Investigation of Quaternary Faulting in the City of Memphis and Shelby County, Tennessee

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Investigations Undertaken

The city of Memphis and Shelby County, Tennessee, are vulnerable to New Madrid seismic zone seismicity (Fig. 1). However, the possibility of active faults lying beneath Shelby County has only recently been assessed (Van Arsdale et al., 2003). Our previous geologic and geophysical investigations within Memphis reveal two northeast tending Quaternary faults; the Memphis and Ellendale faults (Fig. 2). Structure contour maps of the top of the Pliocene-Pleistocene Upland Complex (Lafayette gravel), Eocene Upper Claiborne Group, and Eocene Lower Claiborne Group reveal two down-to-the-northwest faults with 20m of displacement. Geologic cross sections reveal thinning of the Pleistocene loess on the east (upthrown) side of the Ellendale fault also suggesting Quaternary faulting. The Ellendale fault passes beneath the Wolf River flood plain in east Memphis. At this location, a cut bank exposes flood plain sands that are folded into an anticline with a wavelength of approximately 100m, minimum amplitude of 4m, and a hinge oriented 10^0N7^0W. The folded point bar sands are truncated by overlying, flat-lying, clayey silt overbank sediments. A 1m wide liquefaction sand dike was found above the crest of the anticline, in the overbank sediments. ^{14}C dates reveal that the folding occurred between AD 390 and AD 450 and the liquefaction occurred post AD 450. Seismic reflection lines show that the fold extends to a depth of over 60m into the Lower Claiborne Group, has a length of over 1 km, and is thus tectonic in origin (Velasco, 2002). The reflection lines also reveal a N25^0E trending down-to-the-west fault with 5m of displacement in the Upper Claiborne Group along the eastern side of the Ellendale fault zone. We believe the N7^0W trending anticline formed during approximately 5m of right lateral strike slip on the Ellendale fault.

In this 2004 project, we have acquired additional seismic reflection lines, electrical conductivity surveys, and bore holes. A deep P-wave seismic reflection line reveals a major down-to-the-east normal fault (herein called the Shelby Farms fault) that appears to have been reactivated as a reverse fault (Figs. 3-4). A shallow S-wave seismic line reveals that this same fault is expressed as an up-to-the-east reverse fault in the near surface Tertiary and Quaternary section (Fig. 5). Electrical conductivity surveys and subsequent bore holes indicate that both the Ellendale and Shelby Farms faults may have Quaternary displacement (Figs. 6-7).

A shallow S-wave seismic reflection line acquired across the Memphis fault reveals apparent Quaternary displacement (Figs. 8-9). An electrical conductivity survey across the Memphis fault also suggests a possible Quaternary fault zone (Fig. 10). Additional borings and trench excavations are planned for the Shelby Farms fault zone with follow up on the Memphis fault pending access approval.

