Lidar-Revised Geologic Map of the Poverty Bay 7.5' Quadrangle, King and Pierce Counties, Washington

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Introduction

For this map, we interpreted a 6-ft-resolution lidar digital elevation model combined with the geology depicted on the Geologic Map of the Poverty Bay 7.5' Quadrangle, King and Pierce Counties, Washington (Booth and others, 2004b). The authors of the 2004 map described, interpreted, and located the geology on the 1:24,000-scale topographic map of the Poverty Bay 7.5' quadrangle.

The topographic map, published in 1997 but compiled in 1957, includes planimetry derived from 1990 imagery and 20-ft contours, nominal horizontal resolution of 40 ft (12 m), and nominal vertical accuracy of 10 ft (3 m). Similar to many surficial geologic maps, much of the geology in Booth and others (2004b) was interpreted from landforms portrayed on the topographic map.

In 2003, the Puget Sound Lidar Consortium obtained a lidar-derived digital elevation model (DEM) for the Puget Sound region including all of the Poverty Bay 7.5' quadrangle. For a brief description of lidar (LIght Detection And Ranging) and this data acquisition program, see Haugerud and others (2003). This new DEM has a horizontal resolution and accuracy of 6 ft (2 m) and vertical accuracy of approximately 1 ft (0.3 m). The greater resolution and accuracy of the lidar DEM have facilitated a new interpretation of the geology, especially the distribution and relative age of some surficial deposits.

Base Map Issues

The absolute positions of geographic features on the published 1:24,000-scale Poverty Bay topographic map do not correspond well with their positions on the lidar DEM. Although we have redrawn all contacts, many adhere closely to their positions on the previous geologic map (Booth and others, 2004b) and these are shown as approximately located. Most contacts drawn or redrawn on the basis of distinct topographic features illustrated by the lidar DEM are shown as solid lines.

There is no digital depiction of stream or road locations that adequately matches the lidar DEM. We have digitized selected roads and streams that are shown on the Poverty Bay topographic map and have referred to Google Earth for road names.

This map is not suitable for site-specific land-use decisions.

Geologic Units and Their Descriptions

We quote most of the Geologic Summary section and the descriptions of units directly from Booth and others (2004b) or modify these descriptions slightly. We quote all of the descriptions of pre-Vashon deposits directly from Booth and others (2004b).

Previous Mapping

The Booth and others (2004b) version of the geology of the Poverty Bay 7.5' quadrangle relied heavily on mapping by Waldron (1961). Booth and Troost used map data from that earlier work with little modification in the southeastern part of the quadrangle, where excellent exposures once visible in the 1950s were largely overgrown. Across most of the rest of the map area, dramatic increase in new exposures caused by development allowed greater insight into the geology, and thus geologic contacts and lithologic descriptions had been revised accordingly. Improvements in the understanding of the stratigraphic framework of Puget Lowland glaciations since Waldron's original (1961) work have led to modifications of both regional and local interpretations of pre-last-glaciation deposits. Booth mapped the area sporadically in 1986 and again in earnest in 1988–89, during preparation of watershed planning documents for the central and western parts of the quadrangle on behalf of King County (1990). Booth and Troost made additional field studies during 1995–99, primarily along the coastal exposures of Puget Sound and in the ravines draining east into the Green River valley. Troost began detailed investigation of the exposures along the Hylebos Waterway in 1995 as part of stratigraphic studies that continue farther west and south (Troost, 1999; Borden and Troost, 2001). We did no additional fieldwork for the lidar interpretation incorporated in this map.

Acknowledgments

Particular acknowledgments are due our colleagues who have shared geologic data, insights, and interpretations throughout the second period of additional mapping: Richard Borden, Ray Wells and Ralph Haugerud (USGS); Timothy Walsh and Patrick Pringle (Washington State Department of Natural Resources); and the late Richard Stewart and Eric Cheney (University of Washington). Jon Hagstrum (USGS) collected and analyzed the paleomagnetic samples. Ralph Haugerud contributed considerable insight to the interpretation of the lidar DEM and helped Tabor with the GIS presentation. He and Gary Petro provided useful reviews of the lidar-revised map.

Geologic Summary

The geology of the Poverty Bay 7.5' quadrangle expresses much of the broad range of Quaternary environments and deposits found throughout the central Puget Lowland. The topography is dominated by an extensive upland plain, mantled by a thin layer of glacial till deposited about 17,000 (14,000 radiocarbon) years ago during the last occupation of the Puget Lowland by a great continental ice sheet. Scattered across this upland surface are the terrace and channel deposits of rivers that issued from the snout of the retreating ice sheet as it withdrew to the north.

Beneath these ice-sheet deposits is a complex sequence of older unconsolidated sediments that extends far below sea level across most of the quadrangle. These older sediments are exposed primarily where modern erosion has sliced through the younger glacial deposits—notably by the Green River, lying a few kilometers east of the east map boundary, and by wave erosion along Puget Sound to the west and southwest. In these areas, the sequences of exposed deposits display both similarities and differences. The older sediments are very compact, having been compressed by one or more glacial advances subsequent to their deposition. Many are also cemented by iron oxides and hydroxides, a consequence of the many tens or hundreds of thousands of years of weathering that they have experienced. Excellent but widely scattered exposures of this older Pleistocene sequence are displayed in the coastal bluffs of the quadrangle and in active and recently abandoned quarries. The quadrangle also is located at the center of the intensively developing urban core of the Puget Lowland region. It includes the northeastern part of the city of Tacoma, the third largest municipality in Washington State, and all or part of the cities of Federal Way, Auburn, Kent, Pacific, Algona, Milton, and Fife. Interstate 5, the main north-south highway through the Pacific Northwest, traverses the length of the quadrangle. Increasing population and a strong transportation network have fostered urban and suburban development in almost every part of the quadrangle. This development, in turn, is causing some of the most rapid geomorphic changes to occur since the wastage of the ice sheet.

Stratigraphy and History

Bedrock

The east-central Puget Lowland is underlain by Eocene to Miocene volcanic and sedimentary rocks (Yount and Gower, 1991; Tabor and others, 2000). In the Poverty Bay 7.5' quadrangle, these rocks are not exposed at the ground surface; the nearest surface exposures are about 6 mi (10 km) north in the Des Moines 7.5' quadrangle (Booth and Waldron, 2004). From very limited borehole data, this Tertiary bedrock lies between 400 and 600 m below the ground surface in the map area (Jones, 1996).

Unconsolidated Deposits

Stratigraphic Framework

Multiple invasions of glacial ice into the Puget Lowland have left a discontinuous record of Pleistocene glacial and interglacial periods. The ice was part of the Cordilleran ice sheet of northwestern North America, which originated to the north in the mountains of British Columbia. During each successive glaciation, the ice sheet advanced into the lowland as a broad tongue, first called the Puget lobe by Bretz (1913).

