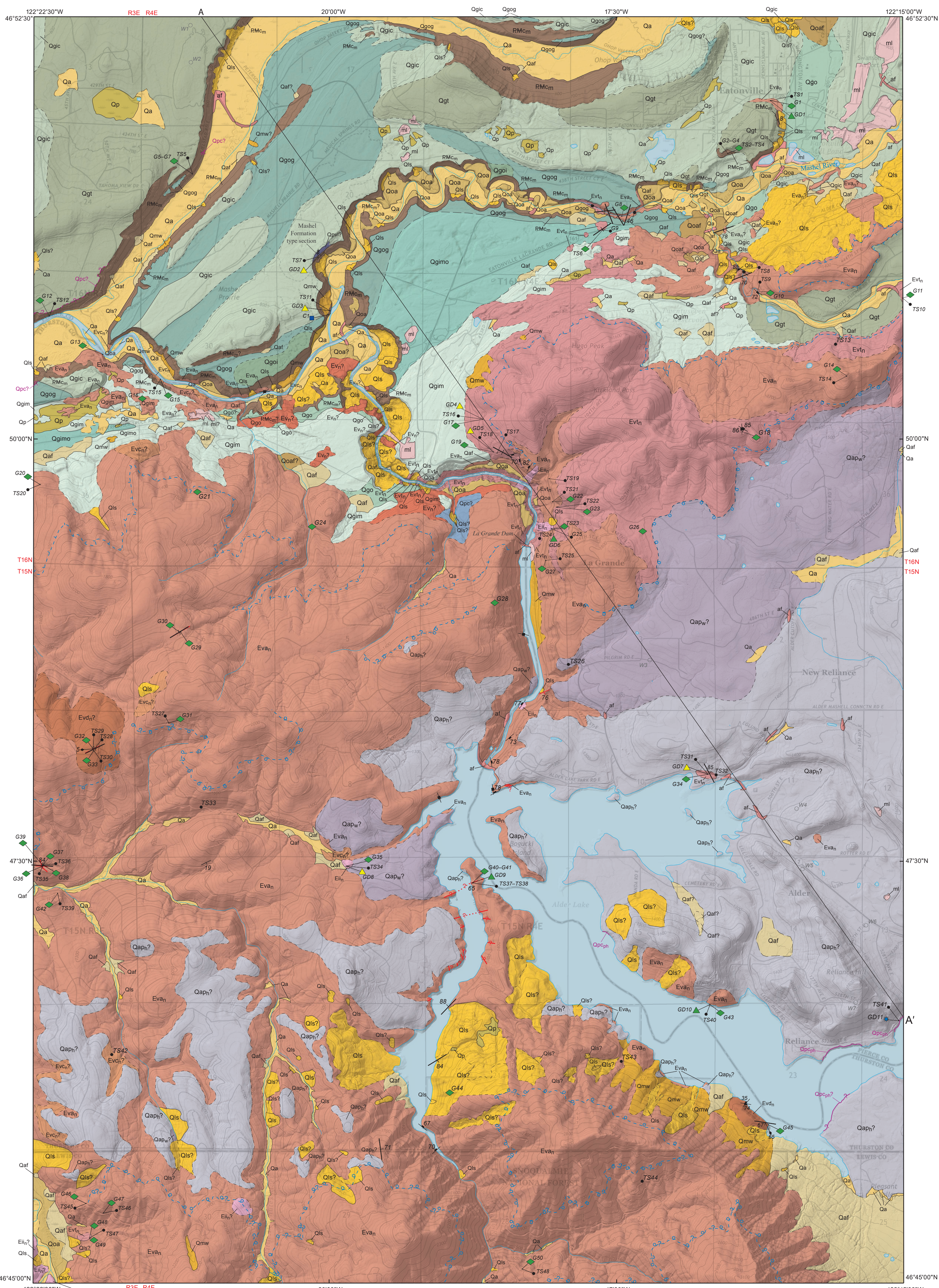


Geologic Map of the Eatonville 7.5-minute Quadrangle, Pierce, Thurston, and Lewis Counties, Washington

Michael Polenz, Crystal A. Lambert, Anita L. Bauer, Jeffrey H. Tepper, Elizabeth A. Nesbitt, Gabriel Legorreta Paulín

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ABSTRACT

We present a geologic map of the Eatonville quadrangle along the Nisqually River in Washington's southeastern Puget Lowland. The map documents ages, stratigraphy, and distribution of glacial, fluvial, and volcanic deposits. We use geochemistry and geochronology to characterize the Eocene Northcraft Formation, which includes volcanic, volcanoclastic, and intermediate intrusive rocks that represent early Eocene volcanism. Analyses of 43 intrusive and extrusive Northcraft samples range from basalt to rhyolite, but andesite is predominant and ~70 percent of samples have adakite traits that point to derivation from an eclogite source within the subducting slab or deep crust. Eight new ages range from ~38–34.5 Ma and confirm that the Northcraft Formation younged, beginning at ~46 Ma in quadrangles to the west and continuing that trend across this map area.

We found no evidence that deformation at the southern margin of the Tacoma basin occurred post-Eocene in this map area. The Tacoma basin's southwest margin is characterized by gradual growth, and aeromagnetic gradients, in contrast to sharper and higher-amplitude gradients across the southern margin of the Tacoma basin. Analysis of existing aeromagnetic and new gravity data suggests that most aeromagnetic highs in the area are from volcanic rocks and intrusive bodies, which are Eocene where exposed and likely of similar age in the basin.

