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Scientific Investigations Map 3239

Table 1. Descriptions of units in McCabe Place trench.

[Color terminology is taken from Munsell Color, Inc. (2002). Terminology regarding texture, roots, clasts, soil-horizon features, and distinctness of contacts is taken from Schoeneberger and others (2002). For lower contact distinctness, the categories are determined by the thickness of the transition zone between units, as follows: Abrupt, 0.5 to < 2 cm; Clear, 2 to <5 cm; Gradual, 5 to <25 cm; Diffuse, >15 cm. Abbreviations and symbols are as follows: b, buried genetic horizon; cm, centimeters; NA, not available; w, incipient color or pedogenic structure development and minimal illuviation; ≈, approximately; <, less than]

Unit (see figure 2)	Lithology	Matrix texture	Color	Roots[1]			Clasts				Stratification	Soil horizon[2]					Cement	Lower contact		Deformation	Genesis
				Quantity	Size	Orientation	Cobbles (percent of unit)	Pebbles (percent of unit)	Angularity	Support		Horizon	Horizon suffix	Structure: Grade	Structure: Size	Structure: Type		Distinctness	Relief		
9A	Sandy silt with ash	Silty clay to silty clay loam (ashy)	7.5YR 3/2	Few Few	Very fine Medium to coarse	Subvertical to vertical Vertical	NA	<1	Subangular to subrounded	Matrix	NA	A	NA	Moderate Weak	Fine to medium Very fine	Platy Prismatic	NA	Abrupt	Smooth to wavy	NA	Modern A horizon; contains ash from 1980 Mount St. Helens eruption.
$8AB_w$	Sandy silt	Sandy clay loam	7.5YR 2.5/2	Few	Medium to coarse	Vertical	NA	<1	Subangular to subrounded	Matrix	NA	B	w	Weak to moderate Weak	Medium to coarse Fine	Prismatic Subangular blocky	NA	Gradual	Smooth	Cut by a normal fault (youngest event in trench)	Colluvium deposited by faulting event that cut unit $7B_w$.
$7B_w$	Sandy silt	Sandy clay loam	7.5YR 3/3	Few	Medium to coarse	Vertical	NA	<2	Subangular to subrounded	Matrix	NA	B	w	Weak	Fine	Subangular blocky	NA	Abrupt to clear	Smooth	Cut by normal faults	Colluvial deposit that buried unit $6AB_b$.
$6AB_b$	Sandy clay	Sandy clay	10YR 3/2	Few	Medium	Vertical	NA	NA	Subangular to subrounded	Matrix	NA	BA	b	Moderate to strong Moderate to strong	Medium to coarse Medium to coarse	Prismatic Subangular blocky	Carbonate(?)	Abrupt	Smooth	Possibly folded in center of trench; cut by several normal faults	Soil formed on preexisting scarp, then buried by colluvium (unit 5).
5	Gravelly silty sand	Loamy sand	10YR 4/4	Few	Very fine to medium	Vertical	40	20	Subangular to subrounded	Matrix	NA	CB	NA	Weak	Fine	Prismatic	Carbonate(?)	Clear	Wavy	Bounded by unconformities; cut by normal faults	NA
4	Sandy silt	(Too indurated for texture analysis)	2.5Y 7/4	Few	Very fine to fine	Subvertical	<1	<2	Subangular to subrounded	Matrix	NA	BA	b	Weak	Coarse	Prismatic	Carbonate(?)	Clear to gradual	Smooth to wavy	Cut by normal faults; bounded by unconformities	Possible buried soil.
3	Sandy silt with volcaniclastic fragments	(Too indurated for texture analysis)	10YR 4/2	Few	Very fine	Subvertical	<2	<3	Subangular to subrounded	Matrix	Possibly graded	CB	NA	Moderate	Coarse	Prismatic	Carbonate(?)	Clear	Wavy	Dips to north; eroded by unconformity; cut by normal faults	NA
$2f_2$	Clay with volcaniclastic fragments	Silty clay	2.5Y 5/4	Few	Very fine to fine	Vertical to subvertical	NA	2	Subangular to subrounded	Matrix	NA	CB	NA	Massive	NA	NA	NA	Abrupt	Irregular and (or) broken	Offset by a normal fault	NA
2f	Sandy silt with lapilli	Sandy clay loam	2.5Y 6/4	Few	Very fine	Subvertical	NA	NA	NA	NA	NA	CB	NA	Weak	Medium	Granular	NA	Clear	Irregular	Unit is both folded and faulted at 8 m	Electron microprobe analysis of lapilli and ash sample indicates correlation with layer Cy in Mount St. Helens tephra set C (Mullineaux, 1996).
2e	Cobbly sandy silt	(Too indurated for texture analysis)	2.5Y 6/3	Few	Very fine to fine	Subvertical	30	20	Subangular to subrounded	Matrix	Slight imbrication	CB	NA	Weak	Medium	Prismatic	Slight (carbonate?)	Clear	Wavy	Dips 20° to 35° to the north, possibly folded at 6 to 7 m	Alluvial-fan deposit.
2d	Sandy silt	(Too indurated for texture analysis)	2.5Y 6/4	Few	Very fine	Subvertical	NA	2	Subrounded	Matrix	NA	CB	NA	Weak	Fine	Prismatic	Very indurated (carbonate?)	Clear	Smooth	Dips 20° to 25° to the north	NA
2c	Gravelly silty sand	Sandy clay loam	2.5Y 6/3	Few	Very fine to fine	Subhorizontal	15	15	Subangular to subrounded	Matrix	Slight imbrication	CB	NA	Weak	Medium	Prismatic	Very weak	NA	Wavy	Dips 20° to 25° to the north	NA
2b	Sandy silt	Sandy clay loam	2.5Y 6/4	Few	Very fine	Vertical	<1	<1	Subangular	Matrix	NA	CB	NA	Moderate	Fine	Prismatic	NA	Abrupt	Abrupt	Dips 20° to 25° to the north	Fine-grained alluvial-fan deposit.
2a	Gravelly silty sand	Sandy clay	2.5Y 7/2	Few	Very fine	Subvertical	8	12	Subangular to subrounded	Matrix	NA	C	NA	Weak	Fine	Granular(?)	NA	NA	Smooth	Dips approximately 25° to the north	Debris-flow and (or) alluvial-fan deposit.
1	Sandy silt	Sandy clay loam	2.5Y 7/3	Few	Very fine to fine	Subvertical	1	≈5	Subangular to subrounded	Matrix	Massive	C	NA	Weak	Fine	Granular(?)	NA	Not visible	Smooth	None observed	NA

