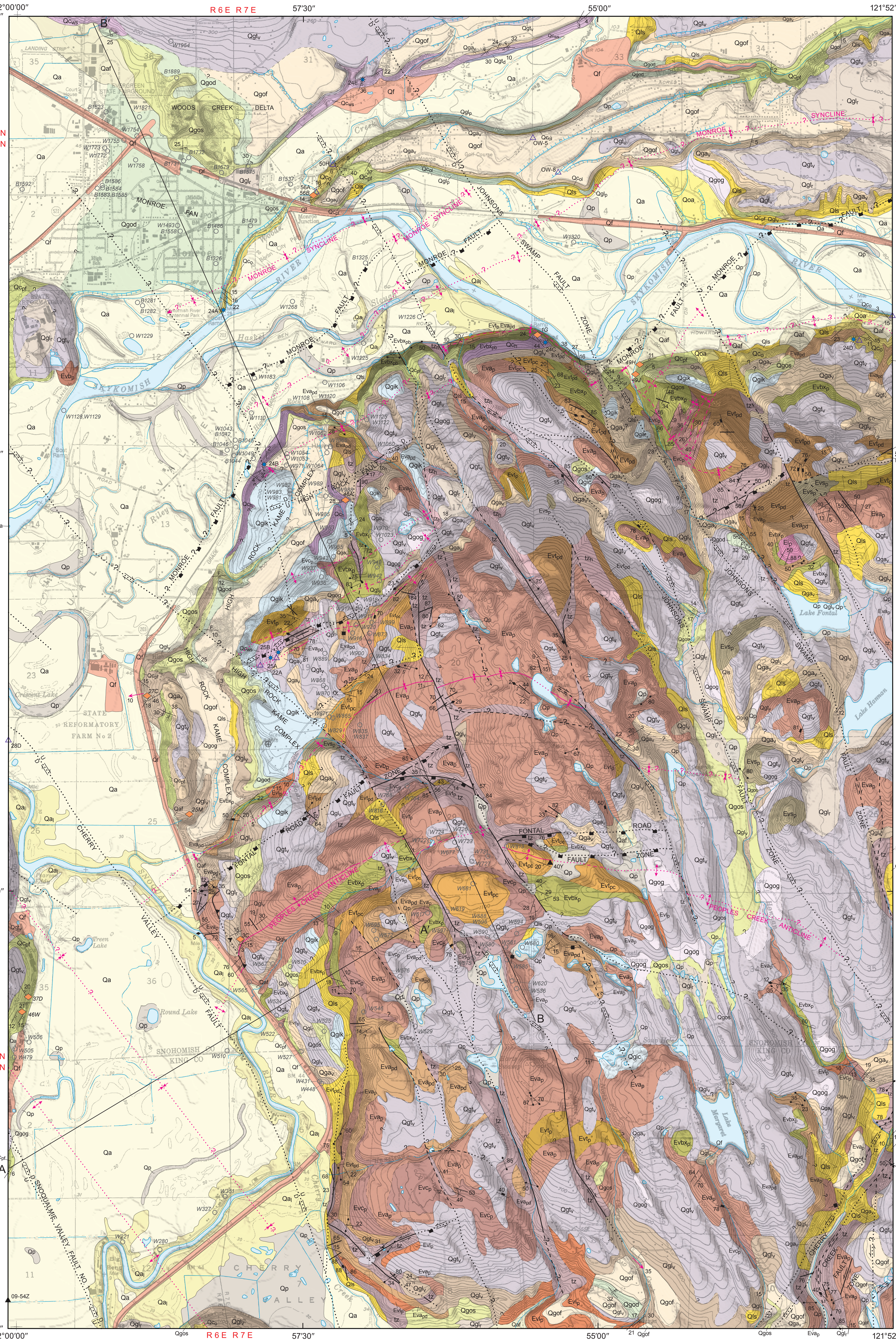
WASHINGTON STATE DEPARTMENT OF
Natural Resources
Peter Goldmark - Commissioner of Public Lands
Division of Geology and Earth Resources
David K. Norman - State Geologist

WASHINGTON DIVISION OF GEOLOGY AND EARTH RESOURCES
OPEN FILE REPORT 2011-1
Monroe 7.5-minute Quadrangle
November 2011
Pamphlet accompanies map

Geologic Map of the Monroe 7.5-minute Quadrangle, King and Snohomish Counties, Washington

by Joe D. Dragovich, Megan L. Anderson, Shannon A. Mahan, Curtis J. Koger, Jennifer H. Saltonstall, James H. MacDonald Jr., Gregory R. Wessel, Bruce A. Stoker, John P. Bethel, Julia E. Labadie, Recep Cakir, Jeffrey D. Bowman, and S. Andrew DuFrane