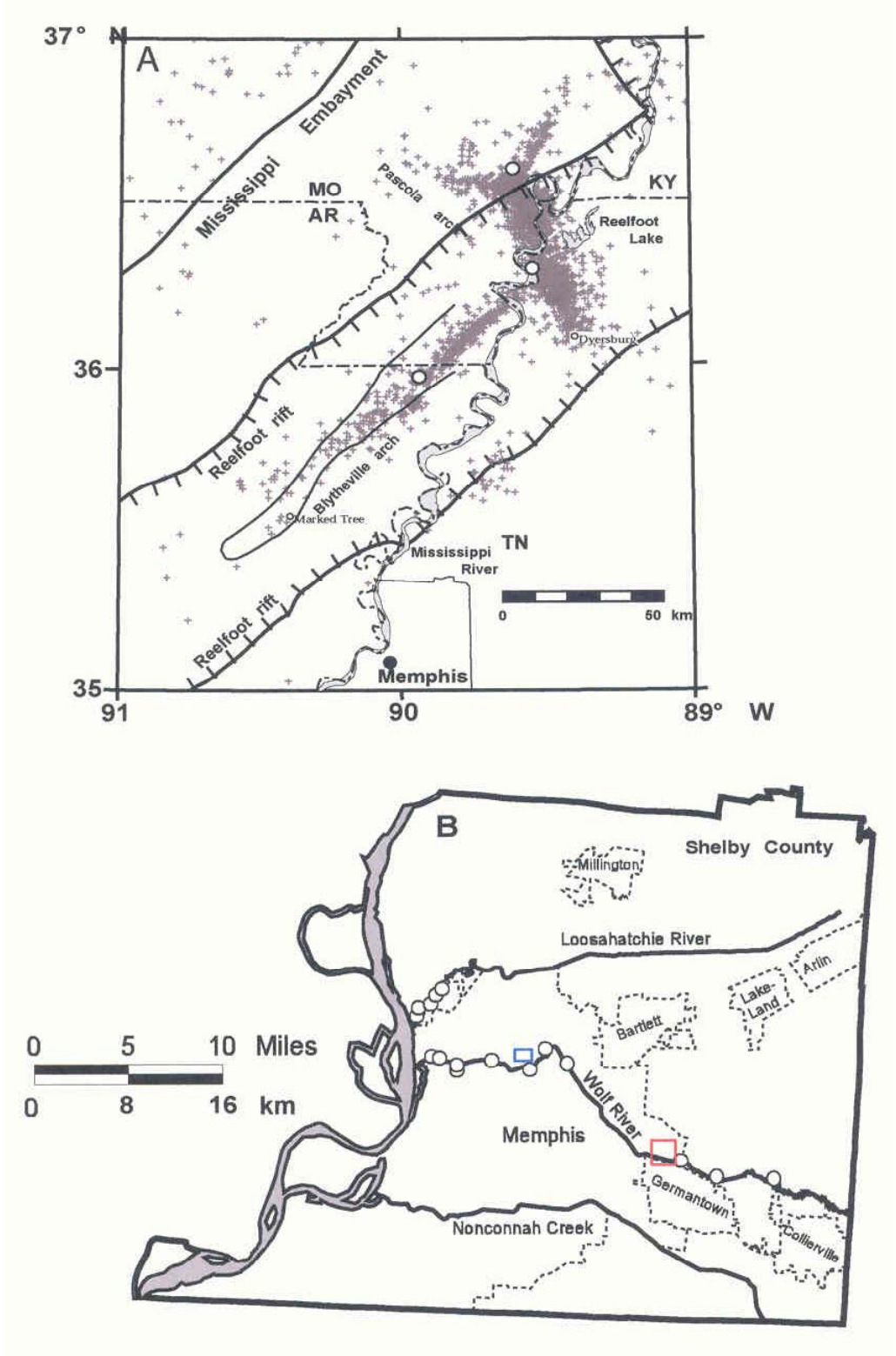

Figure 1. A) New Madrid seismic zone. Crosses are modern earthquakes and circles are estimated locations of the great 1811-1812 earthquakes. B) Memphis in Shelby County, TN. Circles are liquefaction sand dikes. Red box encompasses area of Figures 3. Blue box encompasses area of Figure 9.

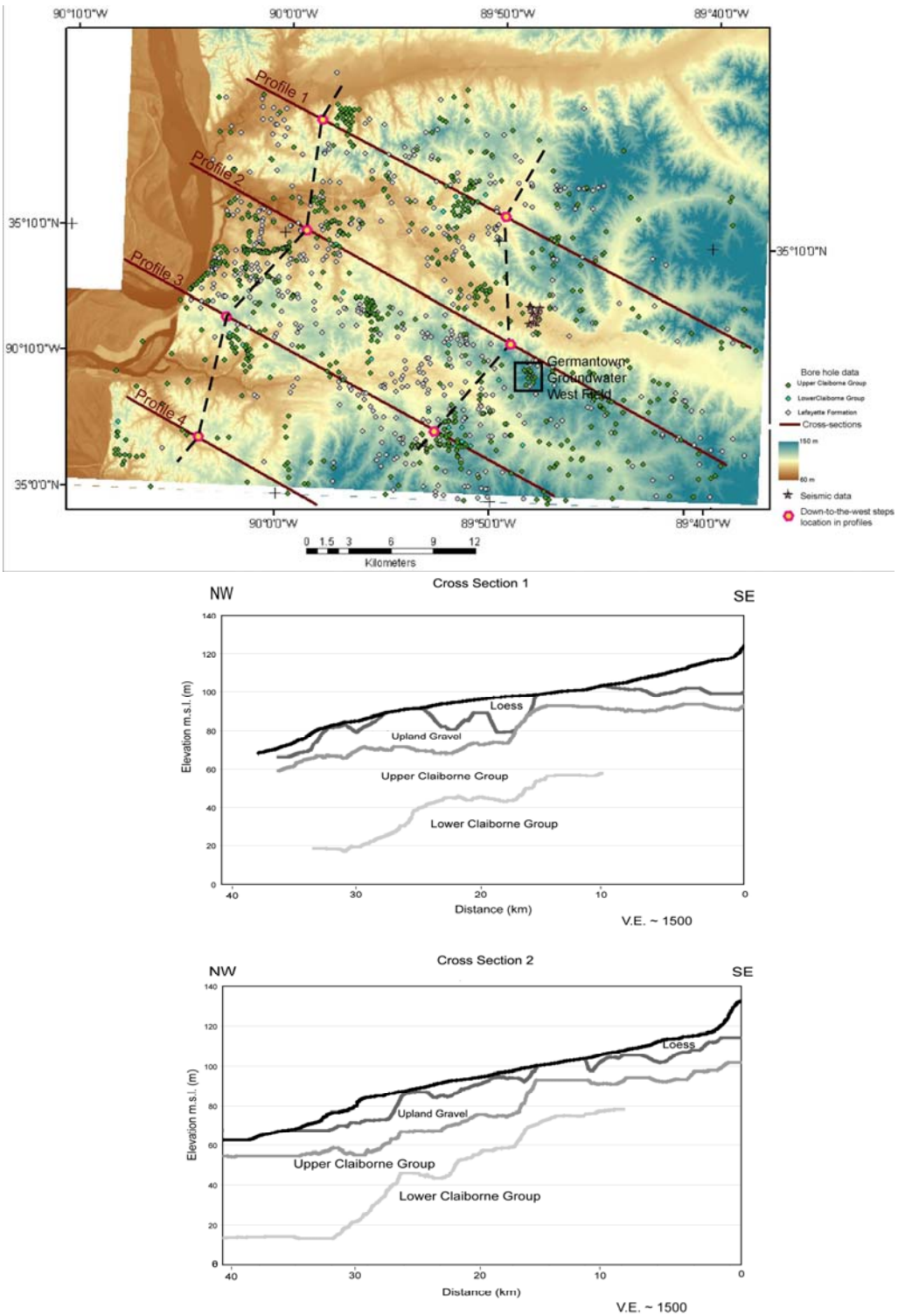

Figure 2. Memphis fault (western) and Ellendale fault (eastern). Dots are bore holes. The eastern fault may actually be the Shelby Farms fault. Profiles 1 and 2 (top) correspond to cross sections 1 and 2 (bottom).

