WASHINGTON STATE DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGY AND EARTH RESOURCES

WASHINGTON DIVISION OF GEOLOGY AND EARTH RESOURCES
MAP SERIES 2016-03

Geologic Map of the Granite Falls 7.5-minute Quadrangle
Pamphlet accompanies map

Geologic Map of the Granite Falls 7.5-minute Quadrangle, Snohomish County, Washington

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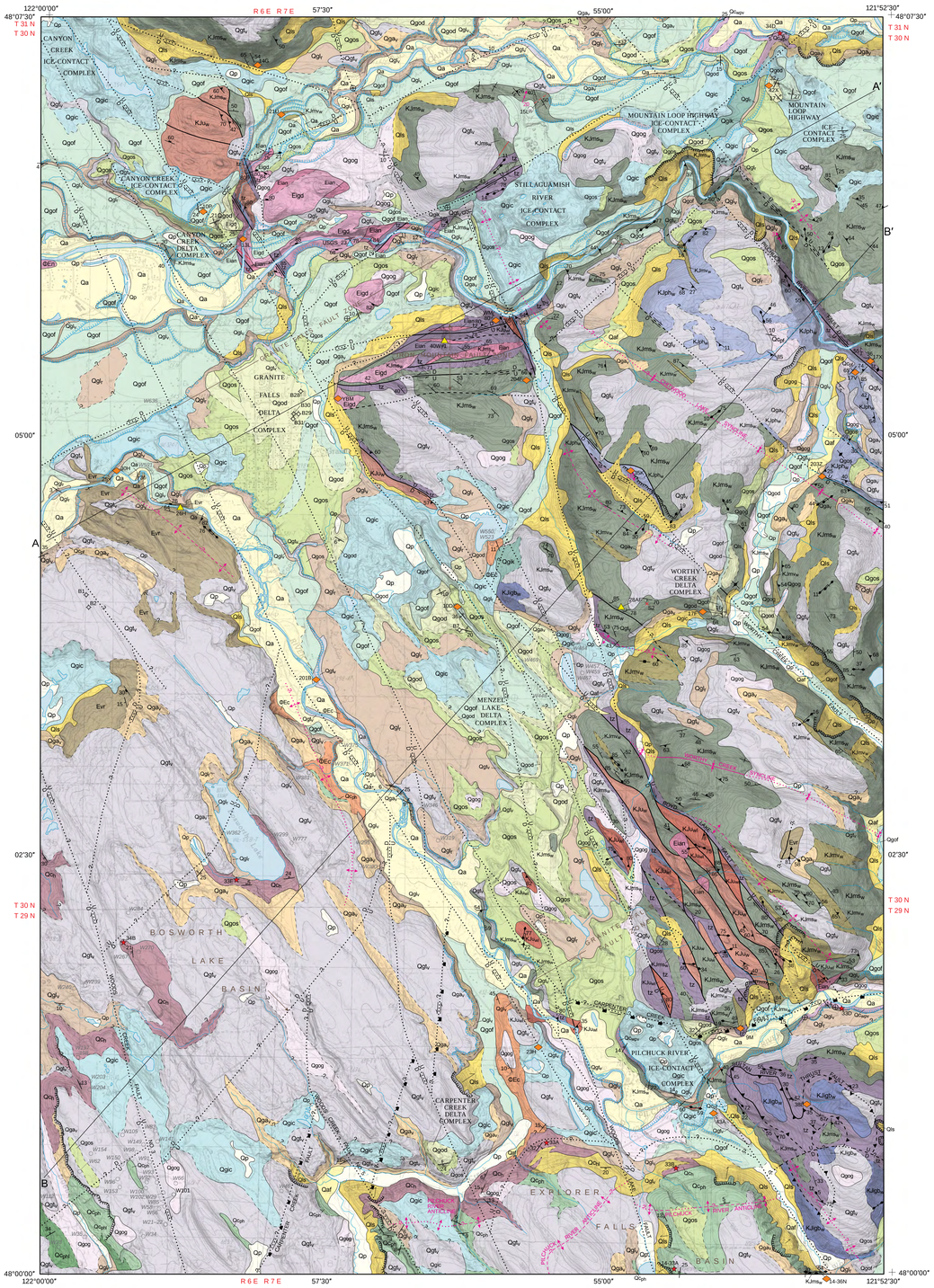


