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Geologic Map of the Tenalquot Prairie and Northern Two-Thirds of the Vail 7.5-minute Quadrangles

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Geologic Map of the Tenalquot Prairie and Northern Two-Thirds of the Vail 7.5-minute Quadrangles, Thurston and Pierce Counties, Washington

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ABSTRACT

The map area includes the Tenalquot Prairie quadrangle and the northern two thirds of the Vail quadrangle in Washington's southern Puget Lowland. This map supports private and public resource management with insights into geologic deposits, structures, and hazards. Based on 59 new whole rock geochemical analyses, all igneous rocks in the map area are from the Northcraft Formation. Eight new radiometric ages between 45.8 ±0.07 Ma and <38.4 ±0.5 Ma establish this unit as the oldest known expression of Cascade arc magmatism. These ages also indicate that Cascade volcanism overlapped the waning stages of Siletzia volcanism.

Preliminary analysis of aeromagnetic and gravity potential fields suggests that the Olympia geophysical lineament results from a normal fault and the Tacoma basin northeast of it contains a significant thickness of shallow igneous rocks that likely are Northcraft Formation. If both are true, then the Olympia fault has experienced no major northeast-down movement since the end of Northcraft Formation volcanism, which our age control suggests may be entirely middle Eocene in the map area.

Vashon glacial sediments, especially outwash, provide productive but easily polluted aquifers for private water wells and the cities of Yelm and Olympia. The extensive outwash gravel terraces in Tenalquot Prairie and the Deschutes River valley also host widespread, enigmatic Mima mounds. Lacustrine sand above outwash gravel and moraine deposits between Tenalquot Prairie and Lake Saint Clair suggest that large outwash channels were somehow later submerged by an ice-dammed lake with a shoreline at 400 ft elevation. Terminal moraines from the eastern (Yelm) and western (Olympia) ice lobes appear as hummocky glacial sediments east, north, and west of Tenalquot Prairie and along the hill front south of the Deschutes River, suggesting Vashon ice did not override Tenalquot Prairie. Heavily weathered pre-Vashon drift extends miles farther south in this area but approximates the Vashon ice limit farther east and west. Bouldery outwash trains and denuded bedrock surfaces in the valleys of Johnson Creek and the Skookumchuck River document massive proglacial meltwater discharge south of all known ice limits.

DESCRIPTION OF MAP UNITS

Holocene to Pleistocene Nonglacial Deposits

af — **Artificial fill (Holocene)**—Cobbles, pebbles, sand, silt, clay, and boulders, all in various amounts, engineered and non-engineered; placed to raise roadbeds and other surfaces. Excludes small or shallow fills (less than 5 ft deep) such as most road-related deposits.

ml — **Modified land (Holocene)**—Locally derived soil, cobbles, pebbles, sand, silt, clay, and boulders, all in various amounts, reworked by excavation and (or) redistribution that modified topography; includes gravel pits and other developments. Excludes small or shallow reworking such as most residential site preparation and road-related modifications with excavations or deposits less than 5 ft deep or thick.

Qp — **Peat (Holocene to Pleistocene)**—Organic and organic-matter-rich mineral sediments (peat, gyttja, muck, silt, clay, and sand) in flat-bottomed depressions or other poorly drained flats; mostly mapped where lidar reveals such landforms and true color or infrared aerial photos reveal or suggest hydrophilic vegetation and (or) wet conditions.

Qa **Qoa** — **Alluvium (Holocene to Pleistocene)**—Floodplain and channel sediments of pebbles, cobbles, boulders, sand, silt, clay, and peat, all in various amounts; loose; mostly well-rounded and moderately to well-sorted; includes Mount Rainier-derived debris flow diamictons, mud flow deposits, and lahar run-out deposits; north of the Deschutes River, unit is lithologically similar to northern-sourced glacial drift; south of the Deschutes River, unit is mostly comprised of andesitic volcanic rocks. The unit forms a highly permeable and productive, generally unconfined aquifer. Unit **Qa** was mapped where alluvial transport appears to be active; unit **Qoa** identifies alluvial deposits that no longer receive sediment.

