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The Monroe Fault, Anticline, and Synclinal Basin—A Potentially Active Fault and Fold System in the Skykomish River Valley, Snohomish County, Washington

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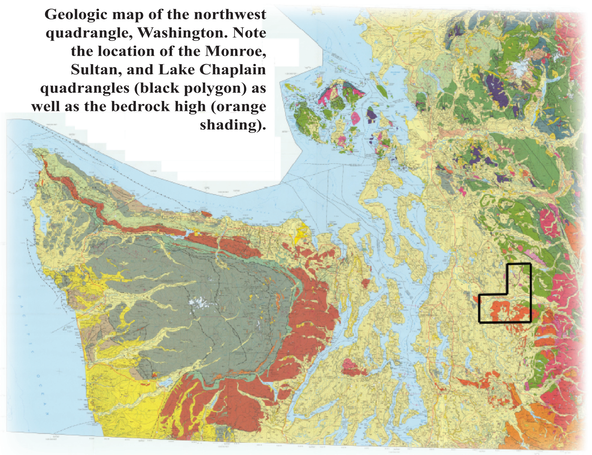
Abstract

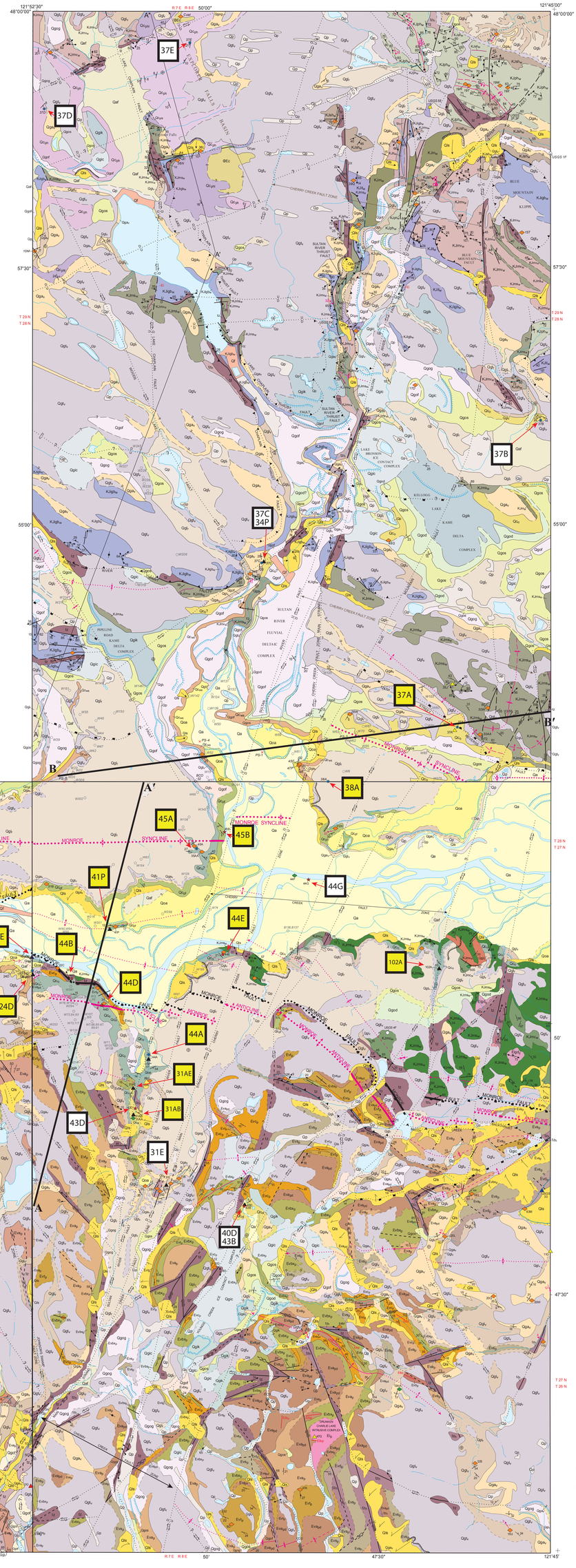
New geologic mapping of the Sultan, Monroe, and Lake Chaplain 7.5' quadrangles reveals a major reverse fault in the lower Skykomish River Valley (SRV) that juxtaposes Eocene Mount Persis volcanic rocks with the Jurassic–Cretaceous western mélange belt. We term this east-trending fault the Monroe fault (MF). The MF is bounded by the Monroe anticline and syncline and was likely an Eocene extensional fault that was rejuvenated as a north-vergent reverse fault driven by regional north-south compression.