[1]For unit 9A, two types of roots were present.

[2]For units 9A, $8AB_w$ and $6AB_b$, two types of soil horizons were present.

Table 2. Inferred sequence of depositional and deformational events documented in the McCabe Place trench.

1 Deposition of units 1, 2a, 2b, 2c, 2d, 2e, 2f, $2f_2$, and 3 (see table 1 for unit numbers and descriptions).

2 Erosion leading to development of lower angular unconformity (shown by orange line in figure 2); formation of soil (unit 4).

3 Normal slip on faults F1, F3, F4, F8, and F9; notably—

Fault F4 with a minimum of 83 centimeters (cm) of vertical separation

Fault F3 with a minimum of 15 cm of vertical separation.

Note that all faults may have lateral motion; strata thicknesses do not match up across faults.

4 Erosion leading to development of middle unconformity (shown by purple line in figure 2).

5 Deposition of unit 5 (inferred to be colluvium). Unit 5 at northern end of the trench could be of a different generation than similar deposits at the southern end.

6 Erosion leading to development of upper unconformity (shown by green line in figure 2).

7 Development of soil (unit $6AB_b$).

8 Slip on fault F5 with a minimum of 65 cm of vertical separation.

9 Deposition of colluvium (unit $7B_w$). Unit $7B_w$ buries unit $6AB_b$ in lower half of trench. Unit $6AB_b$ continues to develop in top of trench (from fault F2 northward).

10 Movement on fault F2 with a minimum vertical separation of approximately 87 cm. Faults F6 and F7 could have moved at the same time as fault F2 but with substantial lateral motion; units between F6 and F7 do not match those on either side and have different colors and lithologies.