Qaf — **Alluvial fan (Holocene to Pleistocene)**—Pebbles, sand, silt, cobbles, and boulders, all in various amounts, deposited in broad, concentric lobes where confined channels spill out onto broader surfaces; gray to brown; loose; subangular to rounded; moderately to poorly sorted; stratified to unstratified. Unit **Qaf** was mostly mapped from fan-shaped landforms expressed in lidar.

Qls — **Landslide deposits (Holocene to Pleistocene)**—Sand, silt, clay, pebbles, cobbles, and boulders, all in various amounts, derived from units upslope; weathering varied; particles angular to rounded; typically loose, unsorted, and jumbled; locally stratified in blocks; mostly mapped from landforms expressed in lidar (for example, hummocky slopes, deranged and disrupted drainages, disrupted or irregular slopes, tilted benches in hillsides, and concave upper and convex lower slope forms).

Qmw — **Colluvium (Holocene to Pleistocene)**—Loose soil, rocks, sand, silt, and clay, all in various amounts, deposited by soil creep and shallow raveling; locally includes small landslides and alluvial fans, but fan-shaped deposits in unit **Qmw** are typically steeper than those in unit **Qaf**; shown where colluvium masks the underlying geology, but may locally include exposures of underlying deposits, especially where those are volcanic; mostly identified from landforms visible in lidar.

Pleistocene Glacial and Nonglacial Sediments

LATE PLEISTOCENE CONTINENTAL GLACIAL SEDIMENTS

Vashon Drift

Qgo — **Recessional or proglacial outwash, undivided**—Pebble gravel, locally cobbly or bouldery; less commonly pebbly sand or sand; gray to pale gray, or mildly weathered to pale brown, brown, or variegated with iron stains; loose and commonly cohesionless; well-rounded to subrounded; moderately sorted to well-sorted and in gravel facies clast-supported, locally with matrix and interbeds of silt and sand; faintly bedded or lacking bedding; lithologically diverse. Locally divided into:

Qgog — **Recessional or proglacial outwash gravel**—Loose pebbles, cobbles, and boulders, all in various amounts, locally with sandy matrix and sand lenses or interbeds; tan to gray; variedly sorted; mostly well rounded; lithologically diverse, with clast assemblages mostly derived from the Yelm ice lobe except near the western map edge, where outwash surfaces locally appear to have been fed by meltwater from the Olympia lobe. Unit thickness is mostly unconstrained, but terrace risers suggest that it may exceed 100 ft. The unit is mostly boulder gravel near the Skookumchuck River and Johnson Creek, consistent with the inference that large meltwater volumes flowed through these corridors when ice blocked all periglacial outwash pathways farther north.

Qgos — **Recessional or proglacial outwash sand**—Sand and silt, locally pebbly or containing minor interbeds of pebble gravel; tan to brown; loose; clasts moderately to well rounded; generally well sorted; varies in thickness from about 4 to 20 ft. Localized exposures of unit **Qgos** at the southern fringe of Tenalquot Prairie suggest patchy interludes of quiet water deposition on this part of the otherwise gravelly terraces. Unit **Qgos** also forms an extensive blanket of sand in the north half of the Tenalquot Prairie quadrangle, where the sand smooths and rounds landforms compared to exposures of the underlying units **Qgim** and **Qgog**. Unit **Qgos** in this area was apparently deposited in an early glacio-recessional, ice-dammed lake that partly overlaps Lakes Nisqually and Russell (Bretz, 1913; Walsh and Logan, 2005) but appears to have reached a higher maximum lake surface around 400 ft.

Qgoi — **Recessional ice-contact outwash**—Sand and gravel deposited in ice-contact braid plains or channels; also sand or mixed sand and gravel in kettle walls, and sand or silt in kettle bottoms—commonly draped with a veneer of post-glacial peat where kettle bottoms are flat; tan to gray; loose; moderately to well-rounded and sorted; gently bedded in undisturbed channels or brain plains, but locally oversteepened and (or) chaotic and disrupted by kettle collapse.