Relations indicate that the SRV has been a structurally-controlled fluvial feature since at least mid-Pleistocene (>300ka). Both Pleistocene nonglacial fluvial deposits and Holocene Skykomish River alluvium have a Skykomish River provenance (SP) reflective of the compositionally distinct Cascade granitic source area. Pleistocene SP alluvium in the SRV is correlated with the "Olympia beds", Whidbey Fm, Hamm Creek Fm, and older nonglacial sequences on the basis of their distribution, geochemical and modal composition, stratigraphy, geophysics, and geochronology. New detrital zircon U-Pb ages from Olympia beds confirm the Cascade provenance of this ancient alluvium. The Monroe anticline overlies the MF as an upper plate, flexural-slip fold. The anticline folds SP Olympia beds as young as ~22 ka according to multiple radiocarbon and OSL/IRSL ages. North of the MF, the Monroe synclinal basin is cored by SP Olympia beds over a long axial area and locally preserves a ~300-m thick composite sequence of folded SP alluvium spanning several nonglacial episodes. Buried Tertiary strata in the syncline suggest growth folding since Oligo–Eocene time. The MF and the Seattle fault systems are similar; they are both east-west trending, north-verging structures responding to regional north-south compression with southerly hanging wall uplifts bounded by major basins to the north.

The NW-trending southern Whidbey Island fault zone (SWIF) extends into the NNW-trending Rattlesnake Mountain fault zone (RMFZ). The MF intersects the SWIF–RMFZ at an azimuthal inflection in this composite structure. We suspect the MF, RMFZ, and SWIF are primarily reverse, strike-slip, and oblique-slip faults, respectively, with the MF an eastward Cascade foothills partition of the SWIF accommodating only north-south contraction.

Geologic map of the northwest quadrangle, Washington. Note the location of the Monroe, Sultan, and Lake Chaplain quadrangles (black polygon) as well as the bedrock high (orange shading).





DESCRIPTION OF MAP UNITS

HOLOCENE NONGLACIAL DEPOSITS

- Qf Artificial fill and modified land
- Qp Peat
- Qa Alluvium
- Qoa Older alluvium (Holocene to latest Pleistocene)
- Qls Landslide deposits (Holocene to latest Pleistocene)
- Qaf Alluvial fan deposits (Holocene to latest Pleistocene)

PLEISTOCENE GLACIAL AND NONGLACIAL DEPOSITS

Vashon recessional deposits

- Qgl(r) Recessional glaciolacustrine (glacial lake) deposits
- Qgos Outwash sand
- Qgod Deltaic outwash and kame deltas
- Qgof Fluvial outwash deposits
- Qgic Ice-contact deposits, undivided
- Qgik Ice-contact kames
- Qgog Outwash gravel deposits, undivided

Vashon advance proglacial and subglacial deposits

- Qgt(v) Lodgment till
- Qga(v) Advance outwash deposits
- Qgl(v) Advance glaciolacustrine deposits

