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PALEOSEISMOLOGY OF THE SOUTHEASTERN MARGIN OF THE REELFOOT RIFT IN THE VICINITY OF MEMPHIS, TENNESSEE

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ABSTRACT

Faults of the southeastern margin of the Reelfoot Rift are expressed as a pronounced topographic lineament in western Tennessee referred to by previous authors as the “Big Creek lineament” and the “Rives lineament.” From its southwestern end in Shelby County, TN (20 km from Memphis) to Dyersburg, TN (100 km to the NE), the lineament is the NW-facing Mississippi River bluff line. From Dyersburg to its northeastern end near Union City, TN (58 km NE of Dyersburg), the lineament is a series of collinear scarps that face primarily northwest. We acquired five shallow seismic reflection profiles (two in this 2002 phase of the project), drilled four push-core transects (two in 2002), and excavated four trenches (three in 2002) that reveal late Quaternary surface faulting along this lineament.

We previously reported results from Porter Gap (16 km SW of Dyersburg) and from Union City. At Union City, the lineament is a 9 m-high NW-facing scarp, and our seismic profile and push-core transect suggest $\geq$1.5 m of Wisconsin down-to-the-northwest faulting. Our seismic profiles, push-core transect, and initial trench at Porter Gap show $\geq$3 m of late Wisconsin or early Holocene up-to-the-west reverse faulting and mid to late Holocene liquefaction at the base of the west-facing river bluffs. However, our seismic profile shows this up-to-the-west fault separates monoclinally folded Eocene strata with 25 m of down-to-the-west structural relief on the fold.

One of our 2002 trenches at Porter Gap was excavated parallel to NE-striking faults and revealed strike-slip offset of a late Wisconsin paleo-channel. This paleo-channel channel is right-laterally offset from between 8 to 15 m, depending on the bearing of the channel axis, across one plane of a zone of multiple parallel faults (additional northeast-striking faults were documented at this site in another trench). Using minimum and maximum values from infrared stimulated luminescence age analyses of the channel fill and the above maximum and minimum displacements, the averaged slip rate on this fault plane from late Wisconsin to present has been between 0.85 mm/y to 0.37 mm/y, suggesting that the total right-lateral slip rate across all fault planes of the rift margin probably accounts for much (if not most) of the late Wisconsin and early Holocene right-lateral strain on the southern segment of the NMSZ fault complex.

In our new work in Shelby County, we acquired two shallow seismic profiles, conducted an electrical conductivity survey, drilled two push-core transects, and excavated a 42 m trench across the west-facing river bluff lineament, and these data show recent faulting. The trench revealed a near-vertical fault plane with ~0.5 m of late Holocene down-to-the-northwest displacement. Fissuring and subsidence adjacent to the fault in the down-dropped block suggest an extensional component that may be due to co-seismic sliding. At the southeastern end of the rift margin lineament, our push-core transect and electrical conductivity survey show ~0.5 m of post-middle Holocene down-to-the-southeast displacement.

We conclude that the southeastern Reelfoot Rift margin is a fault zone with multiple high-angle fault planes dipping both east and west and showing primarily up-to-the-northwest separations, but including faults that show a change in sense of slip down fault dip. In addition, the fault zone is characterized by a gentle anticline. Such variations in dip and sense of separation and broad arching are characteristic of strike-slip systems. The youngest calibrated radiocarbon ages of sediments pre-dating the latest faulting event ($\geq$0.5 m vertical displacement) are 4100 to 3900 yBP at Shelby County and 2790 to 2740 yBP at Porter Gap. Our radiocarbon ages from sediments post-dating the latest faulting are 2120 to 1800 yBP at Shelby County and 945 to 765 yBP at Porter Gap. These age constraints are consistent

with an earthquake circa 2500 to 2000 yBP on the southeastern Reelfoot Rift margin that ruptured $\geq$80 km from Shelby County to Porter Gap.

PREVIOUS INVESTIGATIONS

An alignment of earthquake epicenters follows the zone of faulting along the southeastern margin of the Reelfoot rift in western Tennessee (Braile et al., 1997; Chiu et al., 1997). In western Tennessee, a prominent scarp and topographic lineament may be the surface expression of the eastern rift margin fault zone (Fig. 1)(Fisk, 1944; O'Leary and Simpson, 1977; Wyatt and Stearns, 1988; Cox et al., 2001a). The southern 60% of this lineament is the bluff-line scarp of the Mississippi River Valley. Our initial analysis of drainage basin asymmetry along the Reelfoot rift margin in western Tennessee and Kentucky suggests this fault zone was active over an extended period during Quaternary stream incision (Cox et al., 2001b).

Two areas of the topographic lineament associated with the rift margin were investigated for evidence of paleoseismicity in the initial 1999-2000 phase of our field study: the northern end at Union City, TN; and Porter Gap, Tennessee (Figs. 1 & 2). We investigated these sites for near-surface faulting using a truck-mounted auger, by conducting shallow shear-wave seismic refection surveys, and by trench excavation at one site (Porter Gap, Tennessee). Our early results showed Holocene activity on this fault system. (Results of this NEHRP-funded work are published in Geology, Cox et al. 2001a).

