WASHINGTON STATE DEPARTMENT OF Natural Resources
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Division of Geology and Earth Resources
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WASHINGTON DIVISION OF GEOLOGY AND EARTH RESOURCES
MAP SERIES 2014-02
Center 7.5-minute Quadrangle
Pamphlet accompanies map

Geologic Map of the Center 7.5-minute Quadrangle, Jefferson County, Washington

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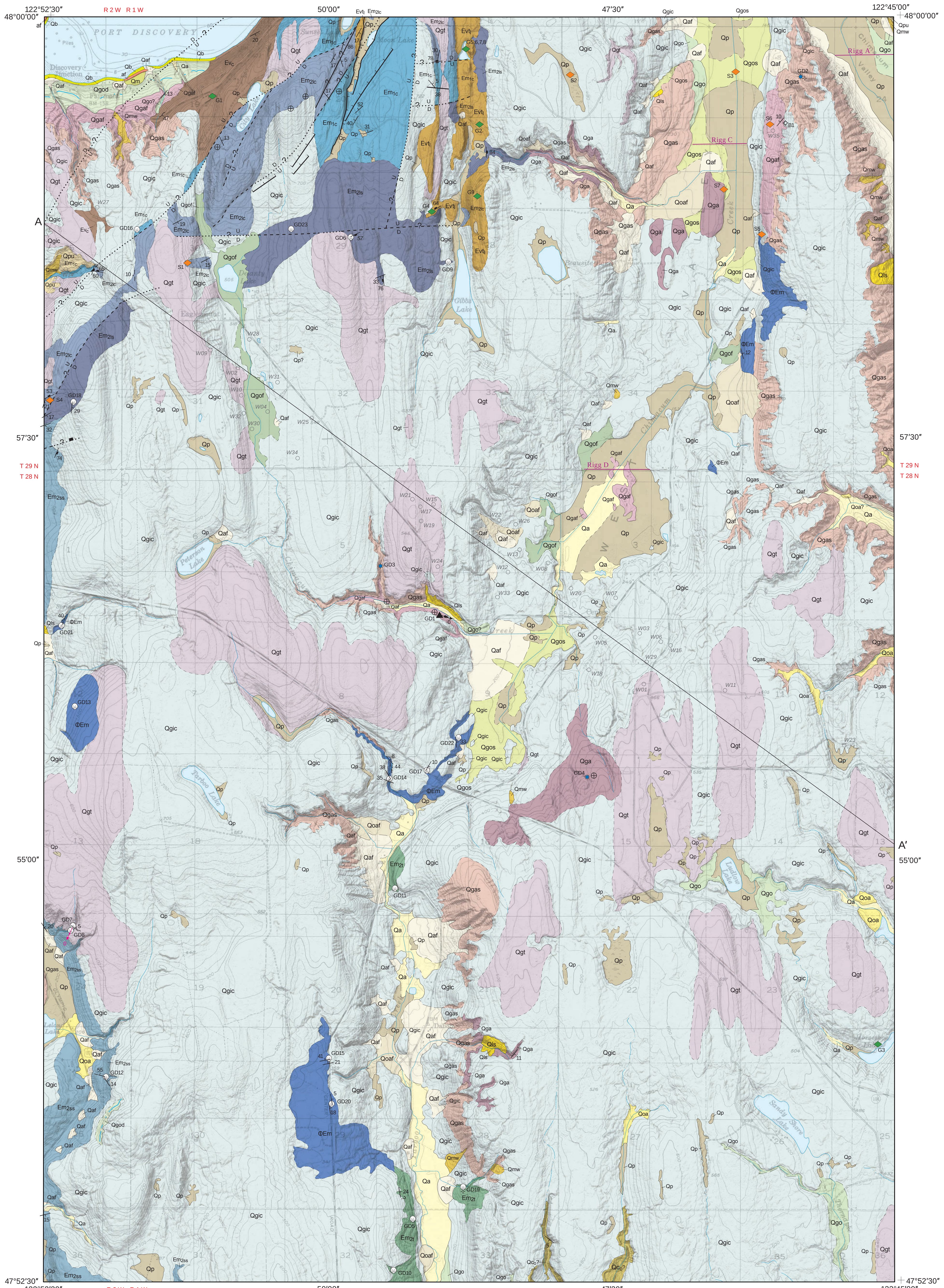
Annette I. Patton, Gabriel Legoretta Paulín, and Recep Cakir

