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## Abstract—No. 387-2 (297674):

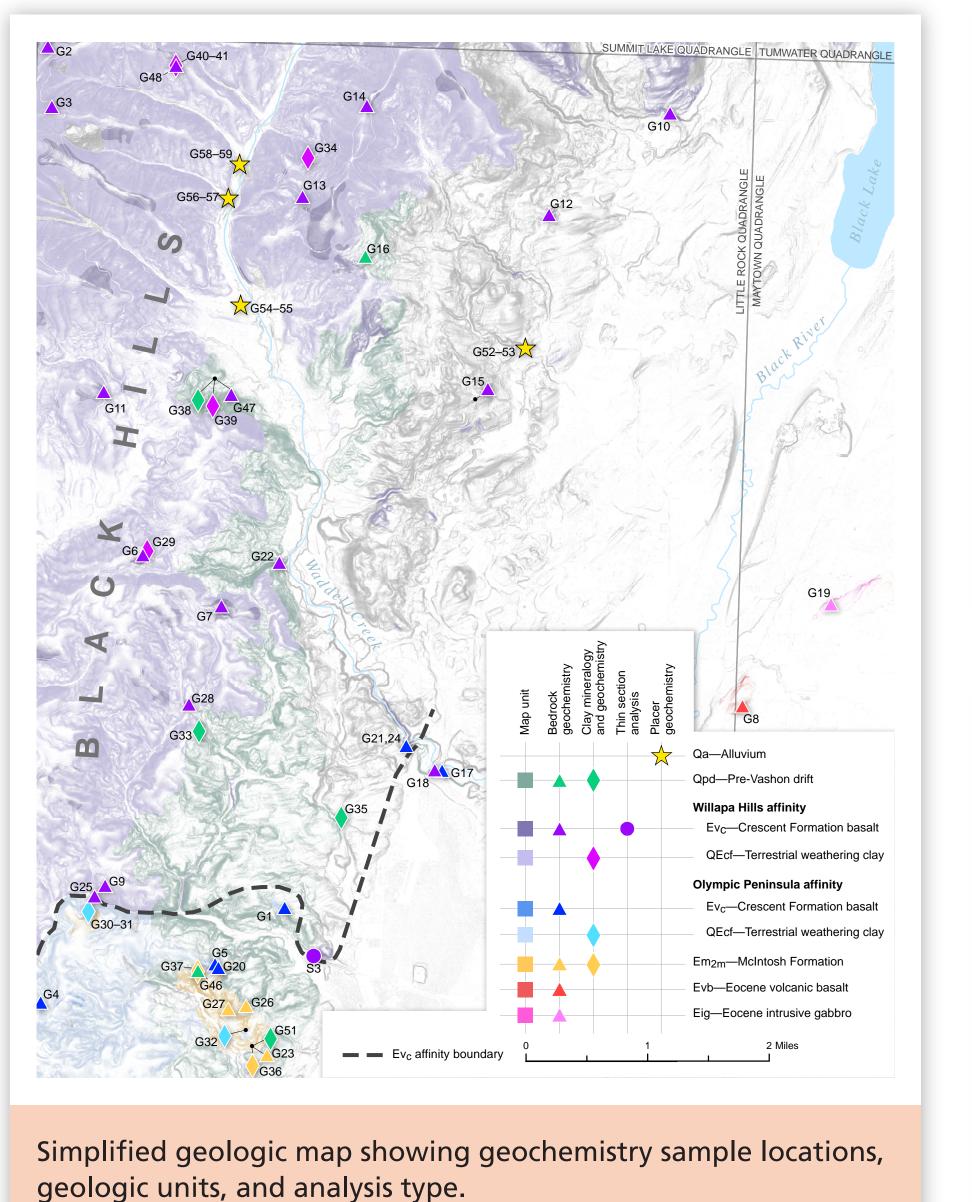
We present a new 1:24,000 scale geologic map of the Littlerock 7.5-minute quadrangle, which straddles the eastern Black Hills and southern Puget Lowland southwest of Olympia and was previously mapped at smaller scales. More detailed geologic mapping is needed for informed land management; forestry, agriculture, recreation, ecologically sensitive areas, and development increasingly compete for natural resources. We support the new map with field work, lidar, subsurface exploration data, aeromagnetic data, geophysical explorations, geochemistry, and new 40Ar/39Ar, detrital zircon U/Pb, luminescence and radiocarbon dates.