The coastal and valley-wall bluffs of the Poverty Bay quadrangle locally display very good exposures of glacial and nonglacial deposits, but their interpretation has been enigmatic to geologists for 100 years (for example, Willis and Smith, 1899). The beach-cliff and valley-wall deposits in the map area were subdivided by Waldron (1961) into older glacial ("Salmon Springs" and "Stuck") units and an intervening nonglacial ("Puyallup") unit, by analogy to deposits described in detail by Crandell (1963) along the east wall of the Puyallup River valley about 12 mi (20 km) southeast of the quadrangle. Continued study over the last three decades, however, has suggested that the sequence of older sediments is more complex than originally recognized. This sequence of older sediments records the complex interfingering of two unrelated but overlapping geologic phenomena—glacial advances from British Columbia and volcanic eruptions from Mount Rainier, about 44 mi (70 km) to the southeast—that are superimposed on the less dramatic, but still ongoing, westward transport of river-borne sediment from the Cascade Range.

Discriminating glacial from nonglacial deposits is fundamentally important to interpreting this sequence. In many parts of the Puget Lowland, this can be accomplished on the basis of rock and mineral assemblages that are related to different source areas (Booth and others, 2004a; McCormack and Troost, 2007). Three major provenances (source areas) have contributed rock clasts and mineral grains to the lowland deposits:

- Northern provenance—Characterized by igneous plutonic and high-grade metamorphic rocks and minerals, which are derived from the North Cascades and Coast Range of British Columbia and which require ice-sheet transport during glacial periods
- Central Cascade provenance—Characterized by the volcanic (primarily) and plutonic igneous rocks and minerals of Tertiary age, which compose most of the Cascade Range east and southeast of the quadrangle and which may have been delivered by local Cascade Range ice but require only river transport for their appearance in the Poverty Bay quadrangle
- Mount Rainier provenance—Characterized by hypersthene andesite and pyroclastic rocks from Mount Rainier, which have been brought into the quadrangle either by normal river transport or by catastrophic volcanic mudflows (lahars). Local alpine glaciers also may have contributed minor amounts of sediment of Central Cascade and Mount Rainier provenances into the quadrangle, but the possible influence of these glaciers cannot be recognized on the basis of source area alone

The naming and regional correlation of the individual glacial advances in the Puget Lowland has had a long history, one that is still evolving. Willis (1898) was first to present evidence for multiple glaciations in the Puget Lowland. More recently, Crandell and others (1958) proposed a sequence of four glaciations, separated by nonglacial intervals, on the basis of stratigraphic sequences in the southern Puget Lowland about 12 mi (20 km) southeast of the quadrangle. Farther north, Easterbrook and others (1967) named and described deposits of three glaciations and their intervening nonglacial periods. Dating of these southern and northern stratigraphic sequences (Easterbrook and others, 1981; Westgate and others, 1987), however, suggests little correlation between them. In its type area east-southeast of the Poverty Bay quadrangle, the Salmon Springs Drift (Crandell and others, 1958), which immediately underlies deposits of the most recent ice-sheet advance (the Vashon Drift), has been shown to be greater than 774,000 yr old on the basis of reversely magnetized sediment present within the unit (Easterbrook and others, 1981). In contrast, the glacial deposits of pre-Vashon Drift age in the north-central Puget Lowland (Possession and Double Bluff Drifts) have been dated between 80,000 and 250,000 yr old using amino-acid racemization and paleomagnetic methods (Blunt and others, 1987).

Deposits Predating the Vashon Stade of the Fraser Glaciation

Various kinds of waterlain sediments are exposed beneath deposits of the most recent ice-sheet advance (which occurred during the Vashon Stade of the Fraser glaciation of Armstrong and others, 1965; hereafter referred to as the Vashon Stade and (or) Fraser glaciation), mainly along the Puget Sound coastline and the Green River valley wall. The thickness of individual layers ranges from a few feet (or meters) to about 30 ft (10 m). The sediments are subdivided primarily on the basis of age, but because dating techniques are relatively imprecise for these sediments, Booth and others (2004a) specified only coarse stratigraphic divisions. In the Poverty Bay quadrangle, they recognized the following three localities of reversely magnetized sediment (Hagstrum and others, 2002): (1) along the west wall of the Green River valley in the southeastern quadrant of the map, where Westgate and others (1987) reported two localities of the 1 Ma Lake Tapps tephra of Crandell (1963) (mapped here within unit Qr); (2) on the coast of Puget Sound near Adelaide (Crandell's sample T7310), where interbedded volcanic and non-volcanic sediments are present (mapped here as unit Qrn); and (3) along the Hylebos Waterway (Crandell's sample T7012), where reversely magnetized material is interbedded with a 1.1 Ma tephra (sample S-5 of R. Stewart, University of Washington, written commun., 1999) (also mapped here within unit Qrn) (fig. 1). Booth and Waldron (2004) noted three other localities of reversely magnetized sediments along the Puget Sound coastline just north of the quadrangle boundary.

Where paleomagnetic determinations are absent, Booth and others (2004b) locally subdivided pre-Fraser deposits (Qpf and Qpo) on the basis of their presumed depositional environments only, and not by age. Exposures were not everywhere adequate, however, to make this determination with confidence. Where organic material or volcanic sediment is abundant, Booth and others (2004b) recognized a likely nonglacial origin (units Qpfn and Qpon). Where deposits contain a suite of sand and (or) gravel lithologies indicative of southward transport from the North Cascades or British Columbia or display sedimentary features characteristic of glacial or proglacial environments, Booth and others (2004b) recognized a likely glacial origin. Because all pre-Fraser-age glacial periods also precede the Olympia nonglacial interval, these deposits are designated as pre-Olympia beds (unit Qpog).

Most pre-Fraser and pre-Olympia-age deposits are further classified on the basis of grain size: coarse, predominantly gravel and sand (units Qpfc or Qpogc); or fine, predominantly silt and clay (units Qpof and Qponf). Areas of glacial till that can be shown at map scale are delineated as unit Qpogt. Along the Green River valley wall, many of the coarse-grained pre-Fraser-age deposits are volcanic rich and probably reflect a Pleistocene record of mudflows during nonglacial intervals from the vicinity of the modern Mount Rainier. We follow the lead of Booth and others (2004b) and make no effort to assign stratigraphic names to subdivisions of the pre-Fraser-age deposits, because absolute age control is limited at present, and so the likelihood of spurious correlations is high. Layers or lenses of diamict of presumed glacial origin, whose deposition predates the Vashon Stade but are too thin to show at map scale, are shown with an X-decorated line (magenta) within areas of units Qpo and Qpog. Their absence elsewhere on the map reflects not only the likely discontinuity of these deposits but also the typically poor exposures across the map area, even under relatively favorable conditions of steep topography and sparse vegetation.

Details of the pre-Fraser-age deposits vary across the quadrangle. The following three subregions, in the eastern, northwestern, and southwestern parts of the map area, each display distinctive characteristics.

