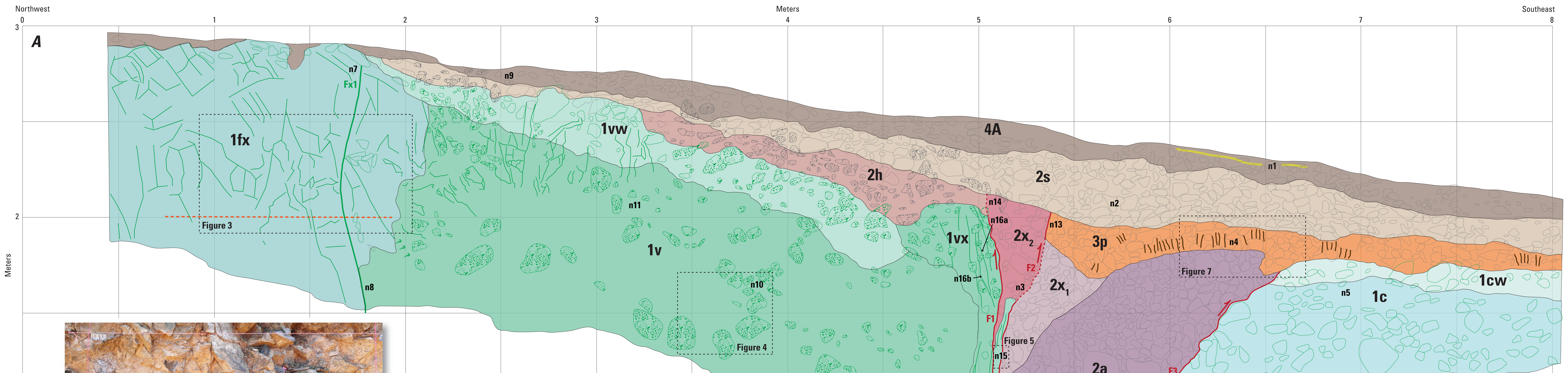


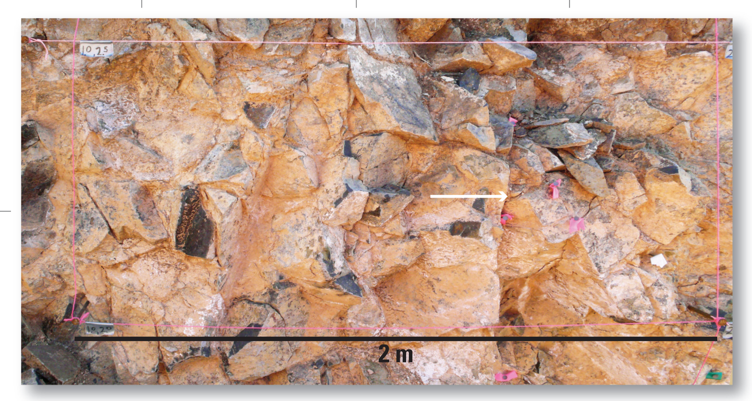


Figure 3. Photograph of aphanitic, nonvesicular basalt showing blocky jointing and fractures that define poorly formed polygonal columns and are characteristic of unit 1fx. The morphology suggests that this part of unit 1fx is a colonnade section of a flow. The orientations of the joints and fractures are represented in the stereogram in figure 8*A*. Structure data suggest that the flow dips gently to the northwest. White arrow and pink flags (in photograph) indicate through-going fracture, Fx1. Field of view is a little over 1 meter.

Figure 2. The Horned Lizard trench in the Boylston Mountains. The location of the trench excavation is shown in figure 1. *A*, Profile of the Horned Lizard trench stratigraphy. *B*, Photomosaic of the Horned Lizard trench.

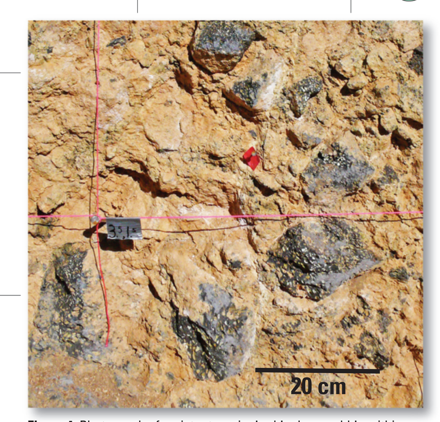


Figure 4. Photograph of resistant, vesicular blocks or rubble within a crumbling, weathered matrix (unit 1v). The morphology suggests that unit 1v might be either (1) the brecciated top or bottom of a flow or (2) the top or bottom of a brecciated flow that grades into the top of a simple flow top as brecciation and rubble decrease upward. cm, centimeters.