New bedrock geochemistry confirms that the Black Hills are cored by Crescent Formation basalt. North of Mima Creek the geochemical signature is similar to Willapa Hills Crescent Fm. South of the creek it is more similar to Olympic Mtns. Crescent Fm. Geochemistry and a new 46.0 Ma 40Ar/39Ar date suggest that basalt east of the Black River is chemically distinct and younger than Crescent Formation but older than nearby intrusive rocks, though all are likely from the same mantle source.

A new 47.4 Ma U/Pb zircon date from tuff in McIntosh Fm. marine sedimentary rocks that overlie Crescent Fm. basalt in the southern Black Hills constrains the transition from Siletzia volcanism and accretion to marine sedimentation.

We mapped glacial deposits from the Vashon stade and at least one prior glaciation that was slightly more extensive; these glaciations created ice dammed lakes in the Waddell Creek valley. New OSL and IRSL dates on fluvial sediments suggest that Possession (MIS4) meltwater drained south via the Black River Valley, although Possession ice never came close to the map area.

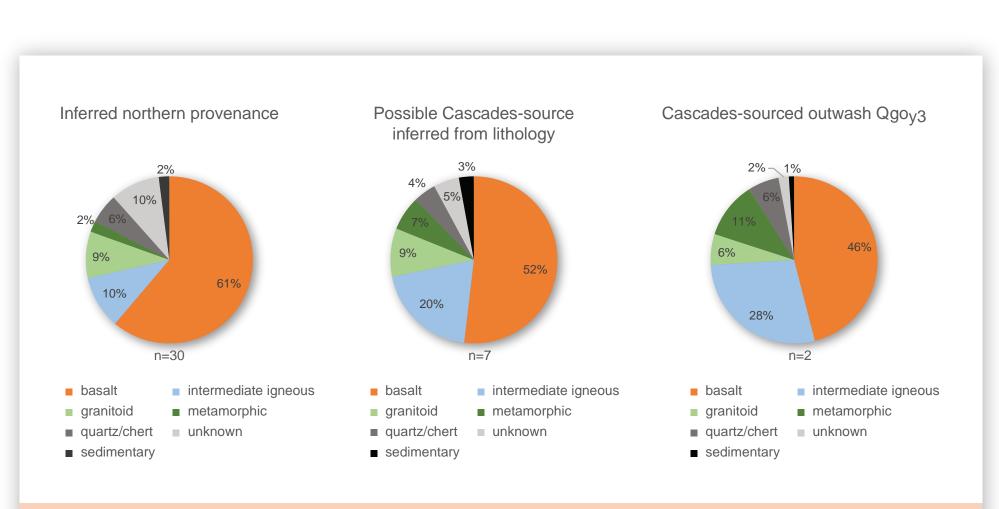
Geochemistry and clay mineral identification by XRD of thick, deeply weathered, clay-rich soils in the Black Hills suggest that most of the Black Hills are unglaciated and have been subaerially weathered since before the Quaternary. Onlapping of Eocene to Miocene marine sediments indicates that the hills have been a topographic high since the Eocene and may never have been buried. Isolated shear exposures and geophysical data suggest a northwest striking, southwest down fault beneath Mima Prairie. This fault may extend structures previously mapped farther southeast, but it has not offset the Vashon outwash terraces.

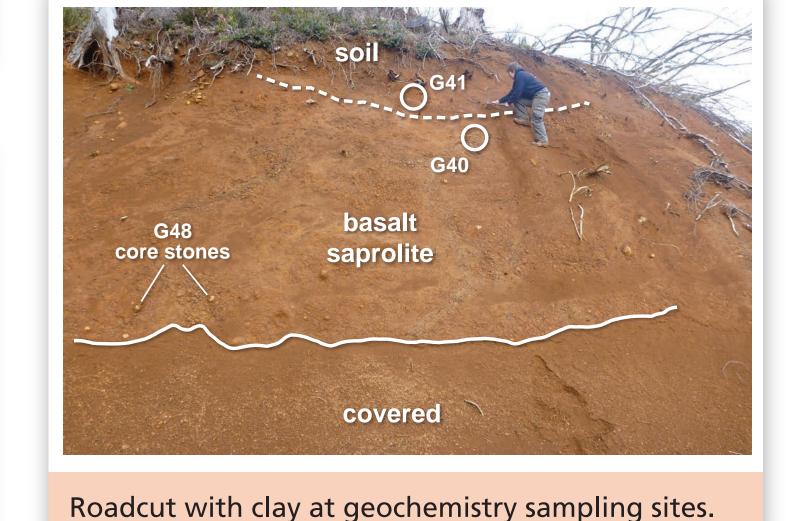


Cross-sectional view of a Mima mound (clast count sites C2 and C3).

