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MISCELLANEOUS FIELD STUDIES MAP MF-2423
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FIELD AND LABORATORY DATA FROM AN EARTHQUAKE HISTORY STUDY OF THE WATERMAN POINT FAULT, KITSAP COUNTY, WASHINGTON

By

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INTRODUCTION

The newly discovered Waterman Point fault is part of the Seattle fault zone, an east-west zone of young thrust faults and folds along the north flank of the Seattle uplift in the central Puget Lowland (fig. 1; Johnson and others, 1999; Brocher and others, 2001; Blakely and others, 2002; ten Brink and others, 2002). The earthquake history of the fault zone is poorly known (Sherrod and others, 2000; Sherrod, 2001; Nelson and others, in press), and efforts to quantify the earthquake hazard posed by the fault zone are hampered by the lack of fault-specific earthquake-recurrence intervals for faults such as the Waterman Point fault (Frankel and others, 2002). Uplifted marine terraces and tsunami deposits record one earthquake of at least magnitude 7 about AD 930-900 (1050-1020 cal yr BP) on the northernmost fault in the Seattle zone (fig. 1; Atwater and Moore, 1992; Bucknam and others, 1992; Atwater, 1999), but the first radiocarbon-measured earthquake-recurrence intervals for a fault in the lowland come from five trenches dug across a recently discovered Holocene fault scarp in the Seattle fault zone on Bainbridge Island (fig. 1; Nelson and others, 2002; in press). The scarp was the first in the Puget Lowland to be identified on Airborne Laser Swath Mapping (ALSM) imagery (Bucknam and others, 1999; Haugerud and others, 2001).

A second similar Holocene scarp was revealed by ALSM surveys flown in Kitsap County by Terrapoint LLC during the winters of 2000 and 2001 (fig. 1; Harding and others, 2002; Haugerud and others, 2003). Funding and support for data acquisition and processing were provided by the USGS, the National Aeronautics and Space Administration, Kitsap County, and the Puget Sound Lidar Consortium. High-resolution digital elevation models (DEMs) of topography derived from ALSM data that were processed to remove vegetation (for example, Harding and Berghoff, 2000) show a south-facing scarp extending 1.6 km across the Point Glover peninsula (fig. 1) northeast of Port Orchard at Waterman Point in the western part of the Seattle fault zone (figs. 1 and 2). Scarp heights along the fault generally decrease from 3-5 m along the western half of the scarp to 1-3 m along the eastern half.

We excavated three backhoe trenches across the scarp of the Waterman Point fault in August 2001 to determine the history of surface-deforming earthquakes since the recession of the Puget Lobe glacier about 16 ka (Porter and Swanson, 1998). The upper 1-3 m of the west walls of the Snowberry and Madrone Ridge trenches were sloped 5-40° from vertical for safety, whereas the east walls were benched (figs. 3 and 4). Lightly shaded colors at the base of the Snowberry trench between m 19.4 and m 21.3 show an exposure dug during backfilling of the trench to expose unit 1 on both sides of fault F1. Trench logging at scales of 1:7 to 1:20 (methods similar to McCalpin, 1998, p. 56-75, and Lindvall and others, 2002) was compiled on photomosaics of 1- to 7-m-long sections of trench wall consisting of 1-m by 1-m (2-m by 2-m for the Nettle Grove trench) rectified photo tiles (700-1200 pixels/m). Stratigraphy on sloping trench walls was projected as much as 2 m eastward into the vertical plane shown on the trench logs. Description of three soil profiles in two trenches helped us tie stratigraphic units to landform development (table 2; McMurphy, 1980; methods of Birkeland, 1999). Paleoecologic study of proglacial lake deposits near the south end of the Snowberry trench was unsuccessful because the deposits were barren of diatoms and macrofossils.

Similar to our earlier report about the similar Toe Jam Hill fault, 3 km to the northeast on Bainbridge Island (Nelson and others, 2002), this map presents primary field and laboratory data from trenches that are being used to develop a latest Pleistocene and Holocene history of large earthquakes on the Waterman Point fault. The map does not show how surface faulting and folding events identified in each trench may correlate among trenches or attempt to use the data presented to develop an earthquake history for the Waterman Point fault. These latter objectives, and how they impact earthquake hazard assessment in the Puget Lowland, are the subject of a future report.

Adjacent to each trench log is a summary explanation of stratigraphic units and notes about important stratigraphic relations or interpretations of units. Neither the colors (used to show inferred genesis) nor the numbers (used to label stratigraphic units) imply direct chronologic correlation of units from trench to trench. Units on logs are numbered approximately from oldest to youngest. Although many units overlap in age, unit numbers show how we mapped packages of sediment formed or deformed by similar processes in approximate chronologic sequence. Unit explanations are presented from left to right and top to bottom to increase readability where space is limited. References to methods of description and analysis in the notes to the radiocarbon and soils data tables are included in the cited references listed below.

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REFERENCES CITED

Atwater, B.F., 1999, Radiocarbon dating of a Seattle earthquake to A.D. 900-930: Seismological Research Letters, v. 70, p. 232.
Atwater, B.F., and Moore, A.L., 1992, A tsunami about 1000 years ago in Puget Sound, Washington: Science, v. 258, p. 1,614-1,617.
Birkeland, P.W., 1999, Soils and geomorphology: New York, Oxford University Press, 430 p.
Blakely, R.J., Wells, R.E., Weaver, C.S., and Johnson, S.Y., 2002, Location, structure, and seismicity of the Seattle fault zone, Washington: Evidence from aeromagnetic anomalies, geologic mapping, and seismic-reflection data: Geological Society of America Bulletin, v. 114, p. 169-177.
Brocher, T.M., Parsons, T., Blakely, R.J., Christensen, N.I., Fisher, M.A., Wells, R.E., and the SHIPS Working Group, 2001, Upper crustal structure in Puget Lowland, Washington: Results from the 1998 seismic hazards investigation in Puget Sound: Journal of Geophysical Research, v. 106, no. B7, p. 13,541-13,564.
Bronk Ramsey, C., 1998, Probability and dating: Radiocarbon, v. 40, p. 461-474.
Bucknam, R.C., Hemphill-Haley, E., and Leopold, E.B., 1992, Abrupt uplift within the past 1700 years at southern Puget Sound, Washington: Science, v. 258, p. 1,611-1,614.
Bucknam, R.C., Sherrod, B.L., and Elfendahl, G., 1999, A fault scarp of probable Holocene age in the Seattle fault zone, Bainbridge Island, Washington: Seismological Research Letters, v. 70, p. 233.
Elder, K.L., McNichol, A.P., and Gagnon, A.R., 1998, Evaluating reproducibility of seawater, inorganic and organic carbon ^{14}C results at the National Ocean Sciences AMS Facility (NOSAMS): Radiocarbon, v. 40, p. 223-230.
Frankel, A.D., Petersen, M.D., Mueller, C.S., Haller, K.M., Wheeler, R.L., Leyendecker, E.V., Wesson, R.L., Harmsen, S.C., Cramer, C.H., Perkins, D.M., Rukstales, K.S., 2002, Documentation for the 2002 update of the national seismic hazard maps: U.S. Geological Survey Open-File Report 02-420, 33 p. (http://geohazards.cr.usgs.gov/eq/of02-420/OFR02-420.pdf).
Gagnon, A.R., McNichol, A.P., Donoghue, J.C., Stuart, D.R., and von Reden, K., 2000, The NOSAMS sample preparation laboratory in the next millennium: Progress after the WOCE program: Nuclear Instruments and Methods in Physical Research B, v. 172, p. 409-415.
Harding, D.J., and Berghoff, G.S., 2000, Fault scarp detection beneath dense vegetation cover—Airborne laser mapping of the Seattle fault zone, Bainbridge Island, Washington State: Proceedings of the American Society of Photogrammetry and Remote Sensing Annual Conference, Washington, D.C., 9 p. on CD.
Harding, D.J., Johnson, S.Y., and Haugerud, R.A., 2002, Folding and rupture of an uplifted Holocene marine platform in the Seattle fault zone, Washington, revealed by Airborne Laser Swath Mapping: Geological Society of America Abstracts with Program, v. 34, no. 5, p. A-107.
Haugerud, R.A., Harding, D.J., Johson, S.Y., Harless, J.L., and Weaver, C.S., 2003, High-resolution lidar topography of the Puget Lowland-a bonanza for earth science: GSA Today, v. 13, p. 4-10.
Johnson, S.Y., Dadisman, S.V., Childs, J.R., and Stanley, W.D., 1999, Active tectonics of the Seattle fault and central Puget Sound, Washington—Implications for earthquake hazards: Geological Society of America Bulletin, v. 111, p. 1,042-1,053.
Lindvall, S.C., Rockwell, T.K., Dawson, T.E., Helms, J.G., Bowman, K.W., 2002, Evidence for two surface ruptures in the past 500 years on the San Andreas fault at Frazier Mountain, California: Bulletin of the Seismological Society of America, v. 92, p. 2,689-2,703.
Machette, M.M., 1989, Slope-morphometric methods, *in* Forman, S.L., ed., Dating methods applicable to Quaternary geologic studies in the western United States: Utah Geological and Mineral Survey, p. 30-42.
McCalpin, J.P., 1998, Paleoseismology: Orlando, Florida, Academic Press, 608 p.
McMurphy, C.J., 1980, Soil survey of Kitsap County area, Washington: Washington, D.C., U.S. Government Printing Office, 73 p.
Nelson, A.R., Johnson, S.Y., Kelsey, H.M., Wells, R.E., Sherrod, B.L., Pezzopane, S.K., Bradley, L.-A., Bucknam, R.C., and Koehler, R.D., 2003, Late Holocene earthquakes on the Toe Jam Hill fault, Seattle fault zone, Bainbridge Island, Washington: Geological Society of America Bulletin, in press.
Nelson, A.R., Johnson, S.Y., Wells, R.E., Pezzopane, S.K., Kelsey, H.M., Sherrod, B.L., Bradley, L.-A., Koehler, R.D., III, Bucknam, R.C., Haugerud, R.A., and LaPrade, W.T., 2002, Field and laboratory data from an earthquake history study of the Toe Jam Hill fault, Bainbridge Island, Washington: U.S. Geological Survey Open-File Report 02-60, 2 plates and 37 p. text (download at http://geology.cr.usgs.gov/greenwood-pubs.html).
Porter, S.C., and Swanson, T.W., 1998, Radiocarbon age constraints on rates of advance and retreat of the Puget Lobe of the Cordilleran ice sheet during the last glaciation: Quaternary Research, v. 50, no. 3, p. 205-213.
Sherrod, B.L., 2001, Evidence for earthquake-induced subsidence about 1100 yr ago in coastal marshes of southern Puget Sound, Washington: Geological Society of America Bulletin, v. 113, p. 1,299-1,311.
Sherrod, B.L., Bucknam, R.C., and Leopold, E.B., 2000, Holocene relative sea level change along the Seattle fault at Restoration Point, Washington: Quaternary Research, v. 54, p. 384-393.
Soil Survey Division Staff, 1993, Soil survey manual: U.S. Department of Agriculture Handbook No. 18, 437 p.
Stuiver, M., Reimer, P.J., Bard, E., Beck, J.W., Burr, G.S., Hughen, K.A., Kromer, B., McCormac, G., Plicht, J.v.d., and Spurk, M., 1998, INTCAL98 radiocarbon age calibration, 24,000-0 cal BP: Radiocarbon, v. 40, p. 1,041-1,084.
Taylor, R.E., Stuiver, M., and Reimer, P.J., 1996, Development and extension of the calibration of the radiocarbon time scale: archaeological applications: Quaternary Science Reviews, v.15, p. 655-668.
ten Brink, U.S., Molzer, P.C., Fisher, M.A., Blakely, R.J., Bucknam, R.C., Parsons, T., Crosson, R.S., and Creager, K.C., 2002, Subsurface geometry and evolution of the Seattle fault zone and the Seattle Basin, Washington: Bulletin of the Seismological Society of America, v. 92, p. 1,737-1,753.