2014

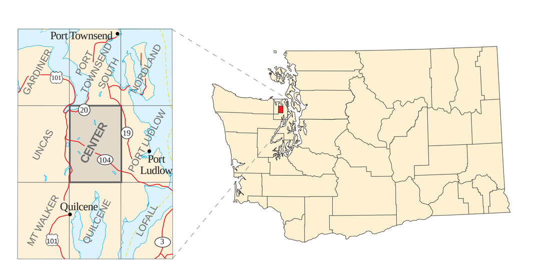


Lambert conformal conic projection
North American Datum of 1927; to place on North American Datum of 1983, move the projection lines approximately 23 meters north and 78 meters east as shown by crosshair corner ticks
Base map from scanned and rectified U.S. Geological Survey Center 7.5-minute quadrangle, 1997
Shaded relief generated from a lidar bare-earth digital elevation model (available from Puget Sound Lidar Consortium, http://pugetsoundlidar.ess.washington.edu/); sun azimuth 340°; sun angle 45°; vertical exaggeration 0.8
GIS by Michael Polenz, Harley O. Gordon, and Ian J. Hubert
Digital cartography by Ian J. Hubert and Anne C. Olson
Editing and production by Jessica L. Czajkowski, Jaretta M. Roloff, and Alexander N. Steely

SCALE 1:24,000
1 MILE; 7000 FEET; 1 KILOMETER
contour interval 20 feet
depth contours in feet—datum is mean lower low water

This geologic map was funded in part by the U.S. Geological Survey National Cooperative Geologic Mapping Program.

16½°
TRUE NORTH; MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 2014



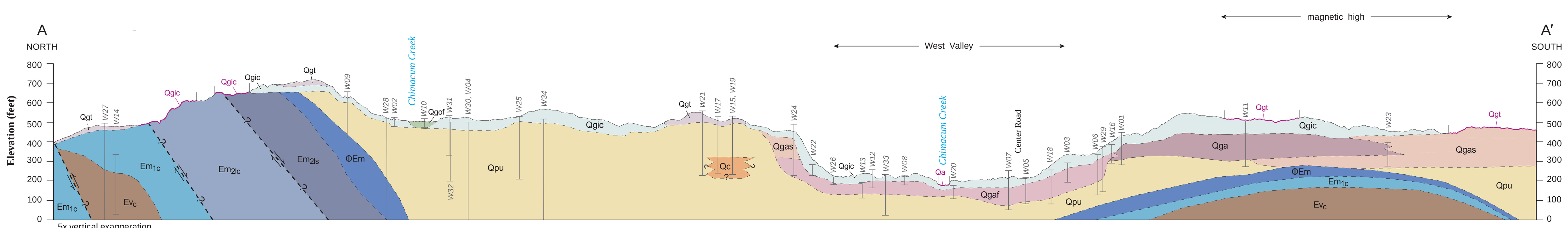
Research supported by the U.S. Geological Survey, National Cooperative Geologic Mapping Program, under USGS award number G13AC00173. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

GEOLOGIC SYMBOLS IN CROSS SECTIONS

Fault—Inferred; identity or existence questionable. Arrows indicate relative vertical motion.

Surficial geologic units too thin to show as polygons at the scale of the cross section.

Water well



MAJOR FINDINGS

- New whole-rock chemical analyses for eight andesite to dacite samples from the Lyre Formation document chemical characteristics of adakites.
- Crustal earthquake clusters beneath the map area reveal no discernable relation to known surficial features and may instead mark contacts between Crescent Formation basalt and adjoining sedimentary rocks.
- Unlike areas to the south and west, the map area yielded very few biostratigraphically constraining fossil samples from bedrock units.
- Everson interstade marine sediments found at 130 ft elevation at Port Discovery imply a similar marine incursion maximum elevation for the map area; field relations strongly suggest that Vashon ice remained in the map area after peak marine incursion.