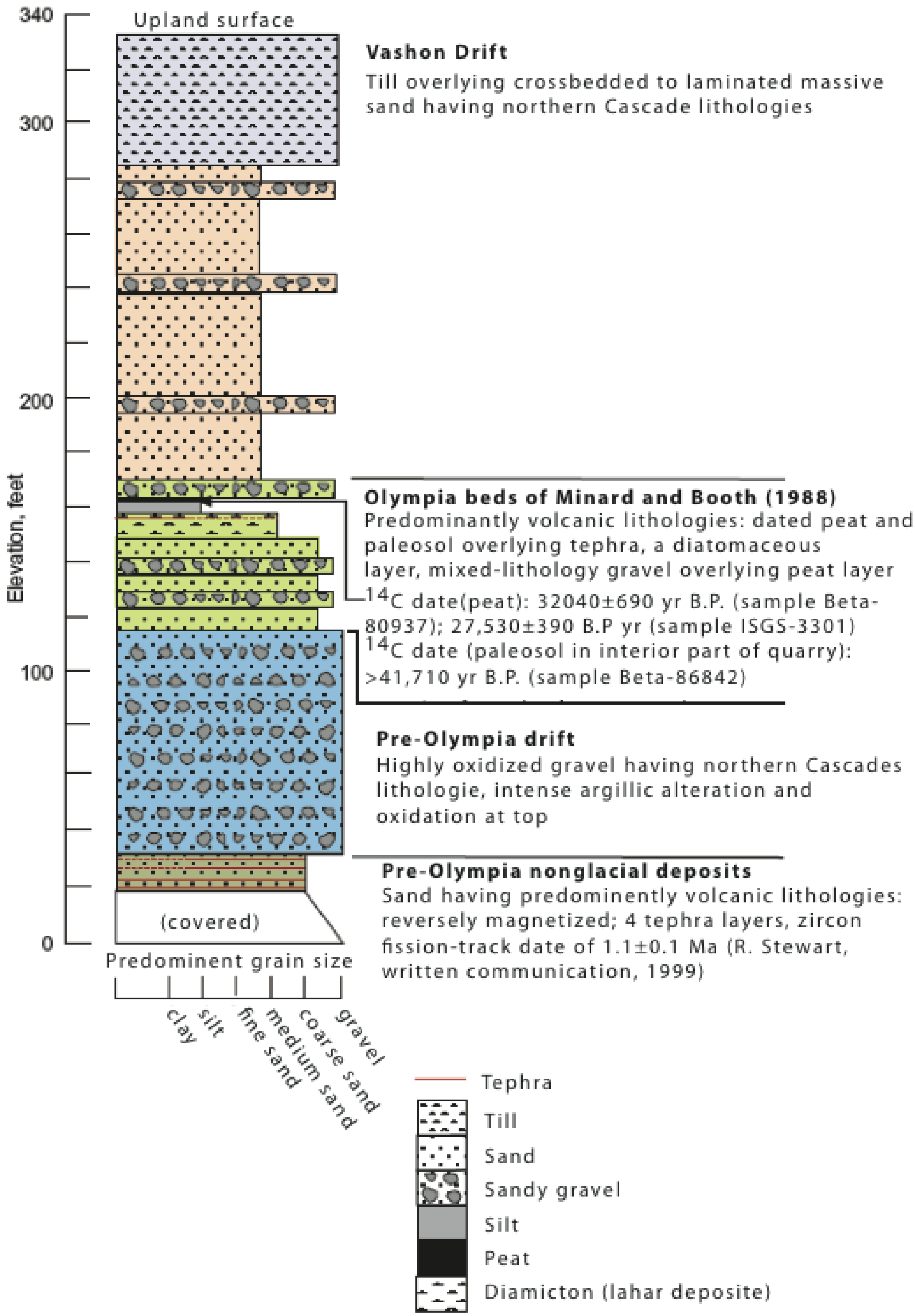

Figure 1. Composite measured section, Hyebos Waterway (lat 77.273° N., long 122.373° W.), showing elevation plotted against grain size. See table 1 for ^{14}C ages.

Green River Valley Wall

Along the western wall of the Green River, near the east edge of the quadrangle, a complex and now rather poorly exposed sequence of glacial and nonglacial sediment is present. Once mined extensively for sand and gravel, most of this 330-ft-high (100-m-high) face is now heavily vegetated, and the several roads that traverse this escarpment and the several stream channels that have carved ravines into it offer only widely scattered exposures.

North of Peasley Canyon, exposures are largely restricted to small gullies, largely choked with landslides and other mass-wastage debris, that, although too small to show at map scale, nonetheless obscure stratigraphic relations. Southeast of Lake Fenwick, however, Waldron (1961) reported an outcrop displaying about 35 ft (10 m) of mudflow-alluvial complex beneath Vashon Drift, exposed in a small ravine; this complex (mapped here as unit Qpfn) consists of interbedded fine- to medium-grained volcanic sand, locally containing pumice fragments and clay lenses, and fine-grained slurry-like mudflows.

South of Peasley Canyon, Booth and others (2004b) mapped a relatively continuous contact at about 200 ft (60 m) altitude between the following two sequences: (1) underlying fluvial sediments, presumed to be of nonglacial origin (mapped here as Qpon) on the basis of the absence of northern provenance lithologies in the deposits, as well as the widely scattered presence of pumice-rich beds, the purplish color of many of the beds, and the local gravel imbrication showing flow to the northwest and (2) overlying deposits that, owing to poor exposures and because they have a more ambiguous origin and may possibly include more than a single glacial or nonglacial interval, we have elected to map as unit Qpfc. At the mouth of Peasley Canyon, Westgate and others (1987) identified an exposure of the 1 Ma Lake Tapps tephra of Crandell (1963) in the underlying sediments; despite its probable nonglacial origin, Booth and others (2004b) mapped it here within the undivided unit Qr (instead of Qrn) because its lateral continuity and stratigraphic relations are largely obscured by vegetation and by modified land associated with the highway through Peasley Canyon. Farther south in the Puyallup quadrangle, Hagstrum and others (2002) also reported a reversely magnetized deposit (their sample T6095) at the base of the Green River valley wall.

At the base of the Green River valley wall in the southeast corner of the quadrangle, a thin discontinuous band of older glacial deposits was mapped by Waldron (1961): north of Algona, Waldron defined it as an undifferentiated glacial deposit; south of Algona, he assigned it to his (oldest) "Stuck glaciation." Since 1961, most of these exposures have disappeared beneath slide debris and vegetation; what remains are isolated outcrops of sand, pebbly silt, and diamict of both glacial and nonglacial origin, including a valley-wall exposure of the 1 Ma Lake Tapps tephra of Crandell (1963) at Algona, identified by Westgate and others (1987). Booth and others (2004b) included all of these deposits in unit Qr because the exposures necessary to depict a more precise discrimination at map scale are absent.