November 2011



Lambert conformal conic projection
North American Datum of 1927; to place on North American Datum of 1983, move the projection lines approximately 19 meters north and 89 meters east as shown by crosshair corner ticks
Base map from scanned and rectified U.S. Geological Survey Monroe 7.5-minute quadrangle, 1993
Shaded relief generated from U.S. Geological Survey 10-meter digital elevation model; sun azimuth 215°; sun angle 45°; vertical exaggeration 3x
Digital cartography and GIS by J. Eric Schuster, Heather A. Littke, Benjamin B. Perry, and Anne C. Olson
Editing and production by Jaretta M. Roloff, Jessica L. Czajkowski, and Karen D. Meyers

SCALE 1:24,000

contour interval 20 feet
supplemental contour interval 10 feet

APPROXIMATE MEAN DECLINATION, 2011

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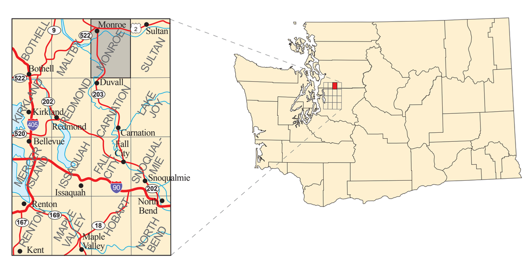


MAJOR FINDINGS

- The Rattlesnake Mountain fault zone (RMFZ) is the southward extension of the southern Whidbey Island fault zone (SWIF), and the Cherry Valley fault of the SWIF forms the northeastern boundary of the Seattle Basin in the map area.
- Snoqualmie and Skykomish River alluvium is similar to sands in the Pleistocene nonglacial deposits (ancient alluvium) that commonly exhibit moderate to intense liquefaction.
- Ancient alluvium is preserved in structural basins, some inverted, between active faults or as elevated tilted bodies.
- The volcanic rocks of Mount Persis in the study area emanated from volcanic center(s) near the eastern edge of the map area.
- Offset along the Monroe fault may be actively uplifting the uplands between High Rock on the north and Cherry Creek on the south.
- The 1996 Duvall earthquake epicenters (max. magnitude 5.3) coincide with the mapped trace of the Cherry Creek fault zone (CCFZ), suggesting that these seismic events may have resulted from shallow displacement along this fault zone.

DESCRIPTION OF MAP UNITS

(see pamphlet for detailed map unit descriptions)

Quaternary Sedimentary Deposits

HOLOCENE NONGLACIAL DEPOSITS

Qf — **Artificial fill and modified land (Holocene)**—Mixed earth materials including sand and gravel fill

Qp — **Peat (Holocene)**—Peat, muck, and organic silt and clay, with local thin beds of tephra

Qa — **Alluvium (Holocene)**—Sand, silt, (cobble) gravel, gravelly sand, sandy pebble gravel, peat, and organic sediments; locally divided into:

Qa$_l$ — **Levee deposits (Holocene)**—Wedge-shaped accumulations of overbank flood sediments along the Snoqualmie and Skykomish Rivers

Qoa — **Older Alluvium (Holocene to latest Pleistocene)**—Cobble to pebble gravel, sand, and silt forming elevated terraces along the margins of the Skykomish valley

Qls — **Landslide deposits (Holocene to latest Pleistocene)**—Diamicton or boulder gravel and local minor sand or gravel

Qaf — **Alluvial fan deposits (Holocene to latest Pleistocene)**—Debris-flow diamicton and alluvial deposits

PLEISTOCENE GLACIAL AND NONGLACIAL DEPOSITS

Recessional Deposits of the Vashon Stade of the Fraser Glaciation

Qgl$_r$ — **Recessional glaciolacustrine deposits**—Soft silt, clayey or sandy silt, and silty sand, typically with scattered dropstones, deposited in proglacial lakes

Qgos — **Outwash sand**—Sand and pebbly sand; dark blue-gray; loose or soft; nonbedded to weakly stratified to plane bedded, laminated, and crossbedded

Qgod — **Deltaic outwash and kame deltas**—Cobble gravel to pebbly sand; loose; moderately to well sorted; thin to very thickly bedded and well stratified

Qgof — **Fluvial outwash deposits**—Bouldery cobble gravel to sand; loose; moderately to well stratified; subhorizontal beds, local crossbedding, and rip-up clasts

Qgic — **Ice-contact deposits, undivided**—Loose bouldery cobble gravel with lesser diamicton, sand (pebbly) sand, and silt; moderately stratified and medium to very thickly bedded; variably sorted with abrupt grain-size changes common. Locally divided into:

Qgk — **Ice-contact kames**—Sand and gravel with scattered lenses of diamicton; may include some kame delta deposits

Qgog — **Outwash gravel deposits, undivided**—Poorly exposed bouldery gravel to pebbly sand; loose; massive to crudely bedded; deposited mostly as ice-contact deposits, including kame outwash bodies

Advance Proglacial and Subglacial Deposits of the Vashon Stade of the Fraser Glaciation

Qgt$_v$ — **Vashon lodgment till**—Diamicton; grayish blue to very dark gray; dense; matrix-supported; unsorted with cobbles and boulders in a silt-sand matrix