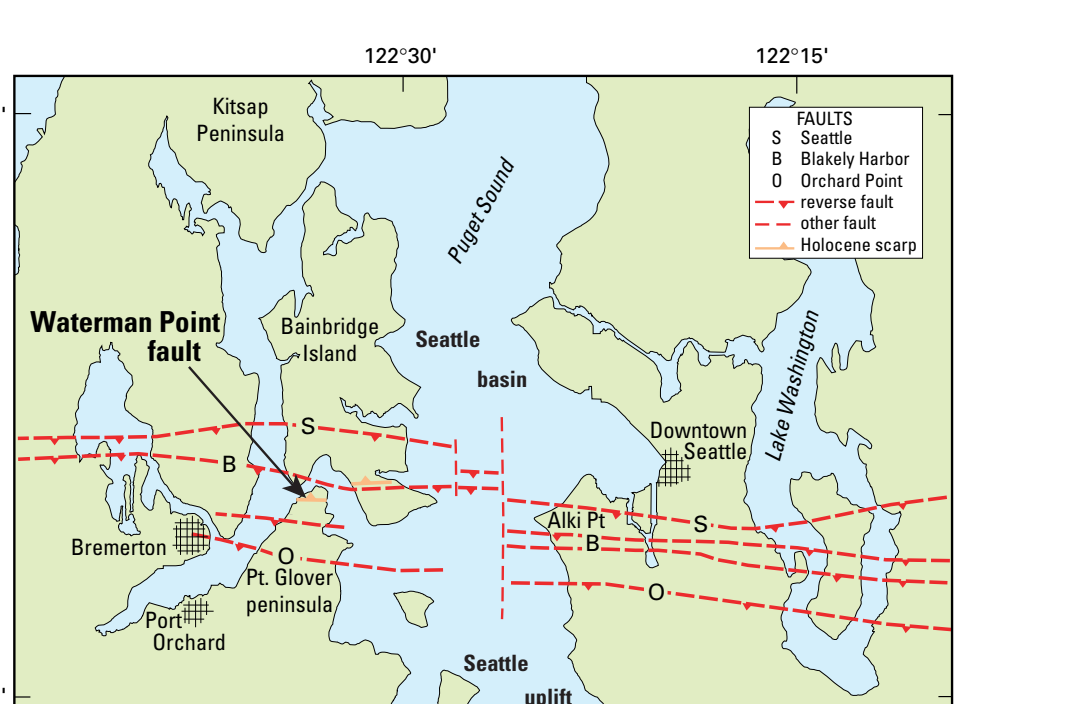


Figure 1. Map showing principal reverse and tear faults of the Seattle fault zone in central Puget Sound and location of the Waterman Point fault marked by a late Holocene scarp (figure 2; after Johnson and others, 1999; Blakely and others, 2002).

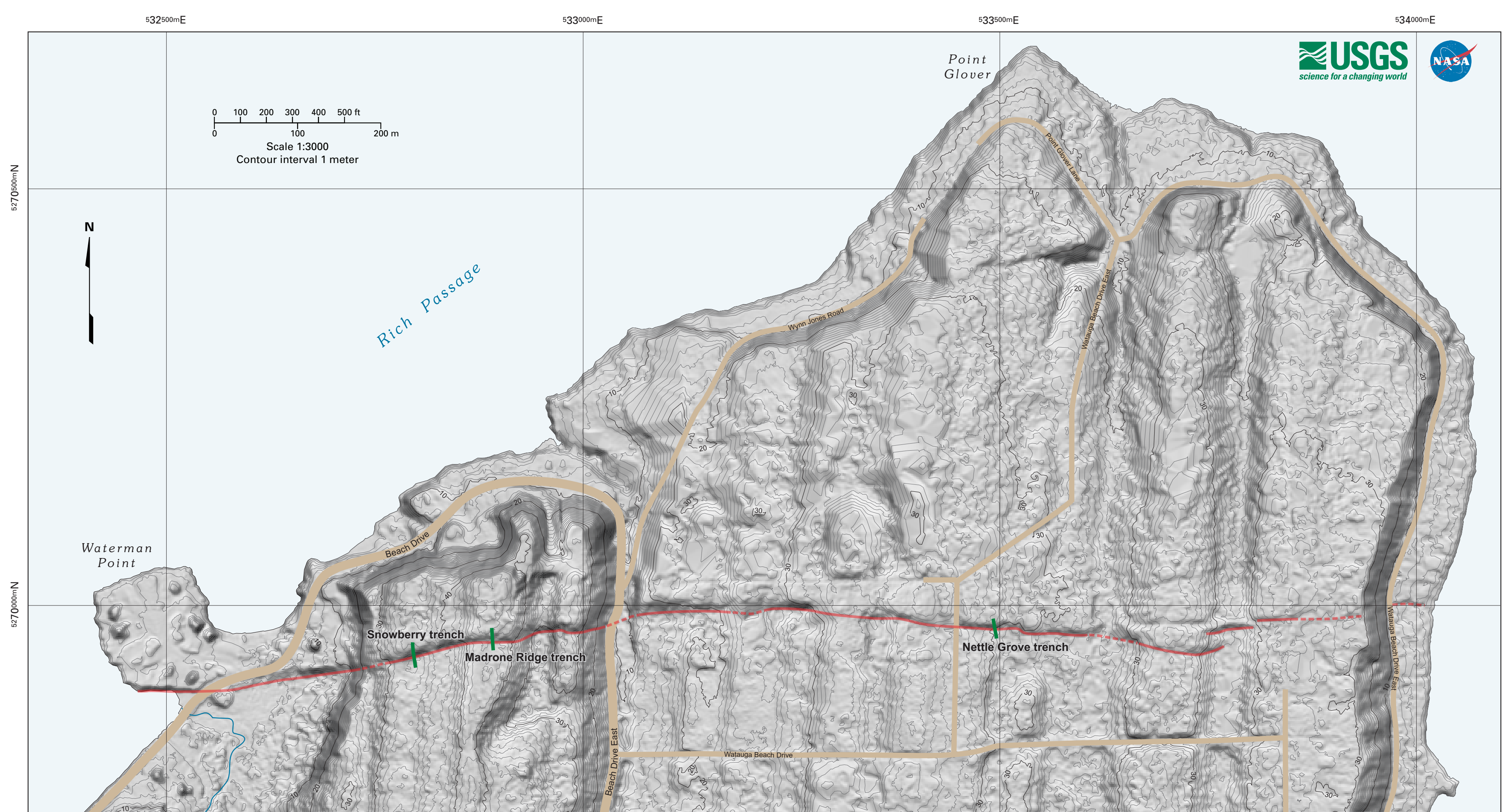
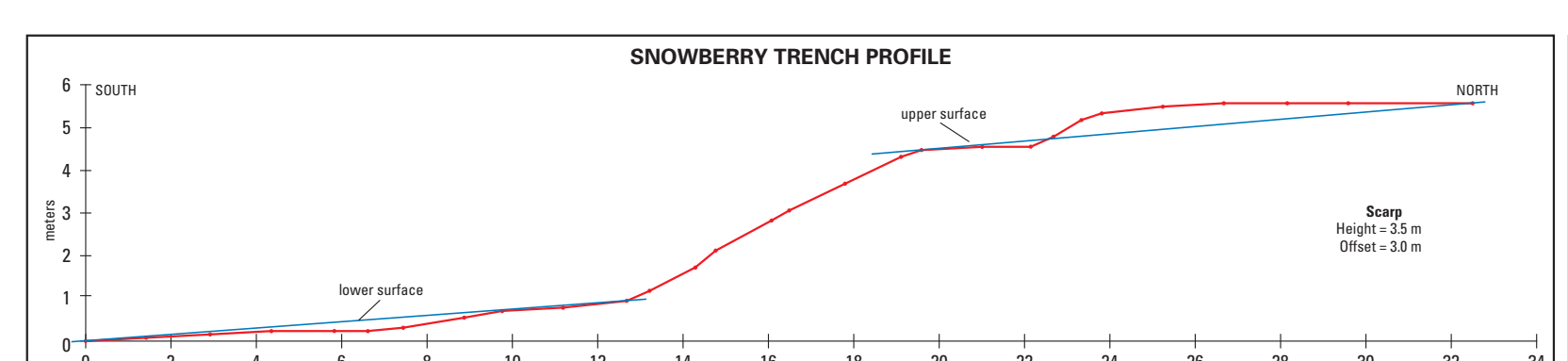
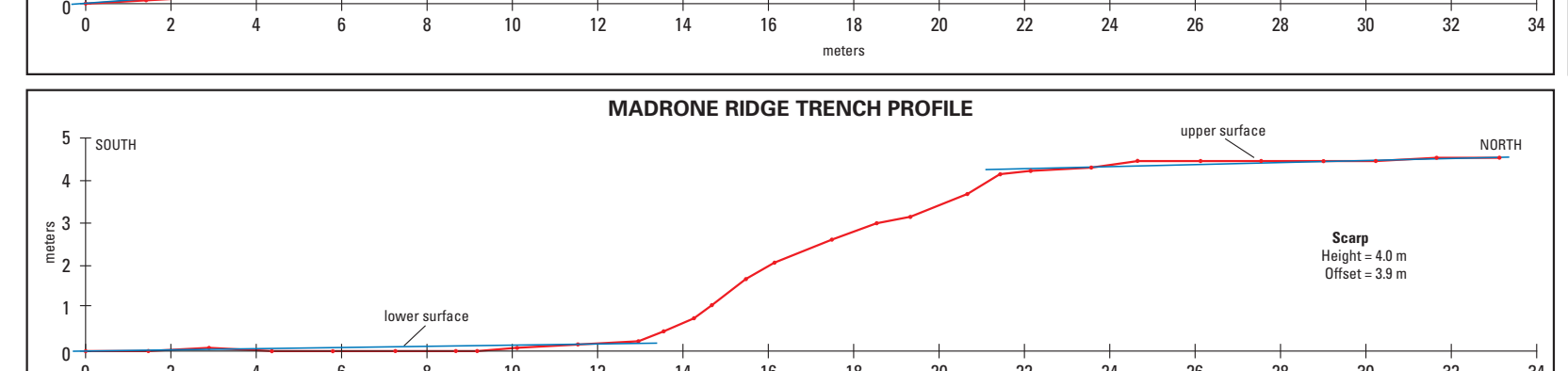
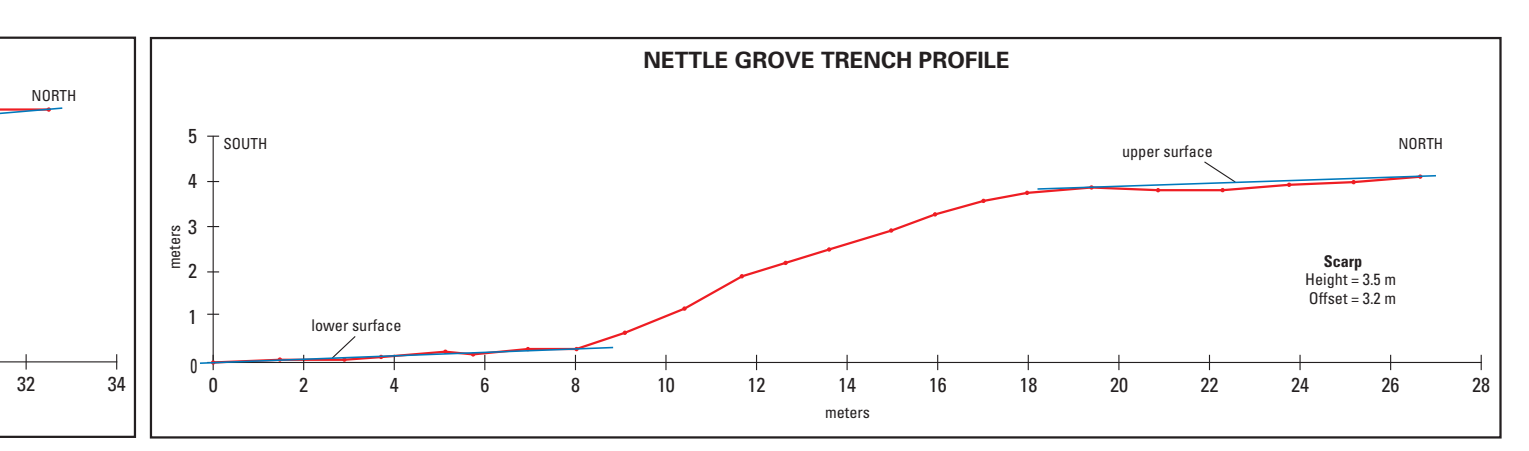