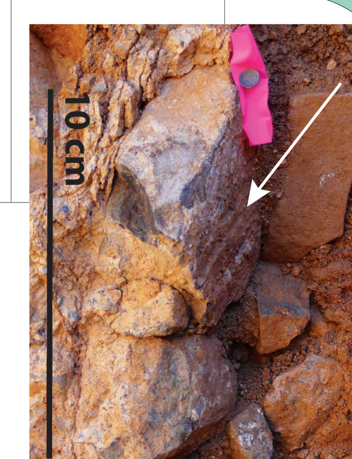


Figure 5. Photograph showing gently southwest-plunging striations (white arrow) on the surface of fault F1. Measurements are shown in figure 8. cm, centimeters.

Figure 6. Photograph of nonvesicular blocks weathering out of a resistant matrix of brecciated unit 1c. cm, centimeters.

Figure 7. Photograph showing detail of prismatic soil structure in unit 3p. White arrow shows approximate vertical extent of prism structure. cm, centimeters.

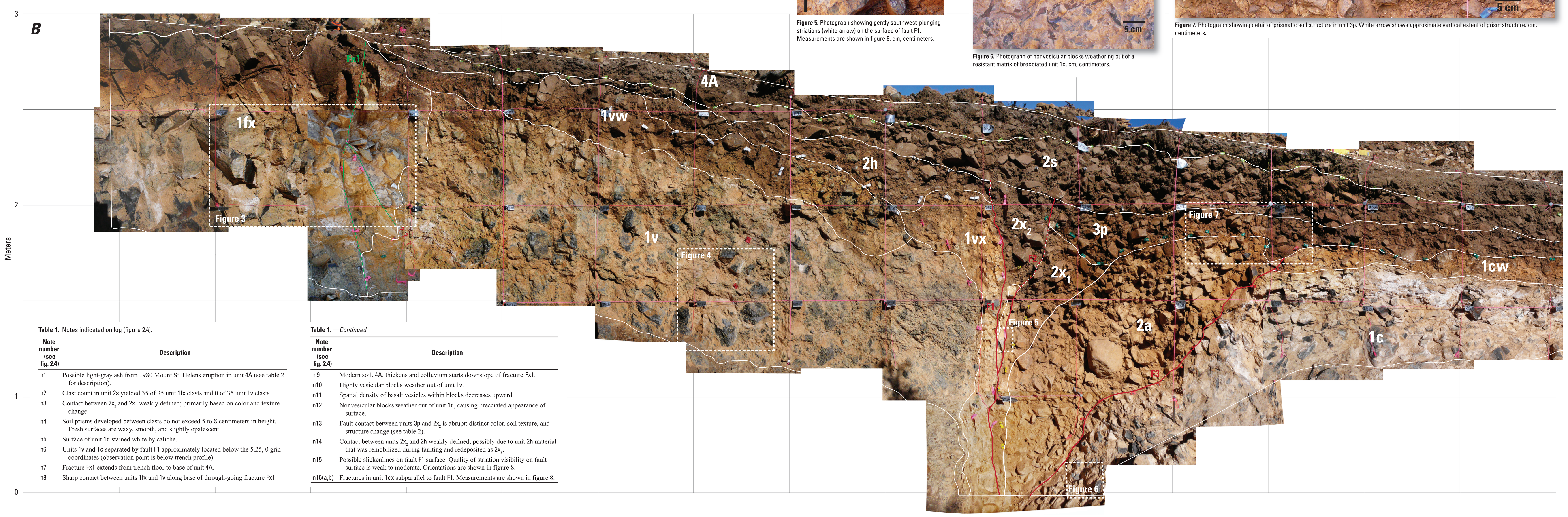


Table 1. Notes indicated on log (figure 2*A*).