MAJOR FINDINGS

- The Explorer Falls basin preserves a thick sequence of weathered Pleistocene Pilchuck River provenance alluvium that has been locally inverted due to on-going regional north-south compression.
- We suggest that the Pilchuck River anticline is a mid-to late-Pleistocene growth fold in the northern part of the Explorer Falls basin—this fold is directly south of the locally active Carpenter Creek fault (CCF) and generally above the Carpenter Creek earthquake cluster (CCEC).
- The northwest-trending right-lateral to oblique-slip Granite Falls fault zone (GFFZ) forms the eastern edge of the Bosworth Lake basin, which is a small, eastern arm of the greater Everett basin.
- The Granite Falls stock is the source for numerous dikes and the sub-volcanic magmatic rhyolites in the map area. The stock is thought to have intruded into a "pull-apart" or extensional structure during regional Eocene transtension.
- Widespread ultramafite within and west of the GFFZ may mark the lowermost thrust of the Eastern mélange belt (EMB) over the Western mélange belt (WMB). Additionally, stratigraphically coherent low-grade metasediments of the WMB were locally mapped east of the GFFZ in the quadrangle.
- Our array of portable seismic instruments deployed around the CCEC has detected micro and minor earthquakes along an east-northeast-trending band that we correlated broadly with the CCF. However, they likely include smaller strains along conjugate faults to the CCF that were generated by earlier larger CCF seismic events.

DESCRIPTION OF MAP UNITS

(see pamphlet for detailed map unit descriptions and Table 1 for sand provenance information)

Quaternary Sedimentary Deposits

HOLOCENE NONGLACIAL DEPOSITS

Qp — **Peat**—Loose or soft peat, muck, and organic silt and clay, locally with diatomite and thin beds of Mazama ash (Rigg, 1958). Peat is found in abandoned river-channel depressions where it is interstratified with alluvial deposits (for example, in the South Fork Stillaguamish River valley) or deposited in upland depressions and kettles over low-permeability glacial deposits such as till or poorly sorted ice-contact deposits.

Qa — **Alluvium**—Sand, silt, gravelly sand, and sandy pebble gravel; locally includes peat and organic sediment and (or) cobble gravel; clasts subrounded to rounded; well stratified and sorted; sand is planar bedded; woody debris and detrital wood are common.

Qls — **Landslide deposits (Holocene to latest Pleistocene)**—Diamicton (unsorted mixture of clay, silt, sand, gravel, and wood debris) or boulder gravel, and local, minor, amounts of sand or gravel. Only large landslides are shown; absence of a mapped landslide does not imply absence of hazard.

Qaf — **Alluvial fan deposits (Holocene to latest Pleistocene)**—Diamicton, alluvial gravel, boulder gravel, and sand; poorly to moderately sorted; moderately stratified to massive; locally contain significant debris flow deposits.

PLEISTOCENE GLACIAL AND NONGLACIAL DEPOSITS

Deposits of the Vashon Stade of the Fraser Glaciation

Vashon Recessional Deposits

Qgf$_r$ — **Vashon recessional glaciolacustrine (glacial lake) deposits**—Silt and clayey or sandy silt to silty sand, typically with scattered dropstones; local lenses or beds of sand or gravel; loose or soft; massive or laminated to thinly bedded; locally displays varve-like rhythmites; deposited in proglacial lakes.

Qgos — **Vashon outwash sand**—Sand and pebbly sand with some interbeds of silty sand, silt, or gravel; loose or soft; unstratified to weakly stratified to planar bedded, laminated, and rarely crossbedded.

Qgod — **Vashon deltaic outwash and kame deltas**—Sandy cobble gravel, gravel, pebbly sand; loose; moderately to well sorted; thin to very thickly bedded; well stratified with conspicuous high-amplitude foreset beds.