DESCRIPTION OF MAP UNITS

(see pamphlet for detailed map unit descriptions)

Quaternary Unconsolidated Deposits

HOLOCENE NONGLACIAL DEPOSITS

af **Artificial fill**—Sand, cobbles, pebbles, boulders, silt, clay, organic matter, rip-rap, and concrete, in varied abundances, placed to elevate the land; engineered or non-engineered.

Qb **Beach deposits**—Sand, pebbles, pebbly sand, cobbles, silt, clay, shells, and isolated boulders; loose; clasts moderately to well rounded and oblate; locally well sorted.

Qm **Saltmarsh deposits**—Organic sediment and (or) loose clay, silt, and sand in a saltwater to brackish coastal wetland.

LATEST PLEISTOCENE TO HOLOCENE NONGLACIAL DEPOSITS

Qp **Peat**—Organic and organic-rich sediment; includes peat, gyttja, muck, silt, and clay; typically in closed depressions.

Qls **Landslide deposits**—Cobbles, pebbles, sand, silt, clay, boulders, and diamicton, in varied abundances, in slide bodies and toes; angular to rounded clasts and grains; unsorted; generally loose, jumbled, and unstratified.

Qmw **Mass wasting deposits**—Cobbles, pebbles, sand, silt, clay, boulders, and diamicton, in varied abundances; loose; generally unsorted, but locally stratified; shown along potentially or demonstrably unstable slopes; includes colluvium and (or) landslides too small to show.

Qa Qoa **Alluvium**—Sand, silt, clay, pebbles and cobbles, and peat; loose; moderately to well sorted; stratified to massive; deposited in flood plains and on terraces. Qoa where relict.

Qaf Qoaf **Alluvial fan deposits**—Pebbles, sand, silt, and cobbles and boulders, in varied abundances; loose; moderately to poorly sorted; stratified; forms concentric lobes where streams emerge from valleys; unit Qoaf where relict.

PLEISTOCENE GLACIAL AND NONGLACIAL DEPOSITS

Vashon Drift (Northern-sourced, Fraser Glaciation)

Qgo **Vashon recessional outwash**—Sand and pebble to cobble gravel; some silt and clay; moderately fresh; loose; clasts subrounded; moderately sorted and stratified. Subdivided into:

Qgos **Vashon recessional outwash sand**—Sand with beds and lenses of pebbles silt and clay; gray to tan; loose; clasts moderately to well rounded; moderately to well sorted.

Qgof **Vashon recessional glacial lake deposits**—Silt, sand, clay, and rare dropstones; gray; loose, locally moderately indurated; moderately to well sorted, laminated or massive.

Qgod **Vashon recessional glacial delta deposits**—Sand with silt and lenses of gravel; gray to pale brown; loose; moderately sorted; moderately indurated and cohesive.

Qgic **Vashon ice-contact deposits**—Diamicton of clay, silt, sand, pebbles, cobbles, and isolated boulders; pebble and cobble gravel, sand, lacustrine mud and isolated boulders; pale to ash-gray, tan, or brown, lightly weathered; loose to compact; poorly to well sorted; massive to well stratified; includes sub-ice-flow and collapse features.

Qgt **Vashon lodgment till**—Diamicton of clay, silt, sand, pebbles, and cobbles, in varied abundances, with isolated boulders; brown to gray; lightly weathered or unweathered; unsorted; unstratified; compact, commonly resembles concrete.

Qga **Vashon advance outwash**—Sand with less common pebble and cobble gravel, silt, and clay; gray to tan; compact; clasts well rounded and well sorted; thinly to thickly bedded. Subdivided into:

Qgas **Vashon advance outwash sand**—Sand with less abundant silt, clay, pebbles, cobbles, or diamicton; pale gray to tan; compact; subrounded to well rounded and well sorted; thinly to thickly bedded.

Qgaf **Vashon advance lacustrine mud**—Silt and clay with interbeds of sand, pebbles, diamicton, and rare dropstones; gray to tan; compact; well sorted; laminated to massive.

Sediments Older Than the Vashon Stade

Pre-Fraser Glacial and Nonglacial Deposits

Qc **Pre-Vashon nonglacial deposits (cross section only)**—Sand, less commonly clay or clayey sand; may contain wood; mostly gray, less commonly brown; compact. Subdivided into:

Qc_o? **Olympia nonglacial deposits**—Sand with less common silt, pebble gravel, minor clay, and minor peat; mostly gray to tan, locally brown or bluish-gray; compact; moderately sorted; mostly horizontally and planar-bedded, with some low-angle crossbeds.

