WASHINGTON STATE DEPARTMENT OF NATURAL RESOURCES
WASHINGTON GEOLOGICAL SURVEY

Geologic Map of the Littlerock 7.5-minute Quadrangle, Thurston County, Washington

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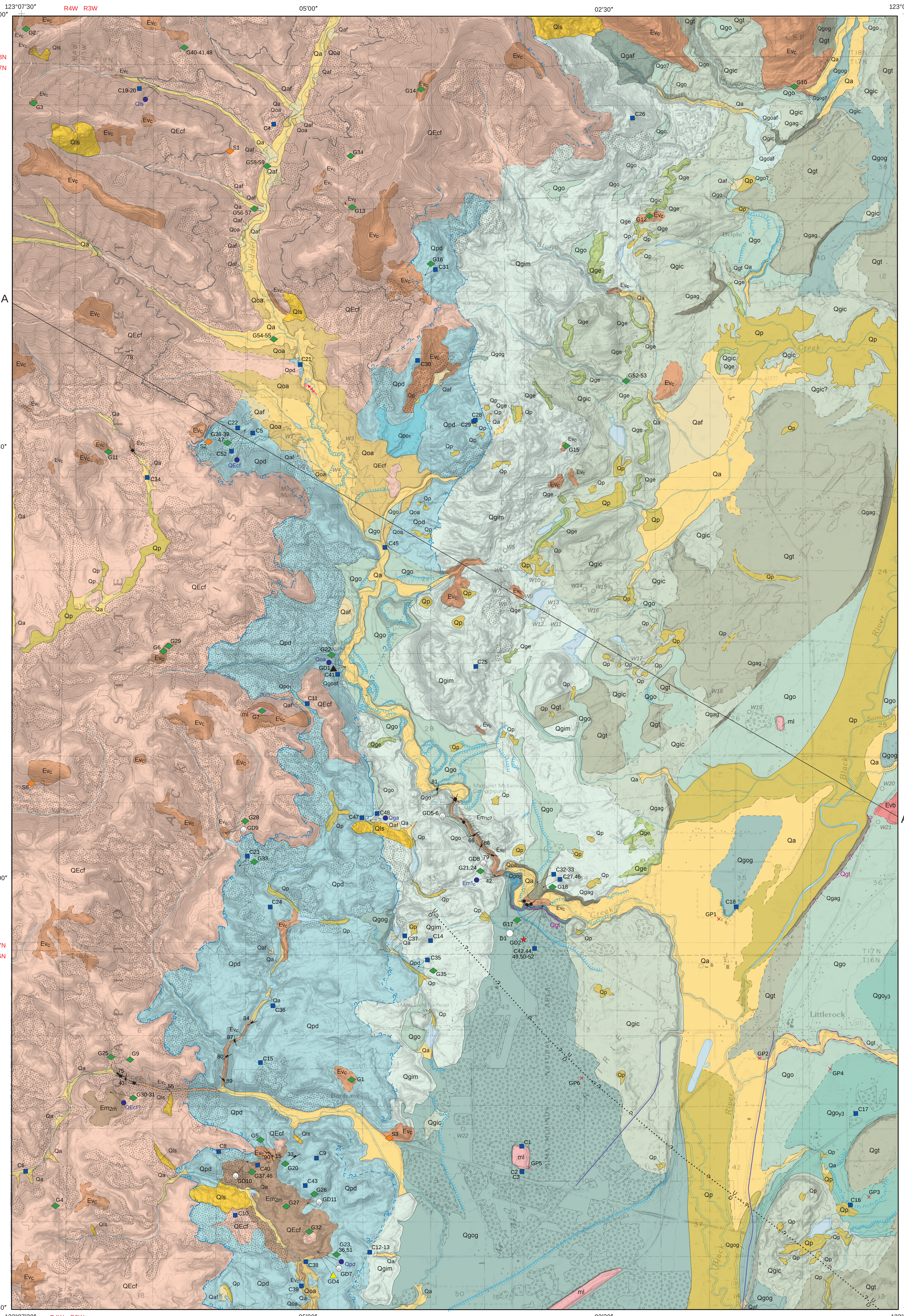