Figure 2. Airborne Laser Swath Mapping (ALSM) image showing the location of the scarp of the Waterman Point fault (inferred fault at base of scarp shown by red line; dashed where uncertain) and exploratory trenches (green lines; names are informal). ALSM survey was conducted by Terrapoint LLC under contract to U.S. Geological Survey and NASA. Digital elevation model (DEM) with contours produced by Susan Rhea from ALSM data. Projection is universal transverse Mercator (UTM), zone 10, NAD 83.







EXPLANATION OF PROFILE SYMBOLS

— Segment of profile measured along the centerline of trenches prior to trenching with a rod and digital level (method of Machette, 1989); red dots show end points of profile segments.

— Surface from which heights and offsets were calculated (method of Machette, 1989)

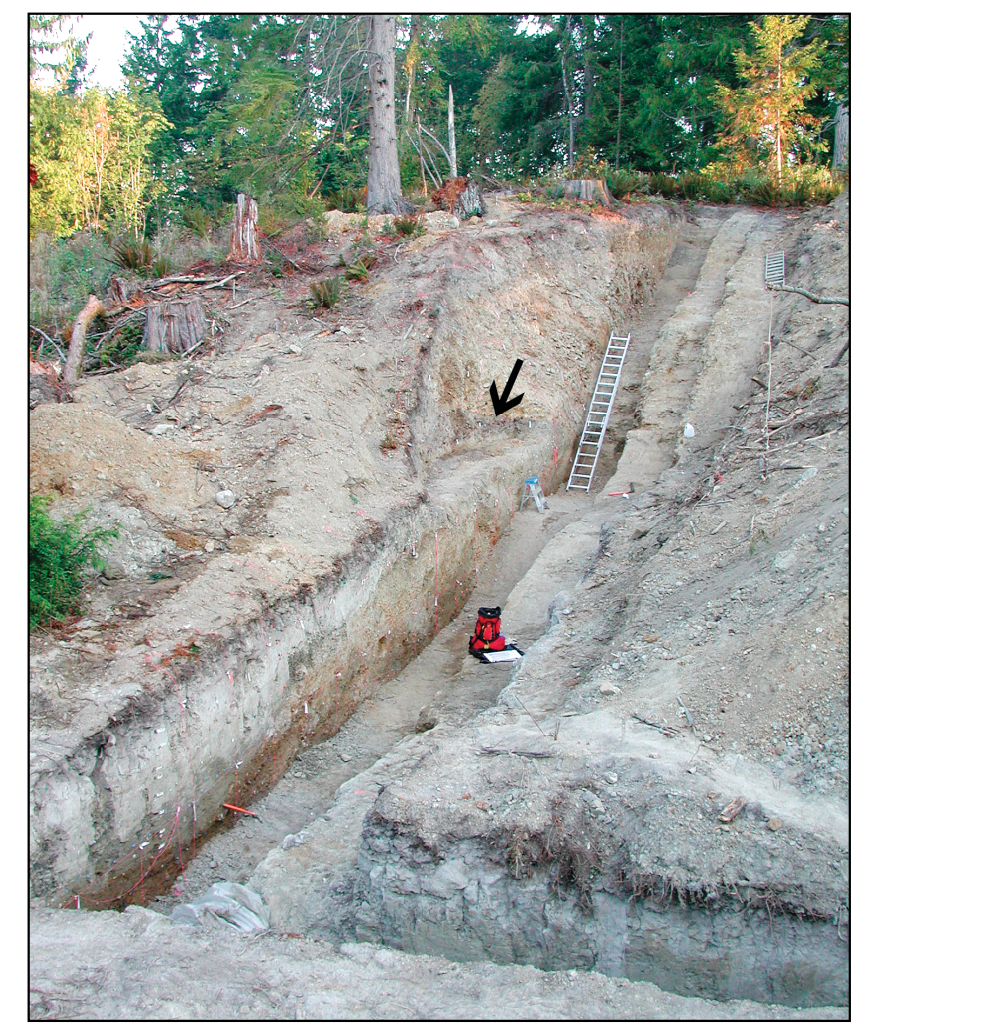
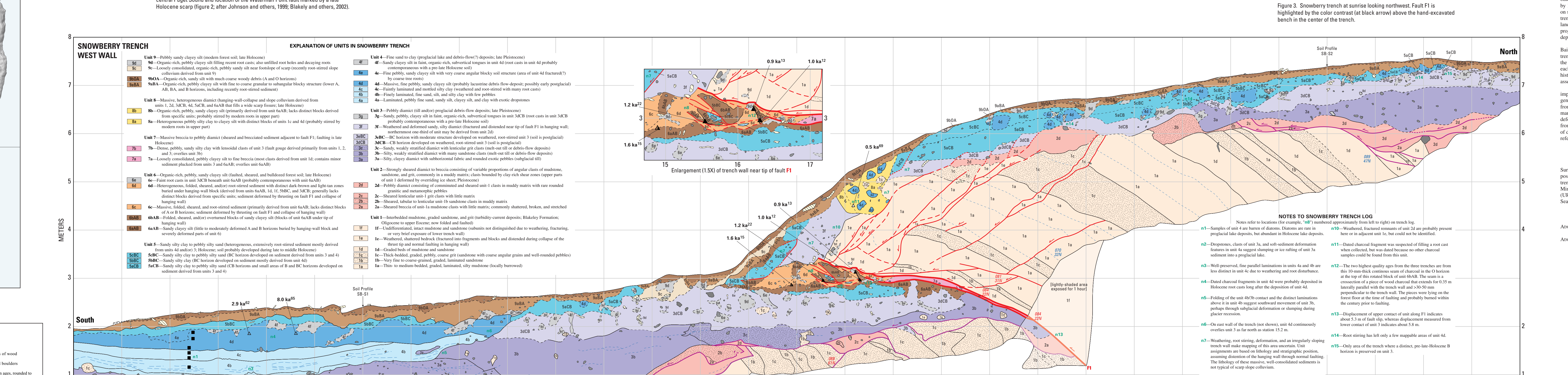


Figure 3. Snowberry trench at sunrise looking northwest. Fault F1 is highlighted by the color contrast (at black arrow) above the hand-excavated bench in the center of the trench.