Poverty Bay Bluff

Along the shores of Poverty Bay, in the northwestern part of the quadrangle, the sequence of pre-Fraser-age deposits appears to be regular and the outcrop pattern at sea level is controlled by the undulating structure in these older beds. The oldest consistently exposed deposit is a laminated silt and clay that has widely scattered organic material (unit Qpogf). Its upper contact lies as high as about 140 ft (43 m) altitude in T. 21 N., R. 4 E. sec. 5, and it descends below sea level altogether both north near Woodman Beach and southwest to near the west edge of the quadrangle. Exposed above this unit is a thicker unit of oxidized sand and gravel that contains local lenses of finer grained sand and silt towards the west and that has gravel lithologies consistent with a northern (glacial) provenance (unit Qpogc); one till layer is well exposed in the creek at Redondo but is less continuously exposed on the hillsides north and west at concordant altitudes. An infrared-stimulated luminescence (IRSL) age of 203±10 ka was obtained on fine-grained sand (sample WA-7 in Mahan and others, 2003) within unit Qpogf, suggesting that the overlying glacial deposits correlate to the Double Bluff and (or) Possession drifts of Easterbrook and others (1967). The oxidized sand and gravel deposit generally can be distinguished from the overlying advance outwash deposits of Vashon age on the basis of its greater oxidation and its overall degree of relative weathering, although in any given exposure these criteria may not be conclusive. Along much of the coast, however, Vashon-age advance outwash deposits are missing (either eroded or never deposited), and so Vashon-age till (unit Qvt) overlies the older material directly.

Just north of Redondo, a till (unit Qpogt) that crops out at sea level appears to underlie the laminated silt and clay (Qpogf). Although the till may be a low draping of Vashon-age sediment, the overall topography suggests that the Vashon-age deposits lie about 250 ft (60 m) higher on the slope. Insofar as this low till lies in the axis of a broad anticline, defined by bedding in the overlying fine sediment, it appears to represent deposition of a glacial advance that preceded both the Vashon-age ice advance and the glacial interval represented by the oxidized gravel and sand outwash (unit Qpogc).

Southwest of Redondo, another till within unit Qpogf crops out near sea level. It is variously clast rich to clast poor, is faintly layered, and is at least 20 ft (6 m) thick. The till descends from the east, concordant with the 12° westerly dip of older strata in this area, and is truncated abruptly within an old large coastal landslide (unit Qols).

Beyond the landslide to the west, till is not exposed again as far as the edge of the map area. In place of till, beds exposed on the coastal bluff west of the landslide are predominantly lacustrine deposits of gray and purplish-gray volcanic sand of Mount Rainier provenance, as well as gray to brown stratified silt and clayey silt. These deposits also include some thin gravel lenses, woody layers, and organic silt beds; the sand is pumiceous locally. About 300 ft. (100 m) west of the landslide, the paleomagnetization of these sediments is reversed (sample T7310 of Hagstrum and others, 2002), and so the deposit is presumably older than 774,000 years (unit Qrn).

Hylebos Waterway Bluff

Only along the bluff northeast of the Hylebos Waterway (see measured section, fig. 1) does absolute age control permit specific assignments for at least part of the pre-Fraser-age deposits. Here, three finite radiocarbon dates (samples ISGS-3301, Beta-80937, and Beta-87981; see table 1) specify interbedded sand, lahar deposits, tephra, and organic material as belonging to the Olympia nonglacial interval (Mullineaux and others, 1965; Armstrong and others, 1965). These deposits (Qob), as much as 16 ft (5 m) thick, directly underlie Vashon-age advance outwash deposits (Qva) and directly overlie oxidized gravel and sand (Qpogc). Where these deposits are absent along this bluff, the contact between the Vashon-age and the pre-Fraser-age deposits remains easily identified on the basis of an abrupt oxidation change and an only gradually varying altitude. One IRSL date of 232±18 ka has been collected from unit Qpogc in this immediate area (sample WA-6 of Mahan and others, 2003). Tephra is present at two other stratigraphic horizons: two layers within unit Qob, near the east edge of T. 21 N., R. 3 E., sec. 36, and four layers within unit Qrn, at an elevation of about 35 ft (10 m), immediately north and northwest of the center of T. 21 N., R. 3 E., sec. 36, which have been fission-track dated at 1.1 Ma (R. Stewart, University of Washington, written commun., 1999).

Table 1. ^{14}C ages in the Poverty Bay quadrangle.

Sample No.	Location[1]	Altitude[1] in m (ft)	Material	Conventional age in ^{14}C yr B.P.[2]	Calibrated age range, in solar yr. B.P.[3]	Map unit	Collected by	Reference
Beta-95340	SW¼SW¼ sec. 25 T. 21 N., R. 3 E.	59 (190)	reworked charcoal (limiting age)	>53,480		Qva	K. Troost[4]	Borden and Troost (2001)
ISGS-3301	SW¼SW¼ sec. 25 T. 21 N., R. 3 E.	50 (160)	organic sediment	27,530±390	31,173-32,769	Qob	K. Troost	Borden and Troost (2001)
Beta-80937	SW¼SW¼ sec. 25 T. 21 N., R. 3 E.	50 (160)	organic sediment	32,040±690	35,096-38,416	Qob	K. Troost	Borden and Troost (2001)
Beta-89875	NW¼SW¼ sec. 31 T. 21 N., R. 4 E.	40 (140)	peat	>46,450		Qob	K. Troost	Borden and Troost (2001)
Beta-86842	SW¼SW¼ sec. 25 T. 21 N., R. 3 E.	73 (240)	organic sediment	>41,710		Qob	K. Troost	Borden and Troost (2001)
Beta-87981	SE¼NE¼ sec. 36 T. 21 N., R. 3 E.	40 (140)	paleosol	36,650±720	40,277-42,722	Qob	K. Troost	Borden and Troost (2001)

[1]Locations and elevation from Booth and others (2004b), which do not always agree with locations on lidar DEM base of this map.

[2]Present is considered to be 1950 A.D.

[3]Calculated with online version of Calib 6.0 (http://calib.qub.ac.uk) using INTCAL09 calibration (Reimer and others, 2009) 2-sigma age range.

[4]University of Washington

Plotted outcrop patterns and sample localities suffer from recent extensive quarrying, which has rendered the topographic base map obsolete in this area. Booth and others (2004b) elected to plot contacts in accord with their presumed map pattern, using the existing contour lines (in other words, how the contacts would appear on the ground surface as contoured), and samples within the stratigraphic unit in which they were collected but otherwise as close to their actual latitude and longitude as possible (but without regard to the contoured elevation). Further modification of the land prior to the lidar survey makes plotting of the sample locations even more problematic. On this map, they are plotted by inspection as shown on Booth and others (2004b), but they are not in close agreement with the Public Land Survey System (PLSS) locations cited in table 1. The locations and altitudes reported in table 1 reflect actual sample locations, however, as of the date of collection.

Age Determinations in and near the Poverty Bay Quadrangle

Few absolute age determinations are available in the Poverty Bay quadrangle, but the surrounding area provides some relevant data. In the northern part of Maple Valley 7.5' quadrangle, about 16 mi (20 km) northeast of the Poverty Bay 7.5' quadrangle, the lowermost till in a sequence of three tills near the base of the north Cedar River valley sidewall (SW¼NW¼ sec. 24, T. 23 N., R. 5 E.) is normally magnetized (D. Easterbrook, oral commun., *in* Booth, 1995). Thus, the entire exposed section of Quaternary sediments in that area is probably post-Salmon Springs (>477,000 years) in age. In the Des Moines 7.5' quadrangle (Booth and Waldron, 2004), reversely magnetized deposits are present within 1.2 mile (2 km) north of the Poverty Bay 7.5' quadrangle, and they are inferred to extend into the northwest corner of the Poverty Bay quadrangle on the basis of textural and structural continuity. Along the walls of both the Green River and the Puyallup River valleys within and southeast of the Poverty Bay quadrangle, Easterbrook and others (1988) reported a suite of reversely magnetized samples in and near the type sections of the Orting, Alderton, Stuck, Puyallup, and Salmon Springs glacial and nonglacial units (Crandell, 1963). These sites include a locality of the Lake Tapps tephra of Crandell (1963) mapped by Westgate and others (1987) in the southeast corner of the Poverty Bay quadrangle.

