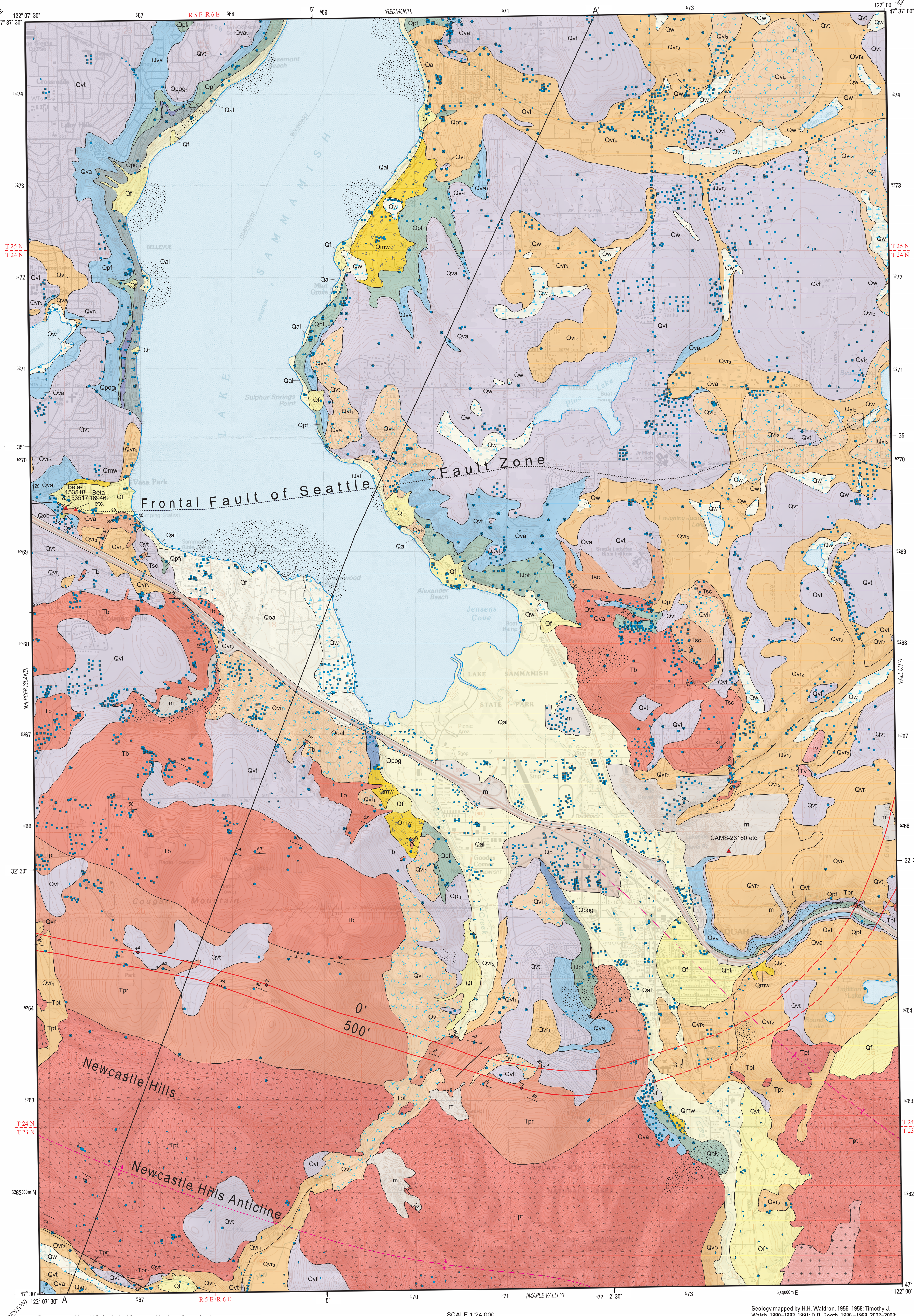
U.S. Department of the Interior
U.S. Geological Survey

Scientific Investigations Map 3211



Base extracted from U.S. Geological Survey and National Ocean Service 1:25,000-scale Digital Raster Graphic (DRG), Bellevue South, WA, 1983. Original 1:25,000-scale published map from U.S. Geological Survey and National Ocean Service, 1977 (revised 1983); topography compiled from aerial photographs taken 1977 and field checked 1979

Shaded relief from U.S. Geological Survey 10-meter Digital Elevation Model (DEM), Issaquah, WA, 1983

Universal Transverse Mercator projection; North American Datum of 1927

APPROXIMATE MEAN DECLINATION, 2012

SCALE 1:24 000

CONTOUR INTERVAL 5 METERS
NATIONAL GEODETIC VERTICAL DATUM OF 1927

MAP LOCATION

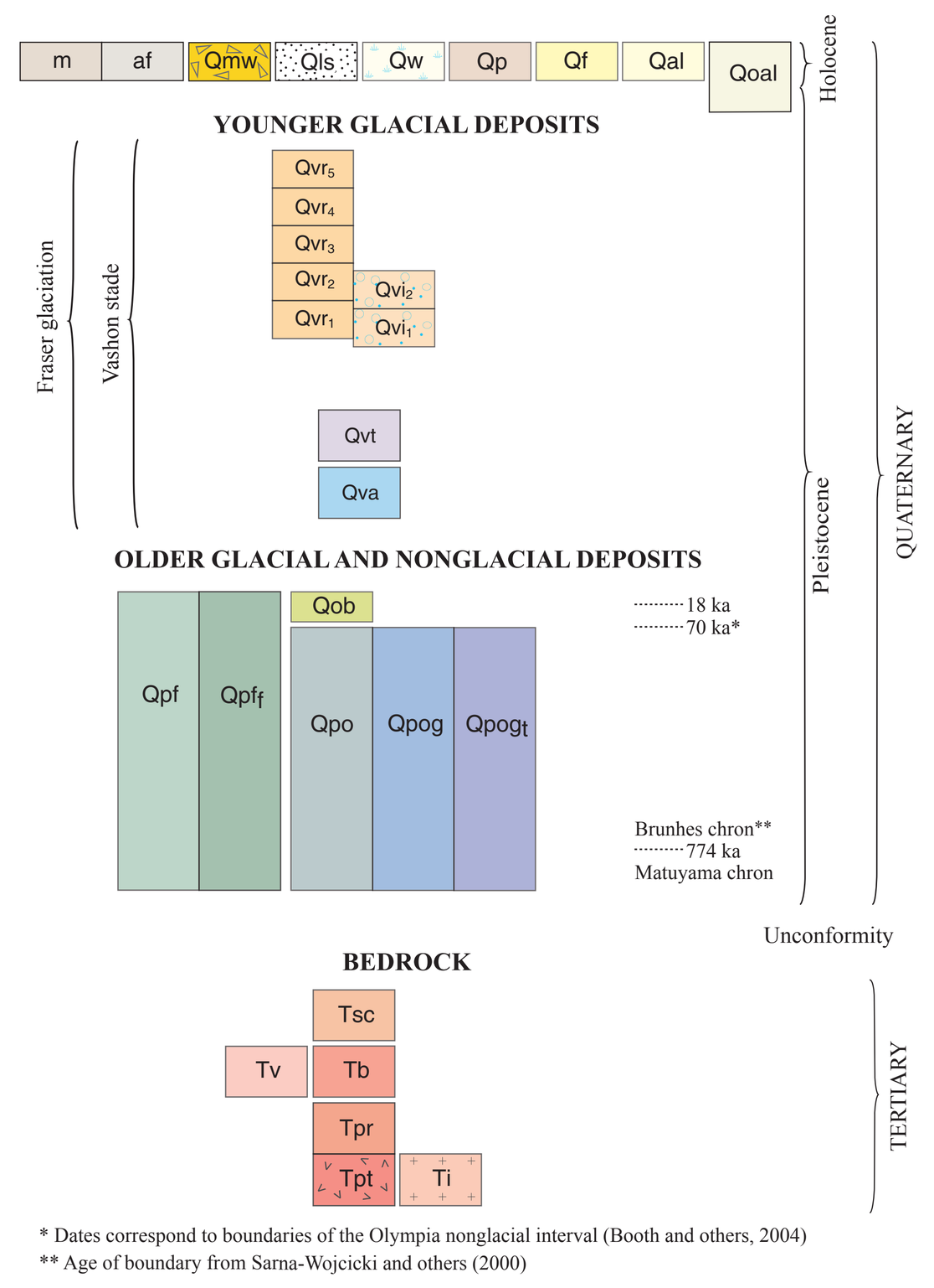
Geology mapped by H.H. Waldron, 1956–1958; Timothy J. Walsh, 1980–1983, 1991; D.B. Booth, 1986–1998, 2002–2003; Kathy G. Troost, 2000–2003.