Qgof — **Vashon fluvial outwash deposits**—Cobble and boulder gravel, gravel, pebbly sand, and interbeds of sand and rare silt; loose; moderately to well stratified; commonly contains medium to very thick subhorizontal beds with bar or ripple crossbedding, imbricated gravel, scour structures, and rip-up clasts.

Qgic — **Vashon ice-contact deposits**—Cobble to boulder gravel and gravel, locally containing diamicton, silty pebble gravel, sand, pebbly sand, and silt; loose or soft; moderately stratified and medium to very thickly bedded; abrupt grain-size changes common. Locally subdivided into:

Qgik — **Vashon ice-contact kames**—Cobble and boulder gravel, gravel, sand, and pebbly sand, with lenses of diamicton; loose; crossbedded, with localized oversteepened or slumped strata; cut-and-fill structures and rip-up clasts of till or silt common.

Qgog — **Vashon outwash gravel deposits, undivided**—Poorly exposed boulder–pebble gravel to pebbly sand; loose; massive to crudely bedded; largely ice-contact deposits; may include any of the gravelly Vashon recessional facies.

Vashon Advance Proglacial and Subglacial Deposits

Qgt$_v$ — **Vashon lodgment till**—Diamicton (unsorted mixture of clay, silt, sand, and gravel); matrix-supported; dense; accreted at the base of the Vashon ice; typically displays a friable shear fabric.

Qgaa$_v$ — **Vashon advance outwash deposits**—Sand and pebble gravel, sand and cobble gravel, and local silt; dense; well sorted and stratified; thinly to thickly bedded; deltaic and bar foreset beds, cut-and-fill structures, and silt rip-up clasts common.

Qgl$_v$ — **Vashon advance glaciolacustrine deposits**—Silt, clayey silt, pebbly silt, and diamicton; stiff to hard, or dense to very dense; locally contains very thin to thick beds of sand, scattered dropstones, and iceberg melt-out or flow till; stratification and sorting vary; massive to thinly bedded, laminated, or varved.

Pre-Fraser Glacial and Nonglacial Deposits

Qcgf — **Pre-Fraser continental nonglacial deposits, ancient Pilchuck River facies, undivided (Pleistocene)**—Sand, silt, or clay, locally with some organic matter and peat, and less sand and gravel; deposited prior to the Fraser glaciation; sand is typically weathered to a yellow-brown-gray; dense; laminated to very thickly bedded and mostly well stratified; may contain charcoal, logs, sticks, disseminated organic matter, trough-and-ripple crossbedding, and graded beds.

Qc$_{wpv}$ — **Whidbey Formation, ancient Pilchuck River valley facies (Pleistocene)**—Sand, silt, clayey silt, and silty sand with less pebbly sand, clay, gravel, and (or) organic sediment (including peat); dense or hard; well sorted and stratified; may contain charcoal, disseminated organic matter, trough-and-ripple crossbedding, graded beds.

Qch — **Hamm Creek nonglacial interval (formation), Pilchuck Valley provenance (Pleistocene)**—Sand, silt, and silty sand, with less pebbly sand, lenses or beds of gravel, clay, and (or) organic sediment with disseminated organic material, wood, charcoal, and plant fossils; sand is weathered to a distinctive bright orange-brown; dense or hard; well sorted and stratified; mostly occurs as laminated to thinly bedded sand and silt, locally with crossbedding or graded beds; rare folded or chaotic bedding.

Qcg — **Hamm Creek nonglacial deposits, locally derived facies (Pleistocene)**—Pebbly sand, sand, with less gravel, cobble gravel, and rare silt; locally contains organic sediments; distinctive dark-bluish gray, weathers grayish brown; dense or hard; thinly to thickly bedded, commonly with lenticular interbeds; low-angle foreset beds rarely observed; well sorted; angular to subrounded grains. These deposits are very lithic rich and contain 50–60 percent WMB-derived metasedimentary grains—meta-argillite, phyllite, metasandstone, and metachert.

