismatch resulted where the edge of an esker, correctly identified by Contreras and others (2010), coincides with the eastern map edge. Contreras and others mapped lodgment till 2000 ft south of the northwest map corner, but we favor unit Qgic based on review of available field data and morphology on both sides, which reveal that ice-contact deposits are at least 7 ft thick in some locations and evidence for underlying lodgment till is absent. Locally divided into:

Qgik **Vashon ice-contact kames and kame deltas**—Pebble- and cobble gravel, sand, some silt, and scattered lenses of diamicton; mostly loose; medium- to very thickly bedded or massive; moderately to well-stratified; commonly contains localized delta foreset beds, crossbedding, cut-and-fill structures, and oversteepened or slumped bedding. These elevated fluvial-deltaic deposits were mapped where sedimentary structures, geomorphology, and (or) geologic setting imply ice buttressing of meltwater streams and lakes along hillslopes, mostly along Lake Cushman between Cushman Hill and Dow Mountain.

Qgim **Vashon Puget lobe end moraine**—Deposits as described for master unit Qgic but interpreted as end moraine of the northern-sourced Puget lobe ice sheet. Moraines are typically marked by abundant ablation till, but that trend was not apparent where we observed the unit (northeast of Lake Cushman).

Qge **Vashon eskers**—Pebble- and cobble gravel, and (typically clean) sand; gray or tan to brown; mostly loose; clasts moderately to well-rounded; typically moderately to well-sorted, but some deposits range to unsorted; observed thickness 5 to 60 ft; highly porous and permeable; forms low, elongate, sinuous hills on fluted uplands or amid other ice-contact deposits; deposited subglacially by meltwater in areas occupied by stagnant ice near the end of the Vashon Stade, or englacially, or supraglacially in ice-walled channels, with deposits later lowered into their present position by melting of the underlying ice. One mile from the southwest corner of the map area (significant site FTE), one esker is flat-topped, stepped, and kettled, similar to recent deposits from englacial or supraglacial flow documented in Iceland (Benn and Evans, 2010). Alternatively, Mokhtari Fard (2002) attributed a flat-topped esker in Sweden to subglacial channel widening and tunnel roof collapse.

Qgt **Vashon lodgment till**—Unsorted, unstratified (but locally banded) mix of clay, silt, sand, pebbles, cobbles, and isolated boulders; typically supported by a sandy matrix; mostly gray, but locally ranging to tan or brown, red, and orange; typically unweathered but locally includes weathered or rotten clasts and matrix (apparently from nearby) and weathered substrate; compact, with well-developed facies resembling concrete, but near the surface commonly hackly and (or) looser and covered by 1 to 10 ft of loose ablation till; clasts commonly striated and faceted, with subangular or rounded edges; deposited directly by glacial ice. Isolated, large boulders (erratics) of plutonic or metamorphic rock are common on till surfaces. Some exposures include layers and lenses of sand, pebbles, and cobbles, locally with shears and joints. Till commonly forms a patchy and seemingly randomly distributed cover, with typical exposures revealing 2 to10 ft thickness. Maximum observed thickness 25 ft (apparent) was upslope of significant site SCVA on east flank of Dow Mountain. Unit Qgt typically dominates, but it is discontinuous on fluted surfaces. Individual drumlins are typically 0.03 to 0.15 mi wide by 0.15 to 1 mi long, with the long axis aligned with ice flow. Unit Qgt is typically in sharp unconformable contact with underlying units, most commonly advance outwash (unit Qga). Unit Qgt lies stratigraphically below unit Qgo. The concrete-like properties of well-developed lodgment till locally form an effective aquitard, but varied till thickness and gradational association with more permeable ice-contact deposits and outwash channels suggest that in the map area the aquitard is commonly leaky, as also noted south and east of the map area by Polenz and others (2009, 2010a). Unit Qgt may include some exposures of Olympic-sourced till (unit Qad) where clast lithology is compatible with an Olympic source and field relations are inconclusive as to provenance, such as at significant site FUT, 0.9 mi east-southeast of the northwestern map area corner. Granitic clasts are very rare in this exposure of 10-ft-thick, well-developed lodgment till. The area to the south, east, and west of this point is dominated by stagnant ice deposits (unit Qgim) that we prefer to interpret as Vashon Puget lobe moraine on the basis of morphology and lithology of most exposures, but an Olympic provenance is reasonable at FUT because Vashon ice was preceded by, may have come in contact with, and according to Long (1975) may also have been followed by Olympic ice in this area. Unit Qgt may also include unrecognized exposures of older till. Obvious candidates for older till are weathered to rotten, red and orange to brown exposures that we mostly observed as thin drapes above weathered basaltic bedrock or soil at higher elevations on Saddle and Dow Mountains and on Cushman Hill (where till was typically too thin or spotty to map). Some prior workers mapped these exposures as pre-Fraser till. We prefer to interpret them as Vashon till, primarily based on inclusion of unweathered clasts and till matrix fragments among the weathered clasts and matrix.