Lambert conformal conic projection
North American Datum of 1927; to place on North American Datum of 1983, move the projection lines approximately 23 meters north and 95 meters east as shown by crosshair corner tics
Base map from scanned and rectified U.S. Geological Survey Littlerock 7.5-minute quadrangle, 1986
Shaded relief generated from a lidar bare-earth digital elevation model (available from the Washington Geological Survey, http://lidarportal.dnr.wa.gov/)
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Digital cartography by Daniel E. Coe
Editing and production by Jessica L. Czajkowski, Jaretta M. Roloff, and Daniel E. Coe

SCALE 1:24,000
1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 KILOMETER
contour interval 40 feet

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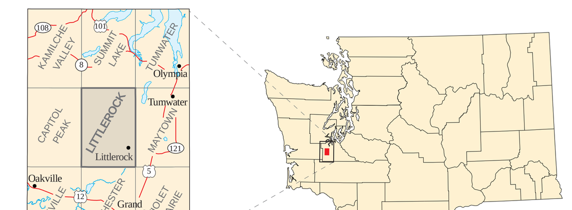
APPROXIMATE MEAN DECLINATION, 2017
16°
TRUE NORTH
MAGNETIC NORTH



MAJOR FINDINGS

- A new ~47.4 Ma laser-ablation U-Pb date on zircon from a slightly reworked airfall tuff provides a close maximum limiting age for the McIntosh Formation.
- A new 46 Ma $^{40}Ar/^{39}Ar$ date suggests that basalt east of the Black Hills is younger than the Crescent Formation in the Black Hills and older than gabbroic intrusive rocks east of the Littlerock quadrangle. Chemical similarities suggest that all of these volcanic rocks shared the same mantle source(s).
- Ice covered the east half of the Littlerock quadrangle during the Vashon glaciation. It was preceded by at least one ice incursion that reached higher elevations farther west in the Black Hills. Each ice incursion appears to have impounded a south-draining lake in the Waddell Creek valley, with an earlier lake reaching at least 800 ft elevation and the Vashon lake reaching close to 465 ft.
- Geochemical traits separate Olympic Mountains–style Crescent basalt in the southern third of Littlerock quadrangle from Willapa Hills–style basalt farther north, likely due to separate eruptive centers. Field relations suggest that the southern basalts are stratigraphically above those farther north.
- Although Possession ice (MIS 4) never came close to the Littlerock quadrangle, new luminescence dates on fluvial deposits imply that Possession meltwater, like Vashon meltwater, drained through the Black River valley, suggesting that the pre-Vashon landscape was similar to the modern southern Puget Lowland.

DESCRIPTION OF MAP UNITS

(see pamphlet for detailed map unit descriptions)

Quaternary Unconsolidated Deposits

POSTGLACIAL DEPOSITS

Holocene Nonglacial Deposits

ml — **Modified land**—Boulders, cobbles, pebbles, sand, silt and clay in varied amounts; locally derived, but redistributed to modify topography.

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 of basalt, siltstone, and sandstone in varied amounts; clasts angular to rounded; unsorted; mostly loose, jumbled, and unstratified; locally retains primary bedding and compaction.

Pleistocene to Holocene Nonglacial Deposits

Qa, Qoa — **Alluvium**—Pebbles, cobbles, sand, silt, clay, peat, and boulders in varied amounts; along streams and on flood plains; gray, or dark brown due to organic matter, locally iron-stained red or yellowish brown; loose; thinly bedded to massive; unit Qoa where relict.

Qaf — **Alluvial fan deposits**—Pebbles, sand, silt, cobbles, and boulders in varied amounts; gray to brown; loose; subangular to rounded; moderately to poorly sorted; stratified to poorly stratified; form concentric lobes.

PLEISTOCENE GLACIAL DEPOSITS

Vashon Drift of the Fraser Glaciation
(All Vashon units are northern-sourced.)