Qc$_{gs}$ — **Pre-Hamm Creek nonglacial deposits, ancient Pilchuck River facies (Pleistocene)**—Pebble gravel, gravelly sand, pebbly sand, sand, silty sand, and silt , locally with some cobble gravel and clay; dense or hard; sand is typically yellowish brown to pale brown, but sometimes grey to blue grey; oxidized and strongly weathered; thin to very thickly bedded; well stratified; rip-up clasts, cross bedding, graded beds, leaves, twigs, charcoal, logs, or disseminated organic matter are common; flame structures are found in a few outcrops.

Qc$_{gm}$ — **Pre-Hamm Creek continental deposits, locally derived facies**—Sand, pebbly sand, sandy pebble gravel, with less gravel, cobble gravel, and rare silt; locally contains peat, logs or organic sediment; dense or hard; sediment has a distinct local Western mélange belt provenance with up to 95 percent WMB-derived metasedimentary grains—meta-argillite, phyllite, metasandstone, and metachert.

Qgf$_{gf}$ — **Pre-Fraser glacial and nonglacial deposits (Pleistocene to Pliocene?)(cross sections only)**—Gravel, boulder gravel, sand, silt, clay, and diamicton; may locally contain peat or organic sediments. This unit is mapped in cross section where pre-Fraser deposits may include older glacial and (or) nonglacial material.

TERTIARY VOLCANIC, INTRUSIVE, AND SEDIMENTARY ROCKS

ΦEc — **Rocks of Bulson Creek of Lovseth (1975)(Oligocene to Eocene)**—Lithic to lithofeldspathic sandstone with less conglomerate, siltstone, and coal with minor claystone. Units ΦEc and ΦEn thicken considerably west of the Granite Falls fault zone and into the Bosworth Lake basin.

ΦEn — **Rocks of Bulson Creek of Lovseth (1975), nearshore to marine facies (Oligocene to Eocene)**—Shale, siltstone, sandstone, and mostly pebble conglomerate. Subsurface information indicates a substantial thickness of unit ΦEn in the northwestern corner of the map area directly west of the Granite Falls fault zone.

Evr — **Rhyolite of Hansen Lake (Eocene)**—Dacitic to rhyolitic ash-flow tuff, lapilli tuff, lapillistone, tuff breccia and flows; glassy to devitrified; medium-potassium calc-alkaline; fragmental tuff and breccia deposits typically dominated by lithic fragments.

Eigd — **Granite Falls stock, main-phase intrusive complex (Eocene)**—Light to dark-grey hornblende granodiorite; hypidiomorphic granular; medium-potassium calc-alkaline; locally grades to minor quartz gabbro near contact complexes along the margins of main phase intrusions.

Eian — **Granite Falls stock, contact complex and dikes (Eocene)**—Contact complex containing medium- to high-K calc-alkaline dacite and rhyolite dikes with lesser andesite and basaltic trachyandesite; locally includes fine-grained to medium-grained gabbro and minor granodiorite bounding the Granite Falls stock (main phase). Also includes solitary dikes and dike complexes intruding fault zones away from the main stock as well as thicker contact complexes bounding the main stock.

MESOZOIC LOW- TO MEDIUM-GRADE METAMORPHIC ROCKS

KJmw — **Western mélange belt of Frizzell and others (1987), undivided (Cretaceous to Jurassic)(cross sections only)**—Meta-argillite, metasandstone, greenstone, metachert, with less metadiabase, metagabbro, metatonalite (metatrondhjemite), slate, (banded) amphibolite and hornblendite, and phyllite; minor marble with metaquartz-diorite and rare ultramafic rocks. Subdivided into:

KJmv$_w$ — **Metavolcanic rocks (Cretaceous to Jurassic)**—Greenstone; derived from metamorphosed basaltic to andesitic tuff, tuff breccia, and lapilli tuff with basaltic to dacitic volcanic flows.