Qga **Vashon advance outwash**—Pebble- and cobble gravel, sand, beds and lenses of silt and clay, and, in some exposures, diamicton (typically glaciolacustrine); clean (<5% silt or clay in matrix) except in glaciolacustrine and less sorted and more angular ice-proximal deposits; gray to tan; generally compact (see fig. 4 of Polenz and others, 2009), but commonly cohesionless; clasts typically well-rounded and well-sorted; very thinly to very thickly bedded; contains planar and graded beds, cut-and-fill structures, trough and ripple crossbeds, and foresets, but also locally ranges to structureless; thickness commonly exceeds 100 ft, especially in ice-proximal lacustrine outwash sections that are draped over bedrock along drainages that flank Dow Mountain. Section thickness in any one location may be minimal, but the lakes climbed up the mountainside over time as ice in the area thickened, so that a hike up the drainage continuously yields the same section, locally leading to more than 500 ft of continuous section, but the thickness of this section at any one location is much less than the accumulated 500 ft. Unit Qga was deposited as proglacial fluvial, deltaic, and lacustrine sediment during Vashon glacial advance and is typically overlain by unit Qgt along a sharp unconformable contact. Where pebble- or cobble gravel with little matrix was seen to dominate the exposed section, subunit Qgag was mapped. Most exposures mapped as master unit Qga are also primarily pebble- or cobble gravel, but they include sand sections or are part of lake sections that are choked with matrix. The lake sections apparently resulted from small lakes impounded between the advancing ice and a local slope, such as at age locations UFCVA and SCVA (respectively south and east of Dow Mountain; see also Polenz and others, 2012). The thickest observed glaciolacustrine section that is largely free of pebbles and cobbles, and thereby suggests a larger lake, is west of Lake Kokanee (significant site LKGL), where dropstones (including some granitics) are sparse in an 80-ft section of stratified glaciolacustrine sand and silt. Glaciolacustrine deposits are also apparent farther south in the same polygon of unit Qga but contain more clasts and are poorly exposed. Debris slides and debris flows associated with significant storms like the “Great Coastal Gale” of December 1–3, 2007, contained ample pebbles and cobbles from unit Qga, confirming that its pebble- to cobble gravel facies (subunit Qgag, even where not separately mapped) is prone to erosion and (or) rapid, hazardous landslides. Springs at the base of subunit Qgag indicate (even where not separately mapped) that it forms an important aquifer reservoir. This aquifer is sensitive to contamination because the fluted upland surface, variably mapped as units Qgt and Qgic, is commonly a “leaky aquitard” as previously suggested by Polenz and others (2009, 2010a). Unit Qga was generally identified based on stratigraphic position beneath Vashon till, the presence of northern-sourced clasts or matrix, and paucity of weathering. Except at age locations UFCVA and SCVA, deposits within the unit are undated and may locally include pre-Vashon northern outwash. Locally divided into:

Qgag **Vashon advance outwash gravel**—Mostly cobble- and pebble gravel, some sand, silt, and clay; mostly clean (<5% silt or clay in matrix) except where ice-proximal (and commonly bordering on diamicton); gray to tan; clasts typically well-rounded and well-sorted; generally compact (see fig. 4 of Polenz and others, 2009), but commonly cohesionless; thinly to very thickly bedded; contains planar and graded beds, cut-and-fill structures, trough and ripple crossbeds, and foresets, but also locally ranges to structureless; maximum observed thickness about 250 ft along Miller Creek. Along the eastern map edge 1 mi north of Sund Creek, a map edge mismatch resulted where Contreras and others (2010) interpreted Fraser drift as 160 ft of ice-contact deposits, whereas we mapped unit Qgag in the lower section based on an orderly exposure of loose outwash above till above compact outwash west of the map edge. A map edge mismatch west of Potlatch, where Polenz and others (2010b) had mapped units Qgt and Qga, and Qaf, is only apparent. The boundaries to units Qgt and Qaf in fact follow the map edge, and unit Qga of Polenz and others (2010b) is dominated by cobble gravel.

Late Pleistocene(?) Glacial Deposits of Undifferentiated or Pre-Vashon Age

Olympic-sourced drift of probable late Pleistocene age (may include Vashon and pre-Vashon deposits)

All Olympic-sourced, late Pleistocene units mapped herein are suspect because the underlying data on both age and provenance are unsatisfactory. Regarding provenance, we found that a lack of diagnostically northern-sourced clasts does not everywhere require association with Olympic ice (see text at beginning of Description of Map Units). Regarding age, we found significant weathering in some thin sections but lacked sufficient data on weathering as an indicator of sediment age in the map area to support confident age assignment. Furthermore, Thackray (2001) observed that, on the west side of the Olympic Range, the Twin Creeks 1 (MIS 2) Olympic ice advance was coeval with the arrival in the Puget Lowland of Vashon Stade (Puget lobe) ice but was less extensive than earlier late Pleistocene (MIS 3 and 4 or 5) advances of Olympic ice. We agree with Thackray (written commun., 2010) that patterns of chronology and extent of ice advances on the southeastern Olympics likely resemble those on the western

Olympics and therefore question whether the uppermost deposits of Olympic drift in the map area are as young as MIS 2. However, (1) Carson (1976) and Long (1975, 1976) advocated a meeting of Olympic alpine and Puget lobe ice in the map area during the Vashon Stade; (2) Bretz (1913) suggested that Olympic ice of what he then called “Vashon” age was extensive enough to form a piedmont glacier that reached east of Hood Canal; (3) subtle apparent fluting atop unit Qgim east of Lake Cushman (fig. 5 in Polenz and others, 2012) supports a post–Puget lobe advance of Fraser(?) Olympic ice into the map area; and (4) Polenz and others (2010b) mapped drift of apparent Olympic provenance south of the Hoodsport quadrangle as probable (but questionable) MIS 2 because clast and till matrix weathering were minor, the exposures appeared immediately subjacent to Vashon Drift, and prior mapping (Carson, 1976) suggested a Fraser age. We extended some of Polenz and others’ (2010b) polygons into the map area and added more near the southern map boundary, but we suspect that some or all of these deposits are earlier late Pleistocene (MIS 3-5), perhaps even older. Based on (inconclusive) lithologic trends, limited weathering, and in deference to prior studies, some of which extended north or west of the Hoodsport quadrangle and (or) considered exposures that are now beneath Lake Cushman (Bretz, 1913; Wilson, 1975; Long, 1976; Carson, 1976, 1980), we also show late(?) Pleistocene Olympic(?) drift (unit Qad) and till (unit Qat) at the northwest end of Cushman Hill, where till overlies deeply weathered basalt and our field data would permit (but not favor) association with Vashon (MIS 2 Olympic or northern) ice, and along portions of the shore of Lake Cushman (where some till appeared fresh or only lightly weathered). We found most till exposures at the northwest end of Cushman Hill to be little weathered in comparison to the saprolitized basalt substrate, but they are commonly red stained (apparently by pre-weathered matrix material derived from underlying saprolite?). One exposure at 1,970 ft elevation (significant site CHWT) revealed a till weathering color profile that freshened downsection, either due to rapid weathering of Fraser-age till due to limited compaction (near the top of the ice) and a high content of pre-weathered basaltic material or due to a pre-Fraser age as suggested by Logan (2003) and advocated for the upper elevations of Cushman Hill by Carson (1980).