Qgo — **Recessional Vashon outwash, undivided**—Pebbles, cobbles, sand, and silt in varied amounts; light gray, weathers to pale brown or tan, light orange where iron stained; loose; well sorted; clasts well rounded; locally lightly cemented; massive to bedded. Divided into:

Qgoaf — **Vashon recessional alluvial fan deposits**—Pebbles, sand, silt, clay, cobbles, and boulders in varied amounts; gray, weathers brown; lightly to heavily weathered; loose; clasts subangular to rounded; moderately to poorly sorted; stratified to poorly stratified; forms concentric lobes.

Qgog — **Vashon recessional outwash gravel**—Pebble to cobble gravel with a coarse sand matrix; pale gray, weathering to tan, red-orange where iron stained; lightly weathered; may be lightly cemented; loose; clasts subrounded to well rounded; well sorted; massive to bedded.

Qgo_{y3} — **Vashon recessional outwash, Yelm lobe**—Sandy pebble gravel; pale gray, locally stained pale yellow to orange-tan; lightly weathered; loose; contains less basalt and more intermediate to felsic volcanic rocks than other Vashon deposits.

Qgic — **Vashon ice-contact deposits**—Patchy lodgment till, ablation till, flow till, and ice proximal outwash of all sizes in varied amounts; pale gray or stained tan to reddish brown; lightly to moderately weathered; clasts mostly well rounded, sand and fines angular to well rounded; poorly sorted to well sorted; massive to bedded. Divided into:

Qgim — **Vashon terminal moraine**—Deposits resemble unit Qgic but tend to be looser and less fluted; chaotic topography, kettles, eskers, varied compaction, and varied texture indicate deposition in contact with stagnant ice; appears to be an ice-marginal moraine.

Qge — **Vashon esker**—Pebbles and sand; medium gray; lightly to moderately weathered; loose; clasts well rounded; well sorted; bedded; forms distinctive long, sinuous hills.

Qgt — **Vashon lodgment till**—Compact diamicton; matrix supported with clasts ranging from pebbles to boulders; light gray, light brown where weathered or basalt rich; lightly to moderately weathered; very compact with little porosity; clasts angular to well rounded; massive or stratified.

Qga — **Vashon advance outwash, undivided**—Cobble gravel, pebble gravel, and sand in varied amounts; pale gray, pale brown where basalt rich or weathered, red to yellow where iron stained; lightly to moderately weathered; compact; well sorted; well rounded; thin to massively bedded. Locally divided into:

Qgaf — **Vashon(?) advance outwash lake deposits**—Clay with sparsely scattered pebbles; blue-gray to brown; clast weathering moderate to heavy; compact; massive.

Qgag — **Vashon advance outwash gravel**—Sandy pebble gravel; pale gray, pale brown where basalt rich or weathered, red to yellow where iron stained; lightly to moderately weathered; compact; well rounded; moderately to well sorted; poorly bedded to unbedded.

Pre-Vashon Glacial Deposits

Qpo_2 — **Possession-age distal outwash**—Northern-sourced sand and pebble gravel; tan to orange; moderately to heavily weathered; compact; clasts subrounded to well rounded; sorting varied; bedded or crossbedded.

Qpo_1 — **Pre-Possession outwash**—Northern-sourced pebble gravel, sand, and silt; dark brown or reddish brown; moderately to heavily weathered; loose; clasts subrounded to well rounded; moderately to well sorted; no bedding.

Qpf — **Pre-Vashon glaciolacustrine deposits (cross section only)**—Gray clay and silt with occasional pebbles; interpreted from well records; age of deposit unclear, but it is beneath pre-Vashon unit Qoa.

Qpd — **Pre-Vashon drift**—Diamicton with small boulders, pebbles, sand, and clay; light brown to deep red; heavily weathered, matrix mostly clay; compaction undetermined; clasts angular to well rounded; unsorted; massive.

Eocene to Quaternary Continental Deposit

QEcf — **Terrestrial weathering clay (Eocene to Quaternary)**—Clay soil and saprolite (halloysite and goethite) concealing underlying bedrock or sediment; locally contains basalt core-stones; red to reddish yellow and reddish brown, locally variegated; loose to dense; structureless, pedogenic, or saprolitic textures; as much as 30 ft thick.