11 Deposition of unit $8AB_w$.

12 Development of the modern A soil horizon (unit 9A). Upper part of unit 9A contains ash from the 1980 eruption of Mount St. Helens.

DISCUSSION

In October 2009, two trenches excavated across an 11-kilometer-long scarp at Wenas Valley in central Washington exposed evidence for late Quaternary deformation. Lidar imagery of the Wenas Valley illuminated the west-northwest-trending, 2- to 8-meter-high scarp as it bisected alluvial fans developed at the mouths of canyons along the south side of Umtanum Ridge (fig. 1*A*). The alignment of the scarp and aeromagnetic lineaments suggested that the scarp may be a product of and controlled by the same tectonic structure that produced the magnetic lineaments (Blakely and others, 2011). Several large landslides mapped in the area demonstrated the potential for large mass-wasting events in the area (fig 1*A)*. In order to test whether the scarp was the result of an earthquake-generated surface rupture or a landslide, trenches were excavated at Hessler Flats and McCabe Place (fig. 1*B*). The profiles of bedrock and soil stratigraphy that underlie the scarp in each trench were photographed, mapped, and described (figs. 2, 3; table 1), and a sequence of depositional and deformational events was established for each trench (tables 2–4).

The exposure in the McCabe Place trench revealed a sequence of volcaniclastic deposits (units 1–3) overlain by soils (units 4, 6 and 9) and alluvial deposits (units 7 and 8), separated by three unconformities. Six normal faults and two possible reverse faults deformed the exposed strata. Crosscutting relations indicated that up to five earthquakes occurred over the last approximately 47 thousand years on a blind reverse fault, and a microprobe analysis of lapilli contained in unit 2 suggested that the earliest faulting occurred after the deposition of Mount St. Helens ash layer Cy 47,000 years before present (B.P.).

The Hessler Flat trench exposure revealed a weathered bedrock (unit 1) that abuts loess and colluvium deposits (units 3 and 2, respectively) and is overlain by soil (unit 8), an upper sequence of loess (unit 7), and colluvium (unit 6). The latter two units bury a distinctive paleosol (unit 4).