Major and trace element geochemistry results

for Littlerock samples.





Lambert conformal conic projection

http://lidarportal.dnr.wa.gov/)

Digital cartography by Daniel E. Coe

North American Datum of 1927; to place on North American Datum of

Shaded relief generated from a lidar bare-earth digital elevation mode

Editing and production by Jessica L. Czajkowski, Jaretta M. Roloff, and

CROSS SECTION EXPLANATION

as polygons at the scale of the

Water well or boring

cross section; tics mark separate

95 meters east as shown by crosshair corner tics

Littlerock 7.5-minute quadrangle, 1986

GIS by Michael Polenz and Jessica L. Vermeer

Base map from scanned and rectified U.S. Geological Survey

(available from the Washington Geological Survey,

1983, move the projection lines approximately 23 meters north and

1000 0 1000 2000 3000 4000 5000 6000

contour interval 40 feet

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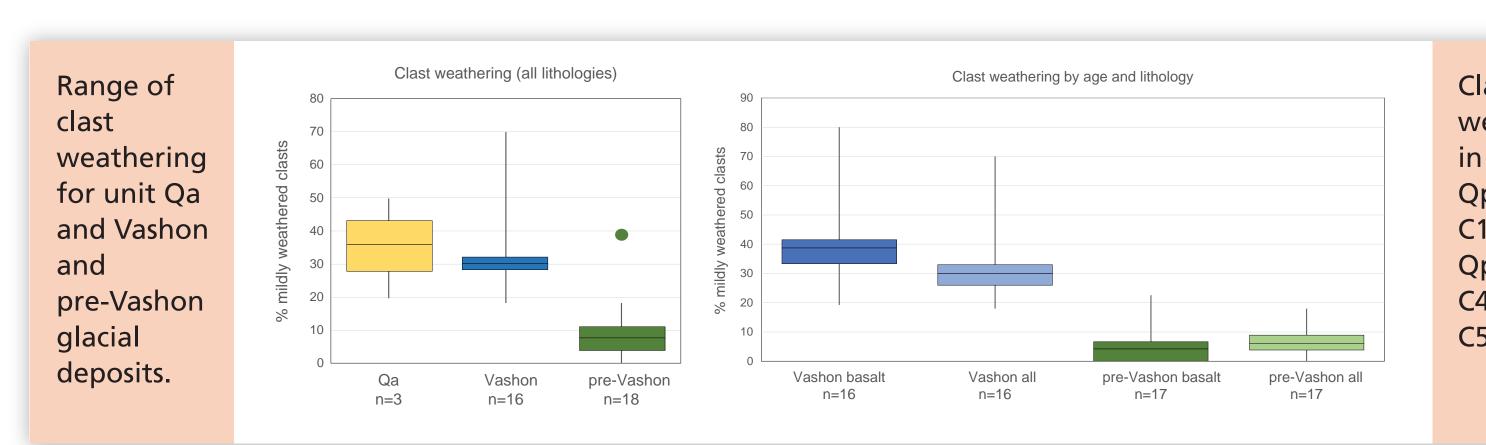
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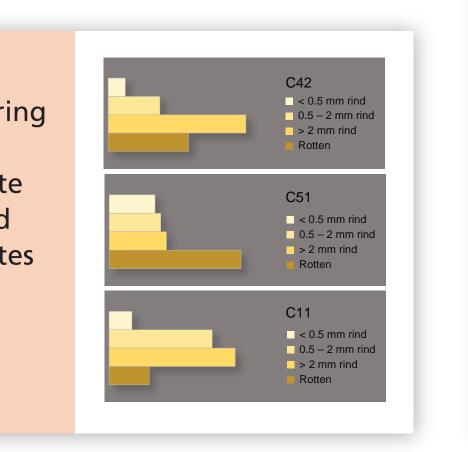
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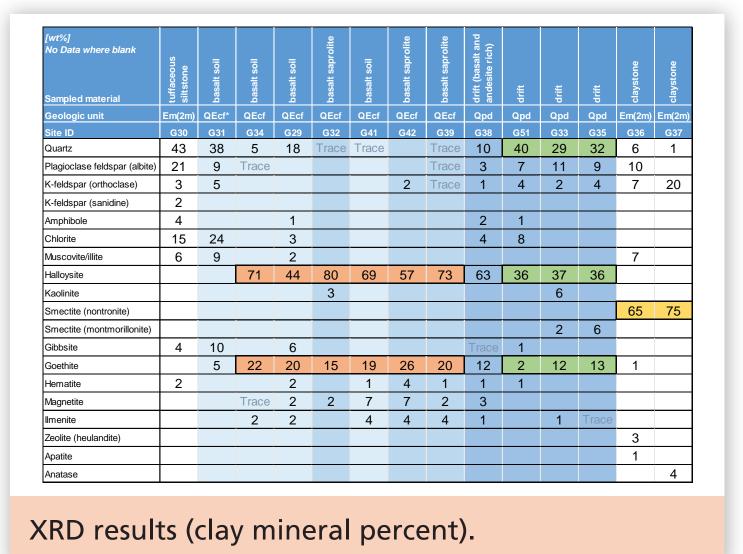
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U.S. Geological Survey National Cooperative Geologic Mapping Program