Tertiary Volcanic and Sedimentary Bedrock

Em_{2m} — **McIntosh Formation (middle Eocene)**—Claystone with tuffaceous interbeds of siltstone and sandstone; tan to dark olive brown; lightly to heavily weathered; moderately lithified; silt- and sand-sized particles angular to rounded; poorly sorted; faintly bedded.

Evb — **Basalt (early middle Eocene)**—Aphanitic basalt; dark gray, weathers to medium gray; mildly weathered; moderately dense; not vesicular; fine grained, porphyritic, trachytic.

$Em_{1c?}$ — **Crescent Formation marine sedimentary rocks (early to middle Eocene)**—Claystone; contains foraminifera and a few silt-size lithic fragments; blue-gray to olive brown; moderately to well lithified; 1–4 cm thick beds.

Ev_c — **Crescent Formation (early to middle Eocene)**—Basalt flows; dark gray or black; lightly to heavily weathered; massive; commonly vesicular; aphanitic to porphyritic; fine- to coarse-grained phenocrysts.

GEOLOGIC SYMBOLS

Mass-wasting landforms (overlay pattern)—Landforms that suggest mass movement on unstable slopes, but evidence for landslide deposits is inconclusive.

Mima mounds (overlay pattern)—Dark brown to black, organic-rich sand to pebbly sand loam soil in regularly spaced round to oval mounds about 2 to 6 ft high and 10 to 30 ft across, with little or no comparable soil between mounds. The black color is mostly due to ash from burned organic matter. NTRMounds rest on Vashon proglacial outwash terraces with a highly permeable substrate of mostly northern-sourced pebbles and cobbles. Mapped where landforms and (or) field-observed deposits indicate the presence of such mounds. Their enigmatic origin is discussed below (*Mima Mounds* in *Paleoenvironmental Interpretation* section).

Contact—solid where location accurate; long-dashed where approximate; short-dashed where inferred

High-angle dip-slip fault—inferred; identity or existence questionable, location concealed; relative motion shown by U and D

Qgt — Geologic unit too thin to show as a polygon—solid where location accurate; long-dashed where approximate; short-dashed where inferred; queried where identity or existence questionable

Continental ice limit, late Wisconsinan—solid where location accurate; long-dashed where approximate; short-dashed where inferred; dotted where concealed; queried where identity or existence questionable

Continental ice limit, pre–late Wisconsinan—long-dashed where approximate; short-dashed where inferred; queried where identity or existence questionable

A —— A′ Cross section line

Fluvial terrace—solid where location accurate; short-dashed where inferred; queried where identity or existence questionable; hachures point down slope

Geophysical data collection line

Former shoreline or marine limit—identity or existence questionable, location accurate

42 Inclined bedding—showing strike and dip

79 Small, minor inclined joint—showing strike and dip

Small, minor vertical or near-vertical joint—showing strike

8 Inclined asymmetric (Z-shaped, clockwise sense of shear) minor fold hinge—showing bearing and plunge

15 Inclined flow bands, lamination, layering, or foliation in igneous rock—showing strike and dip

90 Shear—showing strike and dip

55 Shear—showing strike

GD9 Age site, fossil

GD4 Age site, U-Pb, uranium-lead

GD1 Age site, ^{14}C, carbon-14

GD2 Age site, luminescence (OSL and (or) IRSL)