GIS Database and digital cartography by Scott Shimel, Ralph A. Haugerud, Elizabeth A. Barnett, Matt D. Anders, Alison R. Duvall, Philip Dinterman, John M. Spritzer, and Rowland W. Tabor. Metadata by Rowland W. Tabor

Edited by Thereasa Iki

Manuscript approved for publication May 7, 2012

CORRELATION OF MAP UNITS



* Dates correspond to boundaries of the Olympia nonglacial interval (Booth and others, 2004)
** Age of boundary from Sarna-Wojcicki and others (2000)

DESCRIPTION OF MAP UNITS

NONGLACIAL DEPOSITS

m **Modified land (Holocene)**—Fill or extensively graded natural deposits that obscure or substantially alter original deposit. Includes areas along Interstate Highway 90, office parks northwest of the City of Issaquah, gravel mines northeast of the city, rock quarries along Tibbetts Creek, coal mine spoils southwest of Issaquah, and areas of Lake Sammamish lakeshore development. Locally divided into artificial fill:

af **Artificial fill**—Gravel, sand, and silt, intermixed with concrete and other materials placed as a direct result of human activity. Shown where borehole data provide sufficient information to delineate extent and where greater than about 3 m (10 ft) thick over at least tens of meters in lateral extent. Thin deposits of fill are present elsewhere throughout map area but are not mapped due to lack of information

Qmw **Mass-wastage deposits (Holocene)**—Colluvium, soil, and landslide debris having indistinct morphology. Mapped where underlying deposits and topography obscured. Numerous unmapped areas of mass-wastage deposits occur elsewhere in quadrangle along ravines and sidewalls of Lake Sammamish trough. Thicknesses typically about 3 m (10 ft) but locally may exceed 10 m (30 ft)

Qls **Landslide deposits (Holocene)**—Diamictons composed of broken to internally coherent surficial deposits that have been transported downslope en masse by gravity. Discriminated from other mass-wastage deposits by thickness of identifiable slide deposits, by lateral continuity, and by presence of coherent blocks of geologic materials. On map, deposits are shown by dot pattern over inferred underlying unit(s). Landslides shown on the map beneath the surface of Lake Sammamish are taken from side-scan sonar profiling

Qw **Wetland deposits (Holocene)**—Peat and alluvium; poorly drained and intermittently wet annually. Gradational with units Qal and Qp. Localities are compiled from King County (1983)

Qp **Peat deposits (Holocene)**—Peat accumulations greater than about 1 m thick and of mappable extent. Mostly in the valley of Issaquah Creek. Gradational with units Qw and Qal

Qf **Fan deposits (Holocene)**—Boulders, cobbles, sand, and diamict; deposited in lobate form where streams emerge from confining valleys onto areas of reduced gradients. Located along the shores of Lake Sammamish and at the edge of the Issaquah Creek valley. Gradational contact with unit Qal

Qal **Alluvium (Holocene)**—Cobble gravel, pebbly sand, and sandy silt, moderately sorted; deposited along major stream channels. Locally includes sediments of similar texture and age found in low-lying areas adjacent to Lake Sammamish, particularly beach and shallow lacustrine deposits that are not discriminated at map scale

Qoal **Older alluvium (Holocene and Pleistocene)**—Texturally equivalent to unit Qal but deposits lie at higher altitudes and typically have greater relief than the younger alluvium. May include deposits of late Fraser glaciation age that cannot be unequivocally assigned a pre-Holocene origin, particularly lake-bottom sediments associated with glacial Lake Sammamish that interfinger with flood-plain alluvium. Most extensive exposures are at Greenwood Point, southwest shore of Lake Sammamish, where the deposit forms a late Pleistocene or early Holocene fan of sediment that was shed off ice-contact deposits on the north flank of Cougar Mountain (peak 1459' in section 25, T. 24 N., R. 5 E.)

YOUNGER GLACIAL DEPOSITS

Deposits of Vashon stade of the Fraser glaciation of Armstrong and others (1965) (Pleistocene)

Recessional outwash deposits—Stratified sand and gravel, moderately to well sorted; less common silty sand and silt. Deposited along the four east-west-trending outwash channels that carried glacial meltwater westward into glacial Lake Sammamish from glacial Lake Snoqualmie during ice retreat. Very large foreset bedding is exposed in several of these deposits, reflecting delta growth into the glacial-age lake. The youngest recessional outwash, deposited during the lowest stand of glacial Lake Sammamish immediately prior to full ice retreat from the lowland (Thorson, 1980; Booth, 1990) is located just south of the town of Issaquah. In the eastern and west-central parts of the map area, recessional outwash deposits are subdivided into five deglacial stages on the basis of location and altitude. These deposits are indicated on the map by hyphenated subscripts, from youngest (Qvr_5) to oldest (Qvr_1) stage units:

Qvr_5 **Stage 5**—Defined by a low delta just south of the Issaquah town center at altitudes between 30 and 45 m (100 and 150 ft). It probably reflects the last stage of the recessional lake history in the Puget Lowland (interval 14 of Booth, 1990). During this time, the entire set of interconnected Puget Lowland troughs (Lake Bretz of Waitt and Thorson, 1983) drained through a spillway at an altitude of about 60 m (200 ft) on the northeastern Olympic Peninsula, 50 km (30 mi) northwest of the map area. Isostatic rebound since deglaciation has elevated northern parts of the lowland more than southern parts because the Vashon-age ice sheet was thicker to the north. The relative uplift gradient is now observed to be 0.009 (about 1 m/km, or 5 ft/mi; Thorson, 1980; Booth, 1990). This gradient can be determined from the Stage-5 delta just south of the City of Issaquah, which lies about 30 km downgradient (approximately due south) from its controlling spillway and displays a modern altitude difference between the top of the delta (about equal to the lake elevation) and the lake spillway of 30 m (100 ft)