Qgim — **End moraine**—Pebbly to cobbly till, pebbles, sand, cobbles, silt, clay, and boulders, all in various amounts; gray, tan, and reddish brown; loose to compact; unbedded in till, unbedded to bedded in other facies. Topographic relief in a kettled part of the unit suggests a thickness of at least 160 ft. Most landforms within unit **Qgim** are hummocky. Kettles and eskers are common but drumlins and flutes are not. Less compact than unit **Qgt**. Unit **Qgim** dropped out of melting, stagnant ice at the southwestern margin of the Yelm ice lobe and the southeastern margin of the Olympia ice lobe. The unit is locally supplemented or reworked by ice-contact outwash from meltwater that flowed or ponded along the ice front, which in the Vail quadrangle locally resulted in a kame terrace setting south of the Deschutes River. The geographic distribution of unit **Qgim** documents the terminal positions of the Olympia and Yelm lobe ice fronts at the end of the Vashon ice advance into the map area.

Qgimo — **End moraine draped with outwash**—Glacial outwash pebbles, sand, cobbles, and boulders, all in various amounts, resting on end moraine deposits as described in unit **Qgim**. Thickness is mostly unknown, but we suspect that surficial outwash is mostly less than 10 ft thick. Unit **Qgimo** is distinguished from unit **Qgim** by systematic presence of surficial outwash deposited in ice-contact channel surfaces that are now heavily fragmented by kettles.

Qgimos — **End moraine draped with glaciolacustrine outwash sand**—Glacial outwash sand, locally ranging to pebbly sand or silt, resting on end moraine deposits as described in unit **Qgim**. Thickness is mostly unknown, but we suspect that surficial outwash is mostly less than 10 ft thick. Unit **Qgimos** is distinguished from unit **Qgim** by the systematic presence of smoothed landforms that suggest a surficial drape of lacustrine sand that also covers adjacent apparent lake-bottom surfaces farther north and west (unit **Qgos**).

Qge — **Esker**—Pebbles and sand; medium gray; lightly to moderately weathered; mostly loose; clasts well rounded; well sorted; distinctly channel-bedded in most exposures, with beds commonly oversteepened because source water, confined beneath ice, locally flowed uphill, or because bedding was deformed when englacial and supraglacial deposits sank to the ground during ice melt. Unit **Qge** was deposited by subglacial, englacial, and supraglacial meltwater and is found amid or adjacent to units **Qgic** and **Qgim**. Unit **Qge** is clearly marked by distinctive sinuous hill landforms.

Qgic — **Ice contact deposits**—Undivided till and outwash, consisting of loose to compact diamicton, pebble gravel (locally cobbly), and sand; pale gray to brown and reddish brown; mildly weathered; mostly loose and crumbly in ablation till and outwash, ranging to compact in lodgment till, but typically lacking thick, continuous, or widespread deposits of lodgment till at the ground surface. Unit ranges from cobbles to medium sand, with finer particles common in till matrix, and boulders locally in till and outwash; varied rounding and sorting; northern sourced, mostly from the Yelm ice lobe. Unit thickness is highly varied; much of the unit is likely less than 10 ft thick, but locally may be more than 80 ft thick. Unit **Qgic** is marked by irregular landforms such as kettles, eskers, and rounded channels that commonly connect to eskers; drumlin and flute surfaces are usually fainter and more irregular than those in unit **Qgt**.

Qgt — **Lodgment till**—Diamicton containing boulders, smaller rocks, and sand, with an unsorted or poorly sorted matrix comprised of sand and clay; matrix supported in nearly all exposures; gray to pale reddish brown; mildly to moderately weathered; mostly compact to very compact; clasts well rounded to faceted or angular, and commonly striated; thickness in map area is at least 6 ft in one exposure, but elsewhere is mostly unknown and unit likely pinches out locally; unbedded, but in some exposures flow banded (resembling bedding); northern sourced, mostly from the Yelm ice lobe, but west of Tenalquot Prairie unit is sourced from the Olympia ice lobe. Unit **Qgt** is deposited directly by glacial ice and usually includes a loose, surficial cover of 2 to 10 ft of ablation till and (or) outwash clay, silt, sand, and gravel.