EXPLANATION OF UNITS IN SNOWBERRY TRENCH

Unit 9—Pebbly sandy clayey silt (modern forest soil; late Holocene)
- **9d**—Organic-rich, pebbly clayey silt filling recent root casts; also unfilled root holes and decaying roots
- **9c**—Loosely consolidated, organic-rich, pebbly sandy silt near footslope of scarp (recently root-stirred slope colluvium derived from unit 9)
- **9bOA**—Organic-rich, sandy silt with much coarse woody debris (A and O horizons)
- **9aBA**—Organic-rich, pebbly clayey silt with fine to coarse granular to subangular blocky structure (lower A, AB, BA, and B horizons, including recently root-stirred sediment)

Unit 8—Massive, heterogeneous diamict (hanging-wall-collapse and slope colluvium derived from units 1, 2d, 3dCB, 4d, 5aCB, and 6aAB that fills a wide scarp fissure; late Holocene)
- **8b**—Organic-rich, pebbly, sandy clayey silt (primarily derived from unit 6aAB; lacks distinct blocks derived from specific units; probably stirred by modern roots in upper part)
- **8a**—Heterogeneous pebbly silty clay to clayey silt with distinct blocks of units 1c and 4d (probably stirred by modern roots in upper part)

Unit 7—Massive breccia to pebbly diamict (sheared and brecciated sediment adjacent to fault F1; faulting is late Holocene)
- **7b**—Dense, pebbly, sandy silty clay with lensoidal clasts of unit 3 (fault gouge derived primarily from units 1, 2, and 3; overlies unit 3b)
- **7a**—Loosely consolidated, pebbly clayey silt to fine breccia (most clasts derived from unit 1d; contains minor sediment plucked from units 3 and 6aAB; overlies unit 6aAB)

Unit 6—Organic-rich, pebbly, sandy clayey silt (faulted, sheared, and bulldozed forest soil; late Holocene)
- **6e**—Faint root casts in unit 3dCB beneath unit 6aAB (probably contemporaneous with unit 6aAB)
- **6d**—Heterogeneous, folded, sheared, and(or) root-stirred sediment with distinct dark-brown and light-tan zones buried under hanging-wall block (derived from units 6aAB, 1d, 1f, 5bBC, and 3dCB; generally lacks distinct blocks derived from specific units; sediment deformed by thrusting on fault F1 and collapse of hanging wall)
- **6c**—Massive, folded, sheared, and root-stirred sediment (primarily derived from unit 6aAB; lacks distinct blocks of A or B horizons; sediment deformed by thrusting on fault F1 and collapse of hanging wall)
- **6bAB**—Folded, sheared, and(or) overturned blocks of sandy clayey silt (blocks of unit 6aAB buried under hanging wall)
- **6aAB**—Sandy clayey silt (little to moderately deformed A and B horizons buried by hanging-wall block and severely deformed parts of unit 6)

Unit 5—Sandy silty clay to pebbly silty sand (heterogeneous, extensively root-stirred sediment mostly derived from units 4d and(or) 3; Holocene; soil probably developed during late to middle Holocene)
- **5cBC**—Sandy silty clay to pebbly silty sand (BC horizon developed on sediment derived from units 3 and 4)
- **5bBC**—Sandy silty clay (BC horizon developed on sediment mostly derived from unit 4d)
- **5aCB**—Sandy silty clay to pebbly silty sand (CB horizons and small areas of B and BC horizons developed on sediment derived from units 3 and 4)

Unit 4—Fine sand to clay (proglacial lake and debris-flow(?) deposits; late Pleistocene)
- **4f**—Sandy clayey silt in faint, organic-rich, subvertical tongues in unit 4d (root casts in unit 4d probably contemporaneous with a pre-late Holocene soil)
- **4e**—Fine pebbly, sandy clayey silt with very coarse angular blocky soil structure (area of unit 4d fractured(?) by coarse tree roots)
- **4d**—Massive, fine pebbly, sandy clayey silt (probably lacustrine debris flow-deposit; possibly early postglacial)
- **4c**—Faintly laminated and mottled silty clay (weathered and root-stirred with many root casts)
- **4b**—Finely laminated, fine sand, silt, and silty clay with few pebbles
- **4a**—Laminated, pebbly fine sand, sandy silt, clayey silt, and clay with exotic dropstones

Unit 3—Pebbly diamict (till and(or) proglacial debris-flow deposits; late Pleistocene)
- **3g**—Sandy, pebbly, clayey silt in faint, organic-rich, subvertical tongues in unit 3dCB (root casts in unit 3dCB probably contemporaneous with a pre-late Holocene soil)
- **3f**—Weathered and deformed sandy, silty diamict (fractured and distended near tip of fault F1 in hanging wall; northernmost one-third of unit may be derived from unit 2d)
- **3eBC**—BC horizon with moderate structure developed on weathered, root-stirred unit 3 (soil is postglacial)
- **3dCB**—CB horizon developed on weathered, root-stirred unit 3 (soil is postglacial)
- **3c**—Sandy, weakly stratified diamict with lenticular grit clasts (melt-out till or debris-flow deposits)
- **3b**—Silty, weakly stratified diamict with many sandstone clasts (melt-out till or debris-flow deposits)
- **3a**—Silty, clayey diamict with subhorizontal fabric and rounded exotic pebbles (subglacial till)

Unit 2—Strongly sheared diamict to breccia consisting of variable proportions of angular clasts of mudstone, sandstone, and grit, commonly in a muddy matrix; clasts bounded by clay-rich shear zones (upper parts of unit 1 deformed by overriding ice sheet; Pleistocene)
- **2d**—Pebbly diamict consisting of comminuted and sheared unit-1 clasts in muddy matrix with rare rounded granitic and metamorphic pebbles
- **2c**—Sheared lenticular unit-1 grit clasts with little matrix
- **2b**—Sheared, tabular to lenticular unit-1b sandstone clasts in muddy matrix
- **2a**—Sheared breccia of unit-1a mudstone clasts with little matrix; commonly shattered, broken, and stretched

Unit 1—Interbedded mudstone, graded sandstone, and grit (turbidity-current deposits; Blakeley Formation; Oligocene to upper Eocene; now folded and faulted)
- **1f**—Undifferentiated, intact mudstone and sandstone (subunits not distinguished due to weathering, fracturing, or very brief exposure of lower trench wall)
- **1e**—Weathered, shattered bedrock (fractured into fragments and blocks and distended during collapse of the thrust tip and normal faulting in hanging wall)
- **1d**—Graded beds of mudstone and sandstone
- **1c**—Thick-bedded, graded, pebbly, coarse grit (sandstone with coarse angular grains and well-rounded pebbles)
- **1b**—Very fine to coarse-grained, graded, laminated sandstone
- **1a**—Thin- to medium-bedded, graded, laminated, silty mudstone (locally burrowed)

NOTES TO SNOWBERRY TRENCH LOG

Notes refer to locations (for example, "n8") numbered approximately from left to right) on trench log.

n1—Samples of unit 4 are barren of diatoms. Diatoms are rare in proglacial lake deposits, but abundant in Holocene lake deposits.

n2—Dropstones, clasts of unit 3a, and soft-sediment deformation features in unit 4a suggest slumping or ice rafting of unit 3a sediment into a proglacial lake.

n3—Well-preserved, fine parallel laminations in units 4a and 4b are less distinct in unit 4c due to weathering and root disturbance.

n4—Dated charcoal fragments in unit 4d were probably deposited in Holocene root casts long after the deposition of unit 4d.

n5—Folding of the unit 4b/3b contact and the distinct laminations above it in unit 4b suggest southward movement of unit 3b, perhaps through subglacial deformation or slumping during glacier recession.

n6—On east wall of the trench (not shown), unit 4d continuously overlies unit 3 as far north as station 15.2 m.

n7—Weathering, root stirring, deformation, and an irregularly sloping trench wall make mapping of this area uncertain. Unit assignments are based on lithology and stratigraphic position, assuming distention of the hanging wall through normal faulting. The lithology of these massive, well-consolidated sediments is not typical of scarp slope colluvium.

n8—Distinct shear planes within the jumble of rotated blocks of soil, fragments of bedrock, and glacial and root-stirred sediment suggest rumpling and shearing of unit 6 and the upper parts of units 5 and 3 as the hanging wall collapsed and slid to the south.

n9—Stratigraphic inversion of units 6bAB, 5bBC, and 5cBC shows the rotation of an intact block of soil during thrust faulting.

n10—Weathered, fractured remnants of unit 2d are probably present here or in adjacent unit 1e, but could not be identified.

n11—Dated charcoal fragment was suspected of filling a root cast when collected, but was dated because no other charcoal samples could be found from this unit.

n12—The two highest quality ages from the three trenches are from this 10-mm-thick continuous seam of charcoal in the O horizon at the top of this rotated block of unit 6bAB. The seam is a crossection of a piece of wood charcoal that extends for 0.35 m laterally parallel with the trench wall and >30-50 mm perpendicular to the trench wall. The pieces were lying on the forest floor at the time of faulting and probably burned within the century prior to faulting.

n13—Displacement of upper contact of unit along F1 indicates about 5.3 m of fault slip, whereas displacement measured from lower contact of unit 3 indicates about 5.8 m.

n14—Root stirring has left only a few mappable areas of unit 4d.

n15—Only area of the trench where a distinct, pre-late-Holocene B horizon is preserved on unit 3.