Qvr_4 **Stage 4**—Glacial Lake Snoqualmie drained via the Inglewood Channel near the north boundary of the map (Thorson, 1980; equivalent to interval 10–11 of Booth, 1990), which has a present-day spillway altitude of 110 m (360 ft). The level of glacial Lake Sammamish was unchanged from the end of Stage 3 during this time

Qvr_3 **Stage 3**—Deposition mainly consists of deposits from drainage of glacial Lake Snoqualmie through the valley of the North Fork Issaquah Creek (interval 8–9 of Booth, 1990). Drainage out of glacial Lake Sammamish at this time shifted successively northward through the Cedar Grove, Kennydale, and Eastgate channels, which have present-day spillway altitudes of 107 m (350 ft), 91 m (309 ft), and 98 m (323 ft), respectively (Thorson, 1980). The first two of these channels lie several kilometers south of the map; the third and last-occupied of these channels lies just west of the map boundary and is now the route of Interstate Highway 90 in that area. The quadrangle is inferred to have become ice-free by this time, and, therefore, high terraces near the north edge of the map are also assigned to this stage

Qvr_2 **Stage 2**—Encompasses drainage from glacial Lake Snoqualmie down the present East Fork Issaquah Creek valley in the eastern part of the map, where Interstate Highway 90 is now located (equivalent to interval 5–6 of Booth, 1990). A large delta, built into glacial Lake Sammamish at altitudes about 120–150 m (400–500 ft) above modern sea level, forms the broad plateau underlying Tradition Lake along the east boundary of the map. The altitude of Lake Sammamish during this time was controlled by two spillways south of this delta: one was located along the Hobart Channel (present-day spillway altitude 150 m [490 ft]) at the head of the Issaquah Creek valley (Tabor and others, 2000) and the second one, carrying much less drainage and at a near-equivalent spillway altitude, was located at the upstream (southwest) divide of the Tibbetts Creek valley, about 3 km (2 mi) southwest of Issaquah. East of the town of Issaquah, these recessional, late-Vashon-age deposits mantle a proglacial delta of early Vashon age (Porter and Swanson, 1998)

Qvr_1 **Stage 1**—Consists of deposits prior to significant drainage into the Sammamish trough from the Snoqualmie valley. Near the south end of Lake Sammamish, extensive deposits of valley-wall outwash and ice-contact sediments (see unit Qvi) accumulated during this time. South-flowing meltwater drained up the present-day valleys of both Tibbetts Creek and Issaquah Creek, reflecting a reversal of drainage directions that occurred in these valleys between late-glacial and modern times

Ice-contact deposits—Similar in texture to unit Qvr but contain a much higher percentage of silt intermixed with granular sediments that result in poorly sorted stratified sediment and local diamicts. Also mapped in areas that have collapse features, such as the closed depressions between Laughing Jacobs Lake and Beaver Lake, suggesting deposition against stagnant melting ice. These deposits are indicated on the map by subscripts, from youngest (unit Qvi_2) to oldest (unit Qvi_1). They follow the same age convention described for unit Qvr and are based on the position(s) of the ice tongue in the Lake Sammamish valley necessary to divert water through each associated spillway (and its correspondingly numbered recessional deposit)

Qvi_2 **Stage 2**—Consists of deposits along the southern meltwater channel through the Laughing Jacobs Lake area

Qvi_1 **Stage 1**—Consists of deposits flanking both sides of the Lake Sammamish trough, in the vicinity of Monahan (east side) and above Greenwood Point (west side), and along the valleys of the Tibbetts Creek and lower Issaquah Creek

Qvt **Till**—Compact diamict containing subrounded to well-rounded clasts, glacially transported and deposited. Generally forms an undulating surface a few meters to a few tens of meters thick. Also found more sporadically within areas of ice-contact deposits (unit Qvi)

Qva **Advance outwash deposits**—Well-sorted sand and gravel; deposited by streams issuing from advancing ice sheet. Generally not oxidized; mostly devoid of silt or clay, except near the base of the unit. Well exposed along much of the Sammamish trough sidewall. High susceptibility to water erosion has resulted in large prehistoric ravines; runoff from recently urbanized areas has resulted in rapidly expanding new gullies

OLDER GLACIAL AND NONGLACIAL DEPOSITS

Qpf **Undifferentiated sedimentary deposits of pre-Fraser glaciation age (Pleistocene)**—Comprises a variety of deposits that underlie Vashon-age deposits and that otherwise lack numeric age control. Includes unoxidized to slightly oxidized silt and clay that may locally include Olympia-age or early-Vashon-age lacustrine deposit and slightly to moderately oxidized sand and gravel previously mapped by Booth and Minard (1992) as unit Qob. Locally divided into fine-grained deposits:

Qpf_f **Fine-grained deposits**—Predominantly silt and clay

Qob **Olympia beds of Minard and Booth (1988) (Pleistocene)**—Sand and gravel, slightly to moderately oxidized; deposited during nonglacial time in the Puget Lowland by rivers. Mapped only near the west map boundary; one radiocarbon sample provides numeric age control (24,870±50 yr B.P.)

Qpo **Deposits of pre-Olympia age (Pleistocene)**—Interbedded sand, gravel, silt, and diamicts of indeterminate age and origin. Very dense. Locally divided into glacial deposits:

Qpog **Glacial deposits**—Weakly to strongly oxidized silt, sand, gravel, and rare till of glacial origin. Underlies Vashon-age deposits and, thus, must also be of pre-Olympia age. Sediment is of inferred glacial (northern) origin, based on presence of till and clasts or mineral grains requiring southward ice-sheet transport. Locally divided into glacial till:

$Qpog_t$ **Glacial till**—Predominantly till or other diamict where thick enough to show at map scale

BEDROCK

Tsc **Sandstone and conglomerate (Tertiary)**—Sandstone, conglomerate, tuff, and volcaniclastic sandstone, exposed above the southwest and southeast shores of Sammamish Lake. Contains interbeds of lignite, including nearly coherent logs. Bedding is concordant with underlying Blakeley Formation, but stratigraphic position and low degree of lithification had led some previous workers to assign a Quaternary age to this deposit (for example, Liesch and others, 1963). However, available K-Ar ages from one locality range from 9.3 to 14.7 Ma (Yount and Gower, 1991); Ar/Ar laser fusion dating from this unit yields an age of 11.40±0.61 Ma

Tb **Blakeley Formation of Weaver (1912) (Tertiary)**—Medium-grained sandstone, coarse-grained sandstone, conglomerate, airfall tuff, tuffaceous sandstone, and minor siltstone, fresh to highly weathered. Massive to well bedded. Quartz, feldspar, and lithic volcanic grains present in varying amounts. Deposited in a shallow marine to coastal environment; foraminifera collected near the top of this unit yielded a Zemorrian (middle to late Oligocene) age (Walsh, 1984). Distinguished from rocks of underlying Puget Group by presence of marine fossils and by the absence of mica in sandstone facies relative to those of the Renton Formation. Mapped contacts with underlying Puget Group largely adopted from Walsh (1984)