Within the map area, radiocarbon (table 1) and fission track dates have been obtained at several localities along the north shore of the Hylebos Waterway.

Correlation of Pre-Fraser-Age Deposits

Although the seemingly regular sequence of glacial and nonglacial deposits in the three subregions of the quadrangle invites broader correlation, only a few such connections appear warranted using presently available data. One set of correlative sites includes the dated 1.1 Ma locality of unit Qrn along the Hylebos Waterway, which is approximately the same age as previously dated deposits of the Lake Tapps tephra of Crandell (1963) to the southeast (Westgate and others, 1987) along the southern half of the east edge of the map area and at the Salmon Springs glacial unit type locality. Another site in this set has been identified using fission-track dating just west of the town of Sumner, immediately south of the southeast corner of the quadrangle (Troost, 2000).

A second, more speculative set of correlative sites involves the well-exposed and laterally extensive pre-Fraser-age oxidized glacial outwash deposit of the Hylebos Waterway (mapped in unit Qpfgc). This deposit not only is present within the map area but also can be traced readily and continuously to the northwest and southeast beyond the quadrangle boundaries. It is plausibly correlative with mapped areas of Qpfgc above the shores of Poverty Bay, about 5 mi (8 km) north of the Hylebos Waterway, on the basis of its texture, weathering, and stratigraphic position. Its correlation is less certain, however, with deposits mapped as unit Qpf along the Green River valley wall and in Peasley Canyon; these eastern deposits are more heterogeneous and may predate or bracket (in age) what Booth and others (2004b) interpreted to be a single glacial interval represented by the western deposits.

Deposits of the Vashon Stade of the Fraser Glaciation

In contrast to uncertainties in age and stratigraphic assignment of older Pleistocene glacial and nonglacial deposits, the deposits at or near the land surface are readily assigned to the youngest regionally recognized glacial advance, the informal Vashon stade of the Fraser glaciation (Armstrong and others, 1965). During this time an ice sheet progressively advanced along the axis of the Puget Lowland from the north (Clague, 1981), reaching its maximum extent about 17,000 (14,000 radiocarbon) yr B.P. and covering the Puget Lowland to a maximum depth of about 1,500 m (Booth, 1987; Porter and Swanson, 1998). Deposits of the Vashon stade have a variety of textural characteristics and topographic expressions, owing to rapidly changing depositional environments caused by the advance and retreat of the ice sheet. As the ice first advanced, it blocked northward lowland drainage out the Strait of Juan de Fuca, which presently connects Puget Sound with the Pacific Ocean. In the impounded lakes that formed during the change to southerly drainage out of the Puget Lowland, laminated silt and clay were deposited. This material has been mapped to the north and east as either Lawton Clay (see, for example, Waldron and others, 1962) or transitional beds (see, for example, Minard and Booth, 1988; Yount and others, 1993). The latter term reflects the possibility that the unit may include deposits of pre-Vashon-age lowland lakes in addition to those formed in the subsequent ice-dammed environment. Although this depositional environment probably existed in the Poverty Bay quadrangle during both pre- and early-glacial time, no mappable deposits correlative with these units have been recognized. The initiation of the Vashon stade is marked by coarse advance outwash deposits (Qva), which were deposited by streams flowing from the advancing ice sheet. At lower elevations, Qva probably includes deltaic or pro-deltaic deposits. Deposits at least 100 ft (30 m) thick and locally as thick as 300 ft, (100 m) underlie the broad upland areas in the central part of the quadrangle. They inundated the pre-Vashon-age topography of the lowland and constructed a south-sloping surface at an elevation of about 400 ft (120 m) in the area (Booth, 1994). The most extensive outcrops of advance outwash deposits are in the southern part of the quadrangle, where as much as about 400 ft (125 m) of sand and gravel is exposed between the Vashon till and the Olympia beds or older outwash. Most exposures consist of light-gray to very light brown sand, or sand and pebble- to cobble-sized gravel. The outwash varies from poorly to well sorted, and it is typically moderately well to well bedded.

Advance outwash deposits form an important aquifer throughout the Puget Lowland, but this aquifer is particularly significant in the Poverty Bay quadrangle. It is highly permeable and supports most of the major production wells for the cities of Federal Way and Milton (Robinson and Noble, 1992). In the map area, its subsurface distribution forms a southward-narrowing and southward-deepening channel, defined in multiple water-supply wells. The channel begins just landward of the Poverty Bay coastline, at about 200 ft (60 m) elevation, and traverses more than 3 mi (5 km) from Redondo south past the boundaries of the quadrangle. The channel narrows to only a couple of miles wide as it passes south out of the map area in the vicinity of T. 20 N., R. 4 E., sec. 5 (SKCGWAC, 1989). At its deepest known extent, in the center of T. 21 N., R. 4 E., sec. 20, the base of the channel is about 100 ft (30 m) below sea level. Advance outwash deposits farther west are at too high an altitude and are too well drained by the free face above the Hylebos Waterway to provide much water.

As ice covered the region, lodgment till (Qvt) was deposited by the melt-out of debris at the base of the glacier. This heterogeneous, compact sediment blankets the area to depths of, at most, about 100 ft (a few tens of meters); the ground surface underlain by this deposit is locally fluted with elongated hills that have a weak but uniform north-south orientation across the quadrangle. Where present at the surface, the till provides a low-permeability cover to underlying aquifers, reducing recharge but also offering protection from surface contaminants. Where it is overlain by more permeable sediment, the till commonly is still present at depth, and so it slows groundwater migration and recharge. The matrix of the till differs from place to place in relative proportions of clay, silt, and sand, but mostly it is made up of silty sand to sandy silt. In many places, the till is crudely stratified and contains lenses of sand, gravel, and silt. Larger rock fragments, which are scattered throughout the till, are mostly pebble to cobble size; boulders more than 1 m in diameter are present but uncommon; rare boulders more than 4 m in diameter have been observed. Unoxidized till is light gray and compact; where oxidized, the till is light yellowish gray and generally is loosely consolidated. Although a weak brown soil is developed on the till, oxidation rarely extends more than about 3 ft (1 m) into the deposit.

Shortly after 17,000 (14,000 radiocarbon) years ago, the ice margin, which by that time had advanced south of the city of Olympia, about 70 miles (112 km) south of the quadrangle, began to recede. Recession of the ice margin was accompanied by both outwash deposits and ice-dammed lakes, analogous to those formed during the ice advance. Water from the melting ice sheet, and also from the Cascade Range, drained southward and westward, spilling over high divides that later were abandoned as ice pullback exposed lower-elevation drainage routes farther north.