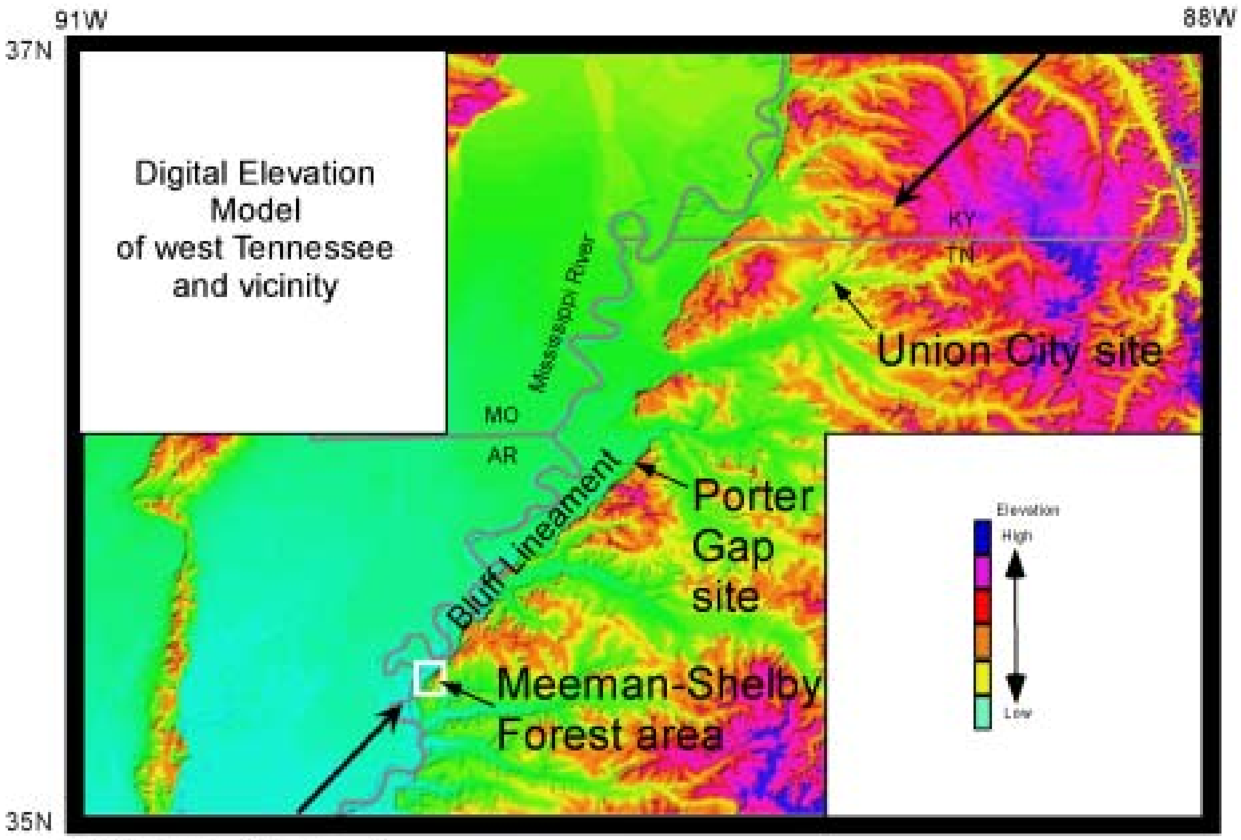

FIGURE 1. Study region.

NEW INVESTIGATIONS

In the 2002 phase, we acquired shear-wave reflection profiles, conducted electrical conductivity surveys, drilled core-hole transects, and excavated trenches sites along the southeastern margin of the Reelfoot rift at Porter Gap, Tennessee and at the southern end of the bluff lineament in Shelby County, TN at Meeman-Shelby Forest State Park (MSF) 15 to 25 km north of the Memphis metropolitan area. We acquired two reflection profiles near MSF and conducted two conductivity surveys, one at Porter Gap and one at MSF. We collected push-cores along two transects near MSF and opened three trenches, one at Meeman-Shelby Forest and two at Porter Gap. Our results document the sense and degree of slip and the chronology of fault movements. Trench walls were logged and photographed, and datable materials collected. Sediment ages were determined by standard and AMS ^{14}C analyses conducted at Beta, Inc., Miami, FL and by infrared stimulated luminescence (IRSL) analyses conducted at Luminescence Dating Research Laboratory, Earth & Environmental Sciences Department, University of Illinois, Chicago, IL. Luminescence dating of sediments has been used successfully to determine slip rates for active faults in several studies (Cox and others, 2000; Chen and others, 2003a; 2003b; Cheong and others, 2003).

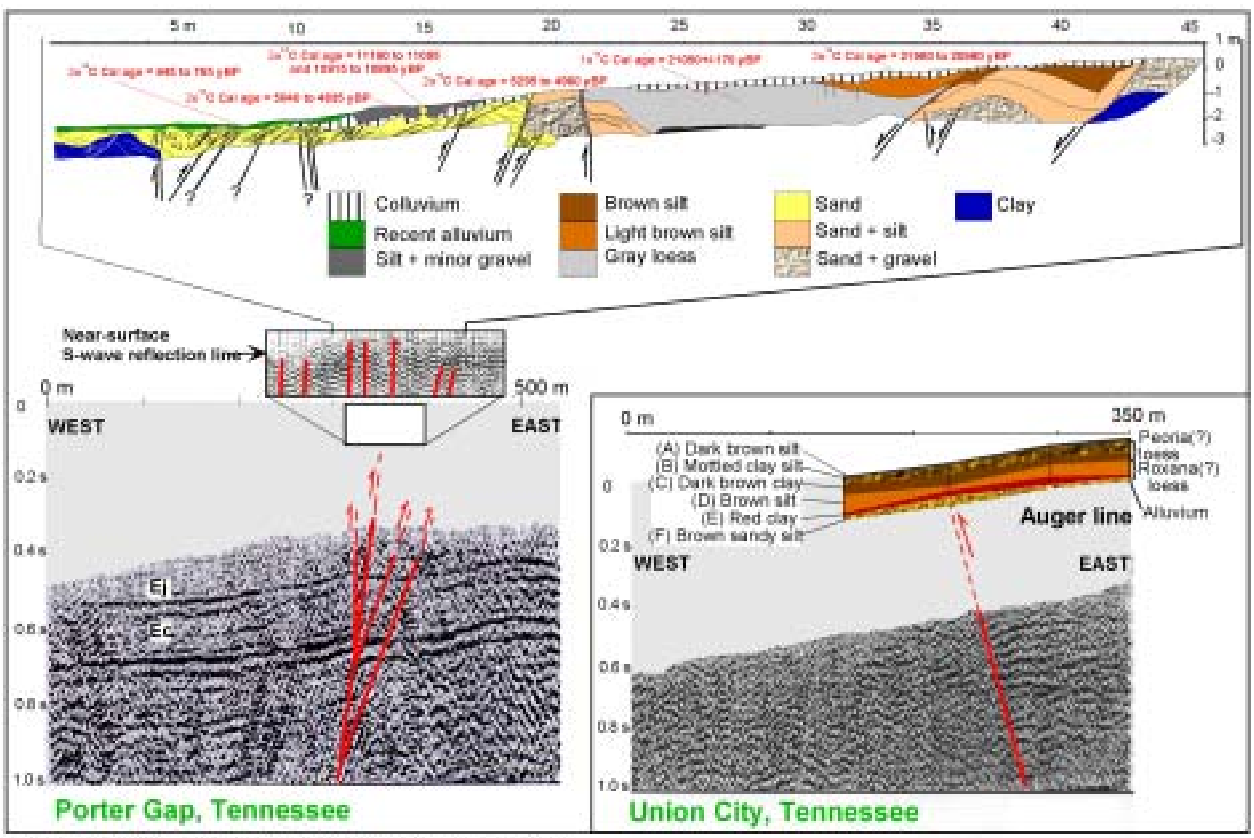

FIGURE 2. Previous 1999-2000 NEHRP investigations.