G17 Geochemistry sample location

W20 Water well

S2 Significant site

$Em1_c$ Geologic unit too small to show as a polygon at map scale

D1 Location of schematic section

GP1 Geophysical data collection location

C42 Clast count sample

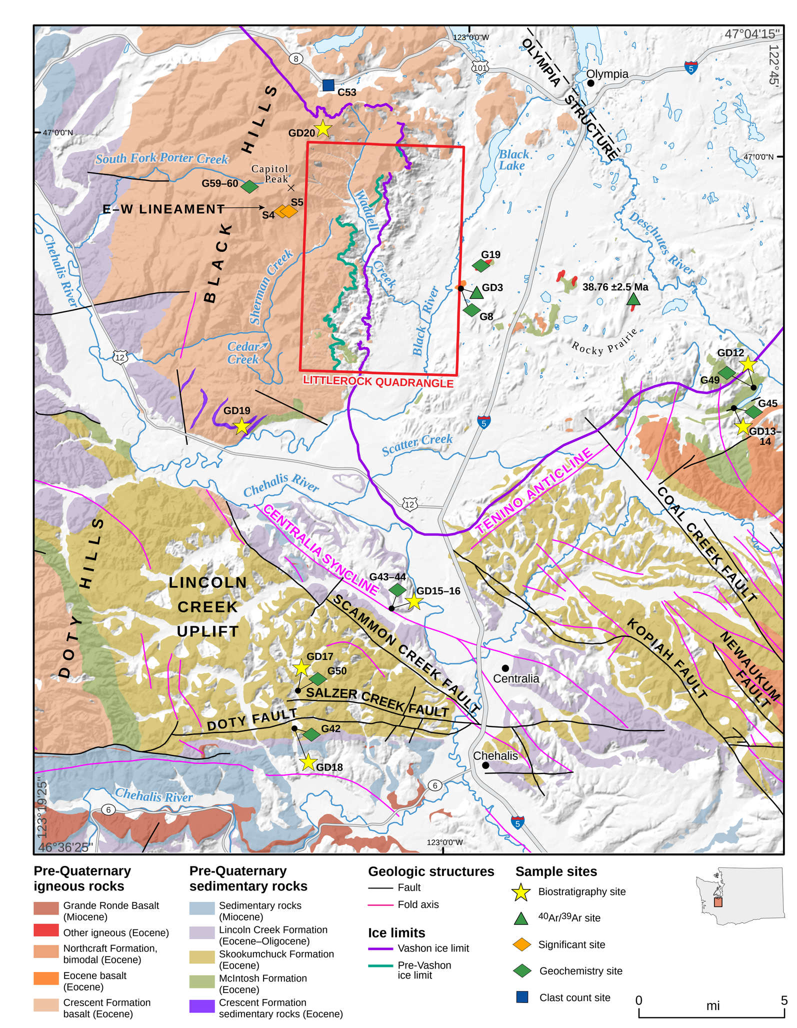


Figure M1. Regional geologic map for the Littlerock quadrangle (red outline). Geologic units and ice limit lines within the quadrangle are from this study. Geologic units, faults, and folds outside the mapping area are adapted from published 1:24,000- and 1:100,000-scale geologic maps. The ice limit outside the Littlerock quadrangle is approximate and modified from Logan and Walsh (2004), Logan and others (2009), and Thorson (1980). Samples shown outside the Littlerock quadrangle provide new reference data (see pamphlet). All samples are from this study, except for site GD19 (Pease and Hoover, 1957; Rau, 2004), GD20 (Rau, 2004), and a 38.76 Ma $^{40}Ar/^{39}Ar$ date from Walsh and Logan (2005).