We revise the age of the Mashel Formation to Pliocene to late Miocene. New detrital zircon ages suggest that sediment near the base and near the top of the Mashel Formation type section in the Eatonville quadrangle is late Miocene, at most ~6 Ma. Outside the type section, the formation yielded a ~4.1 Ma age west of the Eatonville quadrangle.

Our mapping locally refines the maximum extents of the Hayden Creek and Wingate Hill Alpine glaciations and the Vashon continental glaciation. Vashon Drift includes deposits and landforms from the Tanwax flood, and probably from other outburst floods. A late luminiscence age constrains the age of the Hayden Creek ice advance to ~135–124 ka.

LIST OF MAP UNITS

Holocene to Pleistocene Nonglacial Deposits

- Artificial fill (Holocene)**—Mixed earth materials of varied grain size and sorting placed to raise land.
- Modified land (Holocene)**—Mixed earth materials of varied grain size; includes excavations that may expose underlying geologic deposits.
- Peat (Holocene to late Pleistocene)**—Organic and organic-matter-rich sediment (peat, gyttja, muck, silt, clay, and sand) in depressions; mapped where lidar reveals filled depressions and aerial photos suggest hydrophilic vegetation.
- Alluvium (Holocene to late Pleistocene)**—Fluvial and channel sediment of mostly andesitic clasts (pebbles, cobbles, and boulders), as well as sand, silt, clay, and peat, all in varied amounts; mostly well rounded and moderately to well sorted. Unit Qa is mapped where there is evidence for geologically recent alluvial transport. Unit Qob is mapped where similar deposits lack evidence for alluvial deposition in the modern environment.
- Alluvial fan (Holocene to late Pleistocene)**—Pebble to boulder gravel and sand in varied abundances; moderately to poorly sorted; mostly deposited by debris flows and floods. Unit Qaf is mapped where there is evidence for recent deposition, while Qof is mapped where deposition appears older. Units Qaf and Qof are distinguished from other alluvium based primarily on the presence of fan-shaped landforms.
- Colluvium (Holocene to Pleistocene)**—Mixed earth materials of varied grain sizes and sorting, deposited by mass wasting—usually shallow rill and soil creep. Unit Qmw is mapped from landforms that suggest 1.5–8 m-thick colluvium conceals underlying geology. Fan-shaped deposits in unit Qmw are typically steeper than those in unit Qaf, and upslope areas tend to have less defined feeder channels.
- Landslide deposits (Holocene to Pleistocene)**—Mixed earth materials of varied grain sizes and sorting, variably weathered; particles angular to rounded; mostly loose, unsorted, and jumbled, but some exposures include stratified patches, mapped where lidar reveals hummocky slopes, drained and dewatered, tilted benches in hillsides, mid-slope scarps or otherwise disrupted or irregular slopes, concave upper and convex lower slopes. Mapping adopted from Mickelson and others (2017) with minor modifications.