Note number (see fig. 2*A*)	Description
n1	Possible light-gray ash from 1980 Mount St. Helens eruption in unit 4A (see table 2 for description).
n2	Clast count in unit 2s yielded 35 of 35 unit 1fx clasts and 0 of 35 unit 1v clasts.
n3	Contact between $2x_2$ and $2x_1$ weakly defined; primarily based on color and texture change.
n4	Soil prisms developed between clasts do not exceed 5 to 8 centimeters in height. Fresh surfaces are waxy, smooth, and slightly opalescent.
n5	Surface of unit 1c stained white by caliche.
n6	Units 1v and 1c separated by fault F1 approximately located below the 5.25, 0 grid coordinates (observation point is below trench profile).
n7	Fracture Fx1 extends from trench floor to base of unit 4A.
n8	Sharp contact between units 1fx and 1v along base of through-going fracture Fx1.

Table 1.—*Continued*

Note number (see fig. 2*A*)	Description
n9	Modern soil, 4A, thickens and colluvium starts downslope of fracture Fx1.
n10	Highly vesicular blocks weather out of unit 1v.
n11	Spatial density of basalt vesicles within blocks decreases upward.
n12	Nonvesicular blocks weather out of unit 1c, causing brecciated appearance of surface.
n13	Fault contact between units 3p and $2x_2$ is abrupt; distinct color, soil texture, and structure change (see table 2).
n14	Contact between units $2x_2$ and 2h weakly defined, possibly due to unit 2h material that was remobilized during faulting and redeposited as $2x_2$.
n15	Possible slickenlines on fault F1 surface. Quality of striation visibility on fault surface is weak to moderate. Orientations are shown in figure 8.
n16(a,b)	Fractures in unit 1cx subparallel to fault F1. Measurements are shown in figure 8.

Table 2. Description of units in trench.

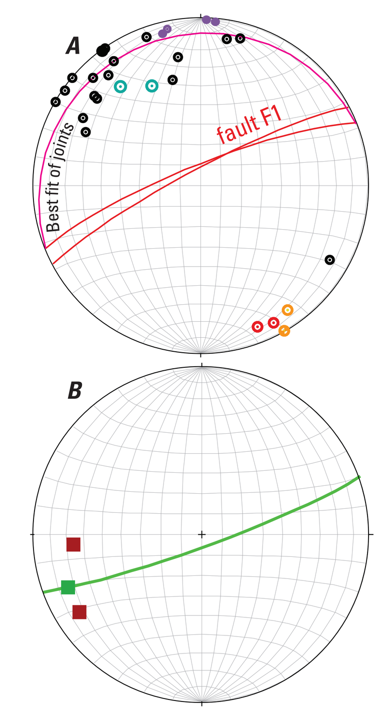
[Color terminology is taken from Munsell Color, Inc. (2002). Terminology regarding texture, roots, clasts, soil-horizon features, and distictness of contacts is taken from Schoneberger and others (2002). NA, not available; <, less than]

Unit (see figure 2*A*)	Texture	Color for dry surface (moist surface)	Roots[1]			Clast descriptions						Stratification
			Size	Quantity	Location	Total area (percent)	Boulders (percent of unit)	Cobbles (percent of unit)	Pebbles (percent of unit)	Angularity	Support	
4A	Clay loam	10 YR 5/3 (10 YR 4/3)	Fine and very coarse	Common and few	Throughout	10	0	80	20	Angular to subangular	Matrix	None
2s	Silty clay	10 YR 4/3 (10 YR 3/3)	Fine and very coarse	Common and few	Throughout	25–35	0	40	60	Angular to subangular (cobbles) Subrounded (pebbles)	Matrix	None
$2x_2$	Silty clay	10 YR 5/4 (10 YR 4/4)	Fine	Few	Throughout	15–20	0	30	70	Subangular to subrounded	Matrix	None
3p	(Too indurated to describe)	7.5 YR 4/4 (7.5 YR 3/3)	Very fine to fine	Common	Throughout	15	0	60	40	Subangular	Matrix	None
2h	Silty clay	10 YR 5/4 (10 YR 4/3)	Fine	Few	Throughout	20	0	20	80	Subangular to subrounded	Matrix	None
$2x_1$	Sandy clay loam	10 YR 6/4 (10 YR 5/4)	Fine	Few	Throughout	15–20	0	30	70		Matrix	None
2a	Sandy clay loam	10 YR 6/6 (7.5 YR 4/6)	Very fine to fine	Few	Matted around rock fragments	35–40	< 1	40	60	Subangular	Matrix	None
1cw	Regolith	10 YR 6/6	Fine	Few	Matted on surface	20	0	50	50	Subangular to subrounded	Matrix	None
1c	Basalt	10 YR 7/3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1vx	Basalt	10 YR 5/4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1vw	Basalt	10 YR 4/3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1v	Basalt	10 YR 7/4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1fx	Basalt	10 YR 7/4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 2.—*continued (columns to the right)*