Qga — **Advance outwash**—Fluvial pebble gravel, cobble gravel, boulder gravel, sand, and lacustrine sand, silt, and clay; mostly observed in sparsely scattered exposures and well records; gray to light brown; compact, but lacks cohesion in well-rounded and well-sorted intervals; mostly moderately or well-rounded; mostly northern-sourced but locally with abundant Cascade Range-sourced particles, especially along and near the Deschutes River, where drainage from the Cascade Range was confined between hillsides and the advancing ice. Distinguished from recessional outwash by greater compaction and stratigraphic position beneath unit **Qgt**; may include pre-Vashon fluvial sediment.

Pre-Vashon drift

Qpd — **Pre-Vashon, northern-sourced glacial sediment, undivided**—Glacial till, pebbles, cobbles, sand, silt, clay, and boulders, all in various amounts; light brown or gray to yellowish-brown, orange, red, or reddish brown; loose or too weathered to preserve evidence of compaction; where not fully weathered to clay, unit includes mostly mafic igneous and intermediate to felsic volcanic clasts. Unit **Qpd** includes direct ice deposits (till), and outwash, locally in close association (in moraine, stagnant ice, or kame deposits). Observed near the southern end of Tenalquot Prairie, in the hills along both sides of Johnson Creek, and on the north-facing slopes south of the Deschutes River, where many exposures were too small and patchy to be mapped.

OTHER PRE-VASHON SEDIMENTS

Qpc — **Pre-Vashon alluvium from the Cascade Range, undivided (late Pleistocene)**—Pebbles, cobbles, sand, silt, clay, peat, boulders, and diamicton; lithologically dominated by volcanolithic clasts of Mount Rainier or other Cascade Range sources; pale gray to light brown and reddish brown; compact. Observed only along the sidewalls of the Nisqually River valley; a luminescence age estimate (age site GD3) from about 155 ft above river level suggests a mid-to-late MIS3 age for that portion of the deposit.

Eocene Volcanic and Sedimentary Rocks

Northcraft Formation volcanic rocks (middle to late Eocene)

Evn — **Undivided igneous rocks**—Dark gray to gray lavas with rare dikes; interbedded volcanic ash, and light brown to tan and olive pyroclastics, flow breccia, lahar deposits, and other volcaniclastics; lapilli ash, and andesitic block-and-ash flow tuffs; locally with intrusions. Locally subdivided into:

Evan — **Andesite and basaltic andesite flows**—Trachyandesite, basaltic trachyandesite, and basalt are less common; locally includes interbedded volcaniclastic and vent breccia; dark olive gray to dark gray and gray, weathers variously orange-brown, brown, and gray; greenish tint in many exposures due to pale-green glass; mostly very fine-grained to glassy or aphanitic; tabular and blocky, or platy jointed. Porphyritic flows are coarse-grained, blocky and tabular, with cryptocrystalline to glassy groundmass. The unit is commonly mined for road rock.

Evcn — **Volcanic ash and volcaniclastic deposits**—Andesitic volcanic ash, crystal lithic vitric lapilli-ash, block-and-ash flow tuffs, and lahars; locally includes interbedded andesite lava flows; light brown to tan to olive, with hackly weathering; groundmass earthy and devitrified, with rare glass shards; lithic fragments typically subangular to angular, with broken crystals; moderately to poorly sorted. Unit is widely exposed in the hills south of the Deschutes River where the upper portions are typically unwelded and the lower portions are both unwelded and partially welded, often in close proximity, consistent with both hot lahars and ash-flow tuffs. Typically underlain and overlain by andesitic and (or) basaltic flows. Interpreted as the pyroclastic facies of andesitic stratovolcanoes.

Evvn — **Volcanic vent breccia**—Lapilli-ash tuff, block-and-ash tuff, bomb tuff (agglutinate), agglomerate, and agglutinous spatter of intermediate to silicic composition; usually reddish-brown; often weathered to clay. Unit marks eruptive vents that were sources for other units of the Northcraft Formation.