Pleistocene Glacial and Nonglacial Sediment

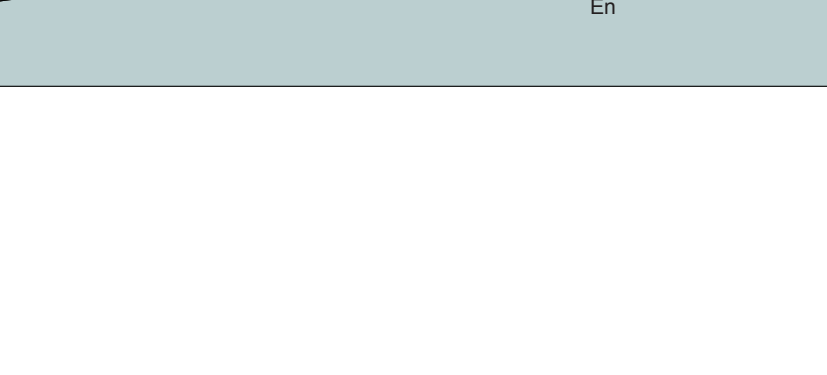
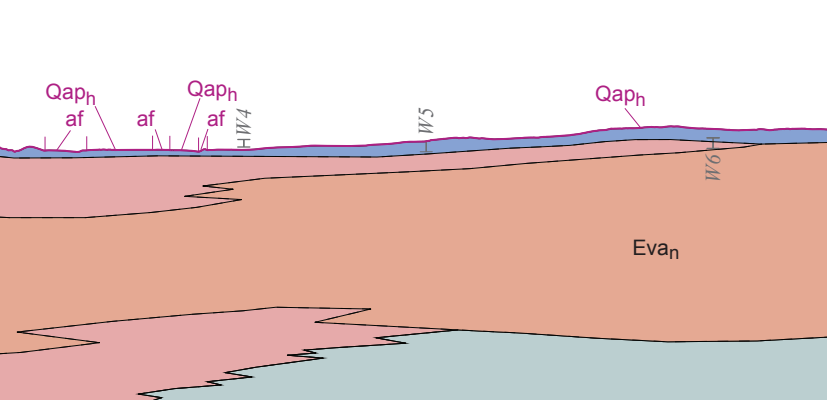
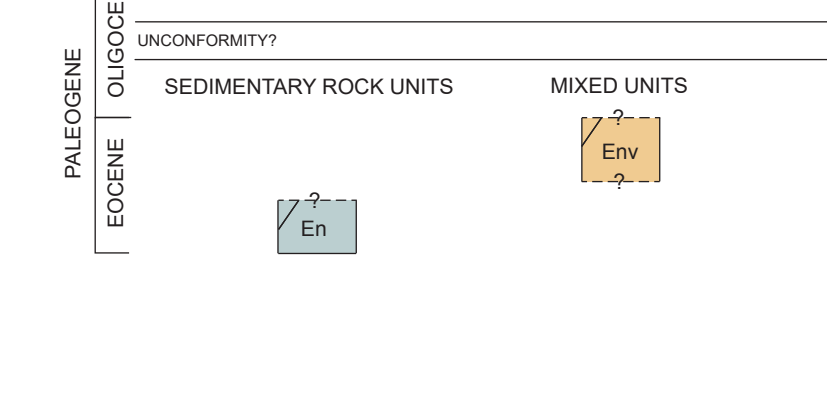
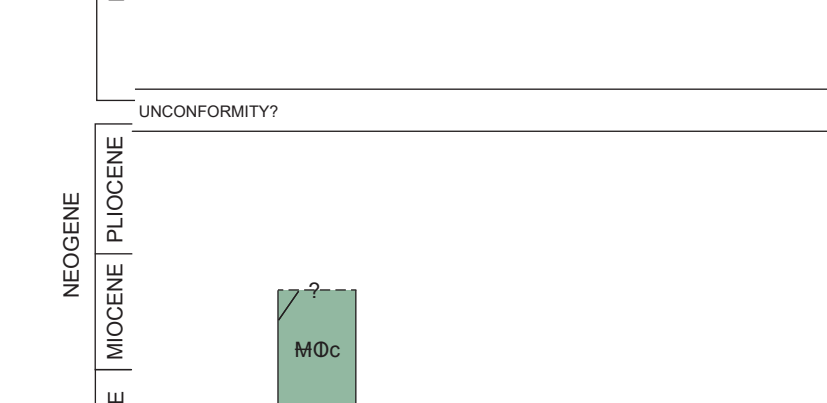
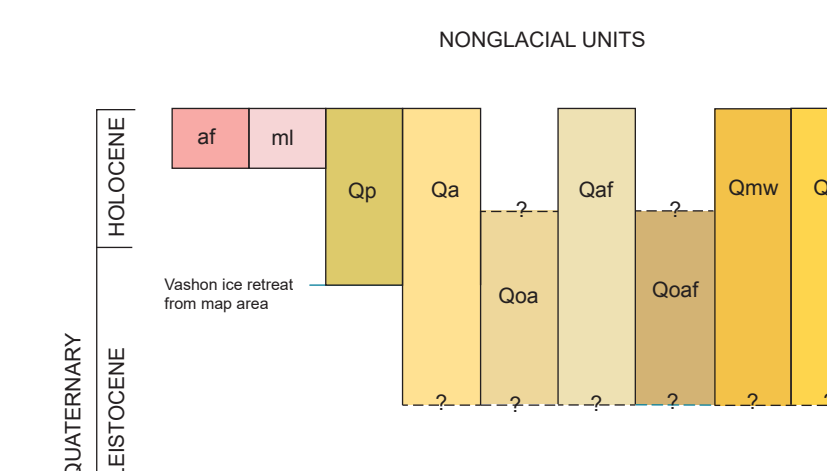
We map as Vashon Drift all sediment deposited by the Puget lobe of the Cordilleran ice sheet and associated processes. Vashon Drift is distinguished from Cascade Range-sourced alpine drift by the presence of 'northern-sourced' rock types, including pink garnets, epidote, schist, gneiss, granite, polycrystalline quartz, mafic igneous rocks, sedimentary rocks, and granulites. In contrast, purely Cascade Range-sourced sediment contains >60 percent intermediate to felsic volcanic rocks—mostly porphyritic andesite, with minor diacite, rhyolite, and basalt.

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- Age site, U-Pb
- Age site, luminiscence
- Age site, ⁴⁰Ar/³⁹Ar
- Geochemistry sample location
- Water well
- Claut count location
- Thin section location

CORRELATION OF MAP UNITS

PERIODS AND EPOCHS BASED ON USGS FACT SHEET 2015-204



PRE-VASHON SEDIMENT

Pre-Vashon Alpine Drift

Hayden Creek Drift, undivided (late Pleistocene)—Diamictic, pebble gravel, and sand; diamictic mostly clast-rich but matrix-supported, with clay-rich sandy matrix; locally includes small black plant fragments; pale gray where dry, dark olive where moist; weathers mostly tan; commonly forms a 1–3-m-thick, clayey soil; clast weathering rinds in diamictic typically 1–3 mm with common to pervasive interior weathered faces; loose to compact; clast lithologies Cascade Range-sourced (Table 2); includes till and lobar deposits; plant fragments common in lobar deposits but rare in till; clasts tend to be well rounded to subangular in lobar deposits but mostly well rounded in till. The age of Hayden Creek Drift appears to be between ~85 and ~105 ka (Sisson and others, 2019; Age site GD1).

Wingate Hill Drift, undivided (late Pleistocene)—Diamictic, pebble gravel, and sand; diamictic mostly clast-rich but matrix-supported, with clay-rich sandy matrix; mostly pale gray to pale yellow; matrix in upper 3–4 m weathered to mostly clay, with mud cracking common in dry exposures; clast and soil weathering more developed than in Qapb (Crandell and Miller, 1974, p. 18–19); clasts mostly well rounded; loose to compact; clast lithologies Cascade Range-sourced; likely includes till and lobar deposits though we were unable to distinguish them due to weathering and poor exposure; may include alluvium based on boulders and gravel only at one site—where the sand and gravel is below till and could predate the unit.