KJms$_w$ — **Metasedimentary rocks (Cretaceous to Jurassic)**—Marine feldspathic to feldspathollithic subquartzose metasandstone, silty metasandstone, meta-argillite, metatuff, tuffaceous metasandstone, and chert-pebble metaconglomerate; lesser metachert and marble found as discontinuous pods. Marble pods might be tectonically emplaced.

KJph$_w$ — **Phyllite (Cretaceous to Jurassic)**—Phyllite, phyllitic metasandstone, meta-argillite, slate, and minor amounts of semischistose rocks, including local foliated metatuffaceous greenschist interbeds. Includes rare tectonic lenses quartz mica schist.

KJgb$_w$ — **Metagabbro (Cretaceous to Jurassic)**—Metagabbro, quartz metagabbro and minor metadiabase dikes or rare zones of felsic pegmatite; regionally, lesser amounts of metatrondhjemite/metatonalite, feldspathic hornblendite and gneissic amphibolite, and rare meta quartz-diorite are reported regionally.

KJ$_{ub}$ — **Ultramafic rocks (Cretaceous to Jurassic)**—Serpentinite with rare serpentinized peridotite or pyroxenite.

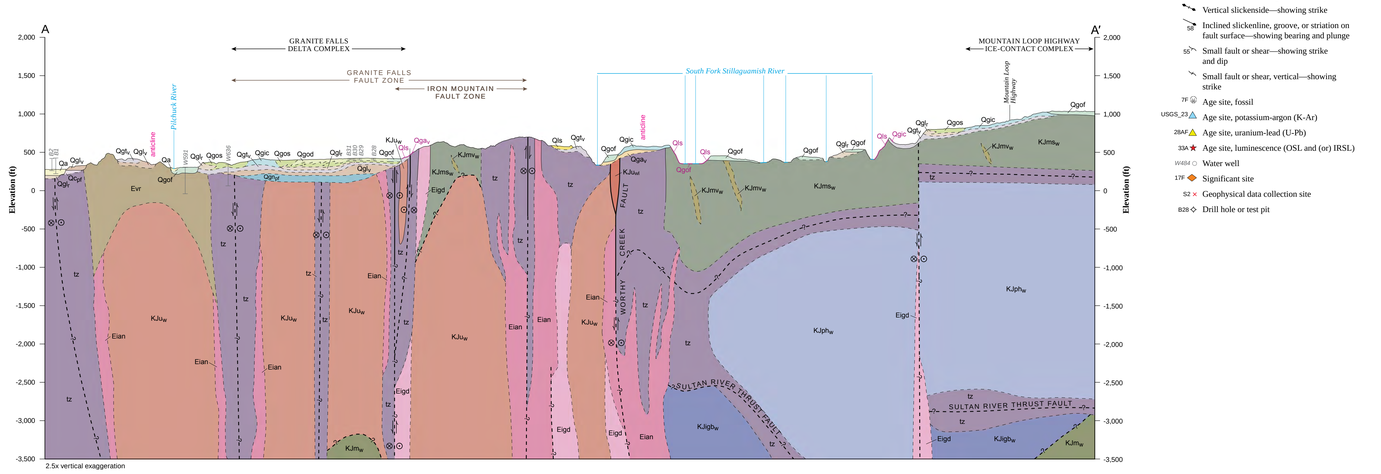
KJ$_{wl}$ — **Listwänite silica-carbonate rocks (Cretaceous to Jurassic)**—Silica-carbonate mineralization products (listwänites) locally contain pods of incompletely altered serpentinite and intense secondarily brecciated silica-carbonate rock.

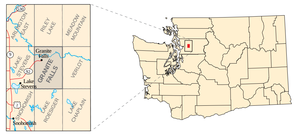
HOLOCENE TO TERTIARY TECTONIC ZONES

tz — **Tectonic zone**—Cataclasite, fault breccia, clay-rich fault gouge, protomylonite, and moderately to strongly slickenlined, fractured, and veined rocks in fault zones; green and yellow to orange to variously colored, mottled, and locally altered.