During ice recession, ice-contact sediments (Qvi) were also being deposited in a variety of environments. The oldest of these deposits are eskers (Qvie), which can be recognized as narrow sinuous ridges traversing the glaciated uplands and which formed as fluvial sand-and-gravel fillings of subglacial tunnels beneath slow-moving or stagnant ice. Although subglacial water was ubiquitous beneath the Vashon-age ice sheet (Booth, 1991), the Poverty Bay quadrangle is one of the few areas of the Puget Lowland where eskers have been mapped. Unfortunately, they are rapidly being obliterated by excavation for sand and gravel, as well as by regrading for the convenience of suburban development. Locally, they also are the preferred paths for elevated sections of state highways.

Kames and kame-terrace deposits, jointly included in unit Qvi (but not mapped separately), are found in the southern and northeastern parts of the map area. Kames are isolated mounds or hummocks of irregular drift deposited in ice-walled depressions; they commonly are associated with kettles, which are depressions or lakes scattered across recessional outwash surfaces that mark the location of melted-out ice blocks. Most kames consist of poorly sorted and poorly bedded sand and pebble to cobble-sized gravel, in which foreset bedding and slumped structures are common. Kame-terrace deposits are composed of glaciofluvial sand and gravel deposited between a valley wall and either active or stagnant ice. In the Poverty Bay quadrangle, the northernmost 3 km of the eastern upland escarpment is mantled by these sediments, forming the southern end of a much more extensive deposit that marks a late-recessional period of fluvial deposition against an ice tongue in the adjacent Green River valley. The sediments consist mostly of silty sand and pebble to cobble-sized gravel; locally they include lenses and pods of till, as well as lenses and beds of sand, silt, and clay.

By the time that the area of the Poverty Bay quadrangle was uncovered by the retreating ice, proglacial drainage was well established across most of the eastern and southern lowland areas. Water was impounded in a large lake that inundated much of the central and southern Puget Lowland because northward drainage was blocked by glacial ice that still filled the northern Puget Lowland. This water body, Pleistocene glacial Lake Russell, drained out through Black Lake, just south of Olympia, into the Chehalis River about 50 mi (80 km) to the southwest of the quadrangle (Thorson, 1980). Although the elevation of the Black Lake spillway was only about 130 ft (40 m) high, the present-day elevation of the ancient shoreline of Pleistocene glacial Lake Russell is now higher because the land surface of the entire Puget Lowland has rebounded since removal of the weight of the ice sheet. More rebound occurred in the north than in the south because the ice was thicker to the north. In the center of the Poverty Bay quadrangle, the amount of rebound relative to the Black Lake spillway has been about 115 ft (35 m), and so the level of glacial Lake Russell during active deposition of recessional outwash (Qvr) can be recognized today at about 250 ft (75 m) elevation (about the level of both Panther Lake, in T. 21 N., R. 4 E., sec. 19 and the large wetland in T. 22 N., R. 4 E., sec. 28). Most of the outwash in the map area lies at higher altitudes, presumably reflecting discharge issuing from the retreating upland ice front.

A lower regional lake level, that of Pleistocene glacial Lake Bretz (Waitt and Thorson, 1983), which reflects the first postglacial access of Puget Sound drainages to the Strait of Juan de Fuca, may also be indicated by lacustrine sediments (Qvrl) that now fill the lower valley of the west branch of Hylebos Creek, in T. 21 N., R. 4 E., secs. 29 and 32 and T. 20 N., R. 4 E., sec. 5. The surface altitude of these lacustrine sediments is concordant with sea level during late recessional time (correcting for subsequent isostatic uplift; Thorson, 1981), but their deposition may also reflect Holocene damming of the valley mouth by the Osceola mudflow (see section below entitled, "Mount Rainier Mudflows;" see also, Dragovich and others, 1994).

Additional deposits associated with recessional lakes are sublacustrine landslides (Qvrls) and fans (Qvrlf). We recognized two of the sublacustrine landslides in Hylebos Creek in the lidar DEM by their headwall scarp, subdued topography, and gentle profile. The lidar DEM reveals a sublacustrine fan on the west side of the valley of the west branch of Hylebos Creek. This fan, prominent on the topographic map, lacks adequate drainage for its size. Sloping terraces (Qvrs) of coarse sand along the coast above Puget Sound appear to be truncated alluvial fans. Their elevation, about 20 to 90 ft (6 to 25 m), suggests that they were deposited subaqueously. Their creeks have incised them, and wave erosion has removed much of their lower parts.

Postglacial Processes and Deposits

Geologic activity since glaciation has included widespread slope failure and stream-channel erosion. As a result of the lowered base level caused by drainage of Pleistocene glacial Lake Russell, streams in the quadrangle began to incise the sequence of glacial and nonglacial deposits that underlies the upland surface. On the upland surface, soil formation has proceeded slowly but has had profound hydrologic consequences. Bare, unweathered till absorbs water very slowly; in contrast, the meter or so of soil that has developed on the till surface since deglaciation has high infiltration capacities and a large capacity to store and then slowly release subsurface runoff. This till-derived "Alderwood" soil (Snyder and others, 1973) blankets the majority of the upland plateau. Its hydrologic properties differ so dramatically from its underlying parent material that the compaction or removal of soil during typical urban or suburban development results in commensurably large hydrologic effects.

Colluvial deposits formed by episodic landslides and rapid soil creep mantle most of the lower slopes of both the coastal bluffs and the Green River valley. Fine-grained layers and interbeds in the underlying older deposits greatly impede the vertical descent of percolating groundwater, which makes the exposed slopes prone to landslides. In these environments, wave or river erosion has developed and maintained steep slopes, and emergent groundwater promotes continued instability. Several ravines descend these slopes, particularly to the east into the Green River valley where urban development has occurred in the heads of these ravines, discharge and the commensurate rate of channel incision has increased dramatically, and the underlying glacial and nonglacial deposits are relatively well exposed.

Colluvium, landslide, and mass-wasting deposits are common. Colluvium, a few inches to several feet (few centimeters to a few meters) thick, covers nearly all the valley walls and slopes. It consists of a mixture of locally derived materials, principally loosely consolidated silty sand and gravel. Small landslides, common in the steep bluffs and slopes, consist of slumps and earth flows caused chiefly by surf erosion or by spring sapping. Individual slides are generally small; however, the ravines and coastal bluffs are replete with slides. Although many are too small to show on the map, they can be quite hazardous in populated areas. Steep slopes in fine-grained units (Qpfn or Qrn) overlain by coarse-grained units (Qpogc or Qva) are particularly susceptible to failure because of groundwater perching. This condition is found in many of the steeply sloping parts of the map area. The lidar DEM reveals many landslides not shown by Booth and others (2004b), although they mapped many mass-wastage deposits along the bluffs above Puget Sound, which we now show as landslides. Booth and others (2004b) describe the most active slide, the Woodmont slide, which reaches sea level in T. 21 N., R. 4 E., sec. 32; movement of the southern part of this slide in early 1997 rendered several houses unsafe for occupancy. Another historically active slide, the Buenna slide in T. 21 N., R. 4 E., sec. 6, displays a particularly clear suite of morphologic features: an abrupt unvegetated headscarp, truncated deposits in the bluff below, and a very large and old fir tree at the center of the downdropped block then standing at an angle of about 10° from vertical. In the mid-1980s, the upper surface of this downdropped block was proposed as the site of a housing subdivision, a plan subsequently abandoned. We recognize other landslides shown on the map on the basis of somewhat less obvious morphologic indicators, particularly the presence of arcuate headscarps. We have queried 17 of 71 mapped landslides, indicating uncertainty in their identification.