Crandell and Miller (1974) suggested correlating Wingate Hill Drift to MIS 6 (~130–200 ka)—Lisieski and Raymo, 2003). Dettlin and Bethel (1981) speculated about on weathering that Wingate Hill deposits may be several hundred thousand years old in the Cowlitz River valley (south of the map area).

Undivided pre-Vashon sediment

Pre-Vashon lobar(?) deposits (late?) Pleistocene—Clast-supported diamictic of pebbles, cobbles, boulders, and matrix of silt, sand, and clay; near base contains rounded rip-up clasts (some ~1 m in size) of mostly fine-grained deposits that we interpret as Mashel Formation; moderately weathered. We observed unit Qp only in a single, mostly inaccessible exposure above age site GD2, resting unconformably on the Mashel Formation type section. We tentatively mapped the diamictic as lobar because we interpreted it as a debris flow deposit and observed only clasts consistent with a volcanic Cascade Range provenance. The age of Qp is late(?) Pleistocene based on its stratigraphic position between Mashel Formation and Vashon Drift and because moderate weathering suggests an age comparable to similar-looking debris flow deposits mapped by Polenz and others (2022, 2023) in a stratigraphically similar position west of the Eatonville quadrangle.

Pre-Vashon, Cascade Range-sourced sediment, undivided (late Pleistocene)—Pebbles, cobbles, bouldery gravel, diamictic, sand, silt, clay, and peat, all in varied amounts; mostly olive gray to pale gray, pale yellowish gray, and pale brown; distinctly more weathered than Vashon Drift—sand mildly to moderately weathered; clast weathering mostly moderate to mild but ranges to rotten; compact; poorly sorted; bedding typically gently rough cross-bedded to planar, and locally absent; Cascade Range-sourced; sand rich in plagioclase and tends to include andesitic, commonly glassy, volcanic lithic fragments, smaller amounts of quartz (or) K-feldspar, and less abundant opaque minerals, pyroxene, biotite, and other minerals; locally subdivided into:

Pre-Hayden Creek, Cascade Range-sourced sediment, undivided (late Pleistocene) (line unit and cross section only)—Both gravel and diamictic contain pebbles, cobbles, boulders, sand, silt, and clay, all in varied amounts; matrix gray to pale brown, orange, and yellow; mildly to strongly weathered, with a probably representative exposure ~1.5 km southwest of age site GD1 revealing a 1–3-m-thick, mostly buff-colored, clayey soil with few clasts; well rounded to angular; well sorted to poorly sorted; cross to planar-bedded, locally ranging to unstratified; Cascade Range-sourced. Unit Qpob underlies Qapb and includes glacial and nonglacial, mostly undated deposits that may range from Hayden Creek advance outwash to sediment older than Wingate Hill Drift. Sand within unit Qpob at age site GD11 (105–124 ka) may be either Hayden Creek advance outwash or older sediment.

PILOCENE TO EOCENE SEDIMENT, SEDIMENTARY ROCK, AND VOLCANICLASTIC ROCK

PILOCENE TO MIOCENE SEDIMENT OF THE MASHEL FORMATION

Continental sediments (Pliocene to late Miocene)—Volcanic-lithic sand and silt with clayey matrix; pumice clasts in some exposures; sections, lenses, and interbeds of pebble gravel with dense, clay-rich matrix; interbeds and lenses of tephra, clay, muck, and peat; plant fragments and imprints, all in varied amounts; compact and stiff but unindurated. Unit PmEn includes an upper part of mostly clay and sand and a lower part of mostly gravel.

Sand and finer sediment are mostly pale yellow, pale gray, and white, moderately to strongly weathered, sand mostly medium to coarse-grained, angular to subrounded, mostly poorly sorted, and distinctly rough cross-bedded or planar-bedded.

Mashel Formation gravel mostly consists of medium to very coarse andesite pebbles, with abundant matrix of clay to cherty sand. The gravel is mostly pale brown to reddish brown. A clast count site C1 just beneath the type section, most clasts had weathering rinds >2 mm thick or were cotton (see Data Supplement for clast counts). Clasts are well-rounded and moderately oblate to spheroidal, moderately sorted, poorly to moderately sorted, and commonly imbricated. Imbrications mostly suggest approximately west to northwest-flowing palaeocurrents.

Most exposures reveal gently west-dip apparent dips that are post-depositional because they tilt peat, lacustrine, and planar floodplain beds.

Mashel Formation is more compact than unit Qp; tends to be more weathered, and more commonly contains pumice, scoria, and volcanic glass, tephra, muck, gyttja(?), and plant macrofossils. We observed pumice clasts and scoria mainly in lobar deposits. Sandy and finer-grained sections of Mashel Formation tend to be pale yellow, pale gray, and white—whereas unit Qp tends to be more yellow to reddish brown and orange.

MIOCENE TO OLILOCENE SEDIMENTARY ROCKS

Sedimentary rocks (Miocene to Oligocene) (cross section only)—Sediment and sedimentary rocks, likely mostly fine-grained and volcanoclastic; inferred between units PmEn and Enw in the northern third of Cross Section A-A' based mainly on observations of fine-grained sediment at 519–1037 ft depth in the Willhoite well 7.6 km northwest of the Eatonville quadrangle (Fig. M1A); denser than PmEn.