Qat **Uppermost Olympic-sourced till**—Unsorted, unstratified (but locally banded) mix of sand, silt, clay, pebbles, cobbles, and isolated boulders; typically supported by a sandy matrix; locally includes interlayers and lenses of sand, pebbles, or cobbles; mostly gray, but typically slightly darker and more reddish or brownish and containing more clay than Vashon till; typically unweathered or only faintly weathered, but locally includes weathered or rotten clasts and matrix material, apparently from nearbyweathered substrate; compact, with well-developed facies resembling concrete; some clasts striated and faceted, with angular or rounded edges, typically more angular than in northern-sourced till; locally sheared and jointed; deposited directly by glacial ice. Observed exposures are as much as 30 ft thick east of Lake Kokanee (significant site QAT), where they are included with unit Qad. Unit Qat is typically in sharp unconformable contact with underlying and overlying units and is stratigraphically bracketed by unit Qad. It may include unrecognized exposures of older till.

Qad **Uppermost Olympic-sourced drift, undivided**—Till and outwash; till portion unsorted, unstratified (but locally banded) mix of clay, silt, sand, and as detailed for unit Qat; outwash portion cobble- to pebble gravel with scattered boulders and a (generally sparse) clayey to sandy, vesicular matrix; gray to reddish brown, with commonly heavy iron-staining but generally unweathered clasts; compact; moderately sorted; generally level-bedded with widespread, gentle crossbeds, but ranging to structureless and locally bordering on diamicton; dominated by Olympic basalt (~75%) and sandstone (~22%), with generally less than 1% Cordilleran plutonic and metamorphic clasts.

Pre-Fraser Olympic-sourced glacial deposits

Most observed exposures of pre-Fraser Olympic-sourced glacial deposits are stratigraphically constrained to a pre-Fraser age. Some or all of units Qad and Qat may similarly predate the Fraser Glaciation (see also the section above on Olympic-sourced drift of probable late Pleistocene age). Conversely, although pre-Fraser deposits are commonly marked by more advanced weathering and a denser, more clayey matrix, some sediment mapped as pre-Fraser drift may be of Fraser age, especially among thick sections of unit Qapo. Varying degrees of weathering suggest multiple Olympic ice advances over a broad age range that spans multiple glaciations, as previously postulated by Carson (1980), who speculated on the presence of pre-Fraser but post-Salmon Springs Olympic drift in the area, and by Polenz and others (2010a,b) south of the map area. Magnetically reversed (Westgate and others, 1987, and this study) glaciolacustrine sediment at Frigid Creek (age location FCT, appendix A in Polenz and others, 2012;

significant site FCRL; Naeser and others, 1984; Birdseye and Carson, 1989) requires an early Pleistocene age for part of the pre-Fraser Olympic-sourced glacial deposits in that area. (See also discussion in Polenz and others, 2010a, of "Fission-Track Age Control and Tephra and Paleomagnetic Data" and "Pre-Fraser Olympic-Source Glacial and Nonglacial Deposits, Undivided"). An early Pleistocene age has also been suggested (Easterbrook and others, 1988) for Olympic drift elsewhere in the map area (see unit Qapd).

Qapo **Pre-Fraser Olympic-sourced outwash gravel**—Cobble- to pebble gravel with scattered boulders and a sandy to clayey matrix; locally ranging to, or more commonly interbedded with, laminated to structureless, glaciolacustrine sand, silt, or clay; gray to light orange-brown to dark reddish brown, especially where weathered, and typically darker and more reddish than northern outwash; variously weathered, ranging from inclusion of fresh clasts to entirely saprolitized; compact; clasts mostly subrounded; moderately sorted; generally level-bedded with widespread, gentle crossbeds, but ranging to structureless and locally bordering on diamicton, especially in widespread, pebbly to cobbly glaciolacustrine facies; dominated by Olympic basalt (~75%) and sandstone (~22%), with less than 5% (southeast end of quadrangle), and, in most exposures, less than 1%, Cordilleran plutonic and metamorphic clasts. Unit thickness is poorly constrained but appears to locally exceed 200 ft along the side walls of Frigid and McTaggert Creeks. Many exposures of unit Qapo were included with unit Qapd, either because till was observed amid the outwash but map scale prohibited separate display, or because even though till was not documented, something suggested its presence. A new radiocarbon date of >43,500 B.P., sampled at valley floor level along McTaggert Creek (age location MTCD; Polenz and others, 2012), indicates that the unit in that part of the map area dates to MIS 3 or older. Some exposures may include Clark Creek Drift (Easterbrook and others, 1988), but insufficient age control prevented definitive determination, as previously discussed by Polenz and others (2010a). A boundary mismatch with unit Qad of Polenz and others (2010b) resulted at Frigid Creek, where Polenz and others (2010b) mapped the uppermost Olympic drift as probable Fraser age, whereas relatively advanced weathering and a ^{14}C infinite date (age location FCP; Carson, 1980; age data table in Polenz and others, 2012) in the Hoodsport quadrangle caused us to favor (but not prove) a pre-Fraser age. (For a discussion of the development of glaciolacustrine facies on slopes, see the discussion of "Timing and Duration of Vashon Ice" in Polenz and others, 2012. A setting similar to that envisioned for Glacial Lake Weatherwax by Carson, 1970, may have introduced coarse deposits into ice-dammed lakes elsewhere in the map area.)