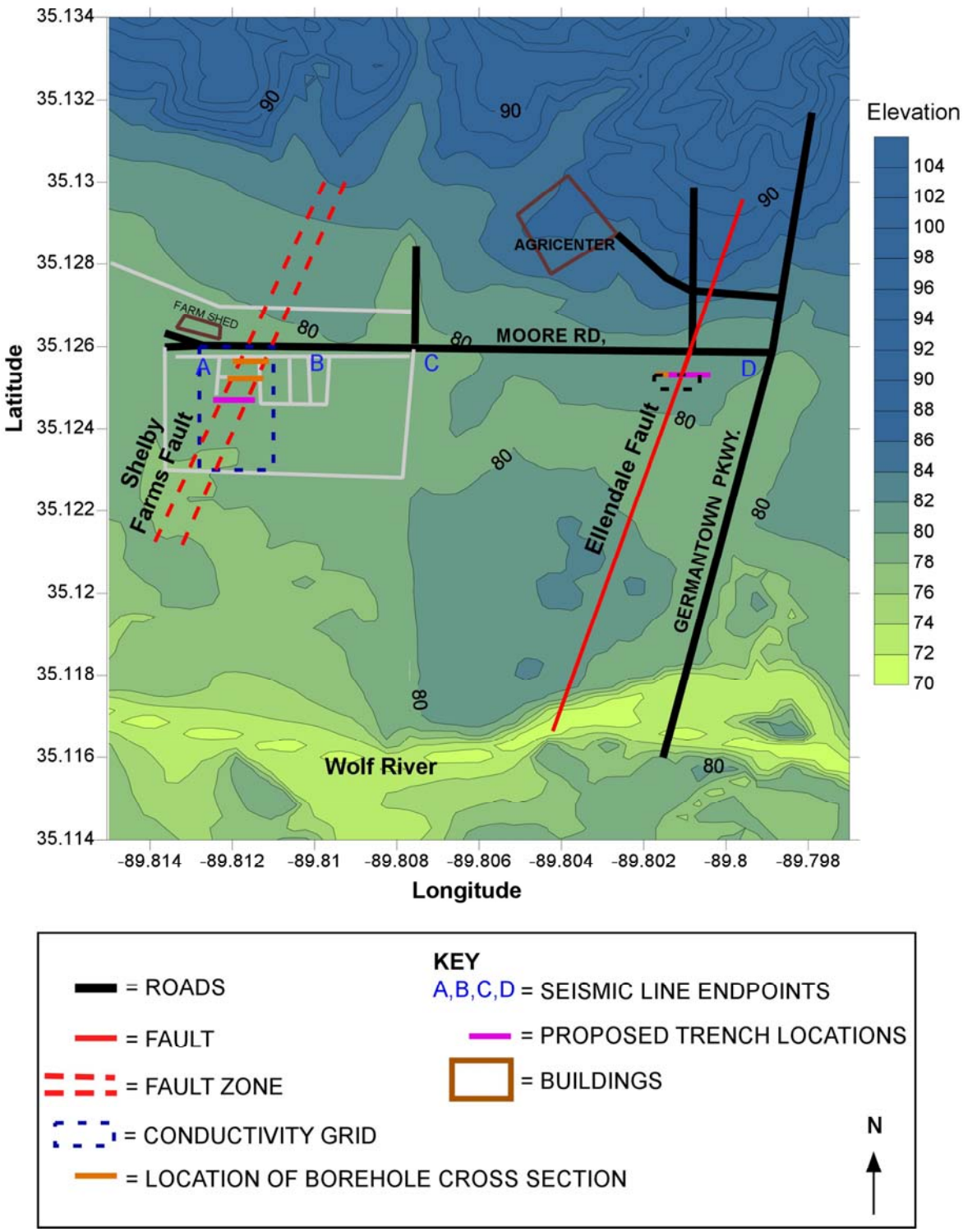

Figure 3. The Ellendale and Shelby Farms faults. Area located as red box in Figure 1B.

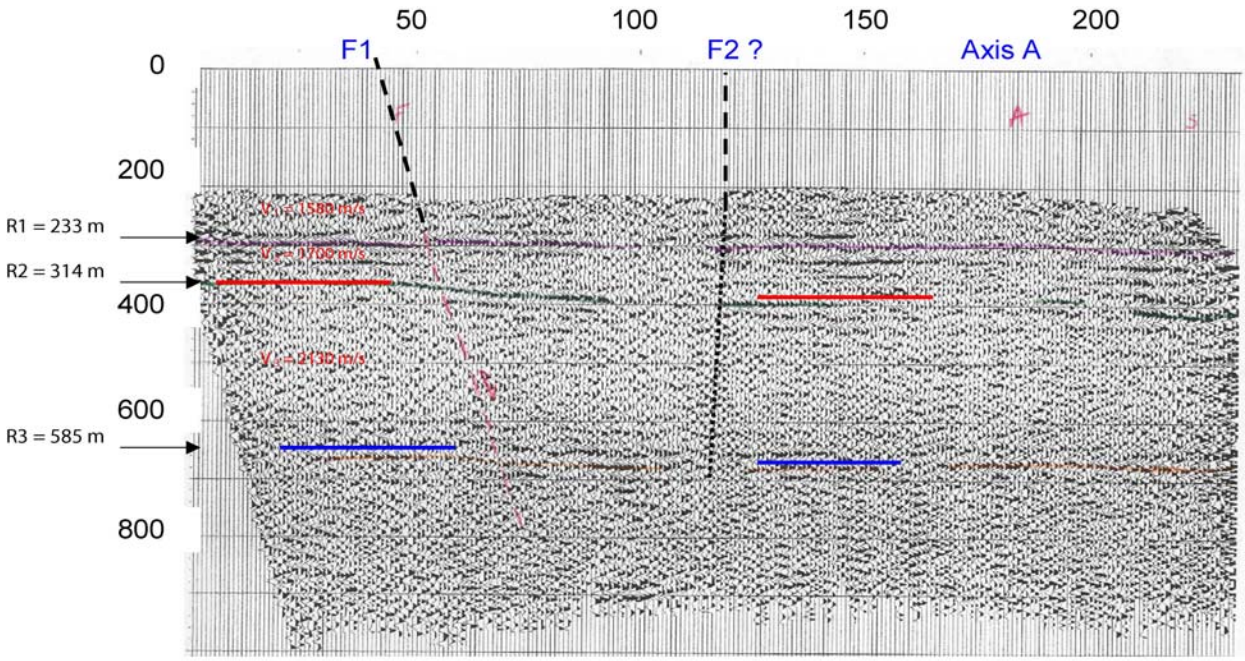

Figure 4. P-wave seismic reflection line revealing Shelby Farms fault (F1). Line located in Figure 3 from A (left) to D (right).