EOCENE SEDIMENTARY ROCKS

Continental to nearshore sedimentary rocks, undivided (early?) to middle Eocene) (cross section only)—Sedimentary rocks inferred in the deeper subsurface along Cross Section A-A'; where they occur 2D-forward modeling of gravity and aeromagnetic trends; weathers reddish gray to reddish brown; locally pink; we infer the unit as ~37.5–40.5 Ma because rhyolite tuff from the east half of the map area yielded ages from 37.4 ± 0.3 to 37.9 ± 0.5 Ma (age sites GD4, GD5, and GD7); diacite tuff from two age sites just west of the map area yielded ~38 Ma ages (age sites GD7 and GD15 of Polenz and others, 2023) and diacite 7.7 km west of the map area yielded ~40.5 Ma age (age site GD9 of Polenz and others, 2023).

UNDIVIDED EOCENE VOLCANIC AND SEDIMENTARY ROCKS

Interbedded volcanic and continental to nearshore sedimentary rocks, undivided (late to middle?) Eocene) (cross section only)—Andesitic lava, tuff, volcanoclastic deposits, and interbedded sedimentary rocks, may include some intrusive rocks; based on observations from 1,037–5,721 ft depth in the Willhoite well and the need in our 2D-forward modeling for rocks at this depth intermediate in density and magnetic susceptibility compared to bounding layers (Fig. M1B).

Basaltic andesite flows (late to middle?) Eocene)—Rhyolitic ash flow to lapilli tuff, varies from crystal to vitric; locally welded; locally intercalated with rhyolite flows(?) and felsic dike(?) gray to tan, pale green, pale yellow to lavender, orange, pink, and in some weathered exposures, charcoal red or maroon; commonly variegated, banded, and altered with epidolization, some cementation, and localized silicification; usually porphyritic with ~1–20 percent phenocrysts of mainly plagioclase.

The rhyolite composition of PmEn in the Eatonville quadrangle contrasts with diacite tuffs of the Northcraft Formation farther west (Polenz and others, 2023). These new zircon U-Pb ages from PmEn range from ~37.4–37.9 Ma (age sites GD4, GD5, and GD7; Table 2).