Pie charts showing clast lithologies from unlithified deposits.







# Geologic Map of the Littlerock 7.5-minute Quadrangle,

## Thurston County, Washington

Michael Polenz, Jessica L. Vermeer, Gabriel Legorreta Paulín, Jeffrey H. Tepper, Shannon A. Mahan, and Recep Cakir

 A new ~47.4 Ma laser-ablation U-Pb date on zircon from a slightly reworked airfall tuff provides a close maximum • A new 46 Ma 40Ar/39Ar 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

rom Willapa Hills–style basalt farther north, likely due to separate eruptive centers. Field relations suggest that the

leposits imply that Possession meltwater, like Vashon meltwater, drained through the Black River valley, uggesting that the pre-Vashon landscape was similar to the modern southern Puget Lowland.

### **DESCRIPTION OF MAP UNITS** see pamphlet for detailed map unit description

### **Quaternary Unconsolidated Deposits** POSTGLACIAL DEPOSITS

**Holocene Nonglacial Deposits** 

- Modified land—Boulders, cobbles, pebbles, sand, silt and clay in varied amounts; locally derived, b Peat—Organic and organic-rich sediment; includes peat, gyttja, muck, silt, and clay; typically in close
- 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
- Alluvial fan deposits—Pebbles, sand, silt, cobbles, and boulders in varied amounts; gray to brown; loose;

### PLEISTOCENE GLACIAL DEPOSITS **Vashon Drift of the Fraser Glaciation**

(All Vashon units are northern-sourced.) Recessional Vashon outwash, undivided—Pebbles, cobbles, sand, and silt in varied amounts; light gr weathers to pale brown or tan, light orange where iron stained; loose; well sorted; clasts well rounded;

- 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 unded; moderately to poorly sorted; stratified to poorly stratified; forms concentric lobes.
- gray, weathering to tan, red-orange where iron stained; lightly weathered; may be lightly emented; loose; clasts subrounded to well rounded; well sorted; massive to bedded. 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

- 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 nostly well rounded, sand and fines angular to well rounded; poorly sorted to well sorted; massive to
- 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. Vashon esker—Pebbles and sand; medium gray; lightly to moderately weathered; loose; clasts
- well rounded; well sorted; bedded; forms distinctive long, sinuous hills. 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.
- 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: Vashon(?) advance outwash lake deposits—Clay with sparsely scattered pebbles; blue-gray brown; clast weathering moderate to heavy; compact; massive.
- 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.
- **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. **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

- 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. 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;

### **Eocene to Quaternary Continental Deposit**

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 **Tertiary Volcanic and Sedimentary Bedrock** 

foraminifera and a few silt-size lithic fragments; blue-gray to olive brown; moderately to well lithified;

**Terrestrial weathering clay (Eocene to Quaternary)**—Clay soil and saprolite (halloysite and goethite)

- 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
- Basalt (early middle Eocene)—Aphanitic basalt; dark gray, weathers to medium gray; mildly weathered; moderately dense; not vesicular; fine grained, porphyritic, trachytic. Crescent Formation marine sedimentary rocks (early to middle Eocene)—Claystone; contains
- 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