Mapped by Alan Nelson (coordinator), Brian Sherrod, Robert Bogar, Harvey Kelsey, Ray Wells, Sam Johnson, Lee-Ann Bradley, Ian Madin, Steve Personius, Vicki McConnell, Frank Hladky, Michael Polenz, and Mark Molinari
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Graphics by Lee-Ann Bradley and Margo Johnson

Excavation by Pat Cearley, Burley, WA
Access provided by James Napoleon and Terry Anderson

EXPLANATION OF COLORS USED TO SHOW GENESIS OF TRENCH LOG UNITS
(colors do not imply correlations from trench to trench)

Oligocene to upper Eocene bedrock (stippled where sandy)	■ ▨	Weathered, root-stirred sediment derived from lake deposits and drift	■
Strongly sheared bedrock and drift	■	Forest A and O horizons	■
Deformed laminated lake deposits	■	Forest B horizons	■
Sheared breccia–mostly drift	■	Sheared, brecciated zones and gouge	■
Diamict (stippled where sandy)	■ ▨	Hanging-wall-collapse colluvium	■
Weathered diamict	■	Root-stirred slope and hanging-wall-collapse colluvium	■
Organic-rich sediment filling root casts	■	Slope colluvium	■
Proglacial lake deposits	■ ■	Fissure fill	■

EXPLANATION OF SYMBOLS IN TRENCHES

Faults
- Distinct primary fault—Faults are numbered separately in red
- Secondary fault, long dashes where indistinct
- Inferred secondary fault
- Bedding plane fault
- Subglacial shear plane produced during glacier flow
- 106 05N Strike (0-360°) and dip (°) of fault

Contacts
- Sharp or distinct
- Gradual or indistinct

Intra-unit bedding or structures
- Sharp or distinct
- Gradual or indistinct
- 095 85N Strike (0-360°) and dip (°) of bedding

Symbols
- Charcoal beds
- Large roots or pieces of wood
- Selected cobbles and boulders
- 1.9 ka^{39} Calibrated radiocarbon ages, rounded to nearest 100 yr (ka is 1000 cal yr BP; dated material is charcoal; superscript is sample number on Table 1)
- ▲ close maximum age for host sediment (probably less than a few hundred years older than sediment)
- ▵ maximum age for host sediment
- △ minimum age for host sediment
- ■ Diatom sample

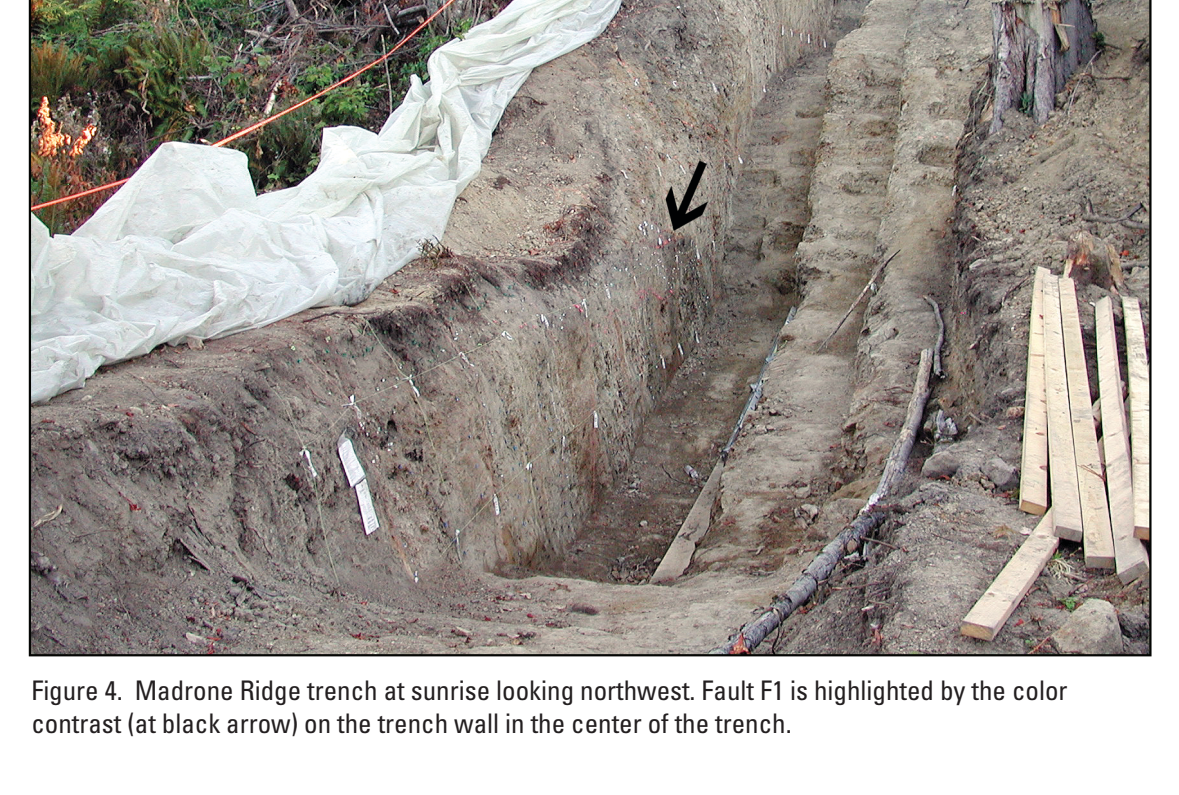


Figure 4. Madrone Ridge trench at sunrise looking northwest. Fault F1 is highlighted by the color contrast (at black arrow) on the trench wall in the center of the trench.

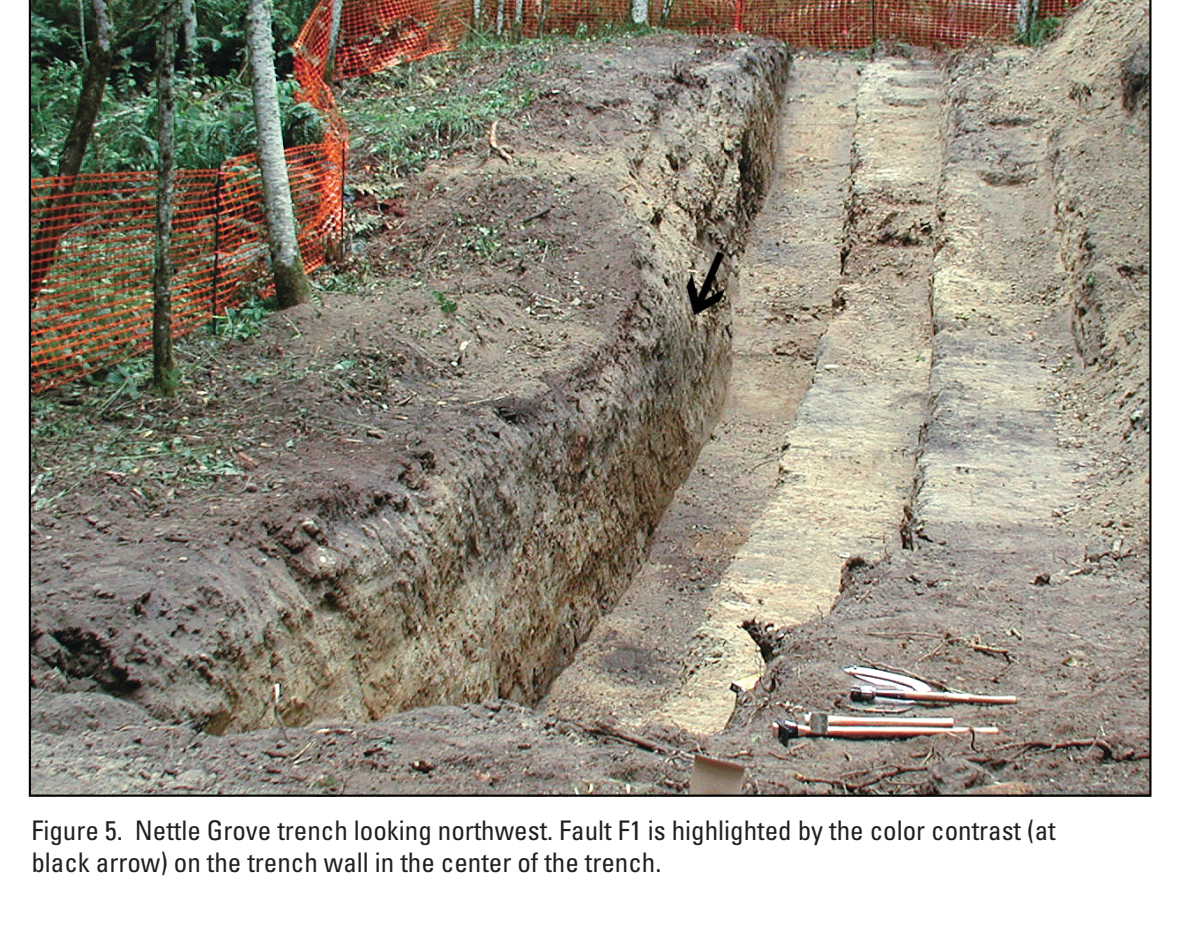
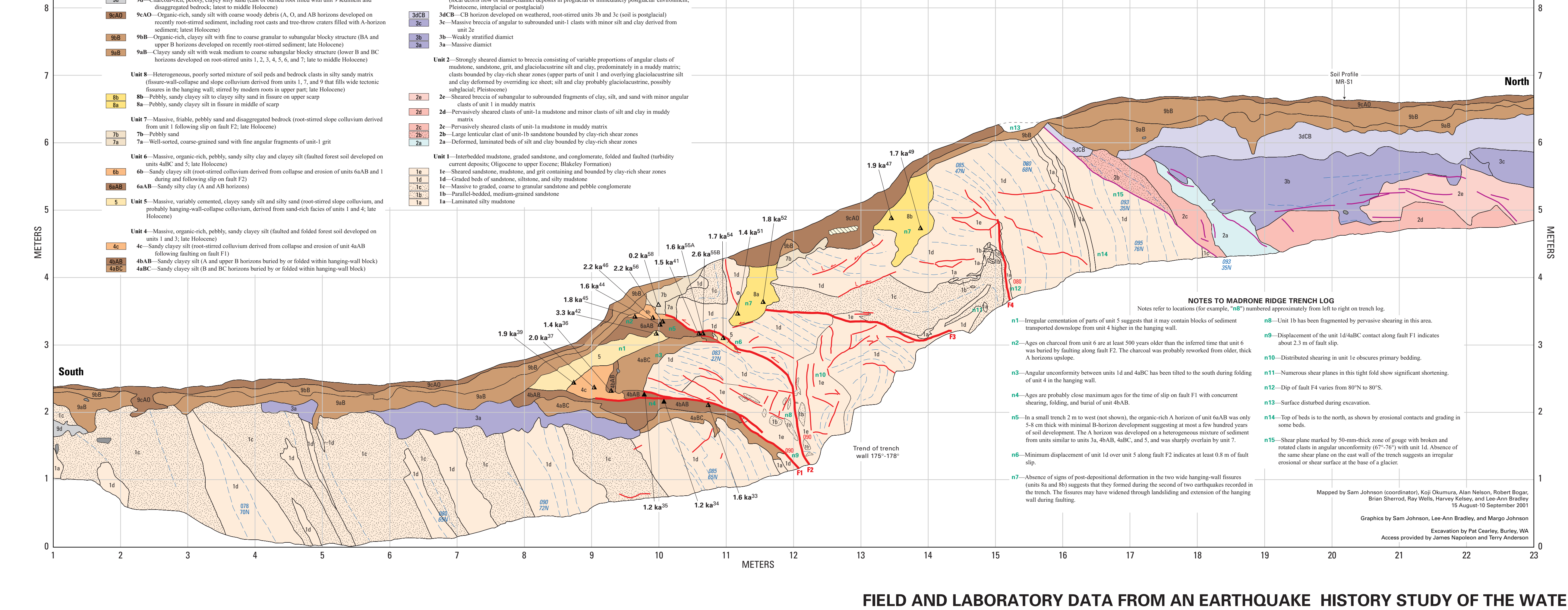