Qpu **Undivided Quaternary sediment older than Vashon Till**—Sand, pebble gravel, silt, clay, diamicton, organic sediment, and boulders, in varied abundance; color and weathering varied; compact; varied grain size, rounding, sorting, and bedding.

Tertiary Sedimentary and Volcanic Bedrock

ΦEm **Undifferentiated sedimentary rocks (late Eocene to early Oligocene)**—Mudstone and siltstone with less common sandstone or claystone; some exposures micaceous; dark to pale-brown in weathered exposures, medium to dark-gray where fresh; locally nodular and hackly in outcrop.

Em_{2t} **Townsend Shale (late Eocene)**—Mudstone, siltstone, and sandstone; commonly micaceous, in places calcareous; brown to gray; spheroidal to hackly weathering common.

Em_{2ss} **Sandstone of Snow Creek (late Eocene)**—Sandstone, siltstone, and mudstone; in places calcareous; gray to brown; well to moderately sorted; angular to subangular.

LYRE FORMATION (MIDDLE EOCENE)

Em_{2ls} **Lyre Formation sandstone and mudstone**—Sandstone, siltstone, and mudstone; thickly bedded; well indurated; quartzose and lithic.

Evt_l **Lyre Formation volcanic tuff and breccia**—Hornblende dacite to andesite breccia with rare lithic tuff interbeds; gray to pale red or brown.

Em_{2lc} **Lyre Formation conglomerate**—Pebble to cobble conglomerate with lenses of sandstone; tan or brown to gray; well indurated; rounded to subrounded; poorly sorted; generally thickly bedded; clasts mostly chert, lesser quartz, basalt, and other rocks.

CRESCENT FORMATION (EARLY TO MIDDLE EOCENE)

Em_{1c} **Crescent Formation sedimentary rocks**—Basaltic conglomerate, sandstone, and mudstone, in places calcareous; dark gray to brown or black, or pale yellow to orange; well indurated; mostly pebble- to cobble-size clasts; poorly sorted; dominantly basaltic clasts with a few clasts of basaltic sedimentary rock.

Ev_c **Crescent Formation basalt**—Basalt, typically in aphanitic flows or breccia with rare pillows; gray to yellow-brown; spheroidal exfoliation common.

GEOLOGIC SYMBOLS

Contact—Solid where location accurate; long dash where approximate; short dashed where inferred; queried where location or existence uncertain

Reverse fault—Short dash where inferred; dotted where concealed; queried where location or existence uncertain; rectangles on upthrown block

High-angle dip-slip fault—Solid where location accurate; short dash where inferred; dotted where concealed; queried where location or existence uncertain; relative movement shown by U and D

A —— A′ Cross section line

Rigg A Peat profile location from Rigg (1958)

Former shoreline—Identity and existence certain, location accurate

Scarp identified from lidar—Identity and existence certain; location accurate; hachures on downslope side

29 Bedding—showing strike and dip

40 Approximate bedding—showing strike and dip

5 Crenulated, warped, undulatory, or contorted bedding—showing strike and dip

Horizontal bedding

Approximate horizintal bedding

Current flow-direction indicators (flutes, pebble imbrication, etc.)—showing bearing and plunge

74 Joint—showing strike and dip

Minor fold—showing bearing and plunge

38 Minor fault—showing strike and dip

47 Shear—showing strike and dip

GD1 Age sample, radiocarbon (^{14}C)