A major block slide in the vicinity of Lake Fenwick has dropped Vashon-age and pre-Vashon-age deposits en masse into the Green River valley along highly visible east-facing scarps up to 200 ft (60 m) high. Unit symbols for deposits involved in this slide are shown in parentheses. This area probably collapsed into the Green River valley, resulting in the formation of Lake Fenwick shortly after a major ice tongue withdrew from the valley. The lower part of this slide block has been buried by the Osceola mudflow and alluvial deposits described below.

A northwest-facing escarpment northeast of Woodmont Beach, ranging up to 40 ft (12 m) high, suggests that a similar block slide has dropped Vashon till (Qvt) and possibly underlying pre-Vashon-age deposits (Qpogc) down to the northwest.

Although older landslides may be more stable than younger ones, no implication of stability is intended in this landslide classification. This map is not suitable for site-specific land-use decisions.

Mount Rainier Mudflows

Mount Rainier has exerted a profound influence on the geology of the quadrangle, even though this active volcano currently does not drain directly into the Green River. Episodic eruptions have triggered massive landslides on the flanks of the mountain, whose debris in turn mixed with water from the rapidly melting snowfields and glaciers. The resulting slurry of mixed sediment and water moves rapidly down one or more of the river valleys that radiate from the mountain, emerging onto the lowland as a mudflow (or lahar) whenever the volume of material is sufficient. The Osceola mudflow of Crandell and Waldron (1956) is one of the largest recognized volcanic mudflows in the world. Originally thought to be an alpine till (Willis, 1898), it was later recognized as a lahar deposit from Mount Rainier. The lahar flowed down the flanks and tributary valleys of the volcano, spreading mainly northward upon reaching the Puget Lowland. It entered what is today the Green River valley south of Auburn and continued north past the city of Kent, just northeast of the quadrangle. At the time of the eruption about 5,700 years ago, the lahar deposit covered an area of at least 127 mi^2 (~330 km^2); its average thickness now is about 27 ft (8 m), and its volume is estimated at nearly 0.96 mi^3 (4 km^3) (Dragovich and others, 1994). The deposit can be recognized because of its groundwater retarding properties, even at depths of more than 200 ft (60 m) below the modern ground surface (Dragovich and others, 1994).

The Osceola mudflow is a useful stratigraphic marker in the lower Green River valley. All of the 100–200 ft (30–60 m) of sediment that overlies the mudflow, which now fills the valley from just east of the quadrangle north and northwest to the modern shore of Puget Sound, has been deposited by river transport in the last 5,700 years. The mouth of the Green-Duwamish River estuary has advanced northward about 50 miles (80 km) during that time, at a rate of about 30 ft (9 m) per year. This rapid advance reflects the dominant sedimentary contribution of the White River, which flowed northward down the (modern) Green River valley during most of the last 5,700 years. This river carried the voluminous products of both normal fluvial transport and volcanic mudflows throughout much of the late Holocene (Dragovich and others, 1994).

Structure

The Poverty Bay quadrangle occupies a region of observed Holocene seismicity. A vertical displacement of about 7 m about 1,100 years ago has been documented on the Seattle Fault, a major east-west-striking structure about 16 miles (25 km) north of the map area (Bucknam and others, 1992). A network of other faults in the region has been suggested by interpretation of seismic reflection studies in Puget Sound (Johnson and others, 1996). In this quadrangle, faults are visible locally in the pre-Vashon-age sediments, but their tectonic significance is uncertain; they generally are too ambiguous and (or) poorly exposed to display at map scale. Waldron (1961) reported a set of small northeast-striking normal faults that are partly covered by Vashon-age sediment in T. 21 N., R. 4 E., SE¼ sec. 14, but these exposures are no longer visible; he also mapped one fault in the T. 20 N., R. 4 E., NE¼ sec. 2 that we include on the current map. Other observed displacements and truncations, now best exposed along the steep beach cliffs of Puget Sound, are most likely the result of Holocene landsliding. Truncated beds also can be ice derived or glacially overridden, raising the possibility of a nontectonic origin. More gentle deformation in the pre-Fraser-age sediments is widespread, however, and is almost certainly the result of long-term crustal deformation during the Quaternary period (Sherrod and others, 2004; Booth and others, 2004a). No evidence of surface lineaments associated with the Tacoma Fault Zone, which has been projected to pass through the southern part of the map area (Brocher and others, 2004), was found.

DESCRIPTION OF MAP UNITS

NONGLACIAL DEPOSITS

m **Modified land (Holocene)—**Mostly gravel, sand, silt, concrete, and other materials, placed as direct result of human activity. Includes extensive fill surrounding Hylebos Waterway in southwest corner of map, in part gradational with adjacent river alluvium, cut and fill along major highways and interchanges, and some areas of extensive quarrying revealed in Google Earth images. Although far from inclusive, unit also includes large areas of commercial development and adjoining streets. Includes units m and af of Booth and others (2004b). Geologic contacts are shown dotted beneath unit m where possible; in some areas dotted contacts represent distribution of units prior to extensive excavation, as shown on Booth and others (2004b). For this map, we also have added a hachure pattern in areas that are 80–100% hard-surface materials (paving and large buildings) mostly derived by inspection of Google Earth imagery. The extent of these areas is somewhat arbitrary and they include some obviously landscaped terrain

Qw **Wetland deposits (Holocene)—**Peat and alluvium, poorly drained and intermittently wet. Grades into unit Qa. Areas added and modified based on interpretation of lidar DEM and Google Earth images

Qb **Beach deposits (Holocene)—**Well-sorted sand, pebbles, silt, and shells deposited or reworked by wave action. Mostly upper-beach deposits above mean high-water line, locally includes beach deposits below mean high-water line. In places is a thin veneer that overlies older deposits. At stream mouths, grades into unit Qa

Qbo **Beach deposits, old (Holocene)—**Similar to unit Qb but exposed in terraces landward. Scarps at seaward edges of terraces range from 1 to 20 ft (.3–7 m), mostly about 6 to 8 ft (2–3 m) high

Qls **Landslide deposits (Holocene)—**Diamict of broken to internally coherent surficial deposits that have been transported downslope en masse by gravity. Origin uncertain where queried (Qls?)