Qapt **Pre-Fraser Olympic-sourced till**—Unsorted, unstratified (but locally banded) mix of clay, silt, sand, pebbles, cobbles, and isolated boulders; commonly contains clasts or clumps plucked from underlying units; locally includes interbands and lenses of sand, pebbles or cobbles; gray to brown, typically darker and more reddish than northern till; commonly fresh, but elsewhere ranging to distinctly weathered; compact, with well-developed facies resembling concrete; some clasts striated and faceted, with angular or rounded edges; deposited directly by glacial ice and locally sheared and jointed. Maximum exposed thickness may be east of Lake Kokanee (~460–510 ft elevation), where at least 50 ft of till that appears to lack granitic clasts is exposed downsection from more recent Olympic till (mapped as units Qat? and Qad?) at significant site QAT. A pre-Fraser age is supported by weathering observed in thin section, but large, twinned plagioclase crystals, muscovite, and moderately abundant (2–3%) polycrystalline quartz point to a possible northern source. In Clark Creek valley between 250 and 500 ft elevation, light-brown weathered exposures reach at least 25 ft in thickness but were also queried because a relatively high content of granitic clasts (4%, based on a count of 51 clasts) renders Olympic provenance debatable. Along Finch Creek (significant site FCPT), thin section petrography on unit Qapt reveals only moderate weathering, but the exposures appear to be stratigraphically below a >46,000 BP ^{14}C date (age location LFC) from unit Qapd (beneath unit Qpo). One particularly weathered till exposure 0.4 mi west of the eastern map edge and 1.2 mi north of Sund Creek (significant site PLWT, along a power line, shown as point feature in unit Ev_c) was mapped as unit Qapt because we were unable to identify diagnostically northern-sourced protoliths for the rotten clasts within this till, but, due to its severe weathering, we may have missed some. Some tills, such as at the type section of the Clark Creek Drift (significant site CCTS; Easterbrook and others, 1988) were included with undivided unit Qapd. Unit Qapt tends to have sharp unconformable contacts with underlying and overlying units and is stratigraphically bracketed by units Qapo and Qapd.