Qga$_v$ — **Vashon advance outwash**—Sand and gravel; dark green-gray; dense; well sorted and stratified; thinly to thickly bedded; local silt interbeds and (or) rip-up clasts, deltaic and bar foreset beds, cut-and-fill structures

Qgl$_v$ — **Vashon advance glaciolacustrine deposits**—Silt and diamicton; contains scattered dropstones and iceberg melt-out till or flow till; stiff or dense; stratification and sorting variable

Deposits of the Olympia Nonglacial Interval

Qc$_o$ — **Olympia beds, Snoqualmie and Skykomish River provenance**—Sand and silt, with some clay, peat, and (cobble) gravel interbeds; yellowish brown-gray to grayish brown with distinctive orange-gray oxidation; dense; laminated to very thickly bedded and well stratified with liquefaction features common. Locally divided into:

Qc$_{ol}$ — **Olympia beds, local provenance**—Silt, sand, and gravel, with peat and paleosols; dense; thinly to thickly bedded and well stratified and sorted

Deposits of the Possession Glaciation

Qgl$_p$ — **Glaciomarine and glaciolacustrine deposits**—Silt and clay with scattered gravel dropstones; hard or dense; moderately to well sorted and typically massive or moderately stratified; laminations common

Whidbey Formation

Qc$_{wh}$ — **Whidbey Formation, Snoqualmie and Skykomish River provenance**—Sand and silt with some clay, peat, and (cobble) gravel interbeds; yellow-gray or brown, weathering to orange-gray; dense or hard; well sorted and stratified; laminated to thickly bedded; commonly plane bedded; may contain evidence of liquefaction

Deposits of the Double Bluff Glaciation

Qgt$_d$ — **Double Bluff till**—Dominantly diamicton; very dense and massive; basaltic clasts have distinct 1 to 2 mm weathering rinds

Deposits of the Hamm Creek Formation of Troost and others (2005)

Qc$_h$ — **Hamm Creek formation, Snoqualmie and Skykomish River provenance**—Sand and silt with clay, peat, and gravel interbeds; weathered to distinctive orange-brown; dense or hard; well sorted and stratified; laminated to thinly bedded; beds are disrupted from liquefaction

PRE-FRASER GLACIAL AND NONGLACIAL DEPOSITS

Qc$_{pf}$ — **Pre-Fraser continental nonglacial deposits, Snoqualmie and Skykomish River provenance (Pleistocene)**—Sand and silt with clay, peat, and gravel interbeds locally; yellow-brown-gray, weathering to orange or light yellowish brown; dense; laminated to thickly bedded and well stratified; may contain rough and ripple crossbedding, graded beds and liquefaction features

Qgc$_{pf}$ — **Pre-Fraser glacial and nonglacial deposits, undivided (Pleistocene to Pliocene?)(cross sections only)**—Mostly (boulder) gravel, sand and gravel, sand, silt, clay, diamicton, and some wood or peat; dense to very dense

Tertiary Volcanic and Sedimentary Rocks

Mvc — **Volcanic and sedimentary rocks (Miocene)(cross sections only)**—Nonmarine volcanic to tuffaceous sandstone, pebbly sandstone, volcanic to polymictic conglomerate, tuff, claystone, siltstone, and lignite; locally contains volcanic breccia

ΦEn — **Blakeley Formation, nearshore marine deposits (Oligocene to latest Eocene?)(cross sections only)**—Feldspathic to lithic (tuffaceous) sandstone, conglomerate, and tuff; well stratified, and laminated to thickly bedded

ΦEc — **Blakeley Formation, fluvial-deltaic deposits (Oligocene to latest Eocene?)(cross sections only)**—Lithofeldspathic to lithic volcanic sandstone, pebbly sandstone, tuffaceous siltstone, claystone, tuff, lapilli tuff, conglomerate and rare coal; well stratified, and laminated to thickly bedded

Evs$_p$ — **Volcanic rocks of Mount Persis of Tabor and others (1993), undivided (Eocene)**—Volcanic lithic (tuffaceous) sandstone, tuffaceous siltstone, lahar and volcanic (boulder) conglomerate, andesite flows, tuff breccia, and tuff, with minor silty shale, claystone, and coal; vary from andesite to basaltic andesite with some dacite and basalt; locally strongly altered, particularly near tectonic zones (units tz or tz$_h$). Locally divided into:

Eva$_p$ — **Volcanic rocks of Mount Persis, andesite flows (Eocene)**—Andesite flows and rare flow breccia; greenish gray, dark green, or dark gray, weathers to dark reddish brown-gray or yellow-brown-gray

Eva$_{pd}$ — **Volcanic rocks of Mount Persis, dark basaltic andesite flows (Eocene)**—Medium-K calc-alkaline basaltic andesite to andesite flows; typically dark gray to very dark gray, weathers to reddish gray

Evb$_p$ — **Volcanic rocks of Mount Persis, basalt flows (Eocene)**—Medium-K calc-alkaline basalt; massive and dark gray