Unit (see figure 2*A*)	Soil-horizon features				Lower contacts				Postdeposition deformation		Unit genesis and interpretation
	Structure	Size	Distinctness	Rupture resistance (dry)	Distinctness	Underlying unit(s)	Unit surface topography	Unit surface shape	Type	Distinctness	
4A	Granular	Fine	Moderate	Loose	Abrupt to clear	2s	Wavy	Tablet	None apparent	NA	Soil developed after most recent earthquake deformation.
2s	Subangular blocky	Fine	Moderate	Soft	Abrupt	2h or 3p	Wavy	Tablet	None apparent	NA	Colluvium deposited following earthquake that pre-dates development of unit 3p. Mixture of soil and cobbles filled void along fault surface between faults F1 and F3. Later cut by fault that truncates unit 3p and fault F2.
$2x_2$	Subangular blocky	Very fine	Moderate	Moderately hard	Clear	$2x_1$	Smooth	Wedge	None apparent	NA	Colluvium deposited between faults F1 and F2 following last earthquake that offset unit 3p. Contains mixture of units 2h and $2x_1$.
3p	Prismatic	Fine	Moderate	Extremely hard	Abrupt	$2x_1$, 2a, 1cw	Wavy	Tablet	Cut by fault F2, not found on hanging wall. Unit warped between faults F2 and F4	Good	Distinctive prismatic soil formed on colluvial units 2a and $2x_1$ and on unit 3c. Absent on hanging wall; may have eroded from uplifted surface of hanging wall, or may have been incorporated into unit 2h. Merges with modern soil east of 8 meters on grid.
2h	Subangular blocky	Very fine	Weak	Soft	Clear	1v or 1vw	Wavy	Wedge	Faulted by fault F1 at 5 meters, then possibly collapsed into fault zone and integrated into $2x_1$	Moderate	Might be either scarp colluvium from an earthquake that predates unit 3p or former BC-horizon (dominant clast type is unit 1v). Truncated by fault F1.
$2x_1$	Granular	Fine	Moderate	Slightly hard	Abrupt	2a	Smooth	Wedge	Cut by fault F2	Moderate	Colluvium that predates unit 3p, deposited on unit 2a, cut by fault F2, and appears to have been dragged along surface of fault F1 as a thin string of rubble.
2a	Subangular blocky	Fine	Weak	Very hard	Abrupt	1c	Smooth	Wedge	Deposited possibly syndepositionally with the rupture of fault F3	Moderate to good	Deposited as colluvium following earthquake that predates development of unit 3p.
1cw	Granular	Fine	Weak	Moderately hard	Clear	1c	Smooth	Tablet	Cut by fault F3	Good	Weathered top of unit 1c.
1c	NA	NA	NA	NA	NA	NA	NA	NA	Faulted by faults F1 and F3, which are likely joined at depth	Good	Basalt flow of Miocene Grande Ronde Formation.
1vx	NA	NA	NA	NA	NA	NA	NA	NA	Faulted by fault F1	Good	Basalt flow of Miocene Grande Ronde Formation.
1vw	NA	NA	NA	NA	NA	NA	NA	NA	None apparent	NA	Basalt flow of Miocene Grande Ronde Formation.
1v	NA	NA	NA	NA	NA	NA	NA	NA	Faulted by fault F1 and possibly by fault F4	NA	Basalt flow of Miocene Grande Ronde Formation.
1fx	NA	NA	NA	NA	NA	NA	NA	NA	Possibly faulted by fault F4	NA	Basalt flow of Miocene Grande Ronde Formation.

[1]For units 4A and 2s, two types of roots were present.



EXPLANATION

Poles to planes of joints, fractures, and faults
- Joints measured along scan line (see figure 2*A* for location)
- Fracture Fx1
- Splay fracture of fracture Fx1
- Plane measurements of fault F1
- Fractures within unit 1vx subparallel and adjacent to fault F1

Trend, plunge, and pitch of striations measured on fault F1 surface
- Trend and plunge
- Pitch

Figure 8. Equal-area lower-hemisphere stereograms depicting structure data collected at Horned Lizard trench. *A*, Measurements of joints and fractures in unit 1fx taken along a scan line (orange dashed line in figure 2*A*). The near-vertical fault plane, measured on the fault surface, is shown in red (poles and planes). The magenta curve is the best-fit plane derived from the poles of joints measured in unit 1fx. This gently north-dipping plane is the inferred flow-top surface of the basalt bedrock. *B*, Measurements of gently southwest-plunging striations measured on the F1 fault. The green line represents the fault surface on which the pitch was measured. An example of the striations is shown in figure 6. These grooves are moderately expressed on the fault surface. Stereograms were generated using Stereonet 6.3.3X (Allmendinger, 2002).