RESULTS:

Porter Gap, TN, Site

Strike projections of faults revealed in the trenches at Porter Gap, TN (Fig. 3) are consistent with faulting revealed in the seismic profiles at this site (Fig. 2). Trench 2 was excavated transverse to faults indicated by our electrical conductivity survey of this site. The log of trench 2 (Fig. 4) shows the juxtaposition of weathered loess (characteristic of the bluff stratigraphy) on the southeast against Mississippi River alluvium and fill deposits of smaller channels on the northwest. Faults were observed in trench 2 at meter 7.9, meter 8.8, (the eastern and western faults in trench 3, respectively) and meter 14.1. All these faults strike N 20^{o} to 30^{o} E and show steep dips variously east, west, and vertically along strike. A colluvial wedge from meter 3 to meter 7.5 that is consistent with sediment shed from an up-to-the-west scarp in the river alluvium uplifted relative to the surficial loess. We interpret a body of sand from meter 8.9 to meter 10.7 as a possible liquefaction feature because: 1) it is not bedded; and 2) there is a downward-branching "feeder dike" associated with radiating fractures below the sand body. This sand body cross-cuts a fault revealed to have late Holocene displacement in trench 3.

Trench 3 of Porter Gap, TN was excavated parallel to the fault zone, and the excavation began where we crossed prominent faulting in trench 2. Clay shrink-swell processes in the weathered loess have distorted structures revealed in this trench, but fault displacements can be clearly seen in the west wall and the floor (Fig. 5). The logs of the west wall and floor show a Late Wisconsin filled channel that is offset in a right-lateral strike-slip sense by the western of two parallel (or possibly en echelon) faults exposed in the trench floor (Cox and others, 2002). (Figure 6 is a photographic view looking down trench 3 to the northeast). The IRSL age of the Wisconsin channel fill is 19,600±1900 yBP in the central fault block and 19,900±1740 in the western fault block. A late Holocene (~2800 yBP) channel sub-parallel to the fault zone is warped down into the fault plane at meter 14.5. The log of the trench floor shows the western fault offsets the Wisconsin channel facies ~15 meters, assuming the channel axis is at a high angle to the fault plane. If the channel axis is at a low angle to the fault plane, displacement is ~8 meters. Using minimum and maximum IRSL ages of the channel fill and these maximum and minimum displacements, the average slip rate on this fault plane from late Wisconsin to present has been between 0.85 mm/y to 0.37 mm/y. In the west wall of trench 3, a minor mid-Holocene (~4000 yBP) channel at a high angle to the fault zone at meter 9 was not seen in the west wall north of the western fault, thus constraining late Holocene right-lateral slip on this fault plane to <4.5 m (or <1.13 mm/y).

Fault displacements cannot be seen clearly in the east wall of trench 3 due to distortion by deposition of pedogenic clay and clay shrink-swell processes in the weathered loess. Some of the folding of the strata is probably neotectonic, rather than entirely due to shrink-swell processes. The eastern fault seen in the trench floor intersects the east wall at a very low angle, further obscuring the trace of the fault in the wall. Soil horizons appear to dip northwest into the eastern fault. The Late Wisconsin channel observed in the west wall has been faulted out in the east wall, either by down-to-the-east slip or strike slip. The minor mid-Holocene (~4000 yBP) channel at meter 9 in the west wall is present in the east wall at the same level from meter 3 to meter 8.2, permitting only minor late Holocene right-lateral strike-slip or vertical movement, if any, on the eastern fault. The late Holocene (~2800 yBP) channel at meter 16.8 to meter 14.5 and a historic filled channel at meter 3.3 to meter 5.7 in the west wall flowed sub-parallel to the fault zone and were not present in the east wall.

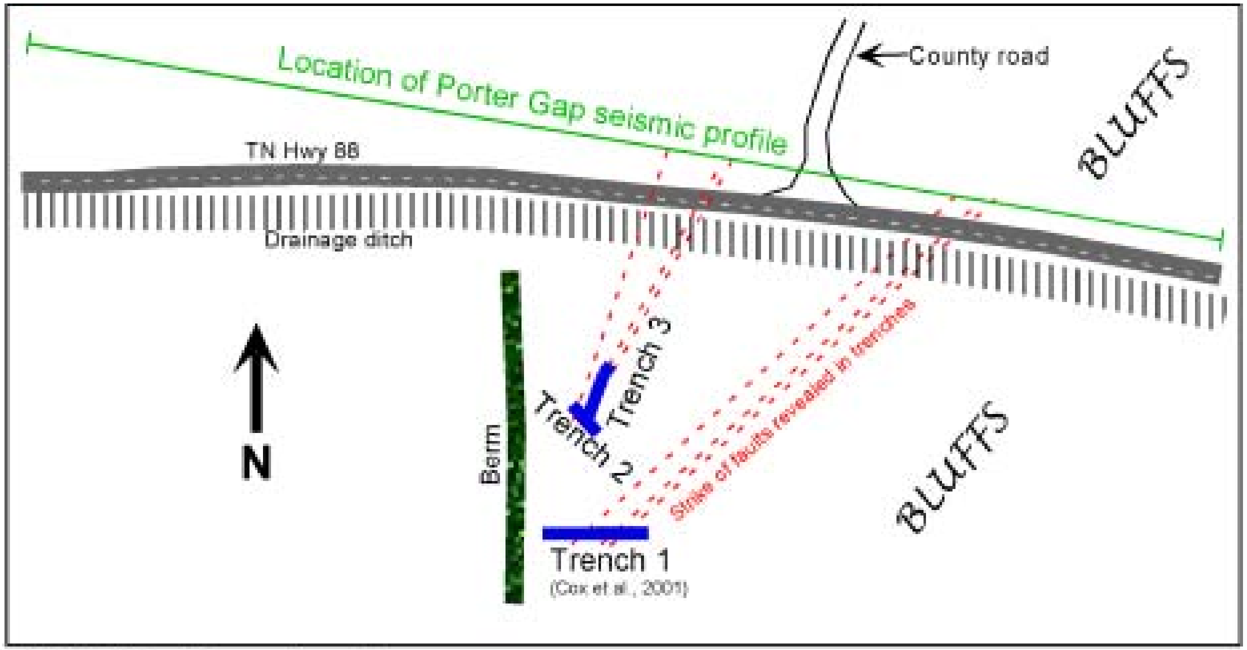

FIGURE 3. Porter Gap site map.