Evt$_p$ — **Volcanic rocks of Mount Persis, tuffs (Eocene)**—Medium-K calc-alkaline dacitic to rhyolitic tuffs; light to dark gray to light yellowish brown; massive

Evt$_{pc}$ — **Volcanic rocks of Mount Persis, cream-colored lapilli tuffs (Eocene)**—Medium-K calc-alkaline dacitic lapilli tuffs, locally with some tuff breccia; typically pale brown, weathering to cream; pumice clasts are white and lithic clasts vary from green to gray

Evt$_{pd}$ — **Volcanic rocks of Mount Persis, dark tuffs (Eocene)**—Medium-K calc-alkaline dacitic to rhyolitic crystal vitric and vitric tuffs; typically dark gray, weathering to brown

Evbx$_p$ — **Volcanic rocks of Mount Persis, volcanic breccia (Eocene)**—Andesitic to dacitic lithic tuff breccia and lapilli tuff; multicolored but generally dark green-gray to gray, weathering to brown

Evbx$_{pb}$ — **Volcanic rocks of Mount Persis, volcanic bomb breccia (Eocene)**—Medium-K calc-alkaline dacitic lithic bomb breccia; typically with reddish gray or dark gray clasts

Evc$_p$ — **Volcanic rocks of Mount Persis, volcaniclastic rocks (Eocene)**—Lithic and feldspatholithic volcanic to tuffaceous sandstone, siltstone, and volcanic conglomerate; color variable but mostly light yellowish brown to very pale brown to light bluish gray; mostly well sorted and stratified

Evl$_p$ — **Volcanic rocks of Mount Persis, lahars (Eocene)**—Cohesive to noncohesive lahar and volcanic (boulder) conglomerate; clasts dark gray, commonly weathered or altered to gray-green; contains subrounded to subangular pebbles to boulders of andesite

Ei$_p$ — **Volcanic rocks of Mount Persis, intrusive complex (Eocene)**—Uniquely textured medium-K calc-alkaline dacite or andesite flows, pumiceous lapilli tuff, and dacitic bomb breccia; bluish gray to gray

Evs$_{pg}$ — **Puget Group, undivided (Eocene)(cross sections only)**—Mostly continental feldspathic to volcanic lithic subquartzose sandstone, siltstone, claystone, lapilli tuff, and tuff and lesser carbonaceous shale, pebble conglomerate, and coal

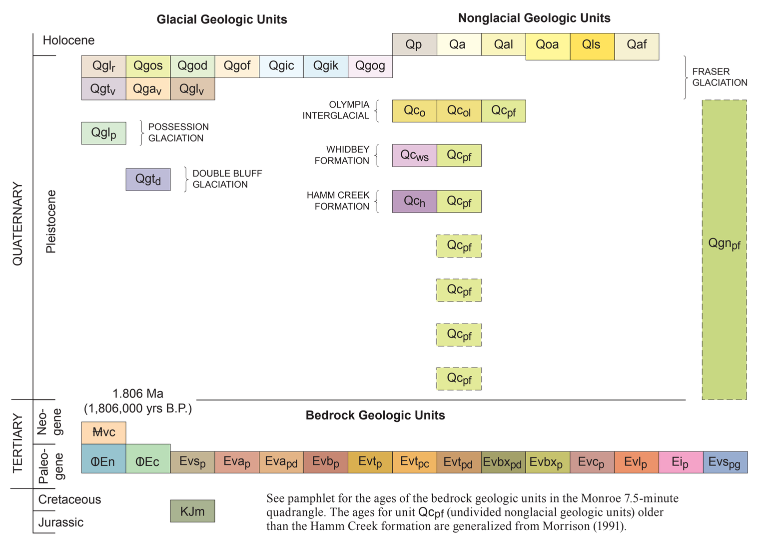
Mesozoic Low-Grade Metamorphic Rocks (Prehnite–Pumpellyite Facies)

KJm — **Western mélange belt of Tabor and others (1993)(Cretaceous to Jurassic) (cross sections only)**—Metamorphosed argillite, sandstone, greenstone, gabbro, and diabase with minor metachert, metatonalite, slate, phyllite, marble, and rare ultramafite

Tertiary to Holocene Tectonic Zones

tz, tz$_h$, Qtz — **Tectonic zone (Tertiary to Holocene)**—Cataclasite, fault breccia, clay-rich fault gouge, protomylonite, and strongly slickensided and fractured rocks in fault zones; variously colored, mottled, and veined as a result of local hydrothermal alteration or strong weathering; **low-temperature, hydrothermally altered zones** (unit tz$_h$) produce a whitish rock; **Quaternary tectonic zones** (unit Qtz) are areas of probable Quaternary deformation shown only on the cross sections

CORRELATION OF MAP UNITS



See pamphlet for the ages of the bedrock geologic units in the Monroe 7.5-minute quadrangle. The ages for unit Qc$_{pf}$ (undivided nonglacial geologic units) older than the Hamm Creek formation are generalized from Morrison (1991).