EXPLANATION

[See table 2 for information on color, texture, and other features]

- **4A** **Modern soil**
- **2s** **Colluvium**—Undeformed, overlies scarp
- **$2x_2$** **Colluvium**—Associated with most recent earthquake
- **3p** **Buried soil**—Bears distinctive prismatic structure
- **2h** **Colluvium**—Found only northwest of fault F1. Incorporates clasts of unit 1v and possibly of eroded unit 3p
- **$2x_1$** **Colluvium**—Associated with earthquake that predates development of unit 3p, either syn-or post-depositional to underlying unit 2a
- **2a** **Colluvium**—Colluvium associated with earthquake that predates development of unit 3p.
- **1cw** **Weathered top of unit 1c (or paleo C-horizon)**
- **1c** **Basalt**—Brecciated, blocky, nonvesicular. Mapped as part of Grande Ronde Formation
- **1vx** **Weathered, fractured unit 1v**—Found adjacent to fault F1. Fractures are subparallel to F1
- **1vw** **Weathered top of unit 1v (or paleo C-horizon)**
- **1v** **Basalt**—Fractured, brecciated, blocky, vesicular. Mapped as part of Grande Ronde Formation
- **1fx** **Basalt**—Jointed, fractured. Possible colonnade section of Grande Ronde Formation
- **n12** **Location of important feature**—See numbered items in table 1 for detailed information about location
- **Contact**
- **F3** **Fault**—Arrows indicate sense of movement. Dashed where inferred or uncertain
- **F3** **Joint or fracture**
- **Scan line along which joints and fractures were measured**
- **Ash layer inferred from Mount St. Helens eruption in 1980**
- **Prismatic soil structure in unit 3p**
- **Cobbles and blocks**
  - Nonvesicular cobble of unit 1fx, transported within deposit
  - Nonvesicular block of unit 1fx, in place
  - Vesicular cobble of unit 1v, transported within deposit
  - Vesicular block of unit 1v, in place

DISCUSSION

The Boylston Mountains anticlinal ridge is one of several that are cored by rocks of the Columbia River Basalt Group and, with the interceding synclinal valleys, constitute the Yakima fold-and-thrust belt of central Washington (fig. 1*A*) (Schuster, 1994; Schuster and others, 1997). Lidar data acquired from the U.S. Army's Yakima Training Center reveal a prominent, northwest-side-up, 65°- to 70°-trending, 3- to 4-meter-high scarp that cuts across the western end of the Boylston Mountains, perpendicular to the mapped anticline (fig. 1*B*) (Blakely and others, 2011). The scarp continues to the northeast from the ridge on the southern side of Park Creek and across the low ridges for a total length of about 3 kilometers. A small stream deeply incises its flood plain where it projects across Johnson Canyon (fig. 1*B*).

In September 2010, two trenches were excavated across this scarp. The most informative of the two, the Horned Lizard trench (46.959N., 120.347W.) was measured and described in detail using a 0.5-square-meter grid (fig. 2) The Horned Lizard trench exposed a shallow basalt unit that was previously mapped as one of several flows making up the Grande Ronde Basalt by Schuster (1994); laboratory paleomagnetic analyses of oriented hand samples collected from the trench correlate this basalt unit with the youngest flow of the Grande Ronde Basalt: the informally named Museum flow of the Sentinel Bluffs Member (Reidel, 2005; Ray Wells and Jonathan Hagstrum, U.S. Geological Survey, written. commun., 2011), which is about 15.5 million years old (mega-annum, or Ma) (Swanson and others, 1979; Reidel and others, 1989). This study subdivides the flow into several descriptive, informal units (units 1cw, 1c, 1vx, 1vw, 1v, 1fx) (figs. 3–6), which are covered by a thin layer of cobbly, silty surface deposits that are less than 1 meter thick across the scarp. The trench excavation within the basalt revealed a deep, wide crack that is coincident with the base of the scarp and filled with wedges of silty gravels that are interpreted to represent at least two generations of fault colluvium (fig. 2). The crack is located between 5 and 6.5 meters on the grid shown in figure 2. The dark-brown, silty clay with a distinctive prismatic structure (unit 3p) (fig. 7) is interpreted to be a buried soil that developed on the surface of the oldest colluvial wedges (units 2a, $2x_1$).