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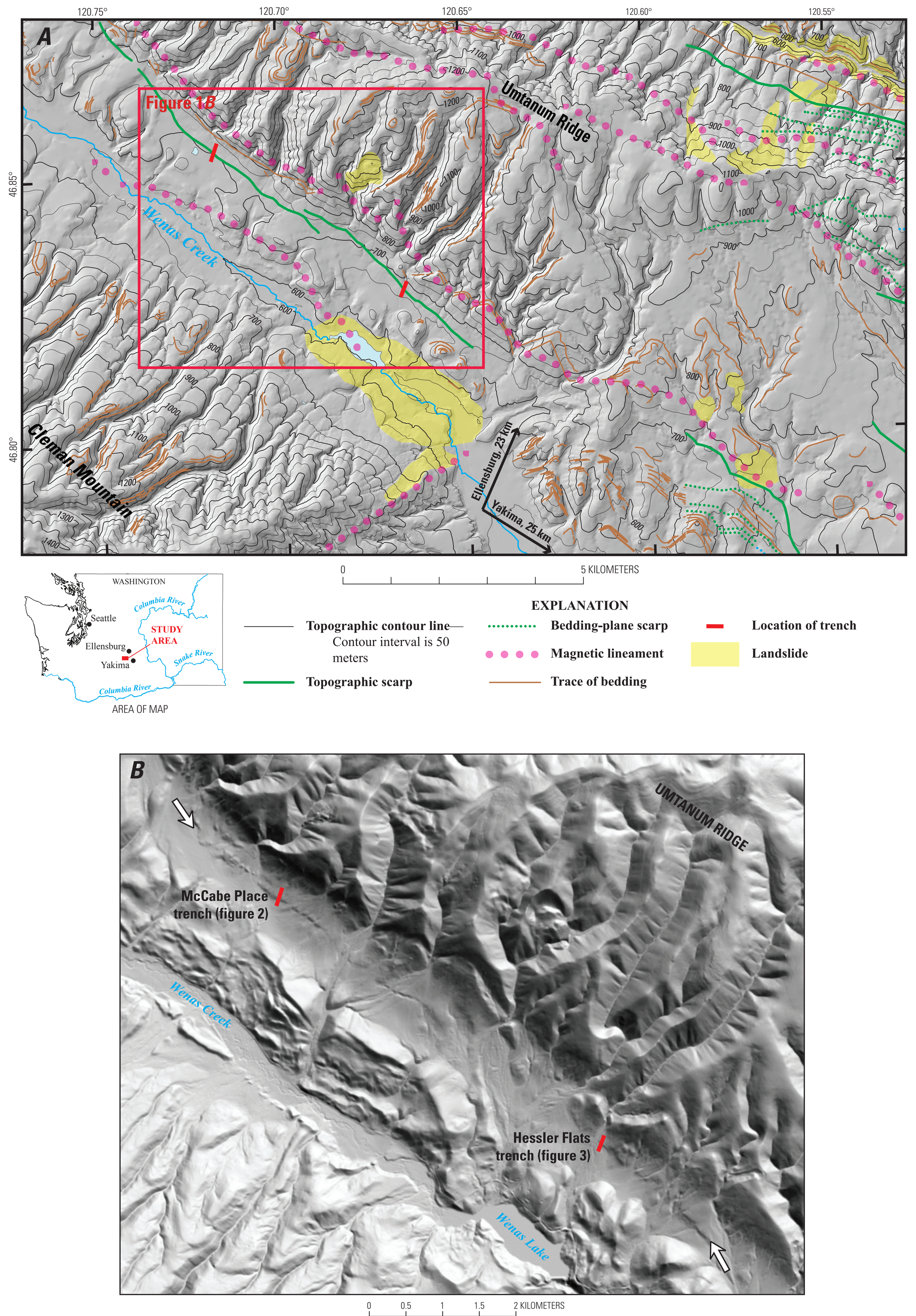