GEOLOGIC SYMBOLS

Contact—Solid where location accurate; dashed where inferred; queried where identity or existence questionable

Fault, unknown offset—Solid where location accurate; dashed where inferred; dotted where concealed; queried where identity or existence questionable

Reverse fault—Solid where location accurate; dashed where inferred; dotted where concealed; queried where identity or existence questionable; rectangles on upthrown block

Thrust fault—Solid where location accurate; dotted where concealed; sawteeth on upper plate

Right-lateral strike-slip fault—Solid where location accurate; dashed where inferred; dotted where concealed; queried where identity or existence questionable; arrows show relative motion

Left-lateral strike-slip fault—Solid where location accurate; dashed where inferred; dotted where concealed; queried where identity or existence questionable; arrows show relative motion

Reverse left-lateral oblique-slip fault—Solid where location accurate; dashed where inferred; dotted where concealed; arrows show relative horizontal motion, rectangles on upthrown block

High-angle right-lateral, oblique-slip fault—Location concealed; queried where identity or existence questionable; arrows show relative horizontal motion; U, upthrown block; D, downthrown block

High-angle left-lateral, oblique-slip fault—Solid where location accurate; dotted where concealed; arrows show relative horizontal motion; U, upthrown block; D, downthrown block

Anticline—Solid where location accurate; dashed where approximate; dotted where concealed; queried where identity or existence questionable

Syncline—Solid where location accurate; dashed where approximate; dotted where concealed; queried where identity or existence questionable; arrowhead shows direction of plunge

Direction of downslope movement of landslide

Fluvial terrace scarp—Identity and existence certain, location accurate, hachures point downscarp

A —— A′ Cross section line

60 Bedding, including flow banding in volcanic rocks of Mount Persis—Showing strike and dip

Horizontal bedding

47 Bedding in unconsolidated sedimentary deposits—Showing strike and dip

F 32 Foreset bedding in unconsolidated sedimentary deposits—Showing strike and dip

50 Joint—Showing strike and dip

Vertical or near-vertical joint—Showing strike

75 Minor fault—Showing strike and dip

Minor vertical or near-vertical fault—Showing strike

54 Slickensided surface—Showing strike and dip

Vertical slickensided surface—Showing strike

10 Minor ice-shear folds in unit Qgl$_v$—Showing bearing and plunge

S 5 Slip lineation or slickensides on a fault or shear surface—Showing bearing and plunge of offset

50 Mylonitic foliation—Showing strike and dip

W619 Water well

46W Significant site

40Y Age-date sample, U-Pb, uranium-lead

56A Age-date sample, ^{14}C, carbon-14

25A Age-date sample, optically stimulated luminescence

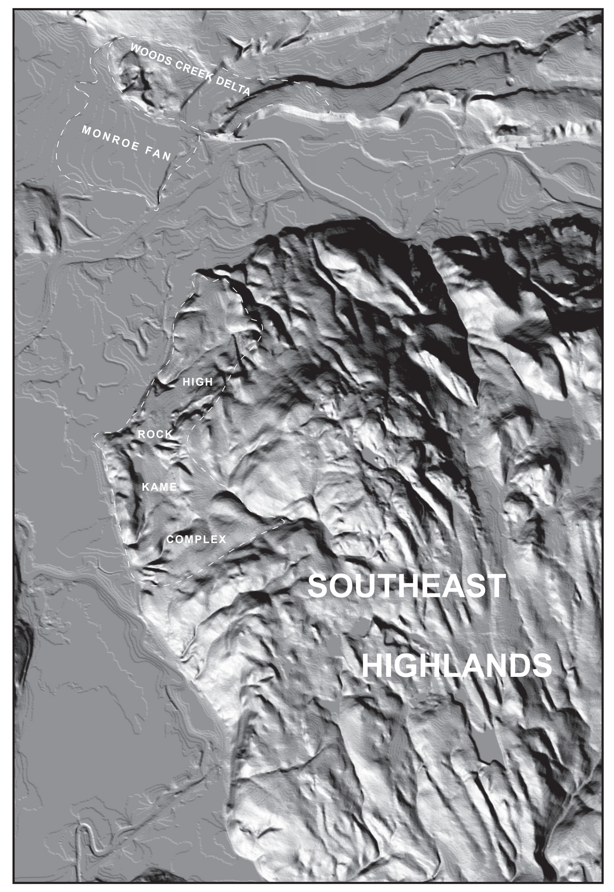


Figure 3. Shaded relief map of the Monroe 7.5-minute quadrangle. Generated from U.S. Geological Survey 10-meter digital elevation model (DEM); sun azimuth 215°; sun angle 45°; vertical exaggeration 3X.