GD2 Age sample, optically stimulated luminescence

GD14 Age sample, fossil

G2 Geochemistry sample location

B1 Geotechnical boring

S6 Significant site

W07 Water well

CORRELATION OF MAP UNITS

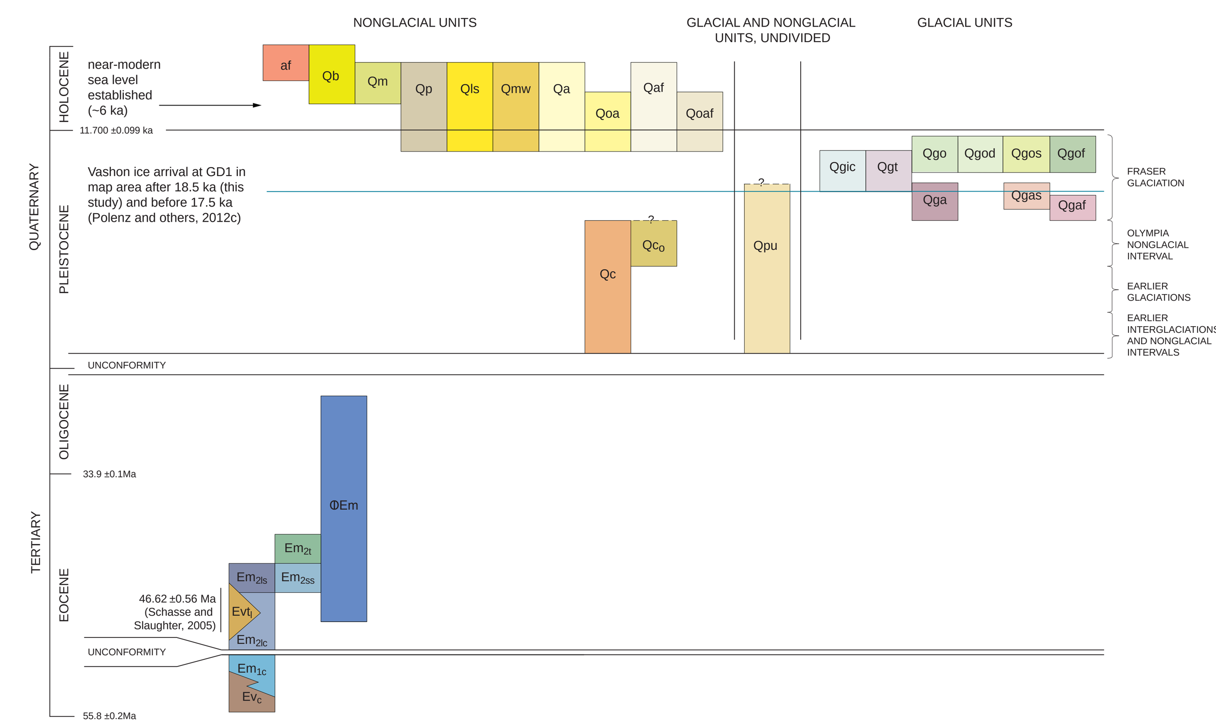


Table M1. Summary of new age estimates for the map area. See Tables A1–A3 (pamphlet) for details.

Age site	TRS	Map unit	Material dated	Analytic method	Age estimate
GD1	sec. 4, T28N R1W	Qgaf	plant fragment	^{14}C (AMS)	14,880 ±60 ^{14}C yr BP (18.470–18.300 ka and 18.090–17.960 ka)
GD2	sec. 23, T29N R1W	Qgas	sand	IRSL	17.060 ±1.040 ka
				OSL	15.760 ±1.180 ka
GD3	sec. 5, T28N R1W	Qgas	sand	IRSL	19.260 ±1.390 ka
				OSL	11.810 ±1.010 ka
GD4	sec. 15, T28N R1W	Qga	sand	IRSL	84.430 ±4.970
				OSL	16.540 ±1.510 ka