GEOPHYSICAL MAPPING

Figure M1A

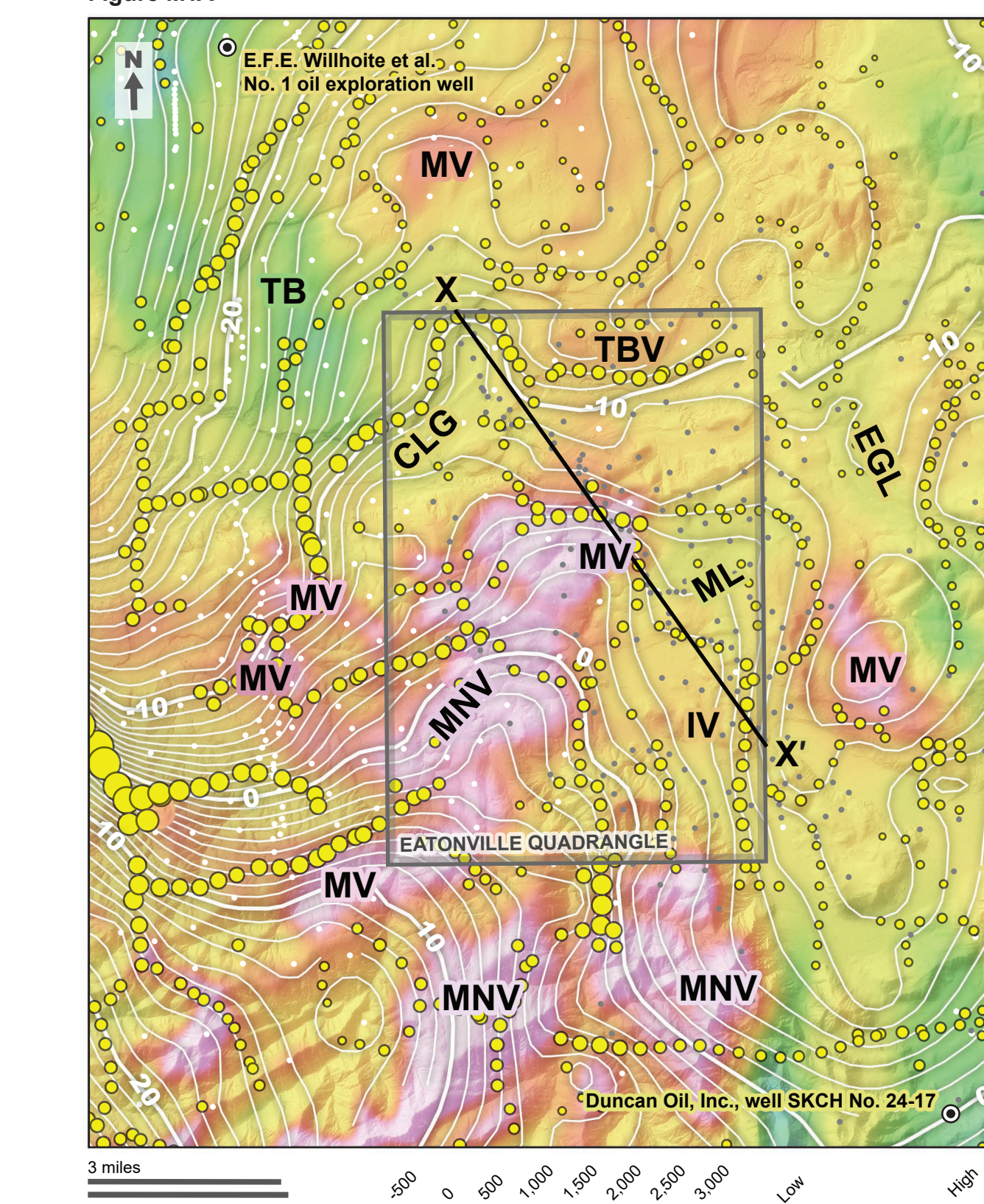


Figure M1B

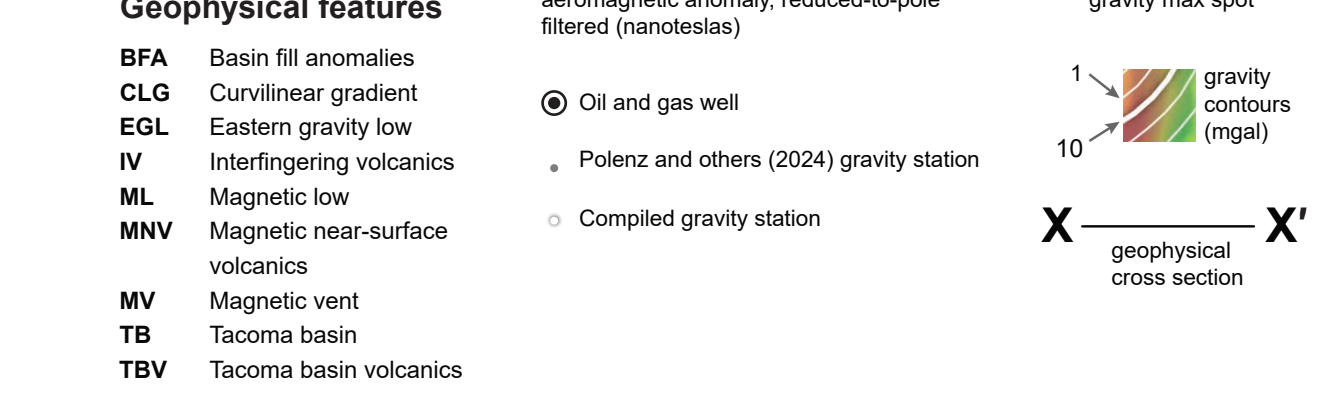


Figure M1A. Combined map of isotropic gravity (contours), reduced-to-pole filtered aeromagnetic map (colors), hillshade image from lidar, and 10 m DEM data (topographic image). Gravity contours are in mGal. Newly collected gravity stations are gray dots; older compiled gravity stations are white dots. Relative size of the gravity map spots is proportional to the magnitude of the gravity gradient in that location. X-X' shows the geophysical location (Fig. M1B), which is collocated with geologic Cross Section A-A'.

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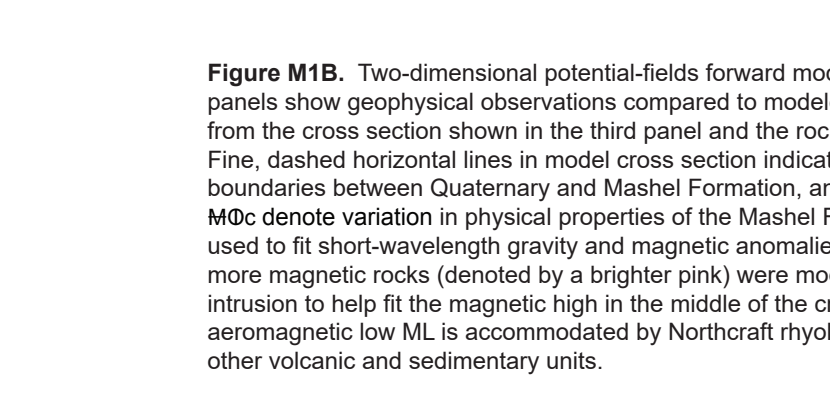
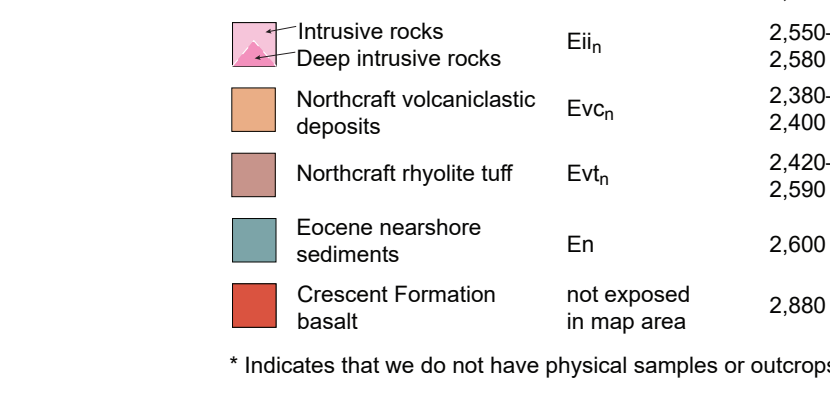
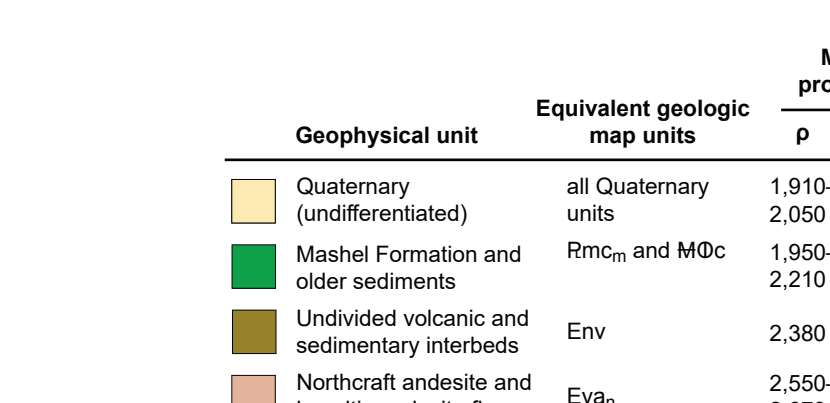
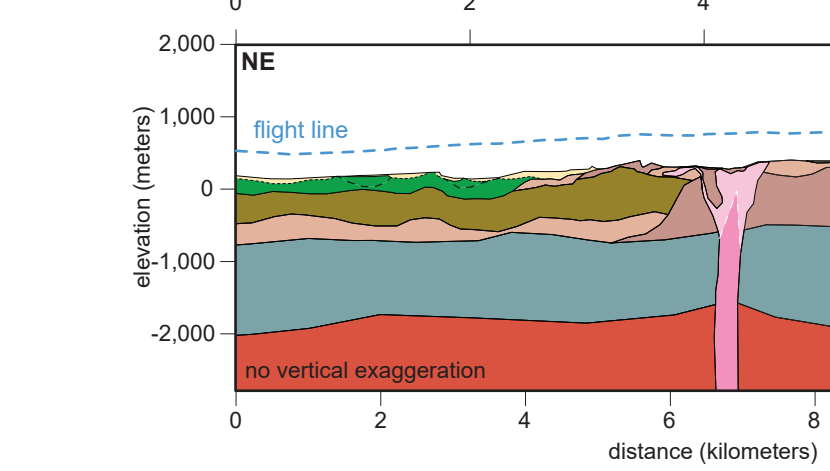
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CORRELATION OF MAP UNITS