AEROMAGNETIC AND GEOPHYSICAL MAP AND CROSS SECTIONS

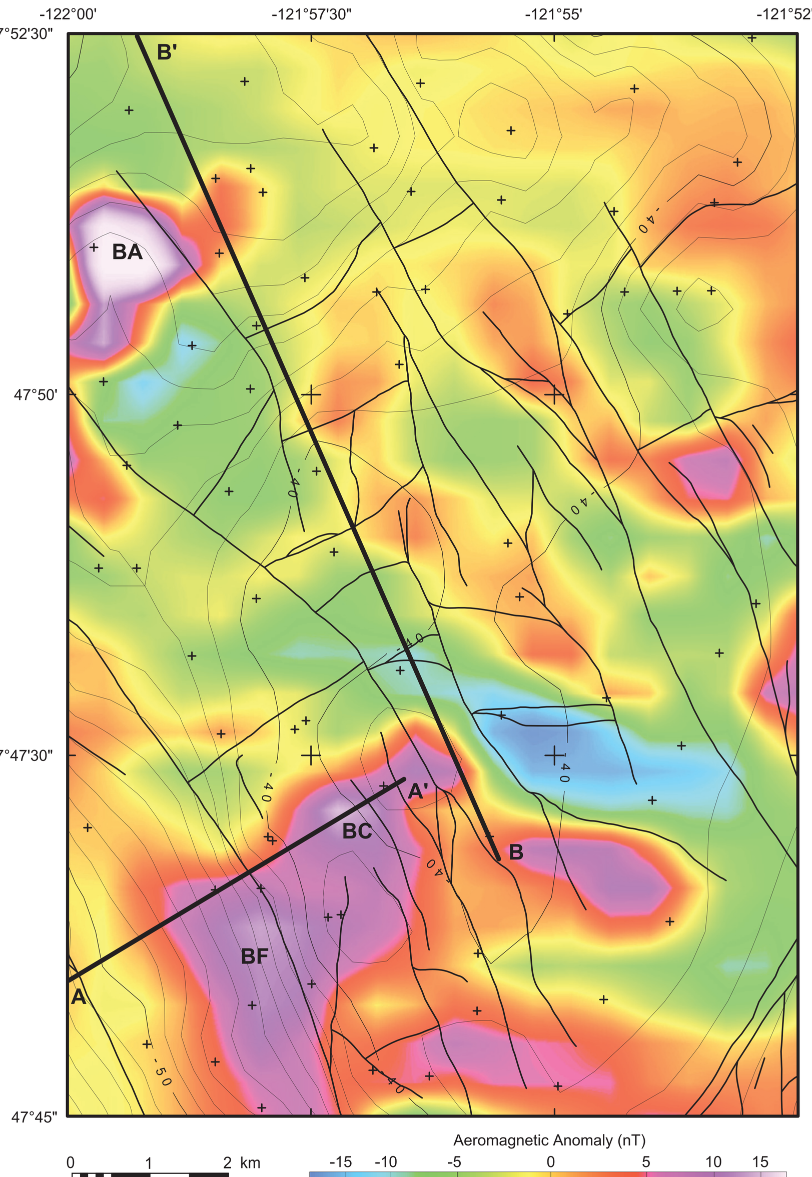