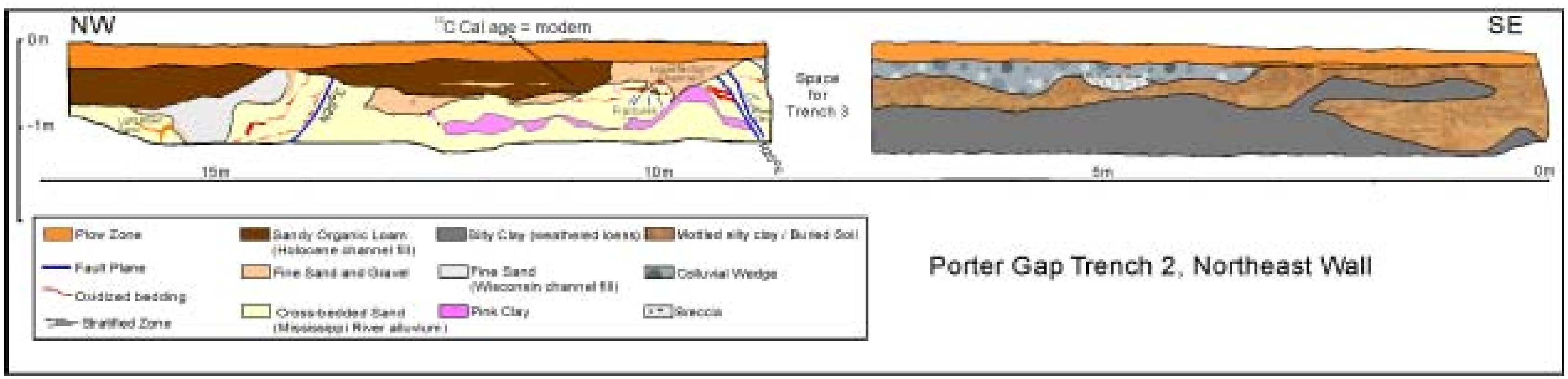

FIGURE 4. Porter Gap trench 2 log.

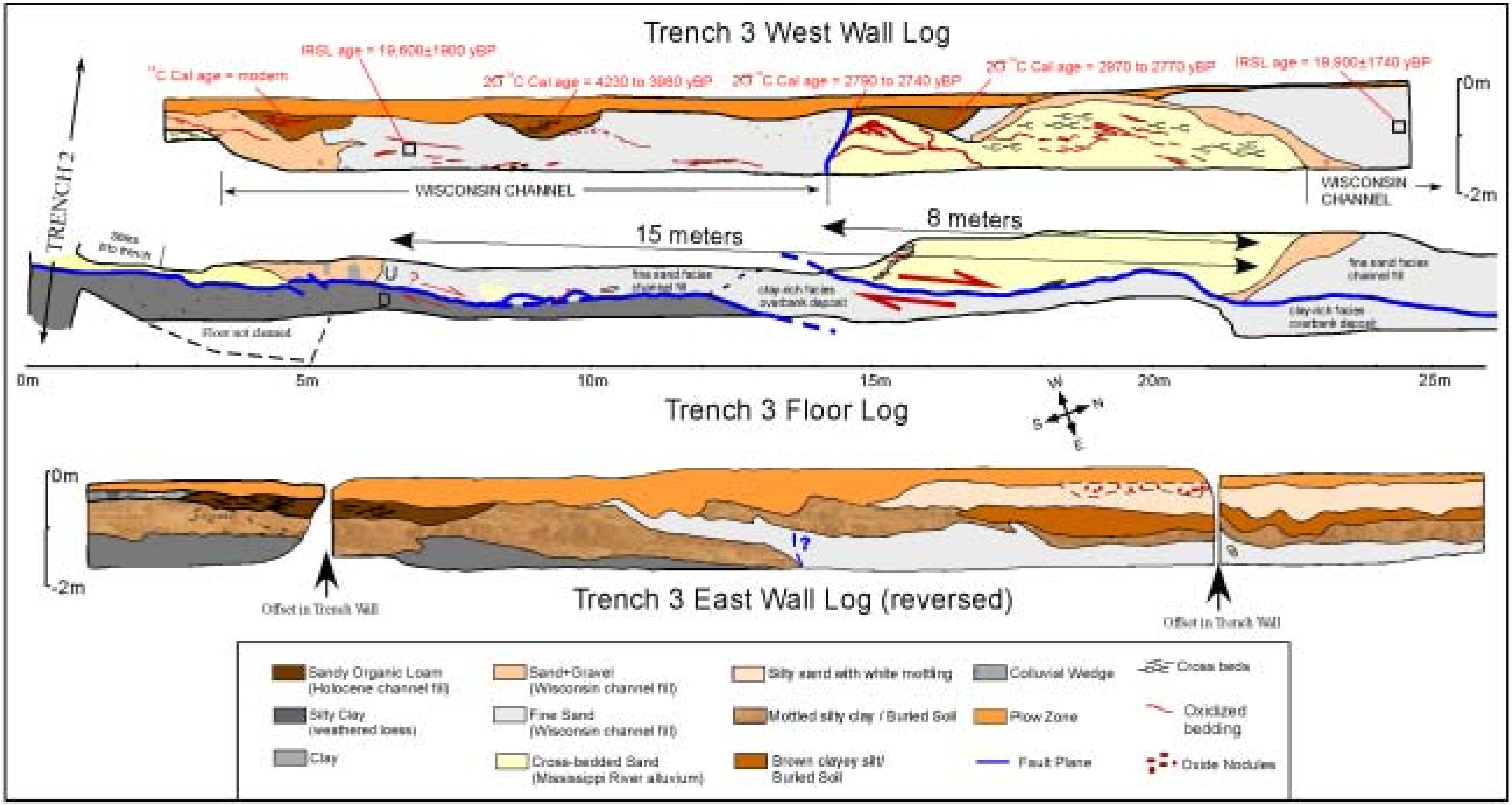

FIGURE 5. Porter Gap trench 3 log.