Qapd **Pre-Fraser Olympic-sourced glacial drift, undivided**—Till, outwash consisting of cobble- and pebble gravel with scattered boulders and a sandy to clayey matrix, and glaciolacustrine deposits dominated by laminated to massive silt, clay, and sand but ranging locally to diamicton and matrix-choked pebble- or cobble gravel; combines units Qapo and Qapt where map scale or limited exposures prevented separate mapping. We suspect that unit Qapd captures multiple Olympic ice advances, based on varied exposure thickness and presence at various elevations and with varied degrees of weathering, although stratigraphic relations between these exposures are insufficiently established to demonstrate multiple ice advances. Unit Qapd includes the type section of the Clark Creek Drift (Easterbrook and others, 1988) along U.S. Highway 101 (significant site CCTS). The identification and possible early Pleistocene age of the Clark Creek Drift there and elsewhere in the map area are further discussed in Polenz and others (2010a,b). We add only that petrographic examination of till from the Clark Creek Drift type section revealed only moderate weathering, less than for some Fraser age drift. Although for some deposits a paucity of weathering coupled with absence of overlying pre-Fraser units suggests that unit Qapd may include Fraser age sediment, new ^{14}C analyses of detrital wood from a possible paleosol along McTaggert Creek and a log in clay near the top of the unit along Finch Creek (age locations MTCD and LFC; appendix A in Polenz and others, 2012) support the pre-Fraser age of the unit. The matrix around the wood at McTaggert Creek lacked foraminifera and contained only very few diatoms that did not provide a paleoclimatic signal (Elizabeth Nesbitt, Burke Museum of Natural History and Culture, written commun., 2010). Similarly, a sample of organic-rich (chocolate brown) silt from significant site MTCS (0.5 mi downvalley of site MTCD) lacked foraminifera (E. Nesbitt, written commun., 2010). A boundary mismatch with unit Qad resulted at Frigid Creek, where Polenz and others (2010) had mapped the uppermost Olympic drift as of probable Fraser age, whereas relatively advanced weathering in the Hoodsport quadrangle caused us to favor (but not prove) a pre-Fraser age. A mismatch against unit ml resulted at the Hood Canal shore, where Contreras and others combined road cut exposures of alpine drift with fill along the shore.

Pre-Fraser northern-sourced glacial deposits

Provided that Easterbrook and others (1988) correctly assessed the age of the Annas Bay Drift at its type section 1.1 mi south of the map area along US 101, some pre-Fraser northern-sourced drift in the map area may date to about 1 Ma. (See also stratigraphic column site ABTS *in* Polenz and others, 2010b, and discussion of age of deposits by Polenz and others, 2010a). Certainly some pre-Vashon northern-sourced drift is distinctly and not just surficially weathered, consistent with such an age. However, a wide range in the degree of weathering suggests that multiple glaciations are included among the pre-Fraser northern-sourced glacial deposits in the map area, and, although we were unable to demonstrate it in any individual section, previous workers have indicated multiple pre-Fraser northern tills in or near the map area (Birdseye and Carson, 1989; Polenz and others, 2010a,b).

Qpo **Pre-Fraser northern-sourced outwash**—Cobble- to pebble gravel with scattered boulders and typically >5% sandy to clayey matrix, with some exposures bordering on diamicton; locally includes beds, lenses, and layers of sand or fines; typically weathered to reddish brown, but locally ranging to gray; compact; clasts typically well-rounded and well-sorted, except in less sorted and more angular ice-proximal deposits; very thinly to very thickly bedded, with planar and graded beds, cut-and-fill structures, trough and ripple crossbeds, and foresets, but also locally ranging to structureless; clasts commonly weathered, some saprolitized, but fresh clasts dominate in some exposures. A clayey matrix and iron and manganese coatings may increase cohesion in some outcrops, but more commonly the overall mass is weakened by weathering. The thickness of unit Qpo is poorly constrained but may exceed 150 ft along Finch Creek. Unit Qpo is shown only in the southeast part of the map area but may have gone unrecognized among pre-Fraser outwash (units Qapo and Qapd) in the west half of the map area, where a lack of granitics could have prevented recognition of northern provenance.

Qpd **Pre-Fraser northern-sourced drift, undivided**—Till and outwash, with till fraction being an unstratified (but locally banded) mix of clay, silt, sand, pebbles, cobbles, and isolated boulders. The till is compact, with well-developed facies resembling concrete. Some exposures include bands and lenses of sand, pebbles, and cobbles. The till was deposited directly by glacial ice and commonly includes clasts or clumps plucked from underlying units, as well as some striated and faceted clasts with angular or rounded edges. It is commonly sheared and jointed and typically in sharp unconformable contact with adjacent units. The outwash fraction generally consists of compact cobble- to pebble gravel, as described for unit Qpo. South of the town of Hoodsport, unit Qpd probably exceeds 100 ft in thickness (not including separately mapped Qpo). East of Lake Cushman, the unit revealed 25 ft of tan, interbedded till and pebble- to cobble gravel with fresh clasts and <5% granitic clasts that is underlain by or laterally grading southward into stiff, tan glaciolacustrine fines with dropstones, some of which are weathered and granitic. Clast weathering, compaction, and tan (rather than gray) color caused assignment of the area to unit Qpd. Unit Qpd is shown where map scale or limited exposures prevented separate mapping of the component units. South of the map area, unit Qpd includes the type section of the Annas Bay Drift (Polenz and others, 2010a,b; Easterbrook and others, 1988).