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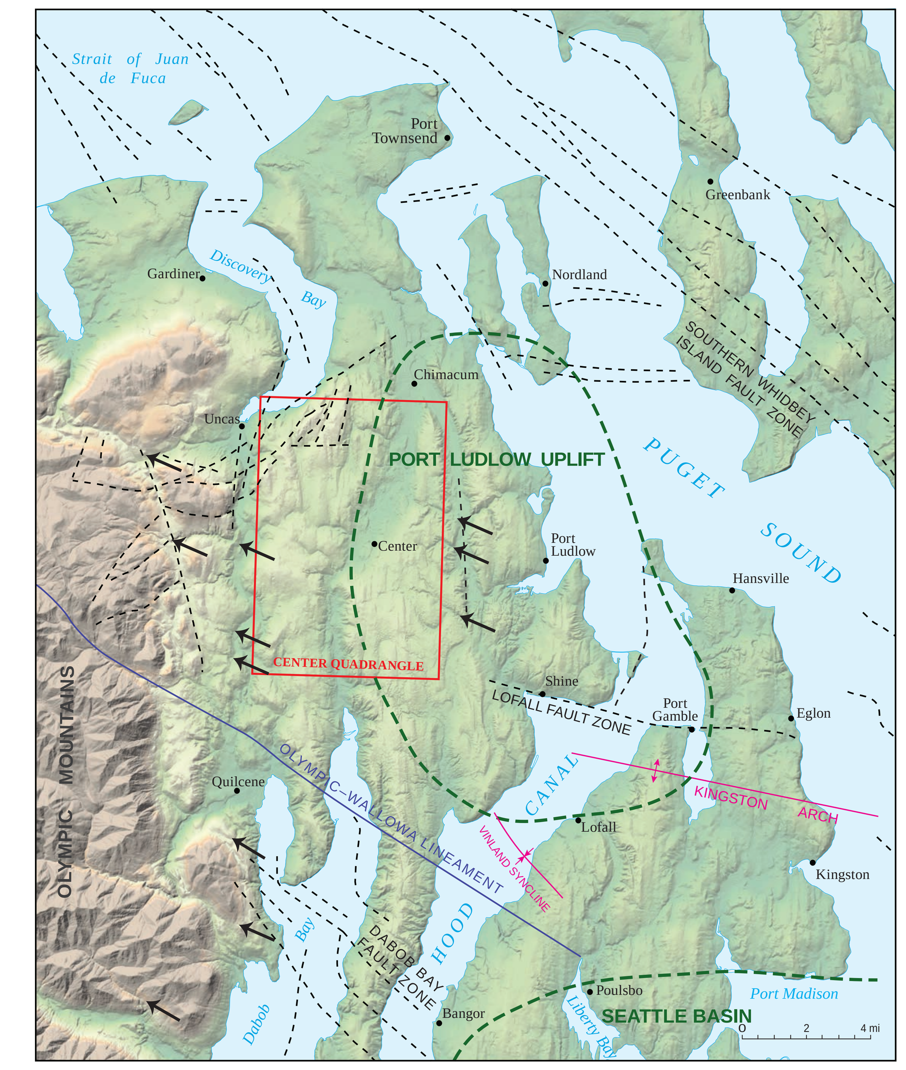

Figure M1. Shaded relief map of regional structures. Black dashed lines indicate faults; black arrows illustrate regional abundance of northwest-trending lineaments. Faults in and south of the Center quadrangle (red rectangle) are from current and recent field investigations (this study; Contreras and others 2014; Polenz and others, 2013), with the exception of the two faults along the south shore of Discovery Bay adapted from Tabor and Cady (1978). Faults west of the quadrangle were mapped by Tabor and others (2011; see also Haeussler and others, 1999). The Olympic–Wallowa lineament is from from Raisz (1945). The Kingston arch, Vinland syncline, and Lofall fault zone are from Brocher and others (2001) as modified by Contreras and others (2013). The fault between the eastern quadrangle boundary and Port Ludlow is from Yount and Gower (1991). All other faults are from Bowman and Czajkowski (2013). Pratt and others (1997) used geophysical information to infer the Port Ludlow uplift and Seattle basin, outlined by green dashed lines.