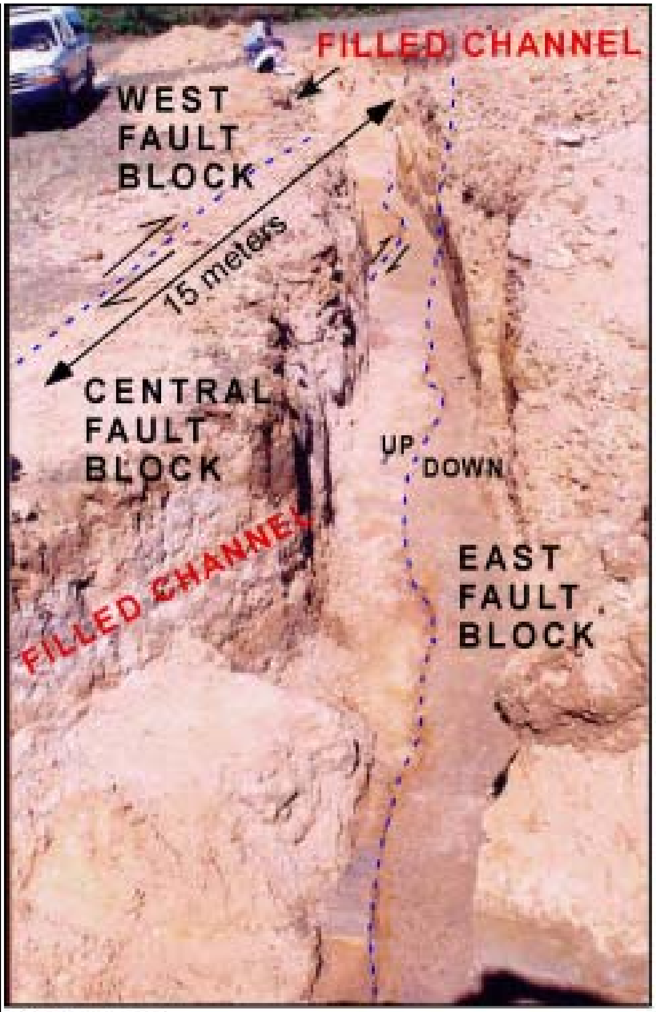

FIGURE 6

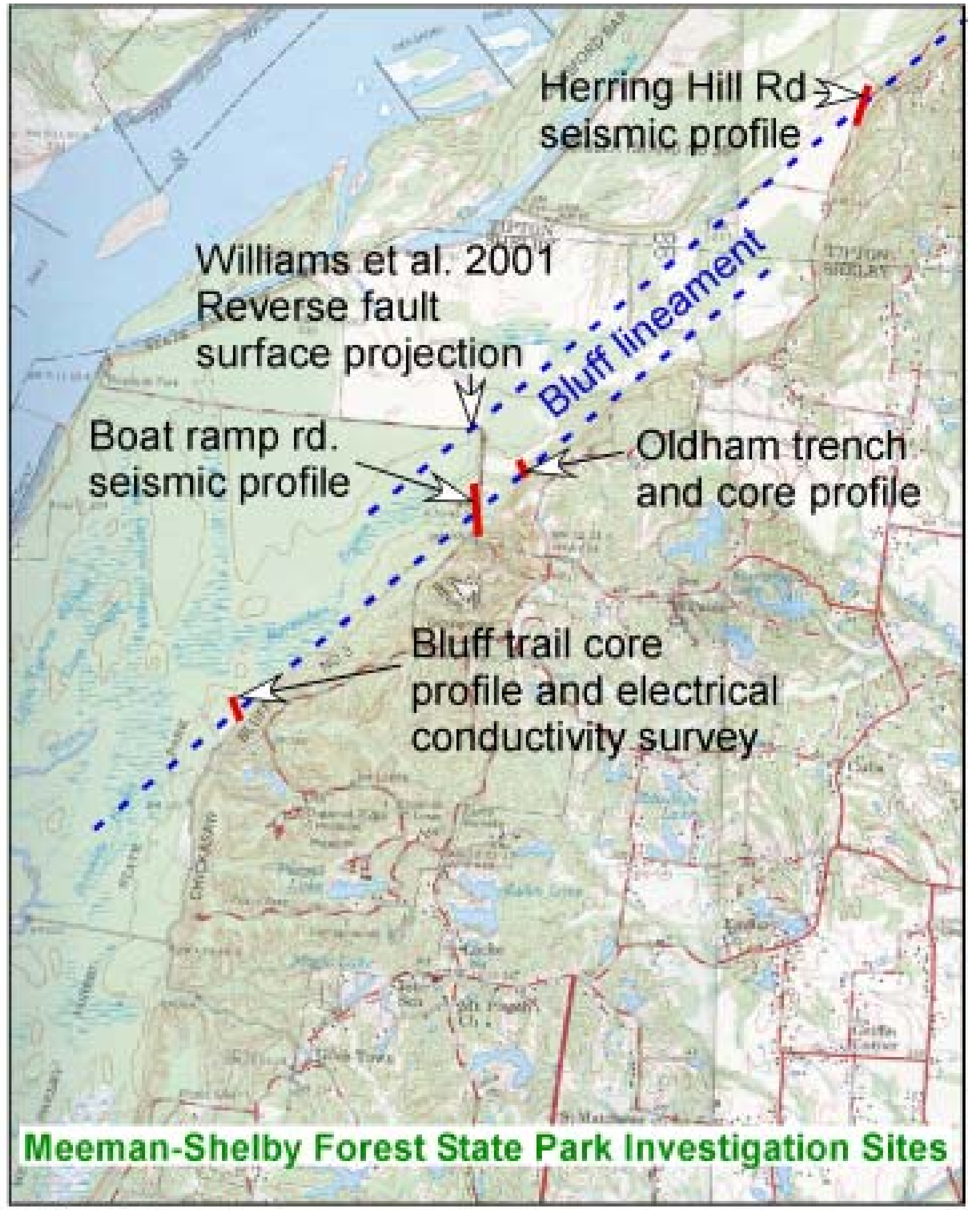

FIGURE 7

Meeman-Shelby Forest State Park Area

In our new work at MSF in Shelby County, we acquired two shallow s-wave seismic reflection profiles, conducted an electrical conductivity survey, drilled two push-core transects, and excavated a 42 m trench across the west-facing river bluff lineament, and these data show recent faulting. The two seismic profiles (Boat-ramp road and Herring Hill road) were each acquired across one of two en echelon bluff lineament segments (Figs. 7 and 8). Prominent reflectors in the profiles are Eocene Jackson Group stratigraphic horizons and the interface between Quaternary alluvium and Eocene units, although surficial alluvial fan stratification can also be discerned on the Boat-ramp road profile.