Results

Shelby County is located within the Mississippi embayment and near the southeastern margin of the Precambrian Reelfoot rift (Fig. 1). The geologic section of the upper 2 km beneath Shelby County consists of Cambrian carbonate rocks overlain by Upper Cretaceous marine and terrestrial sands, silts, and clays, overlain by Tertiary marine and terrestrial sands, silts, and clays (Van Arsdale and TenBrink, 2000). Near-surface Quaternary stratigraphy of Shelby County consists of the Pliocene-Pleistocene Upland Complex (Lafayette gravel) overlain by Pleistocene loess and/or Pleistocene and Holocene alluvium (Autin et al., 1991).

The southeastern margin of the Reelfoot Rift (Fig. 1) has documented Quaternary displacement along the Crittenden County reverse fault 25 km northwest of Memphis (Luzietti et. al., 1992; Williams et. al., 1995). An additional (unnamed) reverse fault has recently been identified approximately 10 km northwest of Memphis (Williams et al., 2001) and Quaternary faulting is being investigated along the Mississippi bluff line immediately northwest of Memphis (Cox et al., 2002). Cox et al. (2001b) have also identified Quaternary faulting within the southeastern margin of the Reelfoot Rift at Porter's Gap, Tennessee, and have argued that this rift margin may be accumulating strain energy. Various investigators (Hildenbrand, 1985; Johnson et. al., 1994; Dart and Swolfs, 1998; Mihills, 1998; Van Arsdale and TenBrink, 2000; Cox et. al., 2001a) have proposed faults beneath Shelby County in a number of regional studies. In addition, sand dikes caused by earthquake liquefaction (Fig. 1) have been found in cut banks of the Wolf and Loosahatchie rivers in Shelby County (Van Arsdale et. al., 1998; Broughton et. al., 2001). Broughton et al. (2001) speculate that the dikes are due to the 1811-

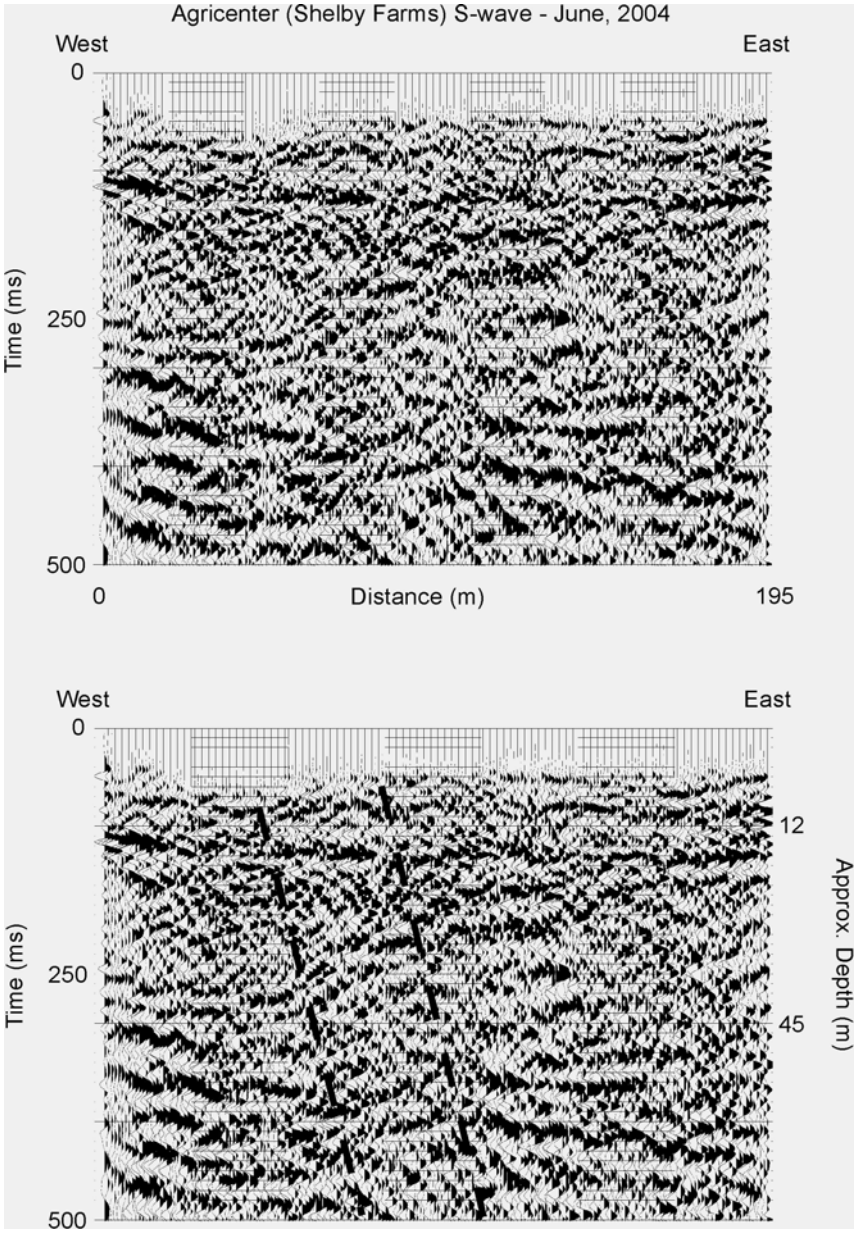

Figure 5. Shallow S-wave seismic reflection line across the Shelby Farms fault (F1 of Figure 4). Apparent drag folding in fault zone suggests up-to-east displacement.