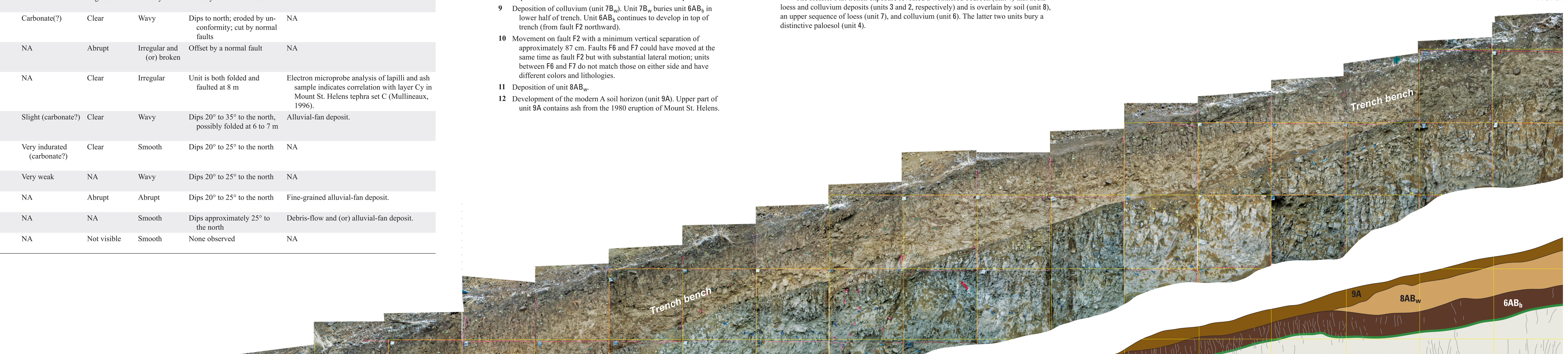
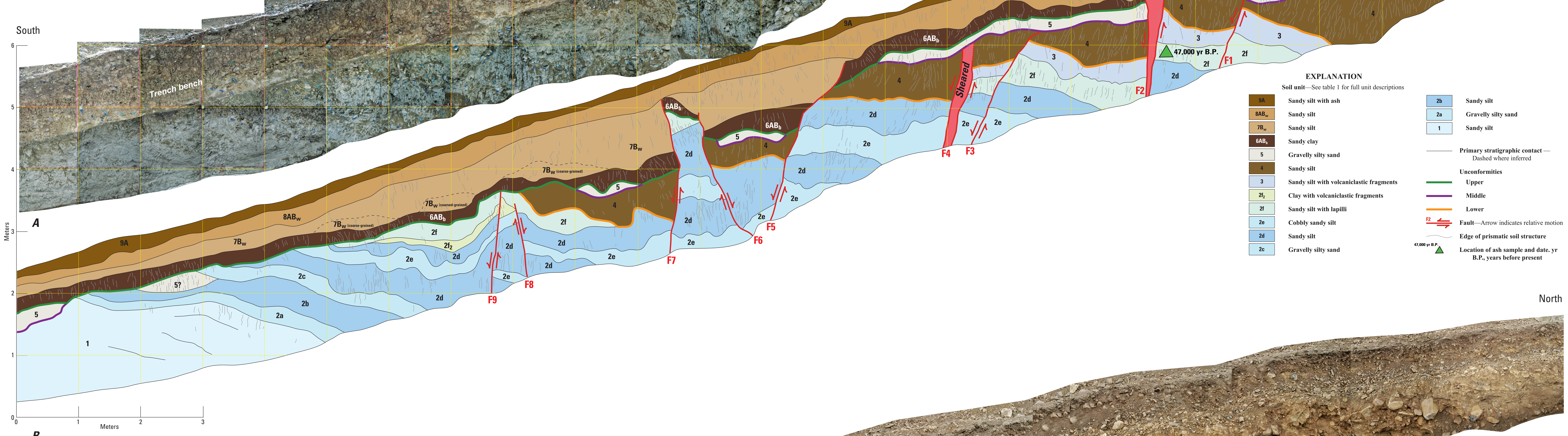
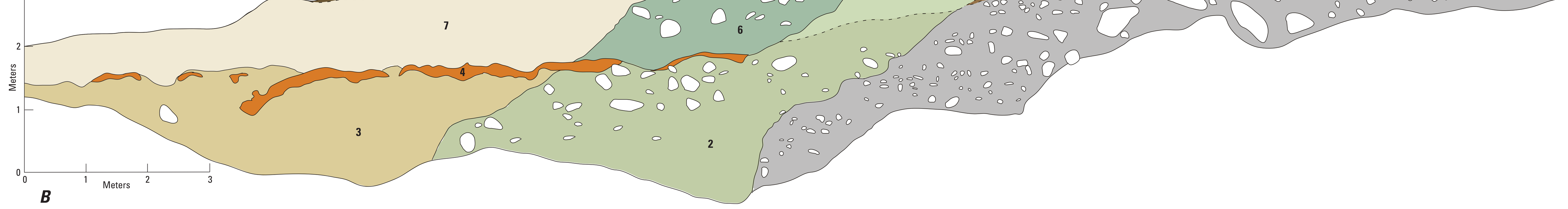