Subsequent faults (F) F1 and F2 truncated the soil and generated another wedge of colluvium (unit $2x_2$); thus, at least two events produced the stratigraphy exposed in the trench. By inference, the reverse motion on faults F1 and F3 ruptured the bedrock, although it is also possible that the rupture was the result of oblique motion recorded by gently southwest-dipping striations on the surface of fault F1 (fig. 8). The two units that were not deformed by the faulting—scarp colluvium (2s) and modern soil (4a)—drape the basalt, the colluvium-filled crack in the basalt, and the buried soil. Evidence constraining the age of faulting is poor; there was no material in the trench to constrain the ages for each rupture event except for the Grande Ronde Basalt, which has a maximum age of 15.5 Ma. Fault F1 is here referred to as the Johnson Canyon fault and movement along it is inferred to be late Quaternary in age given the presence of the scarp on the modern landscape and the incised flood-plain sediments in Johnson Canyon that were apparently warped by reverse motion along the fault.

REFERENCES CITED

Allmendinger, R.W., 2002, Stereonet for Macintosh; Stereonet for Windows: Ithaca, N.Y., Cornell University, Department of Earth and Atmospheric Sciences, 42 p., available only online at http://softwarelibrary.geol.ucsb.edu/OSX/Applications-freeware/EarthSci/. (Accessed March 26, 2012.)

Blakely, R.J., Sherrod, B.L., Weaver, C.S., Wells, R.E., Rohay, A.C., Barnett, E.A., and Knepprath, N.E., 2011, Connecting the Yakima fold and thrust belt to active faults in the Puget Lowland, Washington: Journal of Geophysical Research, v. 116, no. B07105, 33 p., doi:10.1029/2010JB008091.

Munsell Color, Inc., 2009, Munsell Soil Color Book: Grand Rapids, Mich., Munsell Color, Inc., not paginated.

Reidel, S.P., 2005, A lava flow without a source; the Cohassett flow and its compositional components, Sentinel Bluffs Member, Columbia River Basalt Group: Journal of Geology, v. 113, no. 1, p. 1–21. (Also available online at http://www.jstor.org/stable/10.1086/425966.)

Reidel, S.P., Tolan, T.L., Hooper, P.R., Beeson, M.H., Fecht, K.R., Bentley, R.D., and Anderson, J.L., 1989, The Grande Ronde Basalt, Columbia; Stratigraphic descriptions and correlations in Washington, Oregon, and Idaho: Geological Society of America Special Paper 239, p. 21–53, 33 p.

Schoeneberger, P.J., Wysocki, D.A., Benham, E.C., and Broderson, W.D., eds., 2002, Field book for describing and sampling soils (version 2.0): Lincoln, Nebr., Natural Resource Conservation Service, National Soil Survey Center, 228 p., available only online at http://soils.usda.gov/technical/fieldbook/.