1812 New Madrid earthquakes, but they also acknowledge that these Shelby County sand dikes may be due to a local source.

In previous work we interpreted over 600 shallow geotechnical boring logs and deeper water well logs within Memphis and Shelby County (Velasco, 2002) (Fig. 2). Structure contour maps and geologic cross sections (Fig. 2) interpreted from these borings revealed two northeast-striking down-to-the-west faults with approximately 20m of displacement. The cross sections also indicate thinning of the Pleistocene loess across the Ellendale fault.

During the NEHRP 2004 project year we acquired three seismic reflection lines, conducted electrical conductivity surveys, and made geologic borings. An electrical conductivity survey and subsequent borings reveal possible displacement of the Wolf River flood

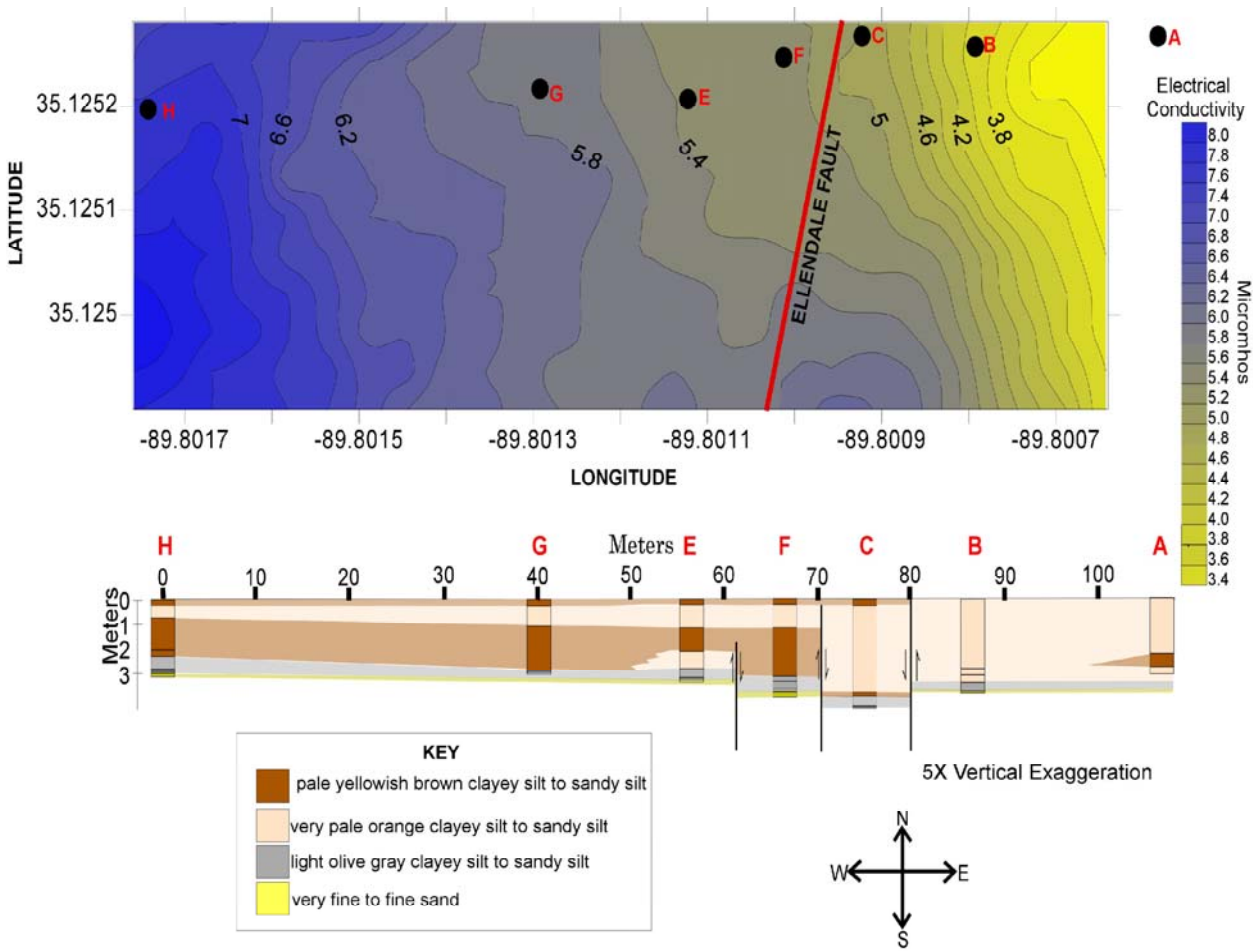

Figure 6. Electrical conductivity survey located in Figure 3 reveals a conductivity change near boring C where the Ellendale fault projects across the survey map. Geologic cross section and possible fault locations interpreted from the borings (A-H).

plain sediments across the Ellendale fault (Fig. 6). A trench will be excavated across the interpreted faults in Figure 6 to determine if indeed the Wolf River flood plain sediments are faulted.

A ~ 2km long and deep P-wave seismic reflection line was acquired during 2004 (Figs. 3-4). This line reveals a major down-to-the-east normal fault that we herein call the Shelby Farms fault. The Shelby Farms fault appears to have been reactivated in Tertiary and perhaps Quaternary time as an up-to-the-east reverse fault. A ~100 m long and shallow S-wave seismic reflection line subsequently acquired across the Shelby Farms fault revealed an apparent up-to-the-east reverse fault zone (Fig. 5). An electrical conductivity survey and borings across this fault (Fig. 7) has tentatively identified displacement of the Wolf River Holocene flood plain sediment.