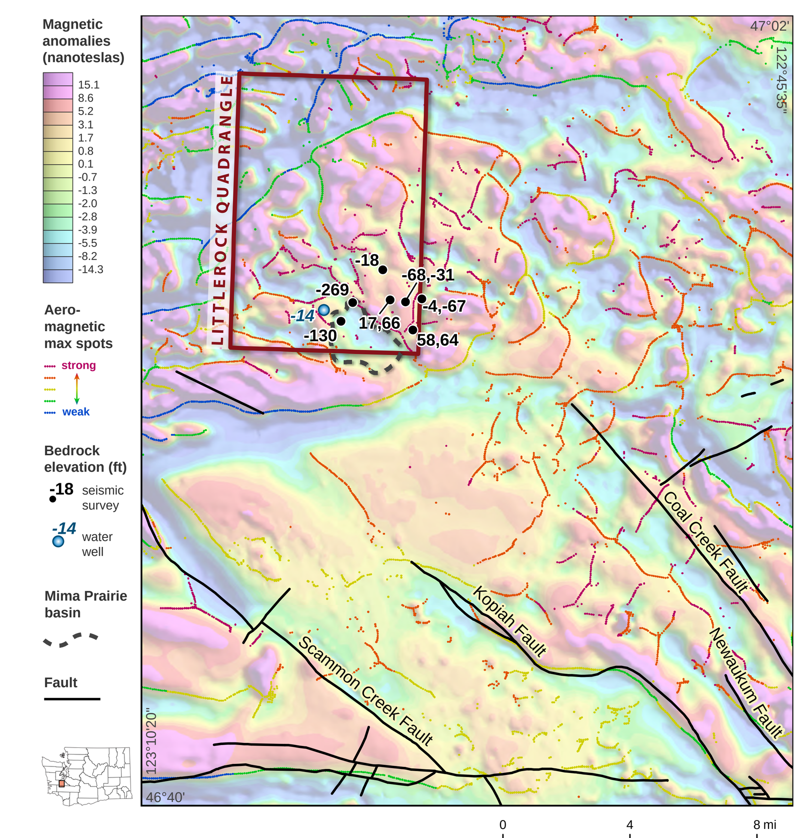
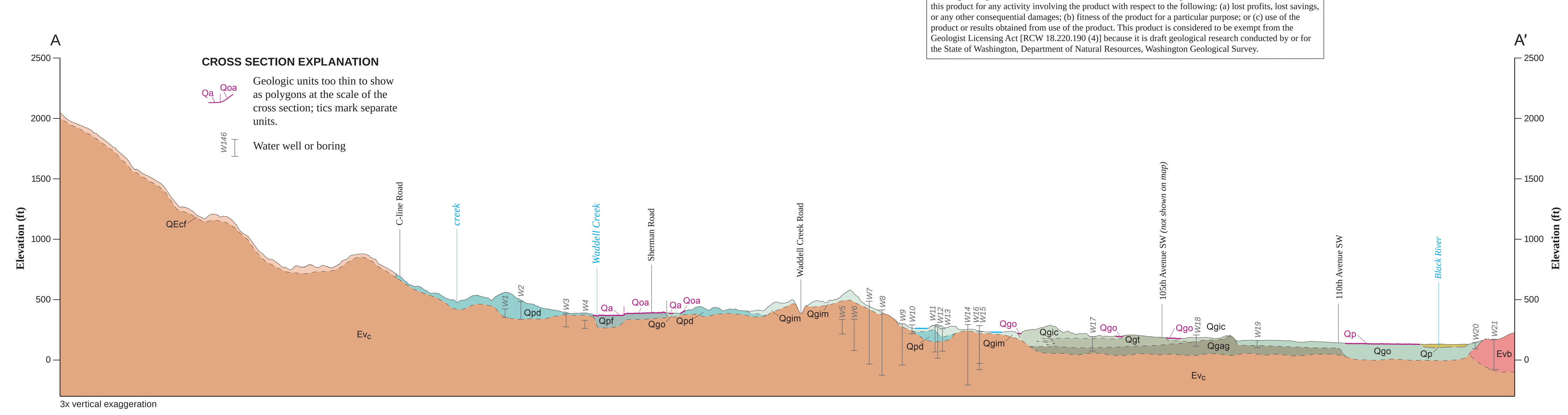


Figure M2. Aeromagnetic image of the Littlerock quadrangle and vicinity. Faults are from Walsh and others (1987). Max spots mark inflections in the aeromagnetic anomalies and tend to form linear clusters (that commonly coincide with topographic lineaments). Mima Prairie basin (informally named here) is delineated based on an aeromagnetic trough. No measurements were made where the magnetic trough is strongest, and basin depth likely exceeds the lowest estimated levels from our seismic depth stations (82 m [270 ft] below sea level). The northwest-trending magnetic anomaly that bounds the northeast side of the basin is aligned with several mapped faults to the southeast and parallels faults observed in the Littlerock quadrangle (see *Structures in the Map Area* and shear symbols on map). Fault names are from Snavely and others (1958).