GEOLOGIC SYMBOLS

- Contact—Solid where location accurate; long-dashed where approximately located; queried where identity or existence questionable
- Fault, unknown offset—Solid where location accurate; short-dashed where inferred; dotted where concealed; queried where identity or existence questionable
- Thrust fault—Solid where location accurate; short-dashed where inferred; dotted where concealed; triangles on upper (structurally higher) plate
- Right-lateral strike-slip fault—Solid where location accurate; dotted where concealed; queried where identity or existence questionable; arrows show relative motion
- Reverse left-lateral, oblique-slip fault—Short-dashed where inferred; dotted where concealed; queried where identity or existence questionable; arrows show relative horizontal motion
- High-angle dip-slip fault—Short-dashed where inferred; dotted where concealed; queried where identity or existence questionable; U, upthrown block; D, downthrown block
- High-angle, oblique-slip fault—Solid where location accurate; short-dashed where inferred; dotted where concealed; queried where identity or existence questionable; arrows show relative horizontal motion; U, upthrown block; D, downthrown block
- Anticline—Solid where location accurate; short-dashed where inferred; dotted where concealed; queried where identity or existence questionable
- Syncline—Solid where location accurate; short dashed where inferred; dotted where concealed; queried where identity or existence questionable
- Fluvial terrace scarp—Identity and existence certain; location accurate; hachures point downslope
- Landslide scarp—Identity and existence certain; location accurate; hachures point downslope
- A —— A′ Cross section line
- Direction of downslope movement of landslide
- 70 Inclined bedding—showing strike and dip
- Vertical bedding—showing strike
- Horizontal bedding
- 70 Inclined bedding in unconsolidated sedimentary deposits—showing strike and dip
- 10 Inclined foreset bedding in unconsolidated sedimentary deposits—showing strike and dip
- 5 Inclined bottomset bedding in unconsolidated sedimentary deposits—showing strike and dip
- 40 Inclined metamorphic or tectonic foliation—showing strike and dip
- Vertical metamorphic or tectonic foliation—showing strike
- Vertical metamorphic or tectonic foliation parallel to bedding—showing strike
- Inclined first-generation metamorphic or tectonic foliation—showing strike and dip
- Inclined second-generation metamorphic or tectonic foliation—showing strike and dip
- 23 Inclined mylonitic foliation—showing strike and dip
- Inclined crenulation lineation—showing bearing and plunge
- 70 Inclined flow banding, lamination, layering, or foliation in igneous rock—showing strike and dip
- 15 Inclined fold hinge of small, minor fold—showing bearing and plunge
- 82 Small, minor inclined joint—showing strike and dip
- Small, minor vertical or near-vertical joint—showing strike
- 65 Slickenside—showing strike and dip
- Vertical slickenside—showing strike
- 50 Inclined slickenline, groove, or striation on fault surface—showing bearing and plunge
- 55 Small fault or shear—showing strike and dip
- Small fault or shear, vertical—showing strike
- 7F Age site, fossil
- USGS_23 Age site, potassium-argon (K-Ar)
- 28AF Age site, uranium-lead (U-Pb)
- 33A Age site, luminescence (OSL and (or) IRSL)
- W484 Water well
- 17F Significant site
- S2 Geophysical data collection site
- B28 Drill hole or test pit





SCALE 1:24,000

1 0.5 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 0.5 0 1 KILOMETER
contour interval 20 feet

16°
MAG. NORTH
TRUE NORTH
APPROXIMATE MEAN DECLINATION, 2016

This geologic map was funded in part by the U.S. Geological Survey National Cooperative Geologic Mapping Program.