Boat-ramp road profile- This profile was acquired along a north-south road that crossed a segment of the bluff-line lineament near two sites (Oldham site and Bluff-trail site) where we investigated surficial faulting via coring, trenching, and electrical conductivity (Fig. 7). A portion of this shallow s-wave profile coincides with a portion of a deeper p-wave profile presented in Williams and others (2001). As on the Porter Gap seismic profile we acquired in the 1999-2000 phase of this project, the Boat-ramp road profile shows a monoclinal fold with down-to-the-northwest structural relief >10 m on Eocene reflectors. In addition, there are multiple steep faults of small-displacement (3 to 5 m) revealed by the profile displacing the Eocene section, and as at Porter Gap, these faults are up-to-the-northwest (with the exception of one fault that changes sense of throw up-section, consistent with strike-slip deformation and the associated juxtaposing of differing stratigraphic thicknesses). Eocene and Quaternary strata are warped into a gentle anticline northwest of the bluff line in this profile. The fault array and anticline are consistent with the upper portion of a flower structure above a strike-slip fault system (Davison, 1994). A paleo-slump can be seen below the steep topography of the bluff line, and it appears to pre-date alluvial fan stratification at the foot of the bluff. This may be a paleo-slump referred to by Jibson and Keefer (1988) near this profile.

Herring Hill road profile- This profile was acquired adjacent to the bluff line across a segment of the bluff lineament that projects toward the southwest through the position of an up-to-the-northwest reverse fault imaged on a p-wave reflection line presented in Williams and others (2001). Similar to the Boat-ramp profile, this profile shows a gentle anticline cut by multiple faults showing both normal and reverse separations, again suggesting the upper portion of a flower structure above a strike-slip fault system. The southern-most fault appears to have up-to-the-southeast separation, whereas the other principal faults show up-to-the-northwest separation at this site.

Oldham core profile and trench site- We collected push-cores along a transect across the topographic lineament at the Oldham site (Figs. 7 and 9), near the Boat-ramp Road seismic profile. These cores revealed a tapering wedge of clay within an alluvial fan that suggests down-to-the-northwest displacement across two faults (~1 m separation on each) within 2 m of the surface. We excavated a 42 m trench adjacent to the core-hole line, and a vertical N 57^{o} E-striking fault with ~0.5 m of down-to-the-northwest displacement was exposed in the trench at meter 36. This fault displaces sediments with ^{14}C ages of ~4000 yBP, and organic-rich sediment from the base of a graben depression over the fault has a ^{14}C age of ~2000 yBP. We interpret this faulting event to have been slightly before 2000 yBP. Based on our core-hole data, we interpret this fault to be the surface expression of a fault, rather than a surficial landslide. However, fissuring and subsidence adjacent to the fault in the down-dropped block suggest an extensional component that may be due to co-seismic sliding. This fault is at the expected surface projection of the southern-most fault revealed in the Boat-ramp road profile, but the