Pre-Fraser glacial deposits of indeterminate provenance

Qpl **Pre-Fraser glaciolacustrine sediment, paleomagnetically reversed**—Silt, sand, and clay; some exposures including lenses and interbeds of matrix-choked, glaciolacustrine(?) pebble gravel, cobble gravel, and pebbly to cobbly diamicton; gray to tan; compact, generally laminated, with few dropstones. Along Frigid Creek, Westgate and others (1987) characterized the unit as magnetically reversed, based on exposures in a 135-ft-thick glaciolacustrine section described by Birdseye and Carson (1989) along a right-bank tributary of Frigid Creek, 0.1 mi north of the southern map edge between 420 and 285 ft elevation. (Lidar suggests 20 ft lower elevations for all points, such that 420 ft = 400 ft by lidar; the above and following elevation statements are unadjusted from the source reference.) The section is covered and unknown between 340 and 290 ft and underlies a ^{14}C-infinite peat (Birdseye and Carson, 1989; Westgate and others, 1987; Easterbrook and others, 1988). A tephra at 380 ft yielded a fission track age estimate of 0.89 ±0.29 Ma (Naeser and others, 1984), and Westgate and others (1987) suggested that the tephra correlates to the Lake Tapps tephra at the Salmon Springs Drift type section of Crandell and others (1958), a hypothesis that is further discussed in Polenz and others (2010a). New paleomagnetic analysis of lakebeds along the valley floor of a north-trending tributary to Frigid Creek (significant site FCRL) expands (northward) the documented extent of magnetically reversed glaciolacustrine sediment. The 300-ft sample elevation (lidar) suggests that the sample corresponds to the gap in the section of Birdseye and Carson and thereby strengthens the argument that all pre-Fraser glaciolacustrine sediment near Frigid Creek is magnetically reversed. South of Lake Kokanee along the eastern valley wall of the North Fork Skokomish River, unit Qpl was identified based on laminations, dropstones, extreme stiffness, and evenly tan-colored weathering. Observed exposures here rest atop Crescent basalt and beneath Vashon advance outwash. Age and magnetic orientation remain undocumented here, and the only evidence for a pre-Fraser age is considerable compaction. Unit Qpl was therefore queried here.

Qpu **Undivided Quaternary sediment (cross section only)**—Pebble- and cobble gravel (locally boulder), diamicton, sand, silt, clay, and organic sediment; compact; color and weathering varied. Shown in cross section where age, character, and provenance of unlithified deposits were unconstrained.

Tertiary Sedimentary and Volcanic Bedrock

Bedrock in the map area consists of Crescent Formation and apparently overlying Tertiary marine sedimentary rocks in seemingly concordant contact with the Crescent Formation and each other. A new Ar-Ar age estimate from Crescent basalt sampled at 1,485 ft elevation on the east flank of Cushman Hill (age location CHU) indicates a unit age of 36.18 ±0.46 Ma (appendix A *in* Polenz and others, 2012).

ΦEm **Marine sedimentary rocks (Oligocene to Eocene?)**—Volcaniclastic marine feldspathic sandstone and mudstone rhythmites; commonly calcitic and typically slightly fossiliferous, some highly fossiliferous exposures along Miller Creek ranging to more than 25% shell fragments, with gastropods being most conspicuous; pale gray to dark gray to dark olive-gray, locally weathered to brown; fine- to coarse-grained; grains mostly subrounded but ranging to well-rounded and angular; poorly to moderately sorted. Bedding is distinct and very thin to medium, with rare thicker beds or massive exposures. Thin sections suggest that the unit may be mineralogically more diverse than Crescent Formation sedimentary rocks. Most outcrops are jointed to hackly; some reveal onion-skin weathering. Near-continuous exposure along