Evdn — **Dacite to rhyolite flows**—Dark lavender gray and light tan, weathers medium gray and yellowish tan; platy to blocky. Earthy, white, elongate feldspar phenocrysts 1–5 mm in length comprise up to 5% of the rock in an earthy, light-colored groundmass; sparse black pyroxene crystals 1–2 mm in length comprise less than 1% of the rock. Unit may represent late-stage(?), small-volume, silicic Northcraft Formation dome building in a mostly andesitic stratovolcano complex.

Eign — **Gabbro**—Medium dark gray, salt-and-pepper gabbro; about 7% fine-grained magnetite, 20% pyroxene, and 75% plagioclase ranging from less than 0.5 to 4 mm; trace hornblende. Secondary zeolite coatings up to 2 mm thick that form multi-centimeter-scale rosettes are found on rare partings of quarry blocks; otherwise fractures are rare; observed only in and near the Columbia Granite Quarry above Skookumchuck Reservoir. An ~38.7 Ma $^{40}Ar/^{39}Ar$ age (age site GD11) indicates this unit is younger than Northcraft Formation farther north in the map area.

Sedimentary rocks

Ensk — **Skookumchuck Formation (middle to late Eocene)(cross section only)**—Terrestrial to deltaic and shallow marine feldspathollithic sandstone and siltstone with coal beds; inferred based on the work of Snavely and others (1951, 1958), but we show unit **Ensk** interfingered with Northcraft Formation based on nearby mapping by Polenz and others (2020).

GEOLOGIC SYMBOLS

- Contact—Solid where location accurate; long-dashed where approximate; short-dashed where inferred
- Normal fault—Identity or existence questionable; short-dashed where inferred; dotted where concealed
- High-angle dip-slip fault—Identity or existence questionable; concealed; relative vertical motion shown by U and D
- Anticline—Long-dashed where approximate; dotted where concealed
- Syncline—Concealed; queried where identity or existence questionable
- A — A′ Cross section line
- Perennial stream
- Intermittent stream
- Fluvial terrace—Location accurate; hachures point down slope; queried where identity or existence questionable
- Former shoreline—Location accurate; queried where identity or existence questionable
- Continental ice limit, pre-late Wisconsinan—Identity or existence questionable, location inferred
- Continental ice limit, late Wisconsinan—Long-dashed where approximate; short-dashed where inferred; queried where identity or existence questionable
- 10 Inclined bedding—showing strike and dip
- 6 Approximate orientation of inclined bedding in unconsolidated deposits or bedrock—showing approximate strike and dip
- 25 Small, minor inclined joint—showing strike and dip
- 8 Inclined slickenline, groove, or striation on fault surface—showing bearing and plunge
- 80 Inclined dike
- 7 Inclined contact—showing dip value and direction
- 25 Inclined flow banding
- 87 Shear—showing strike and dip
- GD4 Age site, U-Pb, uranium-lead
- GD1 Age site, ^{14}C, carbon-14
- GD9 Age site, $^{40}Ar/^{39}Ar$, argon-argon
- GD3 Age site, optically-stimulated luminescence
- G4 Geochemistry sample location
- W1 Water well
- S2 Significant site
- C1 Clast count sample

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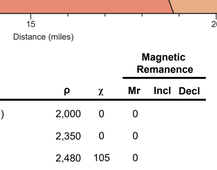
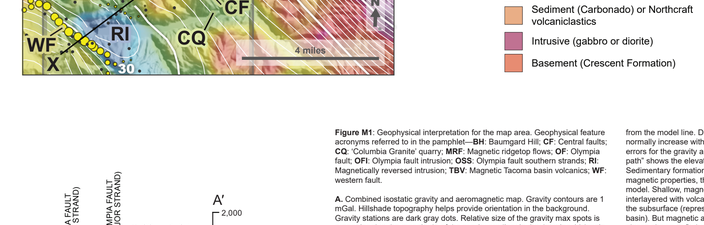