Tv **Volcanic rocks (Tertiary)**—Slightly porphyritic andesite that forms a topographic knob along the North Fork Issaquah Creek valley. Occupies the same stratigraphic relation to the underlying Renton Formation as does the Blakeley Formation of Weaver (1912); probably interbedded with Renton Formation (Tpr)

Ti **Intrusive rocks (Tertiary)**—Porphyritic andesitic to dacitic stock in southeast corner of map area; forms the west slopes of Tiger Mountain and east slope of Squak Mountain just south of the map area. Speculated by Vine (1962) to be subvolcanic intrusion corresponding to the extrusive Tukwila Formation. Contact relations with adjacent unit Tpt not exposed

Puget Group (Tertiary)

Tpr **Renton Formation**—Nonmarine fine- to medium-grained arkosic sandstone and siltstone containing abundant subbituminous coal beds and carbonaceous shale

Tpt **Tukwila Formation**—Andesitic to dacitic volcanic sandstone, siltstone, shale, tuff-breccia, tuff, volcanic mudflow (lahar), carbonaceous shales, and minor lava flows or sills. Typically massive; only local sedimentary interbeds indicate structure. K-Ar age on plagioclase from tuff-breccia at top of unit, about 3 km west of quadrangle, yielded an age of 42.0±2.4 Ma (Turner and others, 1983)

EXPLANATION OF MAP SYMBOLS

Drowned trees

Contact

Fault—Dashed where approximate; dotted where concealed

Anticline—Dashed where approximate; dotted where concealed

Syncline—Dashed where approximate; dotted where concealed

Structural contour—0' and 500' structure contours drawn on the Muldoon coal seam (Renton Formation). Dashed where approximate

Strike and dip of beds

25 **Inclined**

9 **Bedding tops recognized**

85 **Overturned bed**

10 **Forset beds in fluvial deposits**

Beta-153518 **^{14}C age locality**—See table 1 for ages

Exploration Sites

Field exposure with station number

Geotechnical boring

Geotechnical test pit

Cone penetometer test (CPT)

Monitoring or water well

Density probe

GEOLOGIC SUMMARY

INTRODUCTION

The Issaquah area includes several of the most outstanding geologic features of the eastern Puget Lowland region. Folds have warped thousands of meters of Tertiary sedimentary and volcanic rocks. Several hundred meters of both glacial and postglacial sediment have accumulated in a deep glacial trough, which is now partly occupied by Lake Sammamish but which was previously the conduit for massive volumes of meltwater during ice-sheet occupation and retreat. The eastern projection of an east-west-oriented crustal structure, which reflects Tertiary through Holocene fault displacement, extends across the eastern part of the map area (Gower and others, 1985; Yount and others, 1985).

In addition to these geologic features, some of the most rapid human alteration of the landscape in the entire Puget Lowland has occurred here. Since the 19th century, coal was extensively mined and, since the early 1980s, the region has been overtaken by urbanization. In places, this alteration has dramatically accelerated the rate of geomorphic processes. For example, the hillsides have been regraded as a result of mining and quarries throughout the southern one-third of the quadrangle; stream channels have recently incised above the eastern shores of Lake Sammamish; and sediments have deposited on the lakeshore and into the lake itself.

PREVIOUS MAPPING

This map follows prior mapping by Booth and Minard (1992), who mapped the geology of the Issaquah 7.5′ quadrangle. They mapped outcrops exposed in road cuts, stream banks, construction excavation sites, and a few selected well logs. Previous work, particularly Liesch and others (1963) and Curran (1965), also provided a useful introduction to the area; many of the bedrock contacts are compiled from Walsh (1984). More recently, the digital compilation of geotechnical explorations and water-well logs and LIDAR (LIght Distance And Ranging) topography from airborne laser rangefinding (Haugerud and others, 2003) provide a wealth of new geologic data. Additional fieldwork in 2002 and 2003 emphasized both reinterpretation of the stratigraphy along the nearshore areas of Lake Sammamish and investigations of the fault just west of Lake Sammamish near Interstate 90. This map thus reflects the current status of geologic information and understanding in this region of the Puget Lowland.

ACKNOWLEDGMENTS

Particular acknowledgments are due our colleagues who have shared geologic data, insights, and interpretations throughout the current period of additional mapping: Brian Sherrod, Ralph Haugerud, and Ray Wells (USGS); Patrick Pringle (Washington State Department of Natural Resources); John Bethel (King County Water and Land Resources Division); and Curtis Koger and Jennifer Hilden Saltonstall (Associated Earth Sciences, Inc.). Technical reviews were provided by Brian Sherrod (USGS) and Joe Dragovich (Washington State Department of Natural Resources). Special thanks are due Jim Minard (USGS), whose preliminary work in the map area and general enthusiasm for unraveling the distribution and history of geologic deposits across the region have provided lasting guidance for those who have followed in his footsteps.

REGIONAL HISTORY AND STRATIGRAPHY

BEDROCK

The east-central Puget Lowland is underlain by Eocene to Miocene volcanic and sedimentary rocks (Yount and Gower, 1991; Tabor and others, 2000), warped into a series of northwest-trending folds. In the Issaquah area, these Tertiary rocks are exposed only in the southern half of the map area. Younger glacial deposits have lapped onto both limbs of the largest of these folds, the Newcastle Hills anticline of Weaver (1916), a bedrock high that extends 50 km to the northwest from the front of the Cascade Range (Mullineaux, 1970) towards the center of the Puget Lowland.

In the map area, the rocks exposed in the core of the Newcastle anticline are assigned to the Puget Group, first named by White (1888). The Puget Group was later revised to include a lower assemblage of volcanic sedimentary rocks, the Tukwila Formation, and an upper unit of arkosic sedimentary rocks and coal, the Renton Formation (Vine, 1962, 1969). The Tukwila Formation is named for the city of Tukwila, about 8 km west-southwest of the map area, where the formation primarily consists of volcanic sandstone, siltstone, and shale along with some volcanic conglomerate, tuff, and a few carbonaceous shales. Fragments of wood and other plant remains are common throughout the Tukwila Formation. Volcanic rocks, particularly welded tuffs, are more abundant in this map area than farther west.

The Renton Formation is named for exposures in and around the city of Renton, located about 5 km west of the map area. The formation conformably overlies the Tukwila Formation and includes the Renton coal measures, which were extensively mined throughout much of the Newcastle Hills in Renton and Issaquah during the late 19th and early 20th centuries. The formation consists mostly of fine- to medium-grained arkosic sandstone and lesser amounts of siltstone, sandy shale, coal, and carbonaceous shale.

The clastic, fluvial rocks of the Puget Group were derived chiefly from a distant eastern source of granites or gneisses (Weaver, 1937). Intermittently, volcanic debris, probably ejected from nearby vents, clogged the sluggish streams and locally dominated sedimentation. Sediments of the group probably were deposited on a low-lying coastal plain just east of a slowly subsiding basin (Buckovic, 1979). Ages from the Puget Group range from middle to late Eocene, although none of the ages are derived from rocks exposed in the map area (Waldron, 1962; Turner and others, 1983; Yount and Gower, 1991). Immediately east of the map area, Vine (1969) estimated a minimum thickness for the Puget Group of 3,400 m (11,200 ft), a thickness that is nearly equaled by the subsurface projection of exposures in the map area (see cross section).