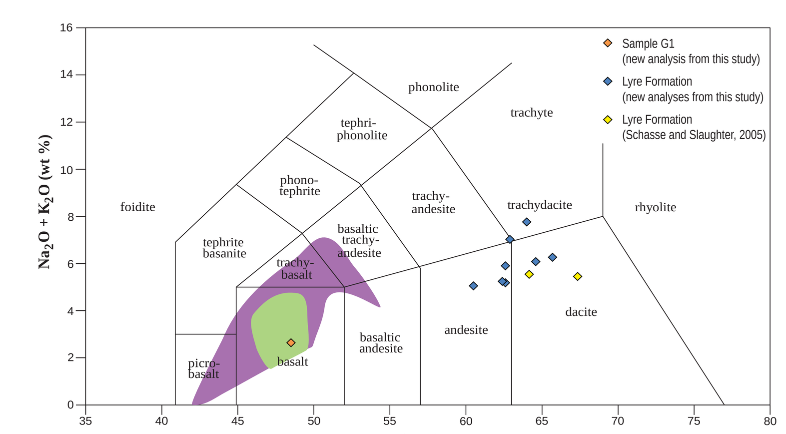

Figure M2. Total alkalis vs. silica plot of igneous rocks (Le Bas and others, 1986). Nine samples are new analyses from the Center quadrangle: eight from the volcanic member of the Lyre Formation (unit Evt_l) and one from basalt that we mapped as Crescent Formation (unit Ev_c). The purple area represents the composition of Crescent Formation basaltic rocks along the eastern and northern margin of the Olympic Peninsula (Schasse and Logan, 1998; Schasse and Wegmann, 2000; Schasse and Polenz, 2002; Polenz and others, 2004, 2012b,c; Schasse and others, 2004; Contreras and others, 2012a)—the smaller green area represents most of those samples. The orange diamond is sample G1 from the Center quadrangle; blue diamonds are new analyses of Lyre Formation volcanic rocks within the map area (samples G2–9); yellow diamonds are previous analyses of Lyre Formation volcanic rocks in the Port Townsend South quadrangle 0.8 and 1.5 mi north of the map area (secs. 15 and 10, T29N R1W; Schasse and Slaughter, 2005). See Table M2 for tabular geochemical and analytical data.

Table M2. New whole-rock geochemical analyses for one basalt and eight andesite to dacite samples from the Center quadrangle. Analyses performed by ALS Global, Vancouver, Canada. Major oxides determined by x-ray fluorescence (XRF) and trace elements by inductively coupled plasma mass spectrometry (ICP-MS). Lab states analytical uncertainties are 5% for major oxides and 10% for trace elements. Major elements normalized to 100% on an anhydrous basis. LOI represents loss on ignition; total iron reported as $Fe_2O_3^T$. Rock types classified on basis of total alkalis vs. silica (Le Bas and others, 1986) (Fig. 2 in pamphlet). Sample G1 is similar in chemical composition to other Crescent Formation samples from nearby quadrangles (Contreras and others, 2012a; Polenz and others, 2004, 2012b,c; Schasse and Logan, 1998; Schasse and others, 2004; Schasse and Polenz, 2002; Schasse and Wegmann, 2000). On a tectonic discrimination diagram (TiO vs. MnO vs. P_2O_5, Mullen, 1983), sample G1 would plot as island-arc tholeiite. Lyre Formation samples display limited major element variation (60.5–65.9 wt % SiO_2, 1.01–3.54 wt % MgO, 4.39–6.84 wt % Na_2O) and have chemical characteristics of adakites (Defant and Drummond, 1990; Martin and others, 2005), including SiO_2 >56 wt %, Na_2O >3.5 wt %, Sr >400 ppm, Sr/Y >40, Yb <1.8 ppm, and La/YbN >10. Adakites of similar composition were found at Chimacum and other scattered localities in the vicinity (Tepper and others, 2004; Wolfe and Tepper, 2004).

Analytical Method—XRF (major oxides)

Geochemistry site		G1	G2	G3	G4	G5	G6	G7	G8	G9
Rock type (unit symbol)		basalt (Ev_c)	andesite (Evt_l)	dacite (Evt_l)	trachyandesite (Evt_l)	andesite (Evt_l)	andesite (Evt_l)	trachydacite (Evt_l)	andesite (Evt_l)	dacite (Evt_l)
Deposit type		flow matrix	breccia? matrix	clast in till (float in unit Qgic)	tuff? matrix	breccia clast	tuff matrix	breccia clast	breccia matrix	tuff matrix
SiO_2	%	48.5	62.6	65.7	62.9	62.6	60.5	64	62.4	64.6
TiO_2	%	1.56	0.49	0.47	0.38	0.56	0.56	0.51	0.53	0.4
Al_2O_3	%	14.8	18.5	16.4	17.3	18.5	18.7	19.3	18.0	18.0
$Fe_2O_3^T$	%	12.01	4.83	4.51	3.93	5.44	5.58	3.58	5.54	4.22
MgO	%	7.75	2.34	2.08	1.43	2.41	3.54	1.01	2.98	1.96
MnO	%	0.31	0.05	0.08	0.10	0.11	0.05	0.05	0.07	0.04
CaO	%	12.35	5.14	4.30	6.94	5.03	5.89	3.63	5.11	4.57
Na_2O	%	2.46	5.09	4.39	6.00	4.36	4.68	6.84	4.65	5.17
K_2O	%	0.14	0.80	1.86	1.02	0.78	0.35	0.96	0.54	0.88
P_2O_5	%	0.14	0.12	0.19	0.08	0.13	0.13	0.13	0.12	0.08
LOI	%	3.15	2.56	0.50	3.73	2.43	3.85	0.84	1.95	1.75
Original Total	%	99.34	99.01	99.03	99.23	98.95	98.79	98.92	99.58	99.09