Table M1. Summary of ages and biostratigraphic analyses from the Littlerock quadrangle and select nearby locations. See *Data Supplement* for more detailed analytical results for biostratigraphy samples from sites GD5 and GD6. Samples from sites GD7 to GD18 did not yield age-diagnostic constraints and are therefore not further characterized, although foraminifera at site GD14 could be identified to genus or family level. Biostratigraphy data from site GD19 is compiled from Pease and Hoover (1957) and is omitted from Appendix A because all pertinent information provided by Pease and Hoover is reproduced here. The radiocarbon date (^{14}C) is given as a calibrated 2σ range (calendar years) to facilitate equivalence to luminescence data and age statements reported elsewhere; luminescence ages (OSL, optically stimulated luminescence; IRSL, infrared-stimulated luminescence) are shown with 1σ uncertainty, and argon ($^{40}Ar/^{39}Ar$) and uranium-lead (U-Pb) ages with 2σ. LA-ICP-MS, laser ablation-inductively coupled plasma-mass spectrometry.

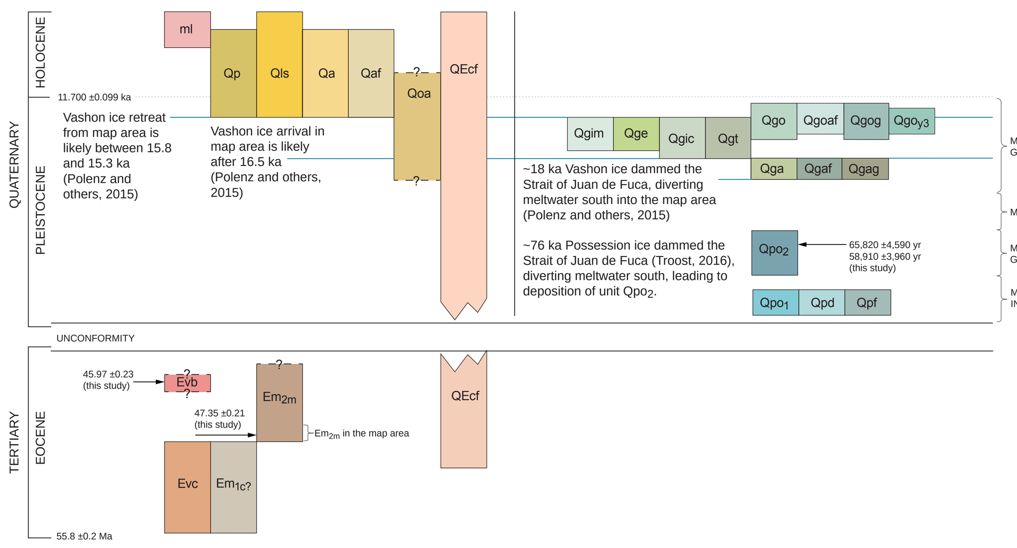
Age site	Unit symbol	Location	Method	Result
Age control data samples				
GD1	Qoa	sec. 29, T17N R3W	^{14}C	17.075–16.850 ka
GD2	Qpo	sec. 34, T17N R3W	OSL IRSL	58.910 ±3.960 ka 65.820 ±4.590 ka
GD3	Evb	sec. 36, T17N R3W	$^{40}Ar/^{39}Ar$ age plateau on plagioclase	45.97 ±0.23 Ma
GD4	Em_{2m}	sec. 8, T16N R3W	U-Pb by LA-ICP-MS on zircon	47.35 ±0.21 Ma[1]
Biostratigraphy samples				
GD5	Em_{1c}?	sec. 33, T17N R3W	Fossil content analysis indicates Eocene age.	
GD6	Em_{1c}?	sec. 33, T17N R3W	Fossil content analysis indicates Eocene age.	
GD7	Em_{2m}	sec. 8, T16N R3W	Fossil content analysis yielded no biostratigraphic constraint.	
GD8	Ev_c	sec. 33, T17N R3W	Fossil content analysis yielded no biostratigraphic constraint.	
GD9	Ev_c	sec. 32, T17N R3W	Fossil content analysis yielded no biostratigraphic constraint.	
GD10	Em_{2m}	sec. 8, T16N R3W	Fossil content analysis yielded no biostratigraphic constraint.	
GD11	Em_{2m}	sec. 8, T16N R3W	Fossil content analysis yielded no biostratigraphic constraint.	
Biostratigraphy samples from sedimentary rocks outside the Littlerock quadrangle				
GD12	Em_{2m}	sec. 14, T16N R1W (Bucoda quadrangle)	Fossil content analysis yielded no biostratigraphic constraint.	
GD13	Em_{2m}	sec. 23, T16N R1W (Bucoda quadrangle)	Fossil content analysis yielded no biostratigraphic constraint.	
GD14	Em_{2m}	sec. 23, T16N R1W (Bucoda quadrangle)	Fossil content analysis yielded no biostratigraphic constraint.	
GD15	Lincoln Creek Formation	sec. 34, T15N R3W (Adna quadrangle)	Fossil content analysis yielded no biostratigraphic constraint.	
GD16	Lincoln Creek Formation	sec. 34, T15N R3W (Adna quadrangle)	Fossil content analysis yielded no biostratigraphic constraint.	
GD17	Skookumchuck Formation	sec. 18, T14N R3W (Adna quadrangle)	Fossil content analysis yielded no biostratigraphic constraint.	
GD18	Skookumchuck Formation	sec. 24, T14N R4W (Adna quadrangle)	Fossil content analysis yielded no biostratigraphic constraint.	
Biostratigraphy samples from sedimentary rocks outside the Littlerock quadrangle, compiled from prior studies				
GD19	Ev_c	sec. 27, T16N R4W (Oakville quadrangle)	Middle Eocene. Compiled from Pease and Hoover (1957): "Two foraminiferal assemblages collected from [sed. rock] strata interbedded with [basalt] flows ... are thought to be middle Eocene in age." Location approximate: sec. 27, T16N R4W; location plotted on Fig. M1 to coincide with more precise location description for same? record no. 119 of Rau (2004), who described his sample as "sandstone" from "lower McIntosh Formation, now considered Crescent Formation".	
GD20	Ev_c	NW cor. sec. 31, T18N R3W (Summit Lake quadrangle)	Middle Eocene Ulatisian Stage. Lithology "limey". Compiled from Rau (2004) record no. 3327, file no. 8743. Location approximate: "NW cor. sec. 31, T18N R3W". Collector: Valintine. Analysis by Weldon Rau (WA Dept. of Nat. Res., 2004). Water depth 50 m or less. Water temperature 25–30° C.	