Overlying the Puget Group, exposures of the Blakeley Formation of Weaver (1912) overlook the south end of Lake Sammamish. The Blakeley Formation consists primarily of medium-grained sandstone that contains local marine fossils that yield a Zemorrian (middle to late Oligocene) age (Walsh, 1984). Bedding is roughly conformable with the underlying Puget Group. In the map area, the exposed thickness of the unit is about 3,400 m (11,000 ft).

The youngest Tertiary bedrock (Tsc) exposed in the quadrangle is not formally named. It conformably overlies the Blakeley Formation and is readily distinguished from the Blakeley by overall coarser sediment size, terrestrial plant fossils, and low degree of lithification. These rocks were once assigned a Quaternary age (Liesch and others, 1963). However, Yount and Gower (1991) report K-Ar ages of 14.7 and 9.3 Ma from an air-fall tuff in this unit on the west side of Sammamish Lake; T.J. Walsh and P.T. Pringle (Washington Division of Geology and Earth Resources) collected pumice overlying a 9-m-thick vitric tuff from this same area and obtained Ar/Ar laser fusion ages of 11.12 Ma on plagioclase and 12.35, 11.12, and 11.14 Ma, averaging 11.40+0.61 Ma (dating by Berkeley Geochronology Center, Berkeley, Calif.). Bedding is concordant with underlying Blakeley Formation; bedding dips mainly to the north. Although only a few hundred meters are now exposed, the uppermost strata almost certainly have been downdropped by the Seattle Fault and subsequently covered by Quaternary deposits.

Although we do not formally correlate this unit (Tsc) with other named deposits of the Puget Lowland, it was likely deposited near-contemporaneously with the Blakely Harbor Formation (Fulmer, 1975), whose type section is about 30 km west of the quadrangle and consists of dated Miocene-age terrestrial sediments. On the regional aeromagnetic survey map of the Puget Lowland (Blakely and others, 2002), the rocks exposed at both the Blakely Harbor Formation type locality and in the map area display a distinctive high-susceptibility signature that can be traced continuously between the two areas, which suggests both a lateral continuity and a similar lithology.

QUATERNARY DEPOSITS

Deposits that form a discontinuous record of glacial and interglacial deposition throughout much of the Quaternary period overlie the Tertiary rocks. Originating in the mountains of British Columbia, multiple invasions of glacial ice into the Puget Lowland defined the southernmost extent of the Cordilleran ice sheet of northwestern North America. During each successive glaciation, ice advanced into the lowland as a broad tongue called the Puget lobe (Bretz, 1913).

In the map area, glacial deposits are unequivocally assigned only to the most recent of these glacial advances, the Vashon stade of the Fraser glaciation of Armstrong and others (1965). Climaxing about 17,000 years ago, ice occupation of the Puget Lowland during the Vashon stade probably spanned less than 2,000 years in total (Porter and Swanson, 1998). Scattered deposits (unit Qpf) in the southern part of the map area suggest an earlier glacial advance, although no assignment or regional correlation can be made because of poor exposure and poor age constraint.

Before the Vashon stade, nonglacial conditions prevailed in the map area for at least several tens of thousands of years. This nonglacial interval, named the Olympia interglaciation by Armstrong and others (1965), is associated with a wide variety of nonglacial deposits across much of the Puget Lowland (Troost, 1999). Booth and Minard (1992) assigned lightly to moderately oxidized fluvial sand and gravel in the northern part of the Issaquah quadrangle to this nonglacial interval (see also Minard and Booth, 1988) on the basis of stratigraphic, textural, and weathering characteristics. The absence of confirming radiocarbon dates, however, coupled with reported Olympia-age deposits over 100 m higher just a few kilometers north of the map area (Saltonstall and others, 2003), suggest that only the more general pre-Fraser age assignment (unit Qpf) is warranted. Similarly, overlying silt and clay that were previously mapped (Booth and Minard, 1992) as post-Olympia-age deposits are also now assigned the more general (but probably more correct) "pre-Fraser age" unit name, discriminated where possible from the underlying deposits only by texture. The unequivocal start of the Vashon stade of the Fraser glaciation of Armstrong and others (1965) is marked by the thick deposits of outwash (Qva) followed by till (Qvt) derived from the advancing ice sheet.

A variety of glacial and postglacial geologic processes have created and modified the Lake Sammamish trough. The trough is weakly reflected in the folded structures of the underlying bedrock, but the modern surface expression of the trough is more pronounced than the underlying warping. That surface expression must largely predate the ice retreat, because lodgment till of Vashon age (Qvt) mantles some of the sidewalls and approaches present-day water level in the northern part of the trough. Slightly younger ice-contact sediments are plastered against the eastern wall at Monohan (Qvi_1). Finally, deposits of the Inglewood delta, a late-glacial recessional feature at the north edge of the map (included in unit Qvr_4), approach and may extend below present-day lake level, well within the confines of the trough itself. Thus, the trough existed prior to final retreat of the ice sheet because these Vashon-age deposits mantle or fill the Lake Sammamish trough.

Geologic activity since glaciation is most pronounced along the walls of the Sammamish trough, where deposits of the ice occupation and retreat have been stripped away by mass movement to reveal the crudely horizontal layering of the underlying early glacial and preglacial material. The sequence of these older deposits, primarily outwash sand and gravel deposits derived from the advancing ice sheet (Qva) that overlie older silt and clay deposits (Qpf), results in a particularly active Holocene environment. Due to the underlying silt and clay deposits that perch groundwater, landslides commonly occur at the contact between unit Qva and unit Qpf. These stratigraphic conditions are common along much of the west wall of the trough and the eastern wall above Jensens Cove, although the resulting landslides are mainly too small or are obscured by trees and human development to show at map scale. The noncohesiveness of the overlying outwash deposits, in addition, has favored rapid and severe erosion by surface water throughout areas underlain by unit Qva.

In the map area, landslides occur in several other geologic settings at many scales, from large mappable slides involving bedrock to small and vegetation-obscured mass movement of glacial sediments too small or indistinct to show at map scale. Landslides shown on the map beneath the surface of Lake Sammamish are mapped from side-scan sonar profiling by Mark L. Holmes and Robert E. Karlin as depicted in Gonzalez (2003). The now-drowned landslide off Greenwood Point at the south end of Lake Sammamish has a rooted old-growth forest; the tree tops are exposed a few feet above the lake level (Logan and Walsh, 1995). The landslide has been attributed to an earthquake on the Seattle Fault about 1,000 years ago (Bucknam and others, 1992), based on the age of one such rooted tree with bark. The age of the outermost rings of the tree, 1,050±60 ^{14}C yr B.P. (Logan and others, 1998), is indistinguishable from the age of trees rooted in a landslide in Lake Washington and the age of organic material in a tsunami deposit at West Point on the west side of Seattle (Atwater and Moore, 1992).

STRUCTURE

The map area contains the northernmost exposures of Tertiary bedrock (units Tb and Tsc) in the east-central Puget Lowland, exposed at the north edge of the Seattle uplift (Blakely and others, 2002). In the southern part of the map area, older bedrock (units Tpt and Tpr) lies at or near the surface; but to the north, the bedrock surface descends steeply (Jones, 1996) and is covered by many hundreds of meters of Quaternary deposits.