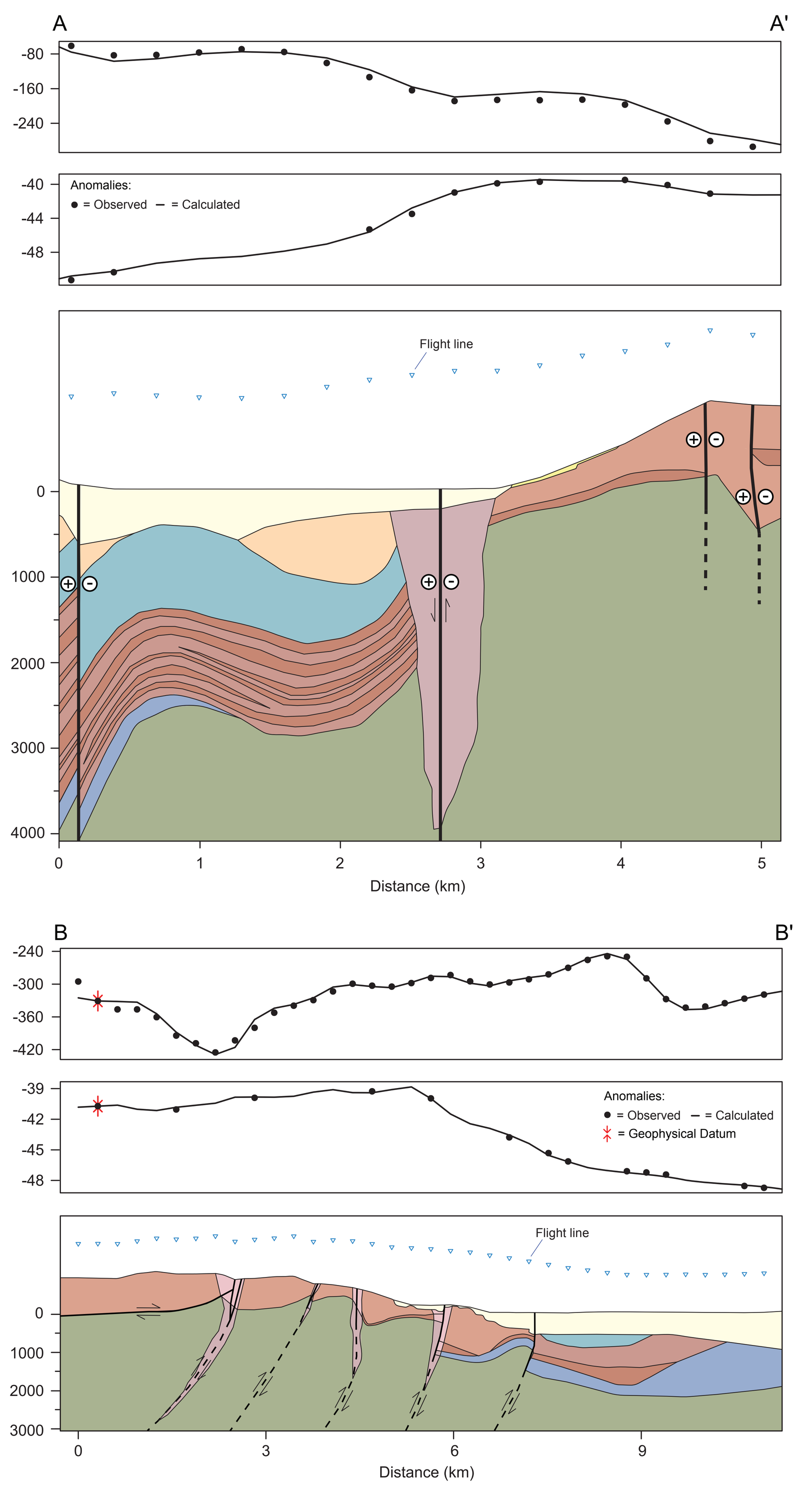
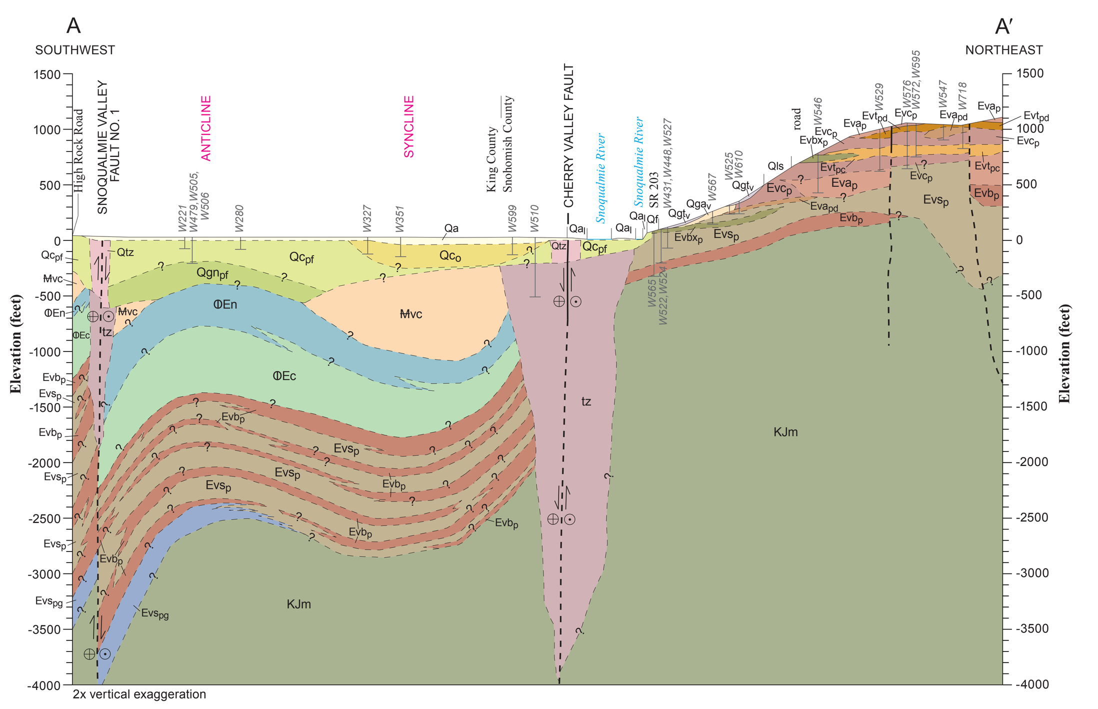