PERIODS AND EPOCHS BASED ON USGS FACT SHEET 2015-204



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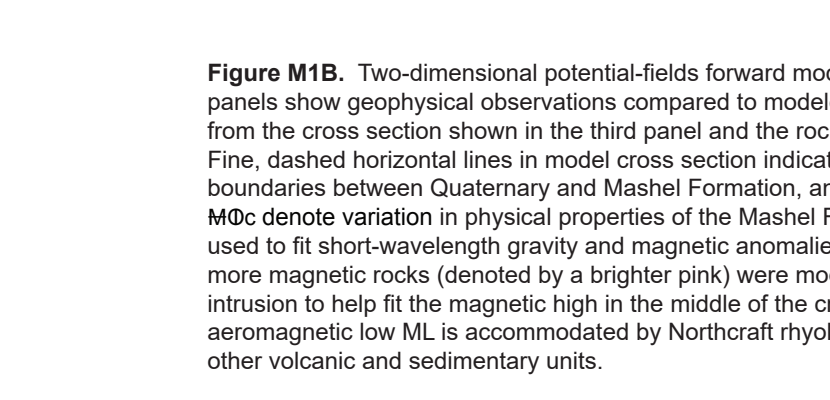
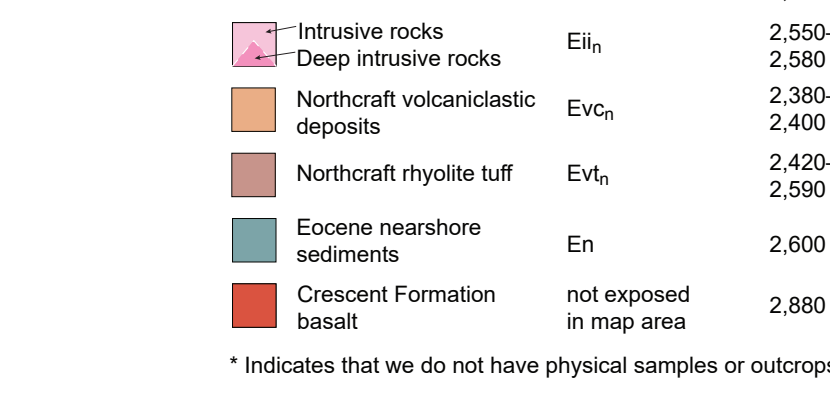
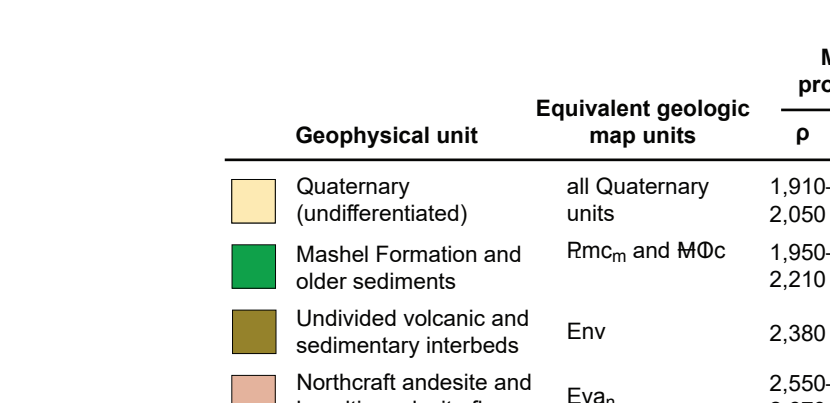
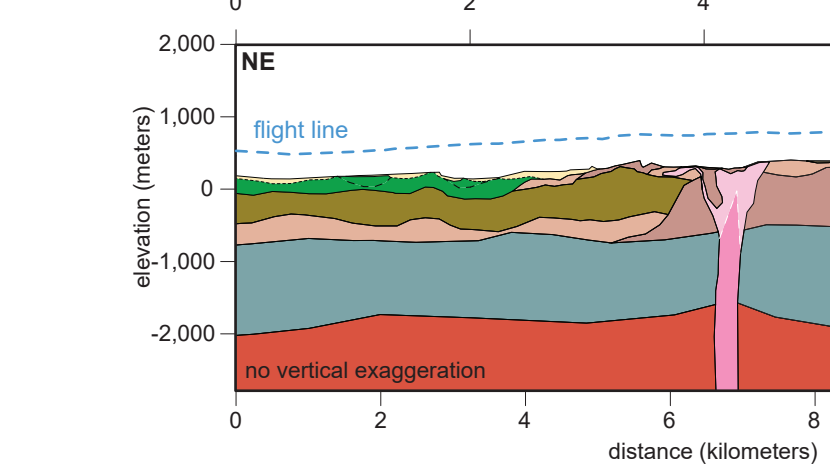
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- Alpine ice limit—circles on glaciated side; inferred; queried where identity or existence questionable
- Continental ice limit—hachures on glaciated side; inferred
- Geologic unit too thin to show as a polygon—short-dashed where inferred; queried where questionable
- Inclined bedding—showing strike and dip
- Small, minor inclined joint—showing strike and dip
- Small, minor, vertical or near-vertical inclined joint
- Small, minor, inclined fault—showing strike and dip
- Small, minor, vertical or near-vertical fault
- Small, minor inclined vein, veinlet, or mineralized stringer
- Age site, U-Pb
- Age site, luminiscence
- Age site, ⁴⁰Ar/³⁹Ar
- Geochemistry sample location
- Water well
- Claut count location
- Thin section location