This observed pattern in the Tertiary bedrock, namely exposure to the south and deep burial to the north, continues along a west-trending lineament between Lake Sammamish and Restoration Point on Bainbridge Island, 30 km west of the map area. Danes and others (1965) first identified and mapped the lineament as a Quaternary fault zone, and it was shown as such on the 1992 edition of this geologic map (Booth and Minard, 1992). The lineament is now widely recognized and is named the Seattle Fault, although detailed structure of the fault is still subject to significant uncertainty (compare, for example, Pratt and others, 1997; Johnson and others, 1999; ten Brink and others, 2002; Brocher and others, 2004). Therefore, the subsurface representation of the fault zone in cross section is speculative, but we attempt to remain consistent with (1) the pattern of surface exposures, (2) the suggestion of blind splays off the main fault suggested by seismic profiling (Liberty, 2003; Liberty and Pratt, 2008), and the depth-to-bedrock data compiled by Jones (1996) but which is admittedly sparse in this part of the Puget Lowland. The mapped fault trace displayed here, namely the surface projection of the frontal fault of the Seattle Fault Zone, follows the high-amplitude geophysical anomaly associated elsewhere with Miocene bedrock (Blakely and others, 2002, their fig. 4) and, in the map area, with faults observed in trenches at Vasa Park (west edge of map) and faults in a seismic-reflection profile east of Pine Lake (east edge of map) (Liberty, 2003, his profile SM1)

Folded bedrock is associated with the frontal fault of the Seattle Fault Zone. East of Lake Sammamish and about 1 km south of the fault trace, locally very steep and overturned dips involve (and must postdate deposition of) unit Tsc. A small anticline southwest of Greenwood Point, also about 1 km south of the projected fault trace, is expressed by opposing dips in unit Tb. The rocks of unit Tsc are apparently coaxially folded with the Newcastle Hills anticline about 6 km to the south, which shows about 10 km of structural relief (Vine, 1962; Walsh, 1984). The structural relief indicates a rate of about 1 mm/yr of north-south shortening since about 10 Ma, a value that lies in the range of crustal strain rates that Booth and others (2004) inferred from deformed Quaternary strata farther west along the axis of the Puget Lowland. Also, fault studies near Vasa Park indicate at least one Holocene event has produced surface ground rupture (Sherrod, 2002).

The only other fault shown on the map appears in the southwest corner; it is exposed a short distance west of the map boundary. The fault was encountered in a mine at Coalfield at a depth of about 60 m (200 ft), where the coal that dips steeply to the south at its outcrop is faulted and becomes overturned (Warren and others, 1945; see Schasse and others (1994) for coal mine map information). The dip of the fault is not constrained, but the sense of drag suggests that it is down-to-the-south. This fault forms the southern boundary of the Seattle Fault Zone; it is coincident with the Orchard Point Fault of Blakely and others (2002) and correlates with the Lowman Beach fault strand of Troost and others (2005).

The structure contours, across the southern part of the map, trace the nearly continuous Muldoon coal seam, a heavily mined seam in the middle of an area of abundant coal strata; data are taken from original mine maps compiled by Walsh (1983). The offset in this bed, shown 3 km south of Lake Sammamish, is the only fault known to cut the coal measures for a distance of about 16 km along strike (Walsh and Lingley, 1991), although the dashed part of the structure contour can only be inferred because the coal has been eroded by glacial activity. The absence of significant offsets in this well-constrained coal layer suggests that, in the eastern part of the Seattle Fault Zone, significant deformation between individual fault strands is not as widespread as farther west (Nelson and others, 2003; Troost and others, 2005).

REFERENCES CITED

Armstrong, J.E., Crandell, D.R., Easterbrook, D.J., and Noble, J.B., 1965, Late Pleistocene stratigraphy and chronology in southwestern British Columbia and northwestern Washington: Geological Society of America Bulletin, v. 76, p. 321–330.

Atwater, B.F., and Moore, A.L., 1992, A tsunami about 1,000 years ago in Puget Sound, Washington: Science, v. 258, no. 5,088, p. 1,614–1,617.

Blakely, R.J., Wells, R.E., Weaver, C.S., and Johnson, S.Y., 2002, Location, structure, and seismicity of the Seattle fault zone, Washington—Evidence from aeromagnetic anomalies, geologic mapping, and seismic-reflection data: Geological Society of America Bulletin, v. 114, no. 2, p. 169–177.

Booth, D.B., 1987, Timing and processes of deglaciation along the southern margin of the Cordilleran ice sheet, in Ruddiman, W.F., and Wright, H.E., Jr., eds., North America and adjacent oceans during the last deglaciation: Boulder, Colorado, Geological Society of America, The Geology of North America, v. K-3, p. 71–90.

Booth, D.B., 1990, Surficial geology of the Skykomish and Snoqualmie Rivers area, Snohomish and King Counties, Washington: U.S. Geological Survey Miscellaneous Investigations Series Map I–1745, scale 1:50,000.

Booth, D.B., 1991, Geologic map of Vashon and Maury Islands, King County, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF–2161, scale 1:24,000.

Booth, D.B., and Minard, J.P., 1992, Geologic map of the Issaquah quadrangle, King County, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF–2206, scale 1:24,000.

Booth, D.B., Troost, K.G., Clague, J.J., and Waitt, R.B., 2004, The Cordilleran ice sheet, Chapter 2 in Gillespie, A., Porter, S.C., and Atwater, B., eds., The Quaternary Period in the United States: International Union for Quaternary Research, Elsevier Press, p. 17–43.

Bretz, J H., 1913, Glaciation of the Puget Sound region: Washington Geological Survey Bulletin 8, 244 p.

Brocher, T.M., Blakely, R.J., and Wells, R.E., 2004, Interpretation of Seattle uplift, Washington, as a passive roof duplex: Bulletin of the Seismological Society of America, v. 94, no. 4, p. 1,379–1,401.

Bucknam, R.C., Hemphill-Haley, E., and Leopold, E.B., 1992, Abrupt uplift within the past 1,700 years at southern Puget Sound, Washington: Science, v. 258, no. 5,088, p. 1,611–1,614.

Buckovic, W.A., 1979, The Eocene deltaic system of west-central Washington, in Armentrout, J.M., Cole, M.R., and TerBest, Harry, Jr., eds., Cenozoic paleography of the western United States: Society of Economic Paleontologists and Mineralogists, Pacific Section, Pacific Coast Paleogeography Symposium 3, p. 147–164.

Crandell, D.R., 1963, Surficial geology and geomorphology of the Lake Tapps quadrangle, Washington: U.S. Geological Survey Professional Paper 388–A, 84 p.

Curran, T.A., 1965, Surficial geology of the Issaquah area, Washington: Seattle, Wash., University of Washington, Department of Geological Sciences, M.S. thesis, 57 p.

Danes, Z.F., Bonno, M., Brau, J.E., Gilham, W.D., Hoffman, T.F., Johansen, D., Jones, M.H., Malfait, Bruce, Masten, J., and Teague, G.O., 1965, Geophysical investigation of the southern Puget Sound area, Washington: Journal of Geophysical Research, v. 70, no. 22, p. 5,573–5,580.