Figure 1. Aeromagnetic and gravity geophysical map of the Monroe quadrangle. Base map is the reduced-to-pole aeromagnetic anomaly map, filtered (upward continued and differenced with original grid) to bring out near-surface magnetic anomalies. Isostatic gravity contours (1 mGal interval) are labeled in mGals. Darker lines are faults from the geologic map. Crosses indicate location of gravity measurements controlling the isostatic gravity grid. **BA**, basalt outcrop; **BF**, basalt flows buried on the edge of the Seattle basin; **BC**, interpreted channelized basalts.



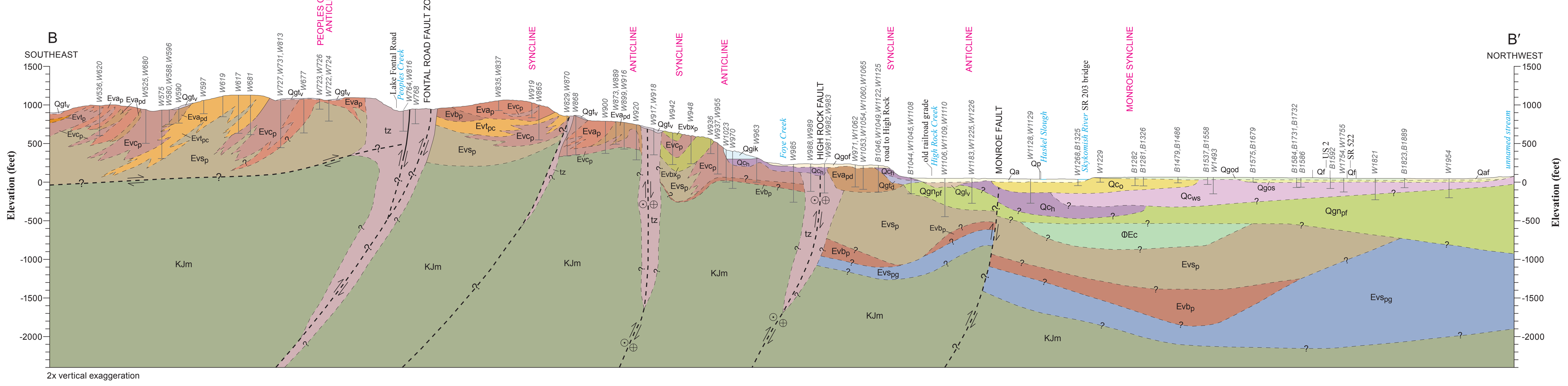
$\Delta\rho$ = -620 X = 2.6 Quaternary deposits
$\Delta\rho$ = -400 X = 1.9 Miocene volcanic and sedimentary rocks
$\Delta\rho$ = -400 X = 0.4 Blakeley Formation (undivided)
Volcanic rocks of Mount Persis
$\Delta\rho$ = -310 X = 12 distal, such as unit Evc$_p$
$\Delta\rho$ = -290 X = 8.3 proximal, such as unit Eva$_p$
$\Delta\rho$ = 30 X = 80 basalt, unit Evb$_p$
$\Delta\rho$ = -340 X = 1.2 cataclasite, like unit tz
$\Delta\rho$ = -270 X = 0 Puget Group
$\Delta\rho$ = 30 X = 1-4 Western mélange belt
$\Delta\rho$ = -10 X = 1.2 cataclasite, like unit tz

Figure 2. Geophysical cross sections A and B. The geophysical cross sections coincide with lithologic cross sections A and B on the geologic map and match predicted gravity and aeromagnetic anomalies from the cross sections to data from the region (2x vertical exaggeration). Aeromagnetic data sampling distance is on the same order of magnitude as the flightline spacing. Gravity stations shown are within 1.5 km of the line. The model is assumed to extend to infinity in both directions perpendicular to the profile. The blue triangles in the lower panel indicate the height of the flight line above the ground for the aeromagnetic data. $\Delta\rho$ is the density contrast relative to normal crust (2670) in kg/m^3; χ is magnetic susceptibility in SI units multiplied by 1000. Datum for model A–A′ is off the eastern end of the line; appropriate modeling of anomalies required placement of the cross section within a larger regional model (Dragovich and others, 2011). Solid lines show fault locations that are well-controlled by the geophysical data. Dashed lines show fault locations that are controlled by geologic mapping at the surface, but are less certain at depth. Percentage of basaltic flows depicted in the volcanic rocks of Mount Persis is directly related to relative changes in magnetism of this unit across the profile. For more information, see Dragovich and others (2011).



FAULT MOVEMENT SYMBOLS IN CROSS SECTIONS
Relative dip-slip movement
Movement toward the viewer
Movement away from the viewer

Some surficial geologic units are too thin to show as polygons at the scale of the cross sections. The extent of these units is shown by short vertical lines that extend upward from the land surface. The geologic unit symbol is placed between the vertical lines or, if space is limited, leadered into the space between the vertical lines.



Lithologic Cross Sections A and B. We collected 742 well logs, about 200 geotechnical borings, and about 300 test pit stratigraphic logs from various sources across the quadrangle as part of our subsurface analysis of the map area. About 370 of the wells are accurately located and thus used during our mapping and analyses. Well log records were used with our surface mapping to increase the accuracy of subsurface projections; some high-quality well data are shown directly. We show a composite well (multiple borings near one location) where well and boring locations are closely spaced and (or) where subsurface geologic conditions are consistent. Although other solutions are possible, our geophysical model of the map area in Dragovich and others (2011) is consistent with the stratigraphic arrangement we postulate. Epicenters near cross sections are provided in Dragovich and others (2011).