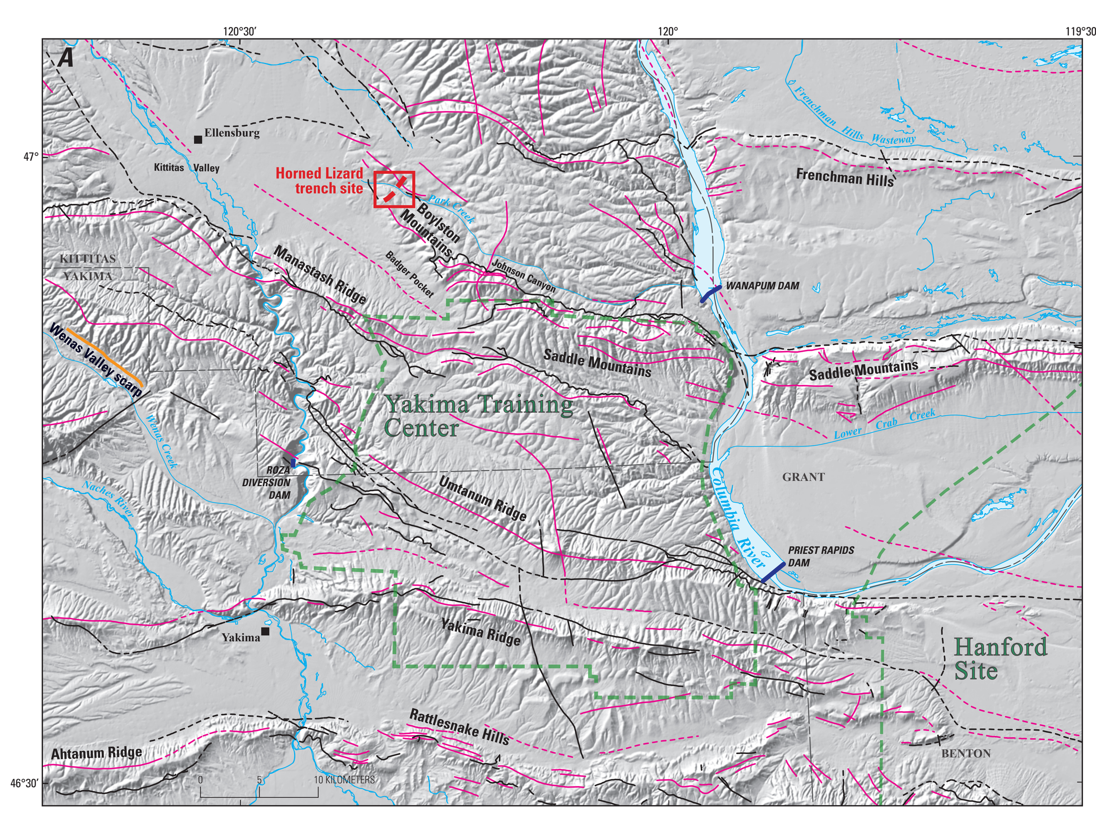
Schuster, J.E., comp., 1994, Geologic map of the east half of the Yakima 1:100,000 quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 94–12, 1 sheet, 1:100,000 scale, 1 pamphlet, 19 p. (Also available online at http://www.dnr.wa.gov/ResearchScience/Pages/Publications.aspx.)

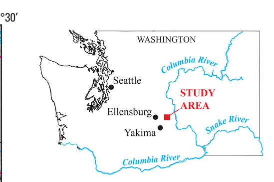
Schuster, J.E., Gulick, C.W., Reidel, S.P., Fecht, K.R., and Zurenko, Stephanie, 1997, Geologic map of Washington—Southeast quadrant: Washington Division of Geology and Earth Resources Geologic Map GM–45, 2 sheets, 1:250,000 scale, 1 pamphlet, 20 p. (Also available online at http://www.dnr.wa.gov/ResearchScience/Pages/Publications.aspx.)

Sherrod, B.L., Barnett, E.A., Knepprath, Nichole, and Foit, F.F., Jr., 2013, Paleoseismology across a possible scarp in the Yakima fold-and-thrust belt, Wenas Valley, Kittatas County, Washington: U.S. Geological Survey Scientific Investigations Map 3212, 1 sheet, available only online at http://pubs.usgs.gov/sim/3212/.

Swanson, D.A., Wright, T.L., Hooper, P.R., and Bentley, R.D., 1979, Revisions in stratigraphic nomenclature of the Columbia River Basalt Group: U.S. Geological Survey Bulletin 1457–G, 59 p. (Also available online at http://pubs.er.usgs.gov/publication/b1457G.)

Washington State Department of Natural Resources, Division of Geology and Earth Resources, 2010, Digital geology of Washington State at 1:100,000 scale (version 3.0): Washington State Department of Natural Resources database available online at http://www.dnr.wa.gov/ResearchScience/Topics/GeosciencesData/Pages/gis_data.aspx/. (Accessed March 21, 2012.)





EXPLANATION

- **Fault**—Modified from Washington State Department of Natural Resources, Division of Geology and Earth Resources (2010). Dashed where inferred
- **Fold**—Modified from Washington State Department of Natural Resources, Division of Geology and Earth Resources (2010). Dashed where inferred
- **Scarp**
- **Boundary of study area**
- **Horned Lizard trench**
- **County boundary**
- **Boundary of U.S. Government facility**—U.S. Army Yakima Training Facility or U.S. Department of Energy Hanford Site