Fulmer, C.V., 1975, Stratigraphy and paleontology of the type Blakeley and Blakely Harbor Formations, in Weaver, D.W., Hornaday, G.R., and Tipton, Ann, eds., Paleogene symposium and selected technical papers [proceedings]; conference on future energy horizons of the Pacific Coast: American Association of Petroleum Geologists, Pacific Section, v. 50, 50th joint annual meeting of Pacific Sections of American Association of Petroleum Geologists, Society of Economic Paleontologists and Mineralogists, and Society of Exploration Geophysicists, Long Beach, Calif., April 23–26, 1975, p. 210–271.

Gonzalez, F.I., comp., 2003, Puget Sound tsunami sources—2002 workshop report: NOAA/Pacific Marine Environmental Laboratory Contribution No. 2526, 36 p.

Gower, H.D., Yount, J.C., and Crosson, R.S., 1985, Seismotectonic map of the Puget Sound region, Washington: U.S. Geological Survey Miscellaneous Investigations Series Map I–1613, scale 1:250,000.

Haugerud, R.A., Harding, D.J., Johnson, S.Y., Harless, J.L., Weaver, C.S., and Sherrod, B.S., 2003, High-resolution Lidar topography of the Puget Lowland, Washington—A bonanza for earth science: GSA Today, v. 13, no. 6, p. 4–10, doi: 10.1130/1052-5173(2003)13<0004:HLTOTP>2.0.CO;2.

Johnson, S.Y., Dadisman, S.V., Childs, J.R., and Stanley, W.D., 1999, Active tectonics of the Seattle fault and central Puget Sound, Washington—Implications for earthquake hazards: Geological Society of America Bulletin, v. 111, no. 7, p. 1,042–1,053.

Jones, M.A., 1996, Thickness of unconsolidated deposits in the Puget Sound Lowland, Washington and British Columbia: U.S. Geological Survey Water-Resources Investigations Report 94–4133, scale 1:455,000.

King County, 1983, King County Wetlands: Seattle, Washington, King County Planning Division, 3 volumes.

Liberty, L.M., 2003, Seismic profiling of the Seattle fault, Lake Sammamish region, Washington: U.S. Geologic Survey National Earthquake Hazard Reduction Program, Final Report, project 03HQGR0132, accessed 10 October 2005 at http://cgiss.boisestate.edu/EQH/Seattle/NEHRP_03HQGR0132_Liberty.pdf

Liberty, L.M., and Pratt, T.L., 2008, Structure of the Eastern Seattle Fault Zone, Washington State—New insights from seismic reflection data: Bulletin of the Seismological Society of America, v. 84, no. 4, p. 1,681–1,695.

Liesch, B.A., Price, C.E., and Walters, K.L., 1963, Geology and ground water resources of northwestern King County, Washington: Washington State Water Supply Bulletin No. 20, 241 p., scale 1:48,000.

Logan, R.L., Schuster, R.L., Pringle, P.T., Walsh, T.J., and Palmer, S.P., 1998, Radiocarbon ages of probable coseismic features from the Olympic Peninsula and Lake Sammamish, Washington: Washington Geology, v. 26, no. 2/3, p. 59–67.

Logan, R.L., and Walsh, T.J., 1995, Evidence for a large prehistoric seismically induced landslide into Lake Sammamish: Washington Geology, v. 23, no. 4, p. 3–5.

Minard, J.P., 1983, Geologic map of the Edmonds East and part of the Edmonds West quadrangles, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF–1541, scale 1:24,000.

Minard, J.P., 1985, Geologic map of the Maltby quadrangle, Snohomish and King Counties, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF–1746, scale 1:24,000.

Minard, J.M., and Booth, D.B., 1988, Geologic map of the Redmond 7.5' quadrangle, King and Snohomish Counties, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF–2016, scale 1:24,000.

Mullineaux, D.R., 1970, Geology of the Auburn, Renton, and Black Diamond quadrangles, King County, Washington: U.S. Geological Survey Professional Paper 672, 92 p.

Nelson, A.R., Johnson, S.Y., Kelsey, H.M., Wells, R.E., Sherrod, B.L., Pezzopane, S.K., Bradley, Lee-Ann, Koehler, R.D., III, and Bucknam, R.C., 2003, Late Holocene earthquakes on the Toe Jam Hill fault, Seattle fault zone, Bainbridge Island, Washington: Geological Society of America Bulletin, v. 115, no. 11, p. 1,388–1,403.

Porter, S.C., and Swanson, T.W., 1998, Radiocarbon age constraints on rates of advance and retreat of the Puget lobe of the Cordilleran ice sheet during the last glaciation: Quaternary Research, v. 50, p. 205–213.

Pratt, T.L., Johnson, S.Y., Potter, C.J., Stephenson, W.J., Finn, C.A., 1997, Seismic reflection images beneath Puget Sound, western Washington State; the Puget Lowland thrust sheet hypothesis: Journal of Geophysical Research, B, Solid Earth and Planets, v. 102, p. 27,469–27,489.

Saltonstall, J.H., Koger, C.J, Sweet, S., and Thompson, S.S., 2003, Olympia age paleotopographic influences on Vashon glaciofluvial sedimentation beneath eastern Bear Creek plateau, King County, Washington [abs.]: Geological Society of America Abstracts with Programs, v. 35, no. 6, p. 109.

Sarna-Wojcicki, A.M., Pringle, M.S., Jr., and Wijbrans, J., 2000, New $^{40}Ar/^{39}Ar$ age of the Bishop Tuff from multiple sites and sediment rate calibration for the Matuyama-Brunhes boundary: Journal of Geophysical Research, B, Solid Earth, v.105, no. B9, p. 21,431–21,443.

Schasse, H.W., Koler, M.L., Eberle, N.A., and Christie, R.A., 1994, The Washington State coal mine map collection—A catalog, index, and user's guide: Washington Division of Geology and Earth Resources Open File Report 94-7, 109 p., accessed July 24, 2003, at http://www.dnr.wa.gov/geology/pdf/ofr94-7.pdf.

Sherrod, B.L., 2002, Late Quaternary surface rupture along the Seattle fault zone near Bellevue, Washington [abs.]: Eos, American Geophysical Union Transactions, v. 83, no. 47, Supplement, p. F1074–F1075.

Tabor, R.W., Frizzell, V.A., Jr., Booth, D.B., and Waitt, R.B., 2000, Geologic map of the Snoqualmie Pass 30- x 60-minute quadrangle, Washington: U.S. Geological Survey Geologic Investigations Series I–2538, scale 1:100,000 [http://pubs.usgs.gov/imap/i2538].

ten Brink, U.S., Molzer, P.C., Fisher, M.A., Blakely, R.J., Bucknam, R.C., Parsons, T.E., Crosson, R.S., and Creager, K.C., 2002, Subsurface geometry and evolution of the Seattle fault zone and the Seattle basin, Washington: Seismological Society of America Bulletin, v. 92, no. 5, p. 1,737–1,753.

Thorson, R.M., 1980, Ice sheet glaciation of the Puget Lowland, Washington, during the Vashon stade: Quaternary Research, v. 13, p. 303–321.

Troost, K.G., 1999, The Olympia nonglacial interval in the southcentral Puget Lowland, Washington: Seattle, University of Washington, M.S. thesis, 123 p.