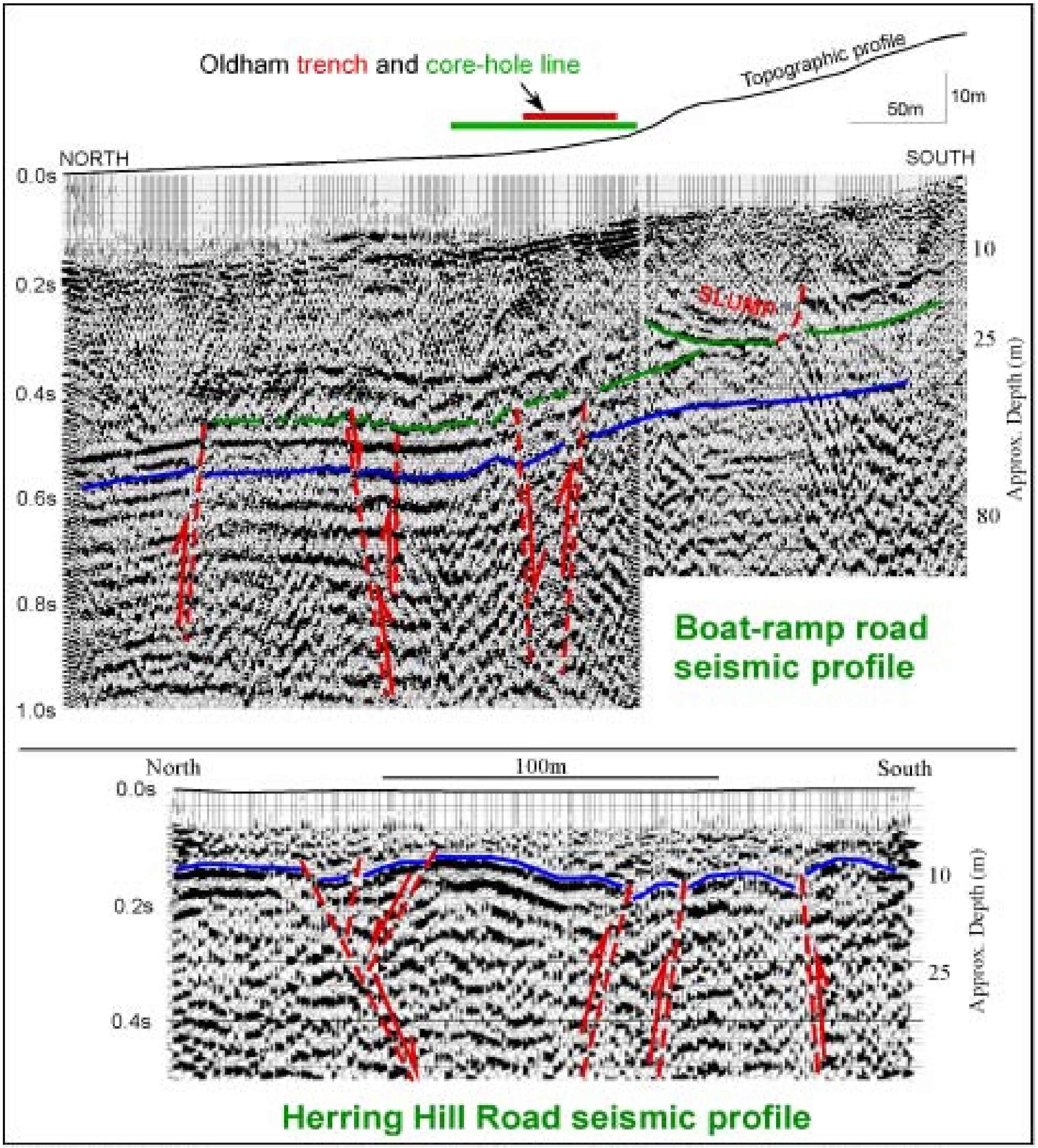

FIGURE 8. 2002 s-wave profiles in the Meeman Shelby Forest State Park vicinity.

sense of throw is wrong. Thus, we postulate that the vertical displacement in the trench is due to co-seismic sliding away from a strike-slip surface rupture. Fissuring and foundering of blocks within the surface rupture zone at this site are similar to surface deformation along the right-lateral strike-slip Lavic Lake and Mesquite Lake faults during the 1999 Hector Mine earthquake in southern California (Treiman and others, 2002). Organic-rich fill of a small fissure at meter 29.8 in the southwest trench wall yielded a ^{14}C age that can accommodate the 1811-1812 New

Madrid earthquake sequence, and indeed, Hough and Martin (2002) suggest that a magnitude 6.1 aftershock of the large December New Madrid earthquake occurred on this fault segment.

Bluff trail site- At the southeastern end of the rift margin lineament, our push-core transect and electrical conductivity survey show ~0.5 m of post-middle Holocene up-to-the-northwest displacement on a N 50° E-striking fault collinear with the bluff-line lineament (Figs. 7 and 10). As at Porter Gap, Boat-ramp road site, and Herring Hill road site, our core profile at this site shows a gentle anticline associated with the up-to-the-northwest faulting. A paleosol circa 7000 yBP at 2.5 to 3 m depth and deeper horizons are deformed, and thinning of the paleosol at the crest of the anticline suggests faulting and folding post-date soil formation (i.e., the soil was erosionally stripped from a tectonic scarp). Younger sediments do not appear to be deformed at this site. Close spacing and alignment of contours on our electrical conductivity map of this site indicates the fault strike. Due to a perched water table in weak sands at this site, we concluded that a trench deep enough to expose the fault plane would not be safe, even with hydraulic shoring.

CONCLUSIONS:

We conclude that the southeastern Reelfoot Rift margin is a fault zone with multiple high-angle fault planes dipping both east and west and showing primarily up-to-the-northwest separations, but including faults that show a change in sense of slip down fault dip. In addition, the fault zone is characterized by a gentle anticline. Such variations in dip and sense of separation and broad arching are characteristic of strike-slip systems. Offset of a Wisconsin paleo-channel at Porter Gap indicates 8 to 15 meters of right-lateral strike-slip.

The youngest calibrated radiocarbon ages of sediments pre-dating the latest faulting event (≥0.5 m vertical displacement) are 4100 to 3900 yBP at Shelby County and 2790 to 2740 yBP at Porter Gap. Our radiocarbon ages from sediments post-dating the latest faulting are 2120 to 1800 yBP at Shelby County and 945 to 765 yBP at Porter Gap. These age constraints are consistent with an earthquake circa 2500 to 2000 yBP on the southeastern Reelfoot Rift margin that ruptured ≥80 km from Shelby County to Porter Gap.

NON-TECHNICAL SUMMARY:

Geophysical surveys, drilling, and excavations were undertaken along the Mississippi River bluff line near Memphis and near Dyersburg to look for evidence of faulting and prehistoric earthquakes. Evidence was found for an earthquake approximately 2000 years ago that was probably of moderate to strong magnitude.

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SEISMIC DATA AVAILABILITY:

Seismic data can be obtained from Dr. Jamie Harris, Department of Geology, Millsaps College, Jackson, MS 39210-0001; Ph. 601-974-1343; harrijb@okra.millsaps.edu.