Qols **Old landslide deposits (Holocene and Pleistocene)—**Similar to unit Qls, but mostly mapped where topographic expression is subdued, overrun by younger landslides, and (or) eroded by streams. Based on their low gradient, large slides along Woodmont Creek could be Pleistocene sub-Lake Russell landslides. Where coherent units visible in massive block slides, unit label is shown in parentheses (Qols)

Qmw **Mass-wastage deposits (Holocene)—**Undifferentiated colluvium, soil, and landslide debris having indistinct morphology. Mapped deposits are in the northeast part of the quadrangle on the west side of the Green River valley

Qf **Alluvial fan deposits (Holocene)—**Boulders, cobbles, gravel, and sand deposited in lobate form where streams emerge from confining valleys and reduced gradients cause sediment loads to be deposited

Qa **Alluvium (Holocene)—**Moderately well sorted deposits of cobble gravel, pebbly sand, and sandy silt along floodplain of Green River. Locally in low areas mostly at grade with streams. Recognized in lidar DEM by smooth surface, but some mapped areas may include older materials

Qoa **Old alluvium (Holocene and Pleistocene)**—Materials similar to Qa, but in terraces above Qa and (or) in depressions with no present-day drainage

YOUNGER GLACIAL DEPOSITS

Deposits of the Vashon Stade of Fraser Glaciation of Armstrong and others (1965) (Pleistocene)

Qvr **Recessional outwash deposits**—Stratified sand and gravel, moderately well sorted to well sorted; less common silty sand and silt. Generally lightly oxidized. Deposited in broad anastomosing outwash channels that carried south-draining glacial meltwater away from the ice margin during ice retreat. Deposits less than about 1 m thick not shown on map. In the area of Lake Dolloff, raised terraces of Qvrm1 are 3–10 ft (1–3 m) above younger valley bottom Qvrm2

Qvrm2 **Younger recessional outwash in lower Mill Creek terrace**

Qvrm1 **Older recessional outwash in higher Mill Creek terrace**

Qvrsg **Subglacial channel deposit**—Materials similar to Qvr, but mostly in more narrow channels, commonly cutting across prominent glacial ridges and (or) without obvious continuing drainage. Some mapped channels may not contain outwash deposits; some may be veneered with Qa. Unmapped in Qvi. (Qvrsg), preserved in Fenwick landslide blocks

Qvra2 **Younger subglacial channel deposit near Auburn**

Qvra1 **Older subglacial channel deposit near Auburn**—Incised by drainage containing unit Qvra2

Qvrl **Recessional lacustrine deposits**—Very fine grained sand, silt, and clay deposited in small lakes during ice recession

Qvrs **Recessional coarse-grained lacustrine deposits**—Coarse-grained sand, forming crude terraces as high as ~88 ft (27 m) above Poverty Bay. Probably remnant heads of sub-lacustrine fans deposited in Lake Russell and (or) Lake Bretz, since eroded by wave action

Qvrf **Sub-lacustrine fan**—Materials similar to unit Qf. Identified by shape, elevation, and fluidal surface texture. West of the west branch of Hylebos Creek. Probably deposited under Lake Russell

Qvrls **Sub-lacustrine landslide**—Materials similar to unit Qls. Identified by shape, elevation, and subdued, smooth surface texture. Upper west branch of Hylebos Creek. Probably deposited under Lake Russell

Qvi **Ice-contact deposits**—Deposits that are similar in texture to unit Qvr but commonly are less well sorted and have silt-rich matrix. Contains lenses and pods of till. Areas of Qvi adjusted from lidar DEM to include irregular topography commonly rich in closed depressions

Qvie **Eskers**—Sinuous ridges of glaciofluvial sand and gravel. Esker shown under water of Lake Killarney mapped by inspection from Google Earth view. (Qvie), preserved in Fenwick landslide blocks

Qvt **Till**—Compact diamict containing subrounded to well-rounded clasts in massive, silt- or sand-rich matrix. Glacially transported and deposited. Generally a few meters to a few tens of meters thick, forming undulatory surface. Also found sporadically within areas mapped as unit Qvi. Contact with older deposits generally mapped from the lidar DEM just below where upland surface breaks into steep-sided gullies. (Qvt), preserved in Fenwick landslide blocks

Qva **Advance outwash deposits**—Well-bedded sand and less common gravel deposited subaqueously or by streams and rivers in front of advancing ice sheet. Almost devoid of silt or clay, except near base of unit. Generally unoxidized and commonly very compact. (Qva), preserved in Fenwick landslide blocks

OLDER GLACIAL AND NONGLACIAL DEPOSITS

Qpf **Deposits of pre-Fraser glaciation age (Pleistocene)**—Weakly to moderately oxidized sand and gravel, lacustrine sediments containing local peat layers, and moderately to strongly oxidized diamict composed of silty matrix and rounded gravel clasts. Includes deposits of both glacial and nonglacial origin

Qpfc **Coarse-grained deposits**—Sand and gravel predominate

Qpfn **Nonglacial deposits**—Abundant organic debris or pumice indicates nonglacial origin

Qob **Olympia beds of Minard and Booth (1988) (Pleistocene)**—As much as 50 ft (15 m) of andesitic and pumiceous sand and lahar deposits, having paleosol developed on upper surface; locally overlain with as much as 3 ft (1 m) of peat and tephra. Assigned to the Olympia nonglacial interval of Mullineaux and others (1965) on the basis of finite radiocarbon dates on peat of 27,530±390, 32,040±690, and 36,650±72 ^{14}C yr B.P. (samples ISGS-3301, Beta-80937, and Beta-87981; table 1). Where sampled, deposit shown as portrayed by Booth and others (2004b) and labeled in parentheses (Qob) on map although site has been totally quarried and (or) regraded

Deposits of Pre-Olympia age (Pleistocene)

Qpof **Fine-grained deposits**—Silt at north edge of map; underlies glacial deposits of pre-Olympia age on adjacent Des Moines 7.5' quadrangle

Qpog **Glacial deposits**—Weakly to strongly oxidized silt, sand, and gravel of glacial origin as determined by clast provenance. Underlies all Vashon-age deposits and so also must be of pre-Olympia age. Locally mapped as the following deposits:

Qpogc **Coarse-grained deposits**—Sand and gravel predominate

Qpogf **Fine-grained deposits**—Silt and clay predominate

Qpogt **Till deposits**—Till or other diamict predominate

Qpon **Nonglacial deposits**—Silt, fine- to medium-grained sand and gravel, pumice, and mudflow, exposed low on valley walls of the Green River

Qr **Reversely magnetized deposits (Pleistocene)**—Silt, fine- to medium-grained sand; volcanic ash, pumice, and mudflows; and compact oxidized till and stratified sand and gravel. Mapped as reversely magnetized where deposits of the Lake Tapps tephra of Crandell (1963), as dated by Westgate and others (1987), lie in close stratigraphic association with these deposits

Qrn **Reversely magnetized nonglacial deposits**—Silt, fine- to medium-grained sand, clay, ash, peat, and mudflow deposits composed of round to subangular clasts of volcanic rock and pumice in dense sandy to highly altered fine-grained matrix. Abundant wood and volcanic debris demonstrate nonglacial origin

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