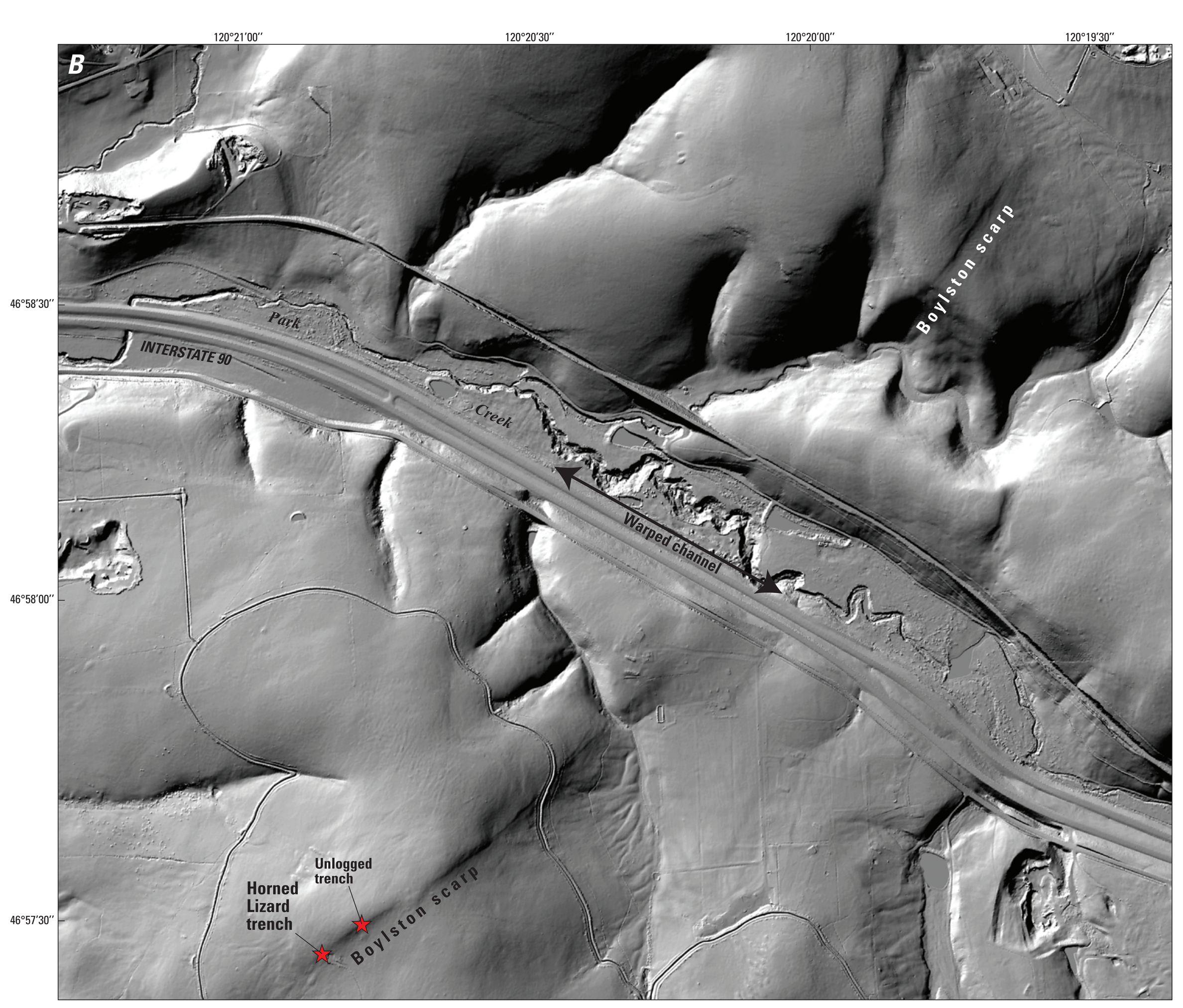


Figure 1. Maps showing study area and vicinity. *A*, Regional shaded-relief map of the Ellensburg-Yakima area of central Washington showing faults, folds, and other features mapped in the Yakima fold-and-thrust belt. See Sherrod and others (2013) for a description of the Wenas Valley scarp. *B*, Shaded-relief map generated from a lidar survey of the Boylston Mountains showing a northeast-trending scarp, the location of the Horned Lizard trench (solid red star), and the potential fault-generated deformation (double-headed white arrow) of Park Creek and its flood plain. Lidar data provided by the U.S. Army Yakima Training Center (2009).

Paleoseismology of a Newly Discovered Scarp in the Yakima Fold-and-Thrust Belt, Kittitas County, Washington

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2013

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