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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 5-40º 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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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

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 under tip of 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)

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)

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.

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.

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.