Miller Creek suggests more than 950 ft of section, although gaps in exposure could hide faults and (or) intervening basalt. (For indications of structural disruption at the southeast end of the section, see discussion of the Miller Creek syncline in Polenz and others, 2012.) The unit was observed only east-southeast of Dow Mountain and appears to be stratigraphically upsection of and typically less weathered than Crescent Formation sedimentary rocks. Several samples were examined but failed to yield enough foraminifera (or diatoms) to permit biostratigraphic assignment to a formation or age (E. Nesbitt, written commun., 2010). Assignment to the Oligocene to Eocene is based on stratigraphic exposure above Crescent basalt and on rhythmic (turbidite?) character, which requires a deeper marine basin than regionally prevailed (?) in the Miocene. (See, for example, the subaerial character of the Blakely Harbor Formation at Bainbridge Island in Haugerud, 2005). The locally calcitic fossiliferous character of unit ΦEm invites comparison to sedimentary rocks that mark the top of the Crescent Formation, as described by Al-Howar (1990), Squires and others (1992), and Babcock and others (1992) at Pulali Point (21 mi north-northeast of the map area). We note that the rocks at Pulali Point include shallow marine deposits, whereas we recognized only apparent turbidites. The more than 950 ft (?) of section we observed seems to be thicker than the section at Pulali Point, and, unlike the rocks at Pulali Point, the exposures we observed lacked intervening basalt amid the rhythmites. Map boundary mismatches resulted along the eastern map edge because we lacked the confidence to assign this unit to a known formation, whereas Contreras and others (2010) identified Lincoln Creek Formation (without compelling stratigraphic control).

Ev_c **Crescent Formation (early to middle Eocene)**—Generally subalkaline tholeiitic basalt, but one of eight chemically analyzed samples is dacite crystal tuff (geochemistry location LCW, west shore of Lake Cushman; geochemical results in Polenz and others, 2012); black to greenish black in unweathered exposures, gray and medium yellow-brown in weathered exposures; commonly exposed in fine- to coarse-grained blocky submarine or subaerial flows that include amygdules of zeolite and chlorite-group minerals; some exposures include dikes. Exposures are locally tachylitic or pillowed and fine-grained and include palagonitized breccias. Mineralogy typically includes plagioclase with intergrowths of augite and disseminated opaque minerals. Replacement of interstitial glass by chlorite and oxidation products is also common. Unit Ev_c is the bedrock beneath most of the map, except along the eastern map edge southeast of Dow Mountain, where overlying sedimentary rocks prevail, and the southeast and southwest ends of the map, where bedrock is not exposed and the uppermost underlying bedrock is undocumented. At the north end of Cushman Hill, Tabor and Cady (1978) suggested that the brecciated “upper” Crescent Formation member that prevails elsewhere in the map area is separated from the “lower” Crescent member to the northwest. Suggestions that the boundary is either tectonic Glassley (1974) or represents a difference in metamorphic grade (Hirsch and Babcock, 2006) are discussed in Polenz and others (2012) and underline the reality that both the location and character of the boundary remain poorly understood, at least in the map area. In light of this uncertainty and written communications from Rowland Tabor and Richard Blakely (both USGS, 2010) we did not separately map the upper and lower members of the Crescent Formation but suggest that a northeast-trending line across the northwest corner of the map may best represent this boundary, although the clarity of that interpretation degrades west of the map area. The line follows a steep aeromagnetic gradient shown by Blakely and others (2009) and would move the boundary of Tabor and Cady (1978) approximately 1 mi northwest. Unit Ev_c is locally divided into:

Em_{1c} **Crescent Formation, sandstone facies (early to middle Eocene)**—Volcaniclastic basaltic sandstone; most exposures rich in feldspar, with lesser quantities of quartz and mafic minerals; some exposures dominated by green and brown glass fragments; chloritoid alteration products widespread; brown to dark green to gray, significantly weathered or rotten in all observed exposures, too weathered to permit satisfactory assessment of sorting, rounding, or bedding. A mappable polygon was identified along the western valley wall of the North Fork Skokomish River on the basis of exposures 0.3 mi north of the southern map edge. A second polygon was mapped at the south end of Dow Mountain west of Dow Creek. Smaller lenses or interbeds are common in Crescent basalt but were not deemed mappable.

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