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 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

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

Geologic unit too thin to show as a polygon—solid where location accurate;

ong-dashed where approximate; short-dashed where inferred; queried where identity

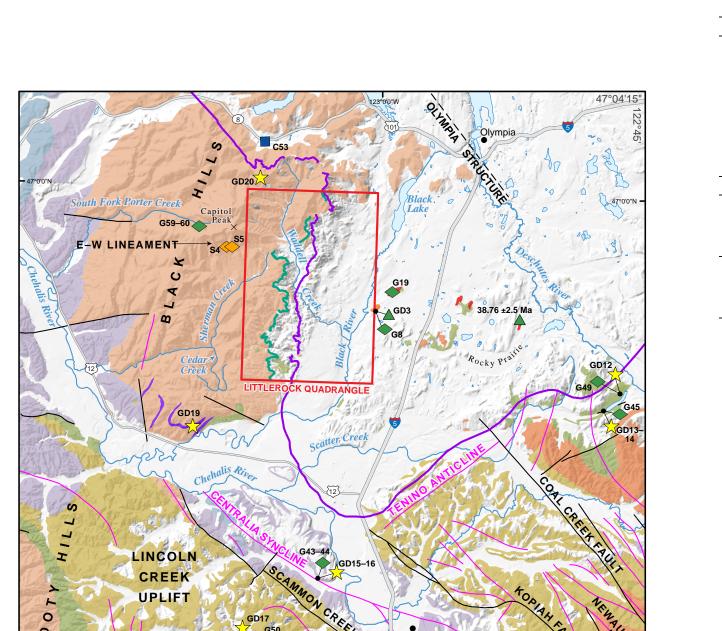
oncealed; relative motion shown by U and D

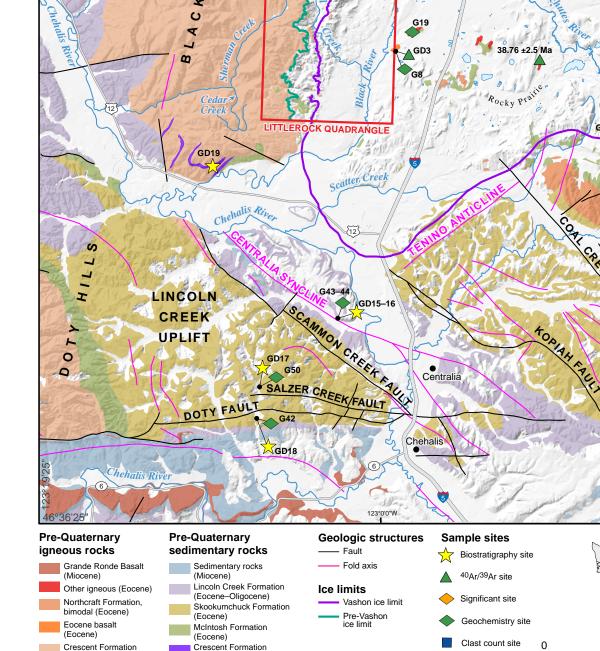
where approximate; short-dashed where inferred; dotted where concealed; queried where identity or existence questionable

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

identity or existence questionable; hachures point down slope

- \_\_\_\_\_?\_\_\_\_ 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
- 5 Inclined flow bands, lamination, layering, or foliation in igneous rock—showing strike and dip
- GD4 Age site, U-Pb, uranium-lead GD1 Age site, <sup>14</sup>C, carbon-14
- GD2 ★ Age site, luminescence (OSL and (or) IRSL)
- <sup>W20</sup>○ Water well
- Geologic unit too small to show as a polygon at map scale
- Geophysical data collection location





e from this study. Geologic units, faults, and folds outside the mapping area are adapted from published 1:24,000- and 100,000-scale geologic maps. The ice limit outside the Littlerock quadrangle is approximate and modified from Logan and Walsl

38.76 Ma <sup>40</sup>Ar/<sup>39</sup>Ar date from Walsh and Logan (2005).

2004), Logan and others (2009), and Thorson (1980). Samples shown outside the Littlerock quadrangle provide new reference data

ee pamphlet). All samples are from this study, except for site GD19 (Pease and Hoover, 1957; Rau, 2004), GD20 (Rau, 2004), and a