Pre-Fraser Glacial and Nonglacial Deposits

- Qc(pf) Pre-Fraser continental nonglacial deposits, ancient Skykomish River facies (Pleistocene)
- Qc(ol) Sediments of the Olympia nonglacial interval, local facies
- Qc(o) Sediments of the Olympia nonglacial interval, ancient Skykomish River facies
- Qglp Glaciomarine and glaciolacustrine deposits of the Possession Glaciation
- Qc(ws) Whidbey Formation, Skykomish River facies (Pleistocene)
- Qgtd Double Bluff till
- Qc(h) Hamm Creek formation, Snoqualmie and Skykomish River provenance
- Qc(ph) Pre-Hamm Creek nonglacial interval continental nonglacial deposits, ancient Pilchuck or Skykomish River facies (Pleistocene)
- Qc(phl) Pre-Hamm Creek nonglacial interval continental deposits, locally derived facies (Pleistocene)
- Qgn(pf) Pre-Fraser glacial and nonglacial deposits, undivided (cross sections only)

TERTIARY SEDIMENTARY ROCKS

- Mve Volcanic and sedimentary rocks (cross sections only)
- OEn Blakeley Formation, nearshore marine deposits (cross sections only)
- OEc Sedimentary rocks, undivided (Oligocene to Eocene)
- Ts Sedimentary or volcaniclastic rocks, undivided (cross sections only)
- Eigd(y) Youngs Creek intrusive complex (cross section B Sultan only)
- Evs(p) Volcanic rocks of Mount Persis of Tabor and others (1993), undivided (Eocene)
  - Eva(p) Andesite flows
  - Eva(pd) Dark basaltic andesite flows
  - Evb(p) Basalt flows and dikes
  - Evt(p) Tuff
  - Evt(pc) Volcanic rocks of Mount Persis, cream-colored lapilli tuffs (Eocene)
  - Evt(pd) Volcanic rocks of Mount Persis, dark tuffs (Eocene)
  - Evbx(p) Volcanic breccia
  - Evbx(pb) Volcanic rocks of Mount Persis, volcanic bomb breccia (Eocene)
  - Evc(p) Volcaniclastic rocks
  - Ei(p) Drunken Charlie Lake intrusive complex
  - Evs(pg) Puget Group, undivided (cross sections only)

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

- KJm(w) Western mélange belt of Tabor and others (1993), undivided (Cretaceous to Jurassic)—Locally divided into:
  - KJmv(w) Metavolcanic rocks
  - KJsh(w) Greenschist
  - KJms(w) Metasedimentary rocks
  - KJph(w) Phyllite
  - KJmc(w) Metachert
  - KJgb(w) Metagabbro
  - KJit(w) Metatonodhjemite