Troost, K.G., Booth, D.B., Wisher, A.P., and Shimel, S.A., 2005, The geologic map of Seattle: U.S. Geological Survey Open-File Report 2005–1252, scale 1:24,000 [http://pubs.usgs.gov/of/2005/1252].

Turner, D.L., Frizzell, V.A., Jr., Triplehorn, D.M., and Naeser, C.W., 1983, Radiometric dating of ash partings in coal of the Eocene Puget Group, Washington—Implications for paleobotanical stages: Geology, v. 11, no. 9, p. 527–531.

Vine, J.D., 1962, Stratigraphy of Eocene rocks in a part of King County, Washington: Washington Division of Mines and Geology Report of Investigations 21, 20 p.

Vine, J.D., 1969, Geology and coal resources of the Cumberland, Hobart, and Maple Valley quadrangles, King County, Washington: U.S. Geological Survey Professional Paper 624, 67 p., 4 pls., scale 1:24,000.

Waitt, R.B., Jr., and Thorson, R.M., 1983, The Cordilleran ice sheet in Washington, Idaho, and Montana, in Porter, S.C., and Wright, H.E., Jr., eds., Late-Quaternary environments of the United States: Minneapolis, University of Minnesota Press, v. 1, p. 53–70.

Waldron, H.H., 1962, Geology of the Des Moines quadrangle, Washington: U.S. Geological Survey Geologic Quadrangle Map GQ–159, scale 1:24,000.

Walsh, T.J., 1983, Map of coal mine workings in part of King County, Washington: Washington Division of Geology and Earth Resources Open-File Report 83–17, 4 p., 1 plate, scale 1:24,000.

Walsh, T.J., 1984, Geology and coal resources of central King County, Washington: Washington Division of Geology and Earth Resources Open-File Report 84–3, scale 1:24,000.

Walsh, T.J., and Lingley, W.S., Jr., 1991, Coal maturation and the natural gas potential of western and central Washington: Washington Division of Geology and Earth Resources Open-File Report 91–2, 26 p.

Warren, W.C., Norbisrath, Hans, Grivetti, R.M., and Brown, S.P., 1945, Preliminary geologic map and brief description of the coal fields of King County, Washington: U.S. Geological Survey Preliminary Map, 1 sheet, scale 1:31,680.

Weaver, C.E., 1912, A preliminary report on the Tertiary paleontology of western Washington: Washington Geological Survey Bulletin 15, 80 p.

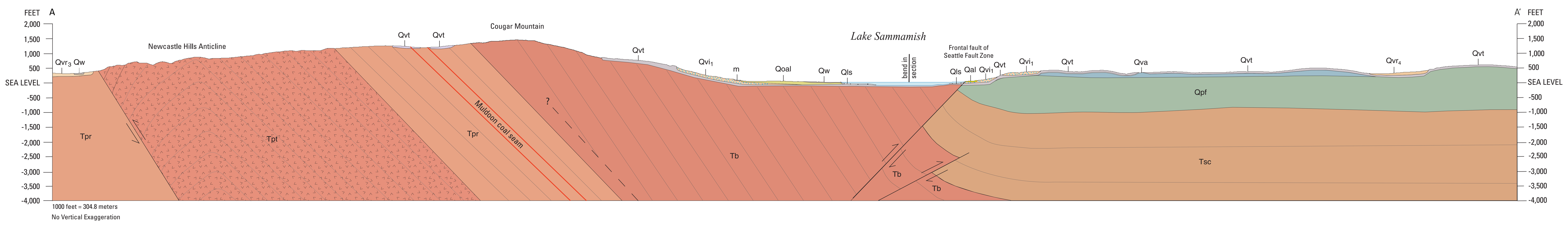
Weaver, C.E., 1916, The Tertiary formations of western Washington: Washington Geological Survey Bulletin 13, 327 p.

Weaver, C.E., 1937, Tertiary stratigraphy of western Washington and northwestern Oregon: University of Washington Publications in Geology, v. 4, 266 p.

White, C.A., 1888, On the Puget Group of Washington Territory: American Journal of Science, 3rd series, v. 36, p. 443–450.

Yount, J.C., Dembroff, G.R., and Barats, G.M., 1985, Map showing depth to bedrock in the Seattle 30' by 60' quadrangle, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF–1692, scale 1:100,000.

Yount, J.C., and Gower, H.D., 1991, Bedrock geologic map of the Seattle 30' by 60' quadrangle, Washington: U.S. Geological Survey Open-File Report 91–147, scale 1:100,000.



1000 feet = 304.8 meters
No Vertical Exaggeration

Table 1. *^{14}C ages from the map area*

Lab No.	Site name	Sample type	Sample No.	^{14}C age, in yr B.P.[1]	Collected by	Dated unit	Pretreatment
Beta-183244	Vasa Park E.trench[2]	charcoal	VP043	420±40	B. Sherrod (USGS)	post Vashon soil	acid/alkali/acid
Beta-183243	Vasa Park E.trench[2]	charcoal	VP033	10,530±50	B. Sherrod	Qmw	acid/alkali/acid
Beta-183242	Vasa Park E.trench[2]	charcoal	VP014	9,830±50	B. Sherrod	Qmw	acid/alkali/acid
Beta-183241	Vasa Park E.trench[2]	charcoal	VP009	11,670±50	B. Sherrod	Qmw	acid/alkali/acid
Beta-171918	Vasa Park E.trench[2]	charcoal	VP035	10,350±40	B. Sherrod	Qmw	acid/alkali/acid
Beta-169462	Vasa Park E.trench[2]	charcoal	VP001	11,550±40	B. Sherrod	Qmw	acid/alkali/acid
Beta-153518	Vasa Park W.trench[3]	charcoal	S-25	4,610±40	K. Troost (Univ. of WA)	post Vashon soil	acid/alkali/acid
Beta-153517	Vasa Park W.trench[3]	charcoal	S-1	34,870±50	K. Troost	Qob	acid/alkali/acid
CAMS-23160 (also 23170, 71, 75, 76, 77)	Issaquah gravel pit	detrital wood	–	14,450±90	Porter and Swanson (1998)	Qva	not specified

[1] Present is considered to be 1950 A.D.
[2] Six reported ^{14}C sites from same location at map scale.
[3] Two reported ^{14}C sites from same location at map scale.

Geologic Map of the East Half of the Bellevue South 7.5' x 15' Quadrangle, Issaquah Area, King County, Washington

By

Derek B. Booth[1], Timothy J. Walsh[2], Kathy Goetz Troost[3], and Scott A. Shimel[3]

2012

[1] Quaternary Research Center, University of Washington
[2] Washington Division of Geology and Earth Resources
[3] The Pacific Northwest Center for Geologic Mapping Studies, University of Washington

For sale by U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225, 1–888–ASK–USGS

Digital files available at http://pubs.usgs.gov/sim/3211/

Suggested Citation: Booth, D.B., Walsh, T.J., Goetz Troost, K., and Shimel, S.A., 2012, Geologic map of the east half of the Bellevue South 7.5' x 15' quadrangle, Issaquah area, King County, Washington: U.S. Geological Survey Scientific Investigations Map 3211, scale 1:24,000. (Available at http://pubs.usgs.gov/sim/3211/.)