Figure 1. Maps showing study area and vicinity. *A*, Regional shaded-relief map (derived from a 10-meter digital elevation model) of the Wenas Valley area of central Washington, showing scarps, bedding traces, landslides, magnetic lineaments, and trench locations (Blakely and others, 2011). km, kilometers. *B*, Shaded-relief map generated from a lidar image of the area showing the location of the Wenas Valley scarp (white arrows) and trenches (red lines).

Figure 2. The McCabe Place trench in the Wenas Valley, central Washington, which was excavated in October 2009 and measured using a 1-meter grid. The location of the trench excavation (46°51′7.06″N., 120°42′46.28″W.) is shown in figure 1. *A*, Photomosaic of the McCabe Place trench. *B*, Profile of the McCabe Place trench stratigraphy. Electron microprobe analysis of lapilli contained in unit 2f indicates a similarity coefficient of 0.98 with the Mount St. Helens set C tephra, which has an age of around 47,000 years before present (B.P.) (Berger and Busacca, 1995).

EXPLANATION

Soil or rock unit

8A **Modern A soil horizon**—Dark-brown, platy, undisturbed sandy silt. Uppermost part contains light-gray ash from 1980 eruption of Mount St. Helens

$8B_w$ **Modern B_w soil horizon**—Brown, cobbly, silty sand between units 1 and 8A. Only appears in hanging wall, or merges with units 5 and 6. Contact with unit 5 is obscured by trench rubble

8BC **Modern BC soil horizon**—Tan, cobbly, silty, sand. Only appears above unit 1 in northern end of trench

7 **Upper loess or valley fill**—Brown, sandy silt that is similar in appearance to unit 3, but is slightly lighter in color, contains some cobbles, and is slightly less compact. No stratification. Much softer than units 3 and 6. Only appears above unit 4, which separates it from unit 3

6 **Upper cobble colluvium**—Brown, silty to sandy cobble colluvium that is similar to unit 2, except with fewer cobbles. Contains more boulders and is a little less dense than unit 5 and is darker brown and finer grained than unit 3. Separated from unit 2 by unit 4

5 **Upper bouldery cobble colluvium**—Brown, silty to sandy cobble colluvium similar to unit 2 except that it is darker brown, contains fewer boulders, and is less compact than unit 2. Contact with unit $8B_w$ obscured by trench rubble

4 **Buried soil**—Distinctive dark-brown, silty soil containing few to no cobbles and pebbles. Present along the top of lower bench. Disappears beneath rubble north of unit 5. Thins out at southern end of trench. May have been disturbed by trench excavation and (or) was eroded away in places

3 **Lower loess or valley fill**—Mostly homogeneous brown, sandy silt. Contains very few cobbles. No stratification. Much softer than units 2 and 4. Slightly darker and more compact than unit 7. Appears to onlap against unit 2. Separated from unit 7 in places by unit 4

2 **Lower bouldery cobble colluvium**—Hard-packed, brown, silty to sandy bouldery cobble colluvium. Includes soil and pieces of bedrock derived from unit 1. Contains tightly packed cobbles nearest to bedrock and boulders. Difficult to scrape. Darker brown than unit $8B_w$. No color change across contact with unit 3, but unit 2 is more compact than unit 3 and its cobbles and boulders disappear in unit 3. Separated from unit 5 in places by unit 4

1 **Weathered basalt bedrock**—Highly weathered basalt with crumbly, dark-yellow weathering surface and fractured, dark-gray fresh surface. Spheroidally weathers into subangular boulders and cobbles. Intact bedrock material forms "matrix" for spheroidally weathered, boulder-sized clasts. Upper contact coincides with benched wall of trench and soil units 8BC, $8B_w$, and 8A

Basalt clast

Contact—Dashed where inferred

Ash—From Mount St. Helens eruption in 1980

Figure 3. The Hessler Flat trench in the Wenas Valley, central Washington, which was excavated in October 2009 and measured using a 1-meter grid. The location of the trench excavation (46°49′41.42″N., 120°40′0.59″W.) is shown in figure 1. *A*, Photomosaic of the Hessler Flat trench. *B*, Profile of the Hessler Flat trench stratigraphy.

Table 3. Inferred sequence of depositional and deformational events documented in the Hessler Flats trench.

1 Emplacement of basalt.

2 Development of soils (units 8A and $8B_w$) on surface of basalt (unit 1), which weathers into cobbles and boulders now found on the scarp surface.

3 Possible folding or faulting (no fault surface is visible), which uplifts the northern side of the weathered basalt (unit 1) and results in the development of a scarp.

4 Deposition of colluvium (unit 2), which incorporates boulders from weathered basalt (unit 1).

5 Deposition of silty loess (unit 3), which fills the valley and onlaps against the scarp.

6 Formation of soil (unit 4) on surface of colluvium (unit 2) and loess (unit 3).

7 Possible north-side-up folding or faulting event, which refreshes scarp, causes further erosion of the weathered basalt (unit 1), and disrupts the soil (unit 4).

8 Deposition of colluvium (units 5 and 6), which incorporates boulders from weathered basalt (unit 1) mostly into unit 6.

9 Deposition of loess (unit 7), which fills the valley.

10 Development of modern soil horizon (unit 8A) develops on surface. Soil units $8B_w$ and 8BC continue to develop. Upper part of unit 8A contains ash from 1980 eruption of Mount St. Helens tephra (shown by dashed gray lines on figure 3).

Paleoseismology of a Possible Fault Scarp in Wenas Valley, Central Washington

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