Analytical Method—ICP-MS (trace elements)

Geochemistry site		G1	G2	G3	G4	G5	G6	G7	G8	G9
Rock type (unit symbol)		basalt (Ev_c)	andesite (Evt_l)	dacite (Evt_l)	trachyandesite (Evt_l)	andesite (Evt_l)	andesite (Evt_l)	trachydacite (Evt_l)	andesite (Evt_l)	dacite (Evt_l)
Ba	ppm	23.4	261.0	680.0	516.0	398.0	347.0	685.0	383.0	244.0
Ce	ppm	14.8	27.5	25.7	22.3	26.9	26.6	28.5	24.9	23.2
Cr	ppm	300	40	30	20	30	30	30	30	30
Cs	ppm	<0.01	0.05	0.37	0.10	0.16	0.19	0.02	0.04	0.13
Dy	ppm	4.74	1.92	2.01	1.58	2.19	1.91	1.31	1.94	1.48
Er	ppm	2.96	1.10	1.22	0.94	1.12	1.17	0.76	1.03	0.75
Eu	ppm	1.20	0.82	0.77	0.65	0.96	0.88	0.61	0.72	0.67
Ga	ppm	20.7	20.5	18.4	18.0	21.1	19.9	18.2	20.4	19.3
Gd	ppm	4.20	2.35	2.36	1.74	2.66	2.56	1.39	2.12	1.80
Hf	ppm	2.5	3.4	3.0	2.9	3.3	2.7	3.4	3.1	2.9
Ho	ppm	0.94	0.37	0.39	0.29	0.42	0.44	0.24	0.36	0.31
La	ppm	5.7	16.2	12.8	12.2	13.9	14.5	15.3	12.8	13.7
Lu	ppm	0.38	0.15	0.19	0.13	0.13	0.13	0.08	0.16	0.11
Nb	ppm	6.4	6.5	4.2	4.7	7.2	6.7	8.1	6.6	4.7
Nd	ppm	11.1	12.1	13.3	9.8	13.2	12.4	10.6	11.6	11.0
Pr	ppm	2.22	3.22	3.17	2.54	3.22	3.12	2.98	2.88	2.85
Rb	ppm	1.4	6.3	30.3	13.3	12.2	4.5	12	7.4	13.4
Sm	ppm	3.23	2.40	2.77	1.97	2.50	2.37	1.91	2.49	2.19
Sn	ppm	1	1	1	<1	1	1	1	1	<1
Sr	ppm	165	413	620	354	429	471	331	409	411
Ta	ppm	0.4	0.5	0.3	0.3	0.5	0.4	0.5	0.5	0.4
Tb	ppm	0.70	0.31	0.32	0.26	0.34	0.32	0.22	0.29	0.26
Th	ppm	0.48	2.46	2.71	2.54	2.34	1.97	2.61	2.33	2.38
Tl	ppm	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Tm	ppm	0.43	0.14	0.19	0.13	0.16	0.16	0.08	0.12	0.14
U	ppm	0.19	0.62	1.01	0.86	0.75	0.76	0.92	0.79	0.61
V	ppm	342	61	73	47	67	70	49	67	53
W	ppm	<1	<1	<1	<1	<1	<1	1	<1	<1
Y	ppm	24.9	11.6	11.0	8.5	11.0	11.2	6.5	9.8	8.0
Yb	ppm	2.19	0.96	1.04	0.71	1.26	1.01	0.63	1.02	0.73
Zr	ppm	83	127	107	108	126	108	130	124	103

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