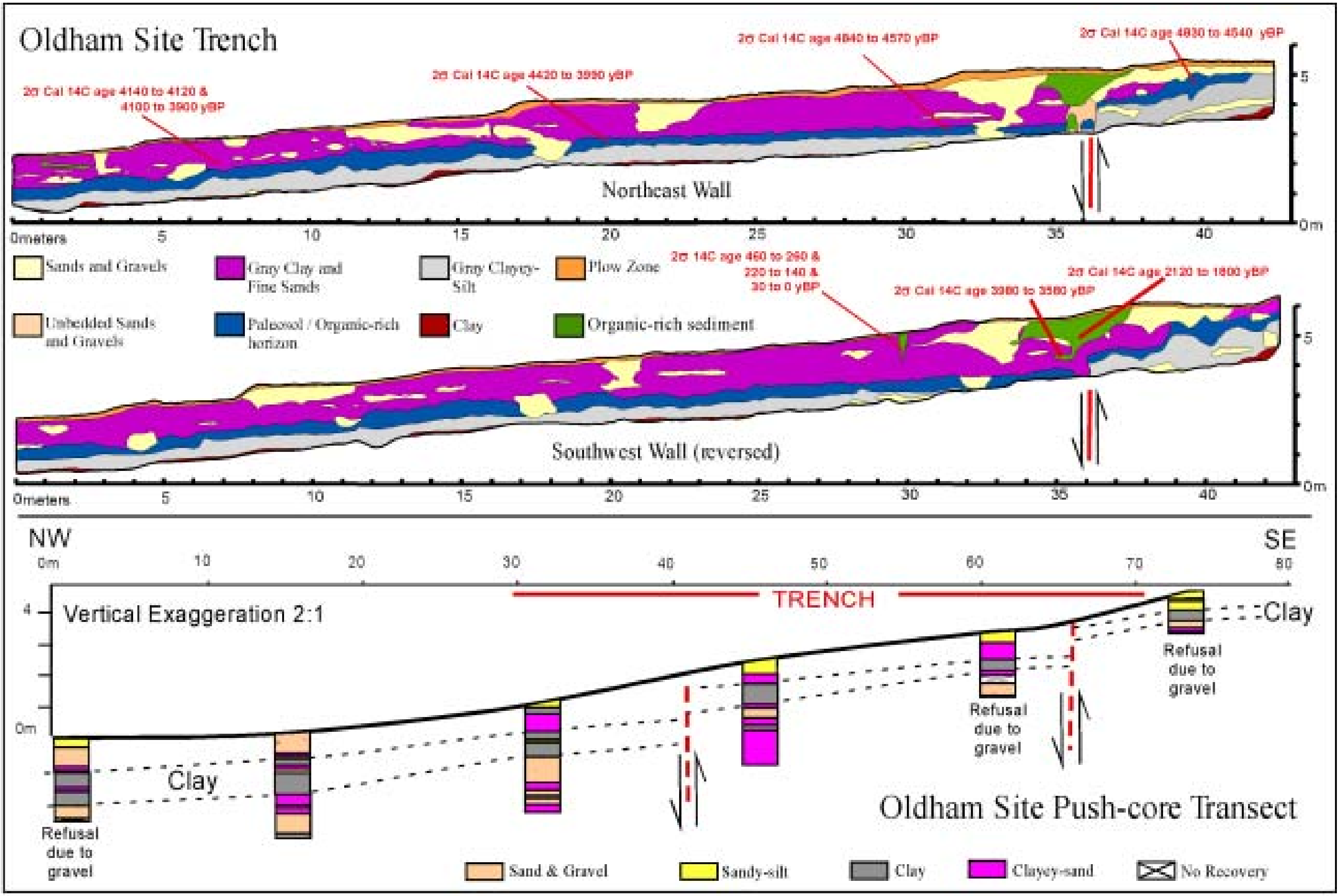

FIGURE 9. Core transect and trench logs of Oldham site.

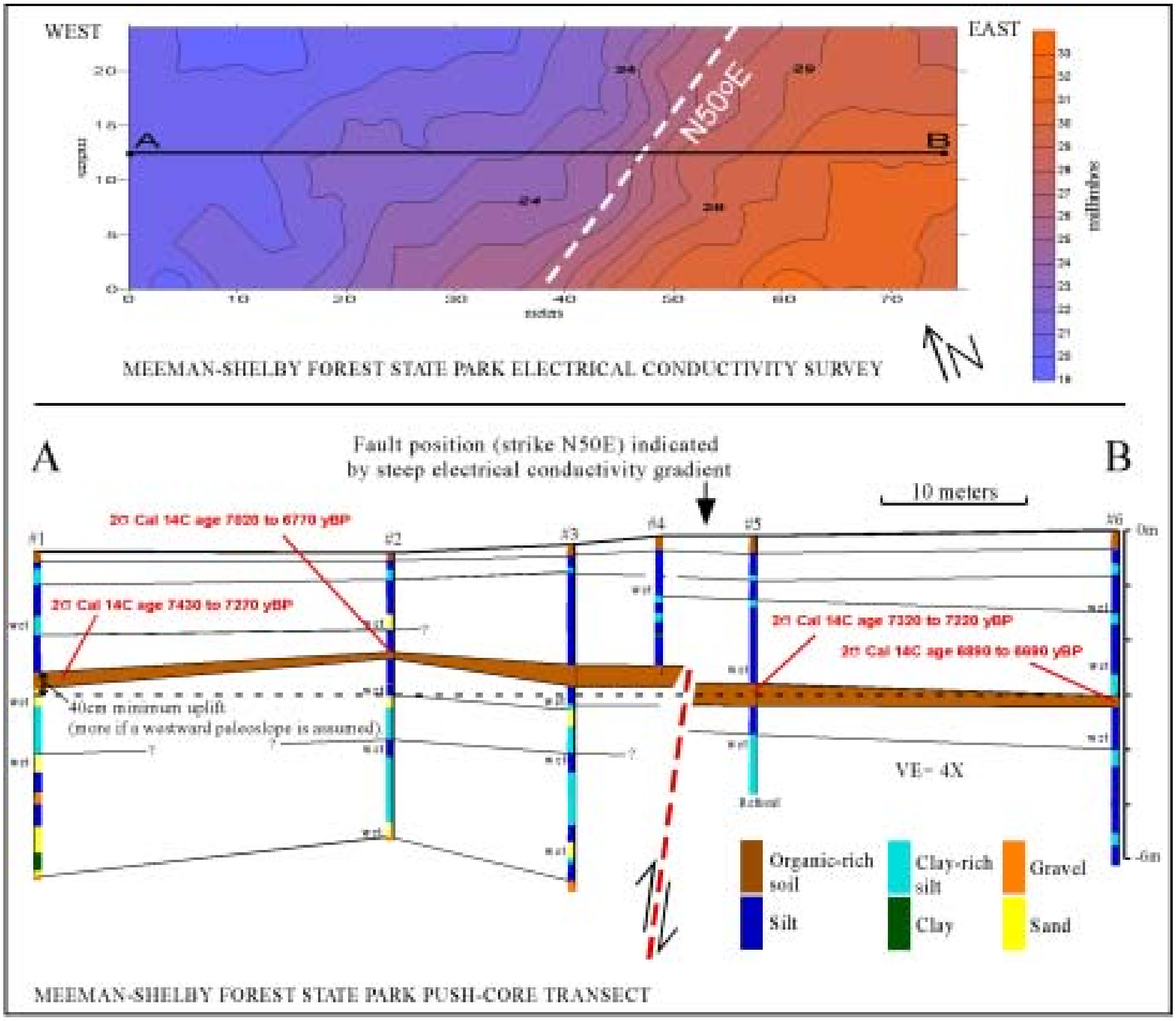

FIGURE 10. Core transect and electrical conductivity map of Bluff trail site.

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