CORRELATION OF MAP UNITS

PERIODS AND EPOCHS BASED ON USGS FACT SHEET 2010-3059



	ρ	χ	Magnetic Remanence Mr	Incl	Decl
Quaternary (undifferentiated)	2,000	0	0		
Post-Northcraft sediment	2,350	0	0		
Northcraft andesite	2,480	105	0		
Sediment (Carbonado) or Northcraft volcaniclastics	2,400	0	0		
Intrusive (gabbro or diorite)	2,790	10	4	-68	196
Basement (Crescent Formation)	2,880	52	0		

Figure M1: Geophysical interpretation for the map area. Geophysical feature acronyms referred to in the pamphlet—**BH**: Baumgard Hill; **CF**: Central faults; **CQ**: 'Columbia Granite' quarry; **MRF**: Magnetic ridgetop flows; **OF**: Olympia fault; **OFI**: Olympia fault intrusion; **OSS**: Olympia fault southern strands; **RI**: Magnetically reversed intrusion; **TBV**: Magnetic Tacoma basin volcanics; **WF**: western fault.

A. Combined isostatic gravity and aeromagnetic map. Gravity contours are 1 mGal. Hillshade topography helps provide orientation in the background. Gravity stations are dark gray dots. Relative size of the gravity max spots is proportional to the magnitude of the gravity gradient in that location. Volcanic flows southwest of Baumgard Hill, capping the ridges, correspond with aeromagnetic highs (**MRF**); their contact with the stratigraphically lower mapped volcaniclastics approximates the boundary between the magnetic high on the ridge tops and the relative lows in the valleys. Gray, dotted line marks the northern edge of where we interpret **TBV** within the Tacoma basin.

B. Two-dimensional potential-fields forward model of Cross Section X–X'. Units and properties shown in the bottom panel predict gravitational and magnetic anomalies shown in the top two panels (ρ–saturated bulk density; χ–magnetic susceptibility x 10^{-3}; Mr–magnetization in A/m; Incl–inclination; Decl–declination). Gravity data shown are no more than 600 m in map view from the model line. Diameters of the gravity and magnetic data points would normally increase with increasing magnitude of the data errors, however errors for the gravity and magnetic data points are too small to show. "Flight path" shows the elevation of the airplane that flew the aeromagnetic survey. Sedimentary formations and volcaniclastics are very similar in density and magnetic properties, therefore we do not attempt to separate them in the model. Shallow, magnetic andesites such as in the Tacoma basin could be interlayered with volcaniclastic rocks at depth and thus extend deeper into the subsurface (represented by stylized interfingering at depth in the Tacoma basin). But magnetic andesites must exist in the shallow subsurface in all the places shown to fit the magnetic data with a geologically reasonable shape for the deposits. Total offset on the Olympia fault (**OF**) is uncertain because it is highly dependent on the poorly constrained Tacoma basin fill density, therefore we do not show the depth of the Tacoma basin modeled. However, it is likely in the range of 22,000–26,000 ft. Properties of the **RI** body are consistent with diorite or gabbro, but it must have a strong reversed remanence. A small branch of this intrusion could be exposed at 'Columbia Granite' quarry, but we do not have the paleomagnetic data to confirm it.

Lambert conformal conic projection
North American Datum of 1927; to place on North American Datum of 1983, move the projection lines approximately 22 meters north and 100 meters east as shown by crosshair corner ties
Base map from scanned and rectified U.S. Geological Survey Tenalquot Prairie 7.5-minute quadrangle, 1990, and Vail 7.5-minute quadrangle, 1990
Shaded relief generated from a lidar bare-earth digital elevation model (available from the Washington Geological Survey, https://lidarportal.dnr.wa.gov/)
GIS by Michael Polenz
Digital cartography by Daniel E. Coe
Editing and production by Susan R. Schnur and Maria A. Furtney

SCALE 1:24,000
1 MILE
1,000 FEET
1 KILOMETER
contour interval 20 feet

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APPROXIMATE MEAN DECLINATION, 2021

CROSS SECTION EXPLANATION

Qp Qa — Geologic units too thin to show as polygons at the scale of the cross section; vertical tics mark separate units.

Arrows show relative fault movement in the plane of the cross section.

W13 — Water well or boring