Figure 5. Nettle Grove trench looking northwest. Fault F1 is highlighted by the color contrast (at black arrow) on the trench wall in the center of the trench.



EXPLANATION OF UNITS IN MADRONE RIDGE TRENCH

Unit 9—Pebbly, sandy clayey silt with woody debris (modern forest soil; middle to latest Holocene)
- **9d**—Charcoal-rich, pebbly, clayey silty sand (cast of burned root filled with unit 9 sediment and disaggregated bedrock; latest to middle Holocene)
- **9cAO**—Organic-rich, sandy silt with coarse woody debris (A, O, and AB horizons developed on recently root-stirred sediment, including root casts and tree-throw craters filled with A-horizon sediment; latest Holocene)
- **9bB**—Organic-rich, clayey silt with fine to coarse granular to subangular blocky structure (BA and upper B horizons developed on recently root-stirred sediment; late Holocene)
- **9aB**—Clayey sandy silt with weak medium to coarse subangular blocky structure (lower B and BC horizons developed on root-stirred units 1, 2, 3, 4, 5, 6, and 7; late to middle Holocene)

Unit 8—Heterogeneous, poorly sorted mixture of soil peds and bedrock clasts in silty sandy matrix (fissure-wall-collapse and slope colluvium derived from units 1, 7, and 9 that fills wide tectonic fissures in the hanging wall; stirred by modern roots in upper part; late Holocene)
- **8b**—Pebbly, sandy clayey silt to clayey silty sand in fissure on upper scarp
- **8a**—Pebbly, sandy clayey silt in fissure in middle of scarp

Unit 7—Massive, friable, pebbly sand and disaggregated bedrock (root-stirred slope colluvium derived from unit 1 following slip on fault F2; late Holocene)
- **7b**—Pebbly sand
- **7a**—Well-sorted, coarse-grained sand with fine angular fragments of unit-1 grit

Unit 6—Massive, organic-rich, pebbly, sandy silty clay and clayey silt (faulted forest soil developed on units 4aBC and 5; late Holocene)
- **6b**—Sandy clayey silt (root-stirred colluvium derived from collapse and erosion of units 6aAB and 1 during and following slip on fault F2)
- **6aAB**—Sandy silty clay (A and AB horizons)

Unit 5—Massive, variably cemented, clayey sandy silt and silty sand (root-stirred slope colluvium, and probably hanging-wall-collapse colluvium, derived from sand-rich facies of units 1 and 4; late Holocene)

Unit 4—Massive, organic-rich, pebbly, sandy clayey silt (faulted and folded forest soil developed on units 1 and 3; late Holocene)
- **4c**—Sandy clayey silt (root-stirred colluvium derived from collapse and erosion of unit 4aAB following faulting on fault F1)
- **4bAB**—Sandy clayey silt (A and upper B horizons buried by or folded within hanging-wall block)
- **4aBC**—Sandy clayey silt (B and BC horizons buried by or folded within hanging-wall block)

Unit 3—Undeformed pebbly diamict with mudstone and sandstone clasts derived entirely from unit 1 (local debris flow or small-channel deposits in proglacial or immediately postglacial environment; Pleistocene, interglacial or postglacial)
- **3dCB**—CB horizon developed on weathered, root-stirred units 3b and 3c (soil is postglacial)
- **3c**—Massive breccia of angular to subrounded unit-1 clasts with minor silt and clay derived from unit 2e
- **3b**—Weakly stratified diamict
- **3a**—Massive diamict

Unit 2—Strongly sheared diamict to breccia consisting of variable proportions of angular clasts of mudstone, sandstone, grit, and glaciolacustrine silt and clay, predominately in a muddy matrix; clasts bounded by clay-rich shear zones (upper parts of unit 1 and overlying glaciolacustrine silt and clay deformed by overriding ice sheet; silt and clay probably glaciolacustrine, possibly subglacial; Pleistocene)
- **2e**—Sheared breccia of subangular to subrounded fragments of clay, silt, and sand with minor angular clasts of unit 1 in muddy matrix
- **2d**—Pervasively sheared clasts of unit-1a mudstone and minor clasts of silt and clay in muddy matrix
- **2c**—Pervasively sheared clasts of unit-1a mudstone in muddy matrix
- **2b**—Large lenticular clast of unit-1b sandstone bounded by clay-rich shear zones
- **2a**—Deformed, laminated beds of silt and clay bounded by clay-rich shear zones

Unit 1—Interbedded mudstone, graded sandstone, and conglomerate, folded and faulted (turbidity current deposits; Oligocene to upper Eocene; Blakeley Formation)
- **1e**—Sheared sandstone, mudstone, and grit containing and bounded by clay-rich shear zones
- **1d**—Graded beds of sandstone, siltstone, and silty mudstone
- **1c**—Massive to graded, coarse to granular sandstone and pebble conglomerate
- **1b**—Parallel-bedded, medium-grained sandstone
- **1a**—Laminated silty mudstone

NOTES TO MADRONE RIDGE TRENCH LOG

Notes refer to locations (for example, "n8") numbered approximately from left to right on trench log.

n1—Irregular cementation of parts of unit 5 suggests that it may contain blocks of sediment transported downslope from unit 4 higher in the hanging wall.

n2—Ages on charcoal from unit 6 are at least 500 years older than the inferred time that unit 6 was buried by faulting along fault F2. The charcoal was probably reworked from older, thick A horizons upslope.

n3—Angular unconformity between units 1d and 4aBC has been tilted to the south during folding of unit 4 in the hanging wall.

n4—Ages are probably close maximum ages for the time of slip on fault F1 with concurrent shearing, folding, and burial of unit 4bAB.

n5—In a small trench 2 m to west (not shown), the organic-rich A horizon of unit 6aAB was only 5-8 cm thick with minimal B-horizon development suggesting at most a few hundred years of soil development. The A horizon was developed on a heterogeneous mixture of sediment from units similar to units 3a, 4bAB, 4aBC, and 5, and was sharply overlain by unit 7.

n6—Minimum displacement of unit 1d over unit 5 along fault F2 indicates at least 0.8 m of fault slip.

n7—Absence of signs of post-depositional deformation in the two wide hanging-wall fissures (units 8a and 8b) suggests that they formed during the second of two earthquakes recorded in the trench. The fissures may have widened through landsliding and extension of the hanging wall during faulting.

n8—Unit 1b has been fragmented by pervasive shearing in this area.

n9—Displacement of the unit 1d/4aBC contact along fault F1 indicates about 2.3 m of fault slip.

n10—Distributed shearing in unit 1e obscures primary bedding.

n11—Numerous shear planes in this tight fold show significant shortening.

n12—Dip of fault F4 varies from 80°N to 80°S.

n13—Surface disturbed during excavation.