HOLOCENE TO TERTIARY TECTONIC ZONES

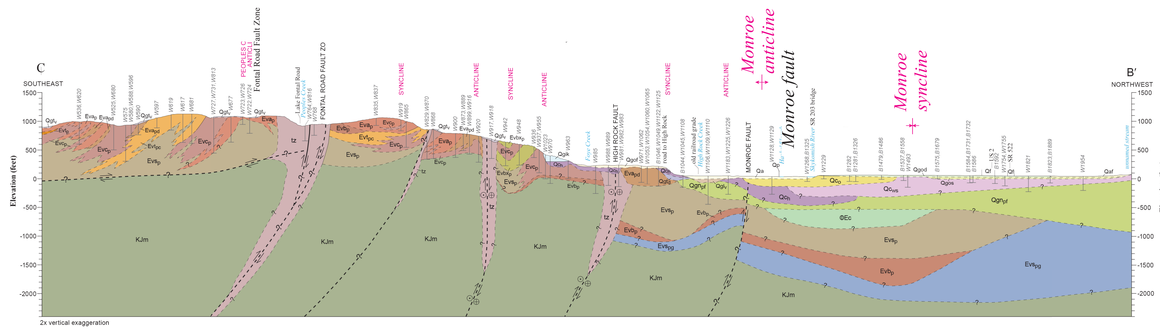
- tz, tz(h), Qtz Tectonic zone

Geologic Symbols

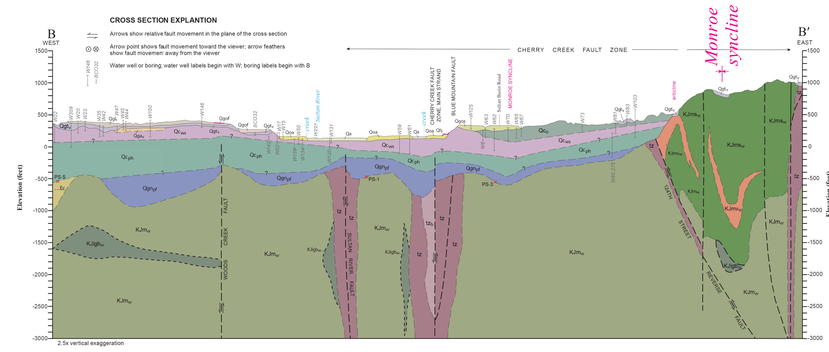
- Contact—Solid where location accurate; long-dashed where approximately located; short-dashed where inferred; queried where identity or existence questionable
- Fault, unknown offset—Solid where location accurate; long-dashed where approximately located; dotted where concealed; identity and existence certain
- Thrust fault—Solid where location accurate; long-dashed where approximately located; short-dashed where inferred; dotted where concealed; queried where identity or existence questionable; sawteeth on upper plate
- Reverse fault—Solid where location accurate; dotted where concealed; queried where identity or existence questionable; rectangles on upthrown block
- High-angle dip-slip fault—Solid where location accurate; long-dashed where approximately located; dotted where concealed; queried where identity or existence questionable; U, upthrown block; D, downthrown block
- Right-lateral strike-slip fault—Long-dashed where approximately located; dotted where concealed; arrows show relative movement
- Left-lateral strike-slip fault—Solid where location accurate; long-dashed where approximately located; short-dashed where inferred; dotted where concealed; queried where identity or existence questionable; arrows show relative movement
- High-angle right-lateral oblique-slip fault—Solid where location accurate; dashed where inferred; dotted where 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; long-dashed where approximately located; dotted where concealed; identity and existence certain; arrows show relative horizontal motion; U, upthrown block; D, downthrown block
- Anticline—Identity and existence certain; solid where accurately located; long-dashed where approximately located; dotted where concealed
- Syncline—Identity and existence certain; solid where accurately located; long-dashed where approximately located; short-dashed where inferred; dotted where concealed
- Overturned anticline—Identity and existence certain; location approximate; beds on one limb are overturned
- Fluvial terrace scarp—Identity and existence certain; location accurate; hachures point downscarp
- Landslide scarp—Identity and existence certain; location accurate; hachures point down slope
- B—B' Cross section line
- Direction of downslope movement of landslide
- Small, minor, inclined fault—showing strike and dip
- Small, minor, vertical or near-vertical fault—showing strike
- Horizontal bedding
- Vertical bedding—showing strike
- Inclined bedding—showing strike and dip
- Inclined bedding in unconsolidated sedimentary deposits—showing strike and dip
- Inclined foreset bedding in unconsolidated sedimentary deposits—showing strike and dip
- Overturned bedding—showing strike and dip
- Inclined crenulation lineation—showing bearing and plunge
- Inclined fold hinge of generic (type unspecified) small, minor, fold—showing bearing and plunge
- Inclined slickenline, groove, or striation on fault surface—showing bearing and plunge
- Inclined slickenside—showing strike and dip
- Vertical slickenside—showing strike
- USGS 19 Geochronology sample, fossil
- USGS 84 Geochronology sample, K-Ar, potassium-argon
- USGS 86 Geochronology sample, U-Pb, uranium-lead
- 37C Geochronology sample, 14C, carbon-14
- 37D Geochronology sample, optically stimulated luminescence
- WELL Water well
- 26 Significant site
- PS-6 Geophysical data collection locality