An S-wave seismic reflection profile was acquired across the Memphis fault (Figs. 1B, 8-9). This S-wave profile reveals faulting within the Tertiary section that may extend into the Quaternary section. An electrical conductivity survey (Fig. 10) reveals a strong conductivity contrast across the western fault in Figure 9 which may indicate near surface Holocene faulting.

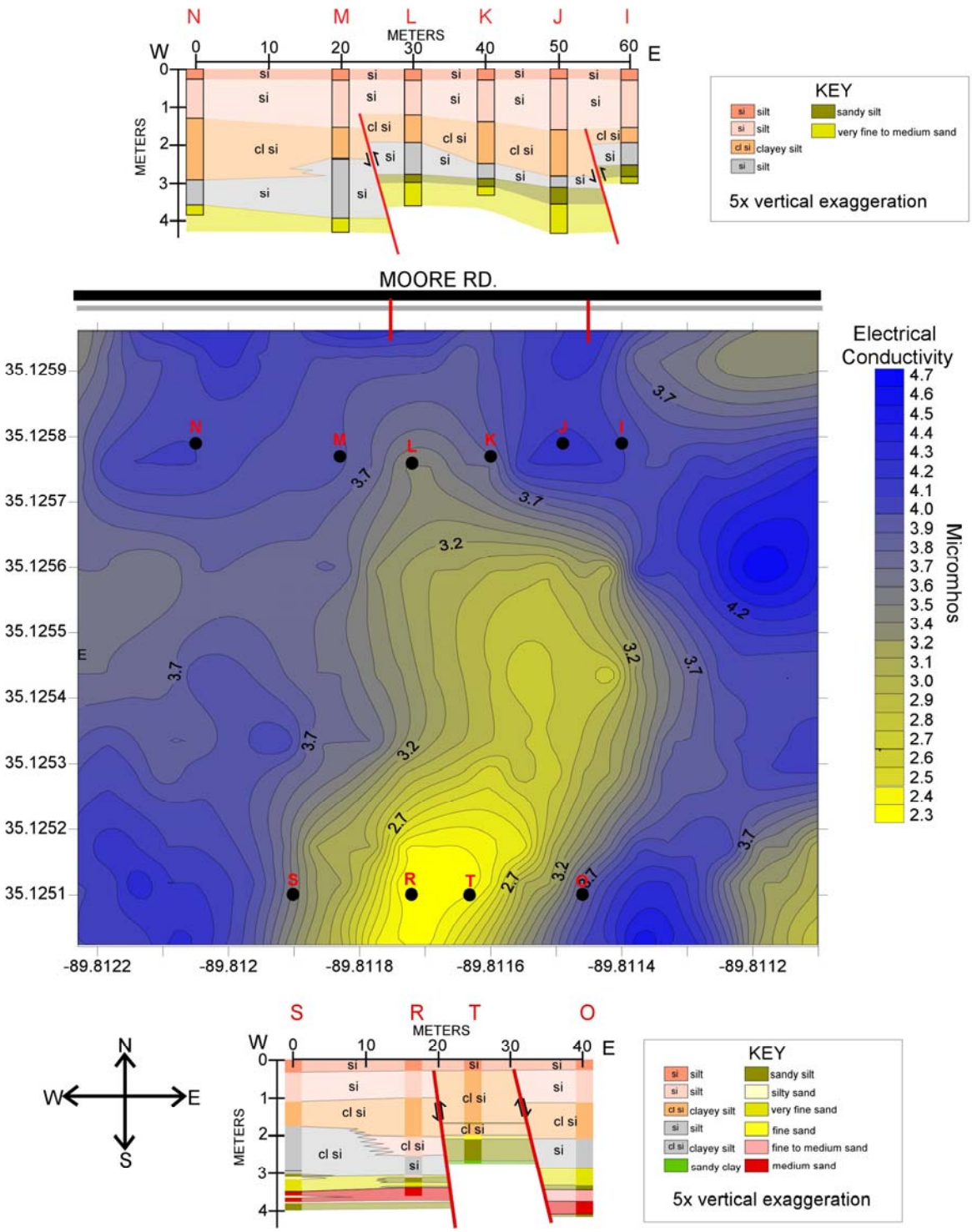

Figure 7. Electrical conductivity survey map and geologic boring (I to T) cross sections across the Shelby Farms fault. Map area is outlined in Figure 3. Vertical red lines extending off Moore Rd. are the faults in the S-wave reflection line of Figure 5.