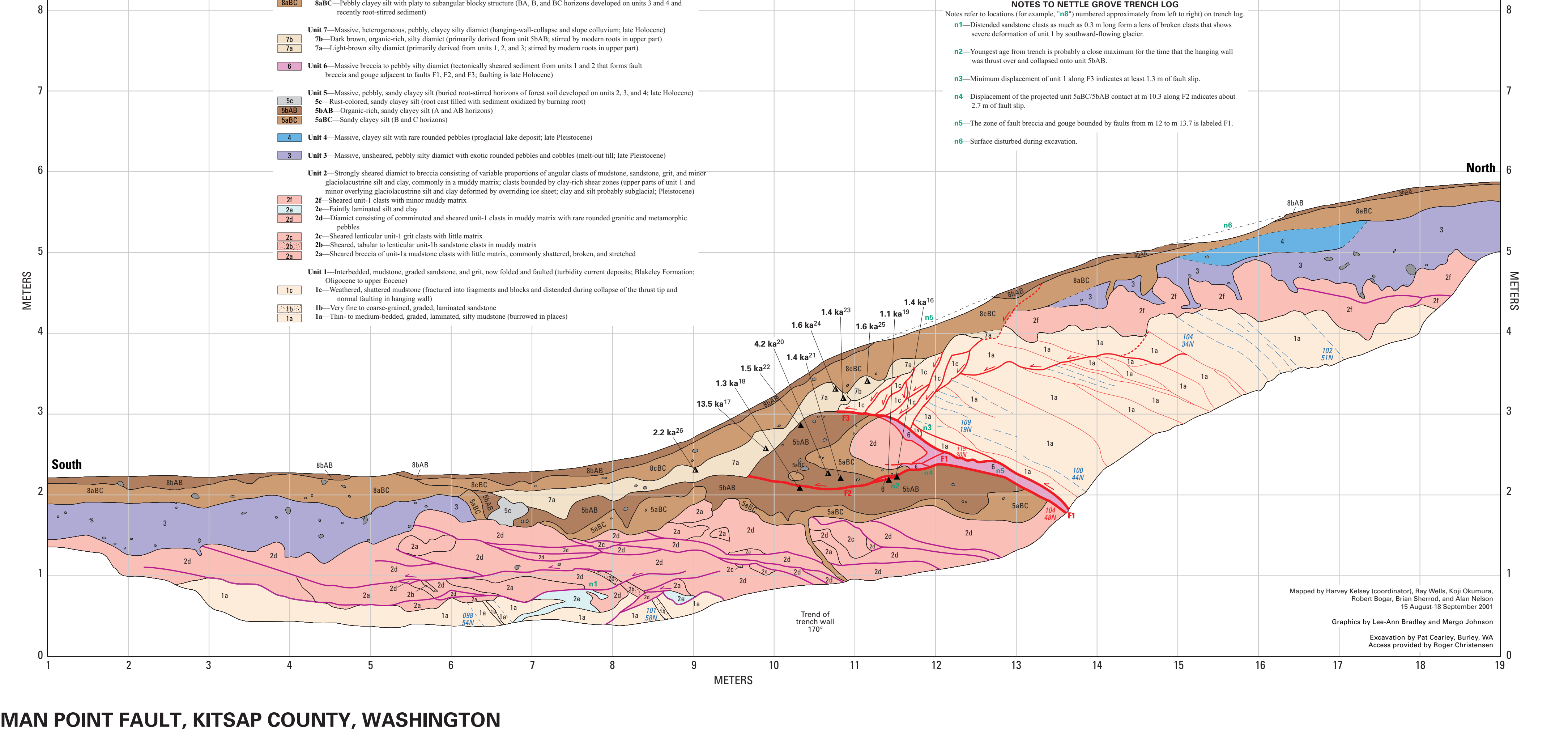
n14—Top of beds is to the north, as shown by erosional contacts and grading in some beds.

n15—Shear plane marked by 50-mm-thick zone of gouge with broken and rotated clasts in angular unconformity (67°-76°) with unit 1d. Absence of the same shear plane on the east wall of the trench suggests an irregular erosional or shear surface at the base of a glacier.

Mapped by Sam Johnson (coordinator), Koji Okumura, Alan Nelson, Robert Bogar, Brian Sherrod, Ray Wells, Harvey Kelsey, and Lee-Ann Bradley
15 August-10 September 2001

Graphics by Sam Johnson, Lee-Ann Bradley, and Margo Johnson

Excavation by Pat Cearley, Burley, WA
Access provided by James Napoleon and Terry Anderson



EXPLANATION OF UNITS IN NETTLE GROVE TRENCH

Unit 8—Massive, sandy clayey silt with woody debris (modern forest soil; late Holocene)
- **8cBC**—Clayey silt with few pebbles and strong subangular blocky structure (BA, B, and BC horizons developed on units 1, 5, and 7, including recently root-stirred sediment; distinct peds may be eroded from hanging-wall B horizons upslope)
- **8bAB**—Organic-rich, sandy clayey silt with rare pebbles and coarse woody debris (O, A, and AB horizons)
- **8aBC**—Pebbly clayey silt with platy to subangular blocky structure (BA, B, and BC horizons developed on units 3 and 4 and recently root-stirred sediment)

Unit 7—Massive, heterogeneous, pebbly, clayey silty diamict (hanging-wall-collapse and slope colluvium; late Holocene)
- **7b**—Dark brown, organic-rich, silty diamict (primarily derived from unit 5bAB; stirred by modern roots in upper part)
- **7a**—Light-brown silty diamict (primarily derived from units 1, 2, and 3; stirred by modern roots in upper part)

Unit 6—Massive breccia to pebbly silty diamict (tectonically sheared sediment from units 1 and 2 that forms fault breccia and gouge adjacent to faults F1, F2, and F3; faulting is late Holocene)

Unit 5—Massive, pebbly, sandy, clayey silt (buried root-stirred horizons of forest soil developed on units 2, 3, and 4; late Holocene)
- **5c**—Rust-colored, sandy clayey silt (root cast filled with sediment oxidized by burning root)
- **5bAB**—Organic-rich, sandy clayey silt (A and AB horizons)
- **5aBC**—Sandy clayey silt (B and C horizons)

Unit 4—Massive, clayey silt with rare rounded pebbles (proglacial lake deposit; late Pleistocene)

Unit 3—Massive, unsheared, pebbly silty diamict with exotic rounded pebbles and cobbles (melt-out till; late Pleistocene)

Unit 2—Strongly sheared diamict to breccia consisting of variable proportions of angular clasts of mudstone, sandstone, grit, and minor glaciolacustrine silt and clay, commonly in a muddy matrix; clasts bounded by clay-rich shear zones (upper parts of unit 1 and minor overlying glaciolacustrine silt and clay deformed by overriding ice sheet; clay and silt probably subglacial; Pleistocene)
- **2f**—Sheared unit-1 clasts with minor muddy matrix
- **2e**—Faintly laminated silt and clay
- **2d**—Diamict consisting of comminuted and sheared unit-1 clasts in muddy matrix with rare rounded granitic and metamorphic pebbles
- **2c**—Sheared lenticular unit-1 grit clasts with little matrix
- **2b**—Sheared, tabular to lenticular unit-1b sandstone clasts in muddy matrix
- **2a**—Sheared breccia of unit-1a mudstone clasts with little matrix, commonly shattered, broken, and stretched

Unit 1—Interbedded, mudstone, graded sandstone, and grit, now folded and faulted (turbidity current deposits; Blakeley Formation; Oligocene to upper Eocene)
- **1c**—Weathered, shattered mudstone (fractured into fragments and blocks and distended during collapse of the thrust tip and normal faulting in hanging wall)
- **1b**—Very fine to coarse-grained, graded, laminated sandstone
- **1a**—Thin- to medium-bedded, graded, laminated, silty mudstone (burrowed in places)

NOTES TO NETTLE GROVE TRENCH LOG

Notes refer to locations (for example, "n8") numbered approximately from left to right) on trench log.

n1—Distended sandstone clasts as much as 0.3 m long form a lens of broken clasts that shows severe deformation of unit 1 by southward-flowing glacier.

n2—Youngest age from trench is probably a close maximum for the time that the hanging wall was thrust over and collapsed onto unit 5bAB.

n3—Minimum displacement of unit 1 along F3 indicates at least 1.3 m of fault slip.

n4—Displacement of the projected unit 5aBC/5bAB contact at m 10.3 along F2 indicates about 2.7 m of fault slip.

n5—The zone of fault breccia and gouge bounded by faults from m 12 to m 13.7 is labeled F1.

n6—Surface disturbed during excavation.

Mapped by Harvey Kelsey (coordinator), Ray Wells, Koji Okumura, Robert Bogar, Brian Sherrod, and Alan Nelson
15 August-18 September 2001