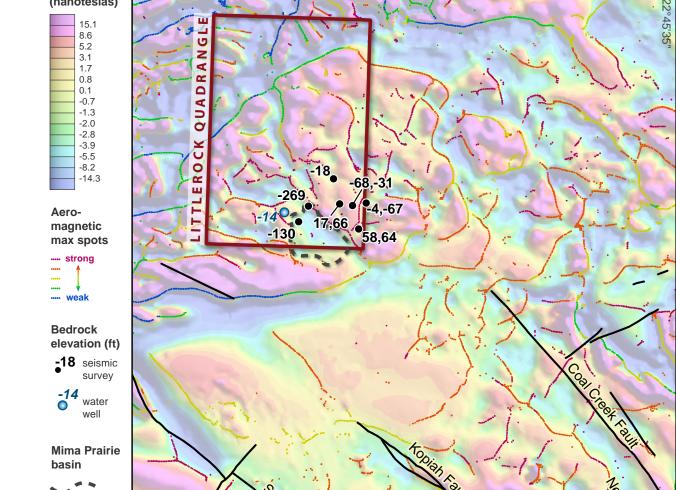


Figure M2. Aeromagnetic image of the Littlerock quadrangle and vicinity. Faults are from Walsh and others (1987). Max spots mark Prairie basin (informally named here) is delineated based on an aeromagnetic trough. No measurements were made where the nagnetic trough is strongest, and basin depth likely exceeds the lowest estimated levels from our seismic depth stations (82 m [270] elow sea level). The northwest-trending magnetic anomaly that bounds the northeast side of the basin is aligned with several mapped aults 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

GD1	Qoa	sec. 29, T17N R3W	<sup>14</sup> C	17.075–16.850 ka
		sec. 34,	OSL	58.910 ±3.960 ka
GD2	Qpo	T17N R3W	IRSL	$65.820 \pm 4.590 \text{ ka}$
GD3	Evb	sec. 36, T17N R3W	<sup>40</sup> Ar/ <sup>39</sup> Ar age plateau on plagioclase	45.97 ±0.23 Ma
GD4	Em <sub>2m</sub>	sec. 8, T16N R3W	U-Pb by LA-ICP-MS on zircon	47.35 ±0.21 Ma <sup>1</sup>
		Biostratigraphy	samples	
GD5	Em <sub>1c</sub> ?	sec. 33, T17N R3W	Fossil content analysis indicates Eocene age.	
GD6	Em <sub>1c</sub> ?	sec. 33, T17N R3W	Fossil content analysis indicates Eocene age.	
GD7	Em <sub>2m</sub>	sec. 8, T16N R3W	Fossil content analysis yielded no biostratigraphic constraint.	
GD8	Ev <sub>c</sub>	sec. 33, T17N R3W	Fossil content analysis yielded no biostratigraphic constraint.	
GD9	Ev <sub>c</sub>	sec. 32, T17N R3W	Fossil content analysis yielded no biostratigraphic constraint.	
GD10	Em <sub>2m</sub>	sec. 8, T16N R3W	Fossil content analysis yielded no biostratigraphic constraint.	
GD11	Em <sub>2m</sub>	sec. 8, T16N R3W	Fossil content analysis yielded no biostratigraphic constraint.	
	Biostratigra	aphy samples from sedimentary ro	ocks outside the Littlerock quadrangle	
		sec. 14,	,	
GD12	Em <sub>2m</sub>	T16N R1W (Bucoda quadrangle)	Fossil content analysis yielded no biostratigraphic constraint.	
GD13	Em <sub>2m</sub>	sec. 23, T16N R1W (Bucoda quadrangle)	Fossil content analysis yielded no biostratigraphic constraint.	
GD14	Em <sub>2m</sub>	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 f	rom sedimentary rocks outside the	e Littlerock quadrangle, compiled from pr	ior studies
GD19	Ev <sub>c</sub>	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 Eocen 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 describe his sample as "sandstone" from "lower McIntosh Formation, now considered Crescent Formation".	

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.

Rau (2004) record no. 3327, file no. 8743. Location approximate:

less. Water temperature 25–30° C.

(Summit Lake quadrangle) Weldon Rau (WA Dept. of Nat. Res., 2004). Water depth 50 m or

IW cor. sec. 31, T18N R3W". Collector: Valintine. Analysis by