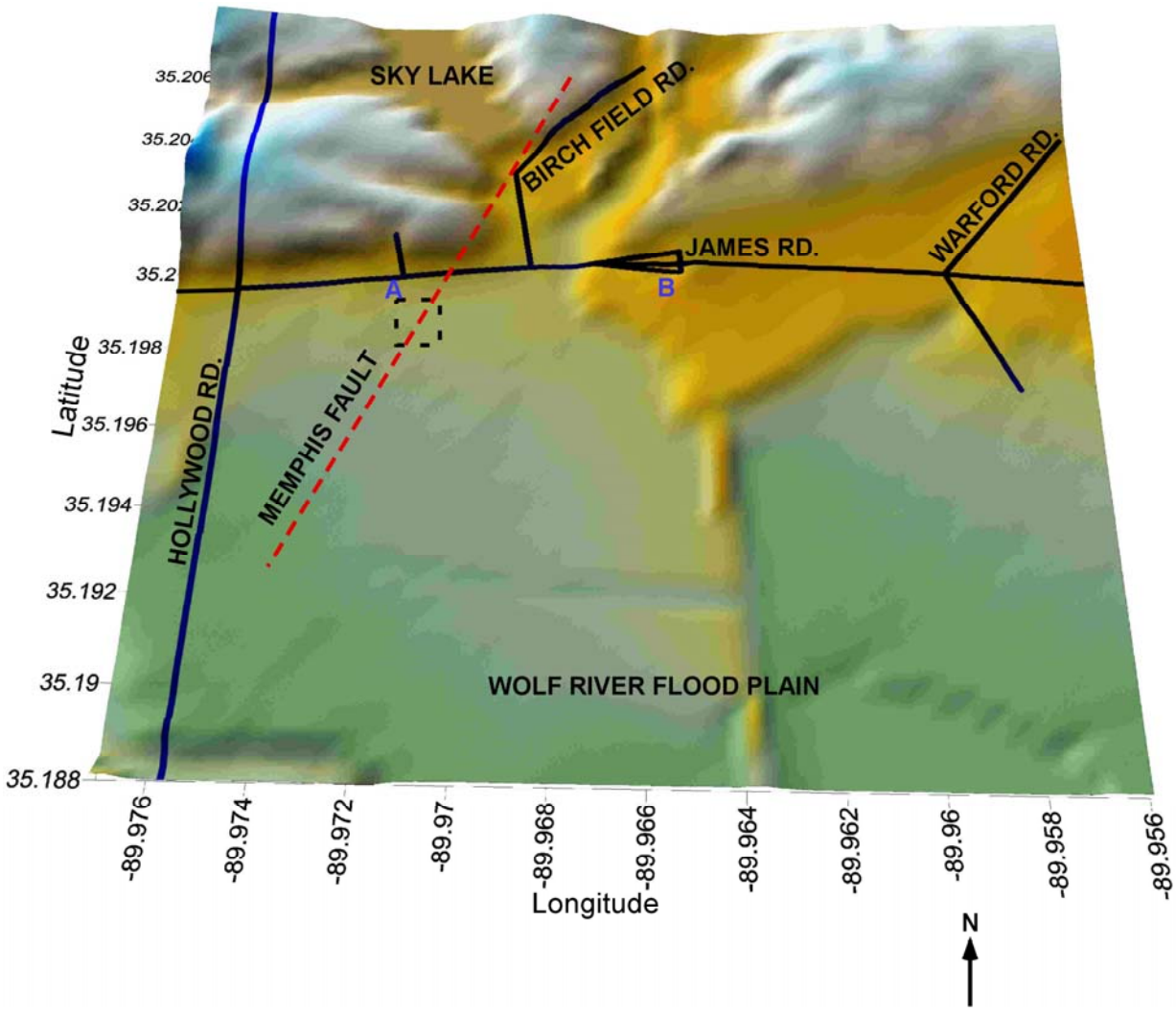

Figure 8. Oblique DEM of the Memphis fault study area located as blue box in Figure 1B. S-wave seismic reflection profile (Fig. 9) is line A-B and the dashed box outlines the electrical conductivity survey of Figure 10.

<u>Non-technical Summary</u>

Three northeast trending faults have been identified beneath Memphis, Tennessee, using geologic borings and seismic reflection profiling. The Ellendale and Shelby Farms faults are in the eastern portion of the city and the Memphis fault is beneath the downtown area. Electrical conductivity surveys were conducted across a portion of all three faults and geologic borings were acquired across the Shelby Farms and Ellendale faults. All three faults appear to have been active in Quaternary time. Trenches will be excavated across the Ellendale and Shelby Farms faults to determine if they have experienced Holocene faulting.

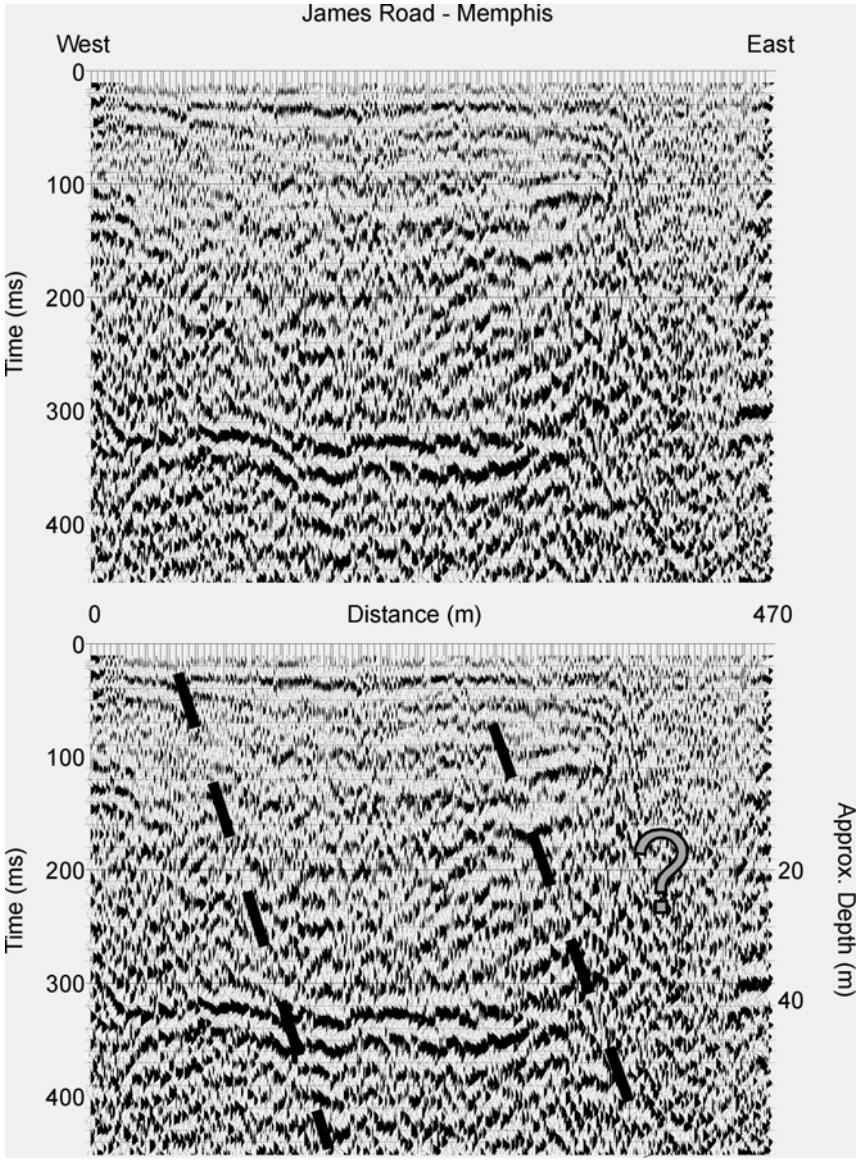

Figure 9. Shallow S-wave seismic reflection profile across the Memphis fault. Line is located in Figure 8.