CORRELATION OF MAP UNITS

PERIODS AND EPOCHS BASED ON USGS FACT SHEET 2015-204



PILOCENE TO EOCENE SEDIMENT, SEDIMENTARY ROCK, AND VOLCANICLASTIC ROCK

PILOCENE TO MIOCENE SEDIMENT OF THE MASHEL FORMATION

Continental sediments (Pliocene to late Miocene)—Volcanic-lithic sand and silt with clayey matrix; pumice clasts in some exposures; sections, lenses, and interbeds of pebble gravel with dense, clay-rich matrix; interbeds and lenses of tephra, clay, muck, and peat; plant fragments and imprints, all in varied amounts; compact and stiff but unindurated. Unit PmEn includes an upper part of mostly clay and sand and a lower part of mostly gravel.

Sand and finer sediment are mostly pale yellow, pale gray, and white, moderately to strongly weathered, sand mostly medium to coarse-grained, angular to subrounded, mostly poorly sorted, and distinctly rough cross-bedded or planar-bedded.

Mashel Formation gravel mostly consists of medium to very coarse andesite pebbles, with abundant matrix of clay to cherty sand. The gravel is mostly pale brown to reddish brown. A clast count site C1 just beneath the type section, most clasts had weathering rinds >2 mm thick or were cotton (see Data Supplement for clast counts). Clasts are well-rounded and moderately oblate to spheroidal, moderately sorted, poorly to moderately sorted, and commonly imbricated. Imbrications mostly suggest approximately west to northwest-flowing palaeocurrents.

Most exposures reveal gently west-dip apparent dips that are post-depositional because they tilt peat, lacustrine, and planar floodplain beds.

Mashel Formation is more compact than unit Qp; tends to be more weathered, and more commonly contains pumice, scoria, and volcanic glass, tephra, muck, gyttja(?), and plant macrofossils. We observed pumice clasts and scoria mainly in lobar deposits. Sandy and finer-grained sections of Mashel Formation tend to be pale yellow, pale gray, and white—whereas unit Qp tends to be more yellow to reddish brown and orange.

MIOCENE TO OLILOCENE SEDIMENTARY ROCKS

Sedimentary rocks (Miocene to Oligocene) (cross section only)—Sediment and sedimentary rocks, likely mostly fine-grained and volcanoclastic; inferred between units PmEn and Enw in the northern third of Cross Section A-A' based mainly on observations of fine-grained sediment at 519–1037 ft depth in the Willhoite well 7.6 km northwest of the Eatonville quadrangle (Fig. M1A); denser than PmEn.

EOCENE SEDIMENTARY ROCKS

Continental to nearshore sedimentary rocks, undivided (early?) to middle Eocene) (cross section only)—Sedimentary rocks inferred in the deeper subsurface along Cross Section A-A'; where they occur 2D-forward modeling of gravity and aeromagnetic trends; weathers reddish gray to reddish brown; locally pink; we infer the unit as ~37.5–40.5 Ma because rhyolite tuff from the east half of the map area yielded ages from 37.4 ± 0.3 to 37.9 ± 0.5 Ma (age sites GD4, GD5, and GD7); diacite tuff from two age sites just west of the map area yielded ~38 Ma ages (age sites GD7 and GD15 of Polenz and others, 2023) and diacite 7.7 km west of the map area yielded ~40.5 Ma age (age site GD9 of Polenz and others, 2023).