Geologic Cross Sections

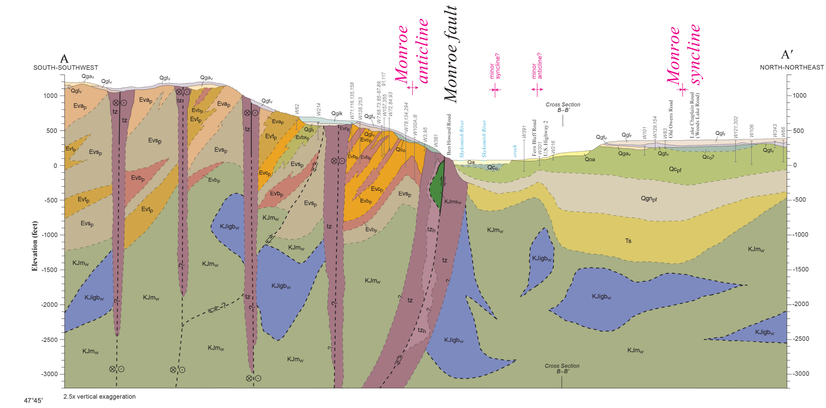
See cross section locations on the geologic map. Note the location of the Monroe fault, anticline, and syncline. Also note the folding and tilting of the latest Pleistocene Olympia beds--the beds are ancient Skykomish alluvium and are deformed by Monroe anticline and syncline.



For analyses of subsurface conditions, we obtained 742 well logs, 200 geotechnical borings, and 300 test pit stratigraphic logs. Most high quality well, boring, and test pit data is shown.



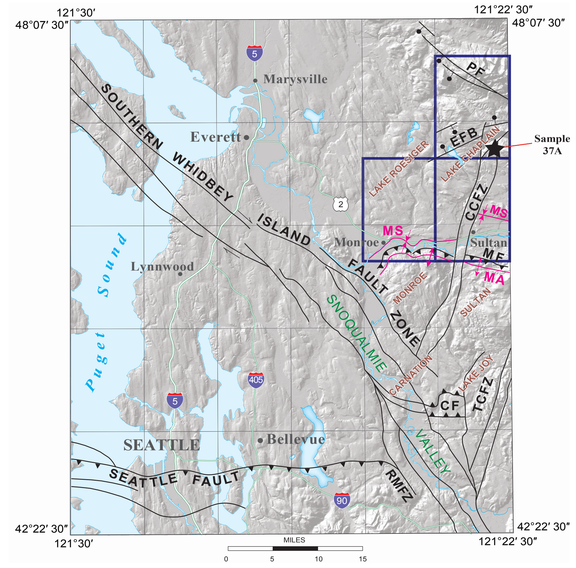
For analyses of subsurface conditions, we obtained 344 well logs, 32 geotechnical borings, and 24 test pit stratigraphic logs. We only show the highest quality well and boring data near the cross sections.



For analysis of subsurface conditions, we obtained 402 stratigraphic logs from wells, geotechnical borings, and test pits. Most high quality well and boring data near the cross sections are shown. Pleistocene ancient SP alluvial sediments, such as the Olympia beds (units Qco and Qcol) are likely folded in the vicinity of the Monroe anticline and syncline, and uplifted by the Monroe fault.

Regional Diagram

Location of three recently mapped quadrangles and major fault zones.



Simplified regional tectonic map of the central Puget Lowland and Cascade foothills. The Tokul Creek fault zone (TCFZ) is similar to the CCFZ. They are likely left-lateral conjugates to the southern Whidbey Island fault zone (SWIF). MF, Monroe fault; CF, Carnation fault; MS, Monroe syncline; MA, Monroe anticline; RMFZ, Rattlesnake Mountain fault zone; EFB, Explorer Falls basin. The bedrock high south of the Monroe fault and north of the Carnation fault is likely uplifted between these two opposing reverse faults. We also show the Pilchuck River fault (PF) of Tabor and others (2002) to the north. The PF and EFB might be part of a family of extensional structures preserving Paleogene to Pleistocene basin sediments.