Graphics by Lee-Ann Bradley and Margo Johnson

Excavation by Pat Cearley, Burley, WA
Access provided by Roger Christensen

TABLE 1. RADIOCARBON DATA FOR TRENCH SAMPLES

Field number	Unit number	Station (m)[1]	Radiocarbon lab number[2]	Lab-reported age (^{14}C yr BP at 1σ)[3]	Calibrated age (cal yr BP at 2σ)[4]	Sample weight (mg)[5]	^{13}C (‰)[6]	Description of dated material[7]
Snowberry trench								
SB-69	8a	16.21, 4.5	OS-33844	410±40	530-310	45.9	-26.4	Flakes of carbonized bark or root sheath
SB-12	6bAB	16.25, 2.95	OS-33840	1117±26	1070-950	79.1	-25.1	Split 15x15x10-mm fragment into halves
SB-13	6bAB	16.20, 3.16	OS-33841	1000±40	980-790	47.0	-25.1	10x5x4-mm fragment
SB-22	6bAB	15.53, 3.91	OS-33846	1262±30	1280-1080	115.3	-25.1	Split 15x10x3-mm fragment into halves
SB-15	6aAB	14.88, 2.85	OS-33842	1660±40	1700-1410	93.5	-25.1	10x10x10-mm fragment
SB-62	4d	3.65, 1.81	OS-33843	2830±45	3080-2790	87.9	-26.9	Two 12x5x4-mm fragments
SB-65	4d	4.63, 1.79	OS-35213	7160±35	8110-7870	67.6	-23.9	15x4x2-mm fragment
Madrone Ridge trench								
MR-49	8b	13.90, 4.72	OS-34041	1760±35	1820-1560	74.6	-24.2	15x6x4-mm fragment
MR-47	8b	13.45, 4.81	OS-34424	1940±30	1950-1820	31.0	-24.9	6x5x4-mm fragment
MR-52	8a	11.54, 3.63	OS-34425	1820±30	1830-1630	52.2	-25.3	8x4x4-mm fragment
MR-51	8a	11.16, 3.45	OS-34042	1540±35	1530-1340	44.3	-25.5	15x4x4-mm fragment
MR-58	7b	9.98, 3.57	OS-33859	165±35	300-0	51.0	-24.9	Two fragments: 15x4x3 and 8x5x1 mm
MR-46	6b	9.91, 3.36	OS-35166	2270±40	2350-2150	81.7	-22.8	Two fragments: 15x4x4 and 8x4x3 mm
MR-45	6b	9.62, 3.38	OS-34040	1850±35	1880-1700	52.8	-24.5	13x4x4-mm fragment
MR-55A	6aAB	10.60, 3.14	OS-34043	1680±45	1710-1420	90.6	-24.4	10x10x5-mm fragment
MR-55B	6aAB	10.60, 3.14	OS-35170	2481±30	2720-2360	35.0	-24.1	Split 18x15x3-mm fragment into halves
MR-41	6aAB	10.58, 3.16	OS-35169	1601±25	1540-1410	47.0	-22.7	Split 13x6x4-mm fragment into halves
MR-56	6aAB	10.07, 3.31	CAMS-84714	2170±70	2340-1990	7.7s (2.5?)	-25.0a	Small fragments from 4x3x1-mm fragment
MR-44	6aAB	10.04, 3.28	OS-35217	1660±40	1700-1410	165s (40?)	-24.6	Small fragments from 4x3x2-mm fragment
MR-54	5	10.94, 3.10	OS-33858	1756±28	1740-1560	163.1	-25.1	10x10x1 -mm fragment
MR-42	5	9.98, 3.16	OS-35216	3070±30	3360-3170	59.6	-24.1	14x6x4-mm fragment
MR-39	4c	8.68, 2.40	OS-34204	1950±40	2000-1810	79.8	-24.9	Two fragments: 12x8x2 and 16x3x2 mm
MR-37	4c	9.04, 2.33	OS-35168	2040±35	2120-1890	66.1	-26.0	Two fragments: 7x6x3 and 10x7x4 mm
MR-36	4bAB	9.25, 2.27	OS-33856	1440±95	1540-1170	64.8	-26.5	12x5x4-mm fragment
MR-33	4bAB	10.73, 2.12	OS-35167	1700±50	1740-1510	127s (20?)	-24.2	Many 4x1x1-mm soft fragments
MR-34	4bAB	10.15, 2.18	OS-35215	1300±30	1290-1170	72.9	-25.8	Five 5x3x2-mm dense fragments
MR-35	4bAB	9.75, 2.25	OS-33855	1290±35	1300-1140	25.9	-25.1	One 5x2x1 and two 8x4x2-mm fragments
Nettle Grove trench								
NG-25	7b	11.17, 3.38	OS-33853	1690±40	1710-1520	26.9	-26.1	9x4x2-mm fragment
NG-23	7a	10.85, 3.20	OS-35214	1520±30	1520-1330	32.3	-25.1	Two 8x6x1-mm platy bark-like fragments
NG-24	7a	10.80, 3.28	OS-34039	1670±30	1690-1510	21.9	-25.9	One 5x4x2 and two 3x2x1-mm fragments
NG-17	7a	9.85, 2.56	OS-33847	11,550±95	13,950-13,150	56.1	-25.4	10x10x7-mm dense fragment
NG-26	7a	9.02, 2.31	OS-33854	2240±30	2350-2150	67.4	-24.7	Two 5x4x2-mm fragments
NG-16	6	11.55, 2.25	OS-35164	1530±45	1530-1320	64.3	-23.5	About 20 3x4-mm flakes
NG-22	5bAB	10.34, 2.78	OS-33850	1640±45	1690-1410	43.2	-25.9	Two fragments: 5x3x2 and 4x2x2 mm
NG-19	5bAB	11.44, 2.21	OS-33852	1181±26	1180-990	63.1	-26.2	Split 20x10x5-mm fragment into halves
NG-18	5bAB	10.32, 2.13	OS-33848	1400±35	1390-1260	25.6	-26.2	Two 10x4x1-mm fragments
NG-21	5aBC	10.75, 2.16	OS-33849	1550±55	1540-1310	41.1	-29.4	One 2x3x4-mm and many smaller fragments
NG-20	5aBC	10.66, 2.23	OS-35165	3820±40	4410-4080	24.7	-25.4	Four 4x4x2-mm fragments

[1] Location (horizontal, vertical) on reference grid used to map west wall of the trench. Superscripts on sample ages shown on logs are the digits of field sample numbers (first column of this table).
[2] Laboratories are: OS, National Ocean Sciences AMS Facility (NOSAMS), Woods Hole Oceanographic Institution, Massachusetts; CAMS, Lawrence Livermore National Laboratories, California.
[3] AMS (accelerator mass spectrometer) ages (methods described in Gagnon and others, 2000). Quoted error for each AMS analysis is the larger of counting error or target reproducibility error. Reported ages for SB-12, SB-22, MR-41, MR-54, MR-55B, and NG-19 are the average of two ages on the same charcoal fragment.
[4] Ages in solar years calculated using OxCal (version 3.4; Bronk Ramsey, 1998; probability method) with the INTCAL98 dataset of Stuiver and others (1998). NOSAMS and Lawrence Livermore's results from the Third International Radiocarbon Comparison show minimal offset from comparison means (for example, Elder and others, 1998), suggesting that no additional interlaboratory variance (error multiplier, for example, Taylor and others, 1996) is required for calibration. Calibrated ages show time intervals of >95% probability distribution at 2σ. Ages shown on logs are modes of calibrated-age distributions rounded to nearest 100 years.
[5] "s" indicates samples with adhering sediment when submitted; weight is a maximum for organic material in the sample; value in parentheses is an estimate of charcoal weight.
[6] Parts per thousand ^{13}C; "a" indicates value assumed, not measured.
[7] Unless indicated otherwise, ages are on angular, unabraded fragments of charcoal with distinct wood cellular structure. In each sample, the largest, most angular, least decayed fragments of charcoal were selected to minimize the chance of analyzing carbon much older than the host sediment. Sediment adhering to fragments was removed with brushes or dental tools in distilled water at magnifications of 6-25X. Charcoal was picked directly from sediment collected from the trench wall.

TABLE 2. FIELD PROPERTIES OF SOIL PROFILES DESCRIBED IN THE SNOWBERRY AND MADRONE RIDGE TRENCHES

Sample number	Horizon[1]	Average depth (cm)	Parent material[2]	Munsell color[3]	Boundary[1]	Volume percent[4] pebbles	Volume percent[4] cobbles	Field texture[1]	Wet consistence[1]	Structure[1]	Clay films[1]
Soil Profile SB-S1 – Snowberry trench, station 6, units 9bOA-4d											
SB-56	AO	0-15	R (9bOA)	5YR 3/2	a w	2-5	0	L	so/po	sg - 1 f gr	0
SB-57	BA	15-33	R (9aBA)	10YR 7/1	g w	2-5	0	SiL	ss/ps	3 m sbk	1 f pfpo
SB-58	BC	33-48	S (5bBC)	2.5Y 7/2	g w	5	0	SiL	s/ps	3 m sbk	1 f pfpo
SB-38	2C	48-78	L (4d)	5Y 7/2	g w	5	0	SiL	ss/ps	m	0
Soil Profile SB-S2 – Snowberry trench, station 26, units 9bOA-3a											
SB-47	AO	0-8	R (9bOA)	10YR 3/4	a w	2-5	0	L	so/ps	sg - 1 f gr	v1 f po
SB-48	BA	8-20	R (9aBA)	10YR 7/2	c w	5	0	SiL	ss/ps	2-3 m sbk	v1 f-d pfpo
SB-49	BC	20-31	SR (5aCB)	2.5Y 7/3	d i	10	<1	SiL	ss/ps	1 m-c sbk	v1 f po
SB-50	2CB	31-82	RT (3dCB)	10YR 6/6	d w	10	<1	SL	ss/ps	1 m-c abk	v1 f po
SB-28	2C	82+	T(3a)	10YR 8/4	—	15	<1	SiL	ss/ps	m	0
Soil Profile MR-S1 – Madrone Ridge trench, station 20.2, units 9aB-3b											
—	O	0-2	R (9cAO)	5YR 2/2	a b	0	0	L	so/po	sg	0
MR-59	A	2-4	R (9cAO)	10YR 6/3	a i	2-5	0	L	so/po	1 f gr	0
MR-60	B	4-16	R (9bB)	10YR 6/3	c w	10	0	SiL	ss/ps	3 vc sbk	1 f po
MR-61	2B	16-37	R (9aB)	10YR 7/2	g w	10	<1	SiL	ss/ps	2 m sbk	2 f popf
MR-62	2CB	37-57	RD (3dCB)	10YR 6/3	g w	20	<1	SiCL	s/p	1 m abk	0
MR-63	2C	57-80	DR(3b)	2.5Y 7/3	d w	20	<1	SiCL	s/ps	m	0

[1] Horizon nomenclature, field properties, and terminology of Soil Survey Staff (1993) and Birkeland (1999). Abbreviations: Boundary – a, abrupt; c, clear; d, diffuse; w, wavy; g, gradual; i, irregular; b, broken; Field Texture – L, loam; SL, sandy loam; SiL, silt loam; SiCL, silty clay loam; Wet Consistence – so, nonsticky; ss, slightly sticky; s, sticky; po, nonplastic; ps, slightly plastic; p, plastic; Structure – sg, single grain; m, massive; 1, weak; 2, moderate; 3, strong; f, fine; m, medium; c, coarse; sbk, subangular blocky; abk, angular blocky; Clay Films – 1, few; 2, common; f, faint; d, distinct; po, in pores; pf, on peds. Profile MR-S1 described by Alan Nelson, 16 September 2001. Profiles SB-S1 and SB-S2 described by Bob Bogar, 13 September 2001, with a few modifications by Alan Nelson.
[2] R, root-stirred sediment derived from units of mixed or variable genesis; S, root-stirred sediment derived primarily from lake deposits; D, root-stirred sediment derived from pebbly drift; L, lake deposits; T, till and other ice-proximal deposits; two letters indicate a mixture of two genetic components. Unit label in parentheses.
[3] Dominant dry color of horizon.
[4] Volume percentages visually estimated in the field to nearest 5%.

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