[1] Lab notes that due to the large number of analyses, the intercept age error is unrealistically low for this technique, and a more realistic estimate of the total uncertainty for the intercept age is ~2% (1 Ma), thus yielding an age range of ~48.4 to 46.4 Ma.



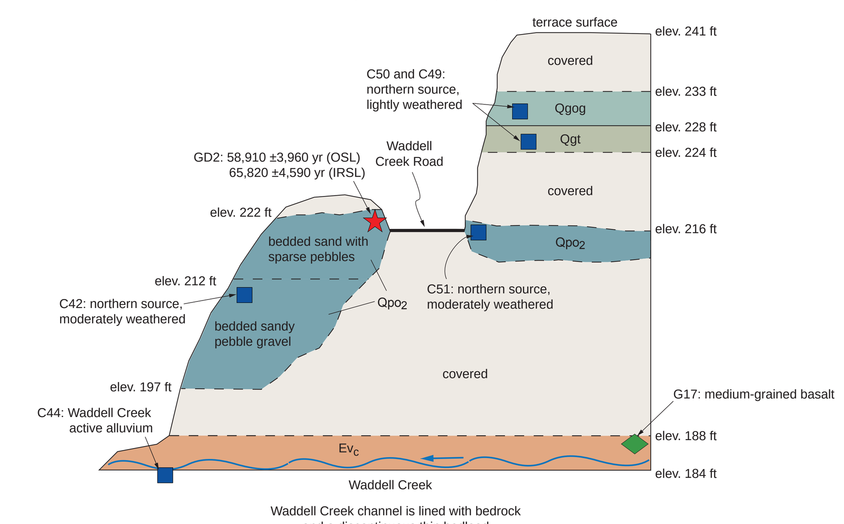
CORRELATION OF MAP UNITS

PERIODS AND EPOCHS BASED ON USGS FACT SHEET 2010-3059



SCHEMATIC DIAGRAM 1

Waddell Creek Road Bridge
(sec. 34, T17N R3W)



Waddell Creek channel is lined with bedrock and a discontinuous thin bedload