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 92 meters east as shown by crosshair corner ticks
Base map from scanned and rectified U.S. Geological Survey Granite Falls 7.5-minute quadrangle, 1989
Shaded relief generated from a lidar bare-earth digital elevation model (available from Puget Sound Lidar Consortium, http://pugetsoundlidar.ess.washington.edu/)
GIS by Skyler P. Mavor
Digital cartography by Daniel E. Coe, and Ian J. Hubert
Layout and production by Daniel E. Coe and Alexander N. Steely

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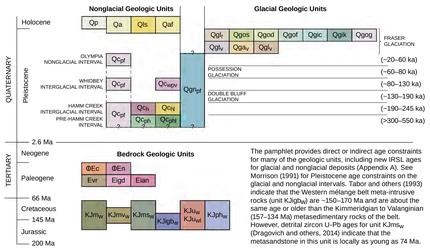
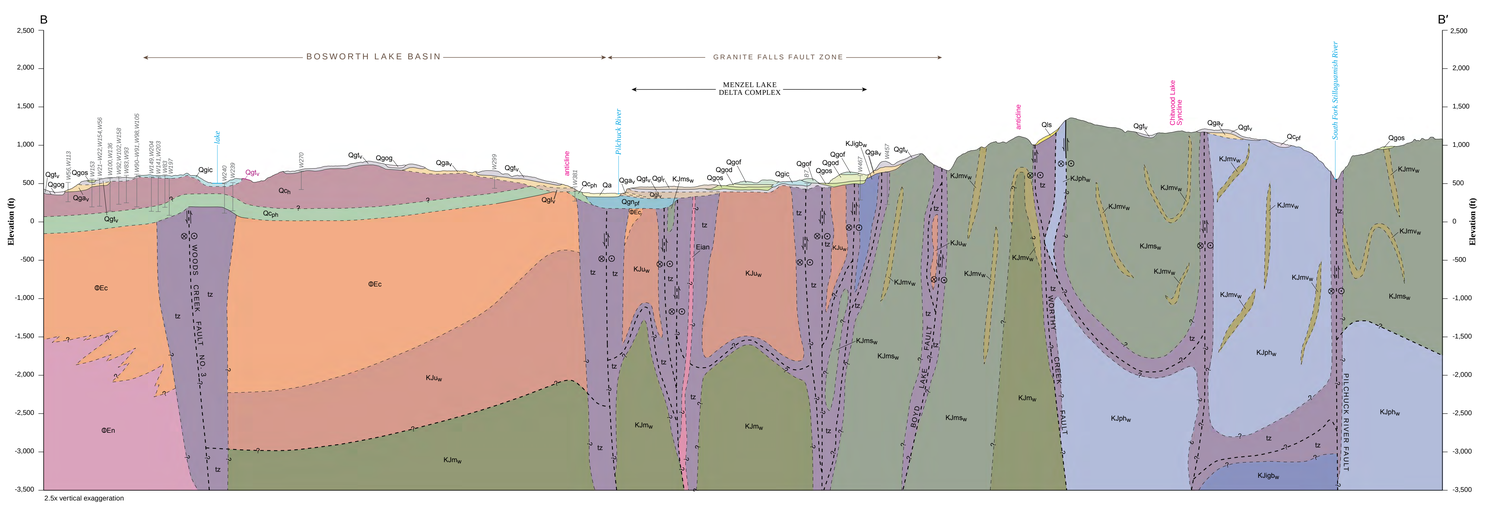
CORRELATION OF MAP UNITS



The pamphlet provides direct or indirect age constraints for many of the geologic units, including new IRSL ages for glacial and nonglacial deposits (Appendix A). See Morrison (1991) for Pleistocene age constraints on the glacial and nonglacial intervals. Tabor and others (1993) indicate that the Western mélange belt meta-intrusive rocks (unit KJgb$_w$) are ~150–170 Ma and are about the same age or older than the Kimmeridgian to Valanginian (157–134 Ma) metasedimentary rocks of the belt. However, detrital zircon U-Pb ages for unit KJm$_w$ (Dragovich and others, 2014) indicate that the metasandstone in this unit is locally as young as 74 Ma.

CROSS SECTION EXPLANATION

- Qgaa$_v$ / Qls — Geologic units too thin to show as polygons at the scale of the cross section. Ticks mark separate units.
- Arrows show relative fault movement in the plane of the cross section.
- Arrow point shows fault movement toward the viewer; arrow feathers show fault movement away from the viewer.
- W146 — Water well or boring



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