References Cited

Autin, W.J., Burns, S.F., Miller, B.J., Saucier, R.T., and Snead, J.I., 1991, Quaternary geology of the Lower Mississippi Valley. In Quaternary Nonglacial Geology: Conterminous U.S.: The Geology of North America, R.B. Morrison (Editor), Geol. Soc. Am., v. K-2, p. 547-582.

Broughton, A.T., Van Arsdale, R.B., and Broughton, J.H., 2001, Liquefaction susceptibility mapping in the city of Memphis and Shelby County, Tennessee. Eng. Geol., v. 62/1-3, p. 207-222.

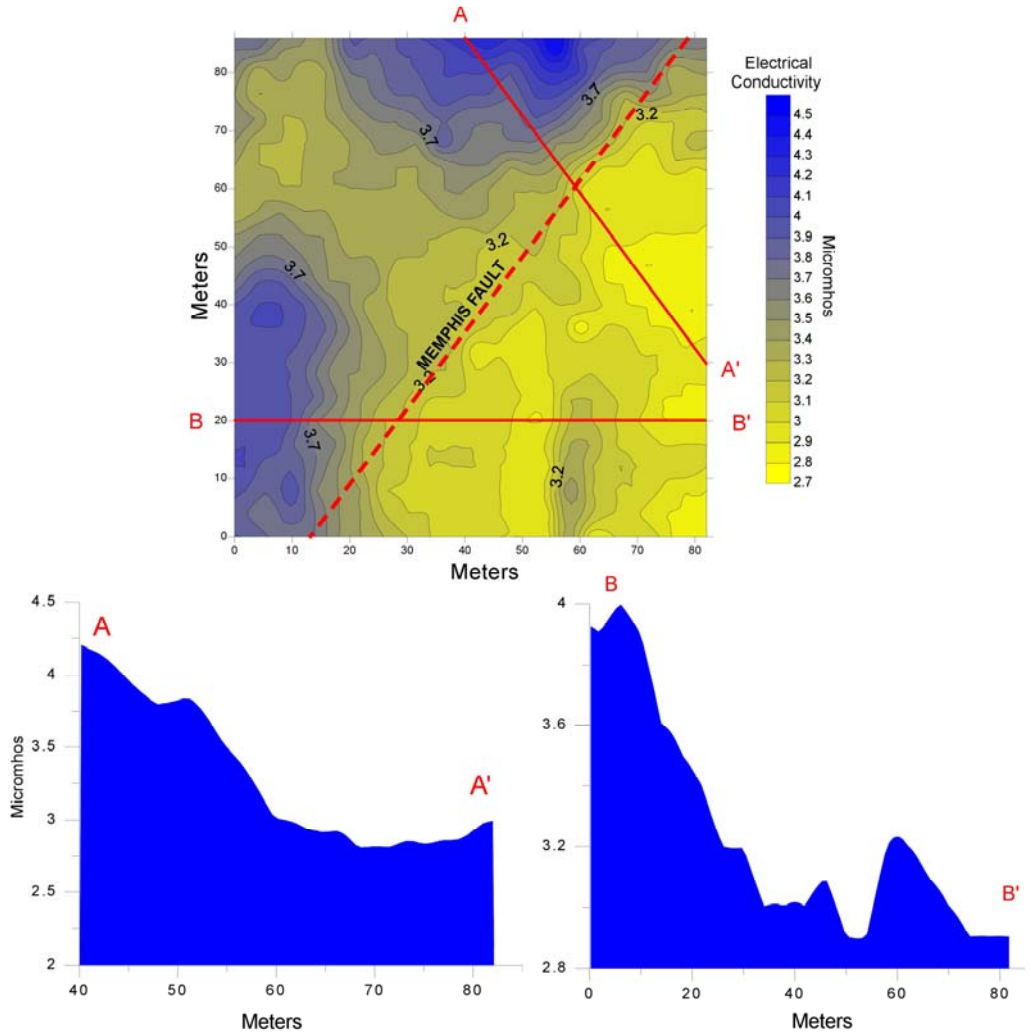

Figure 10. Electrical conductivity survey and conductivity profiles across the projected trace of the Memphis fault.

Cox, R.T., Van Arsdale, R.B., and Harris, J.B., 2001a, Identification of possible Quaternary deformation in the northeastern Mississippi Embayment using quantitative geomorphic analysis of drainage-basin symmetry. Geol. Soc. Am. Bull., v. 113, p. 615-624.

Cox, R.T., Van Arsdale, R.B., Harris, J.B., and Larsen, D., 2001b, Neotectonics of the southeastern Reelfoot Rift zone margin, central United States, and implications for regional strain accommodation. Geology, v. 29, p. 419-422.

Cox, R.T., Van Arsdale, R.B., Larsen, D., Harris, J.B., Cherryholmes, J., 2002, Late Quaternary surface faulting in western Tennessee along the southeastern margin of the Reelfoot rift, Geol. Soc. Am., v. 34, n. 6, p. 28.

Dart, R.L., and Swolfs, H.S., 1998, Contour mapping of relic structures in the Precambrian basement of Reelfoot rift, North American midcontinent. Tectonics, v. 17, n. 2, p. 235-249.

Harding, T.P., 1974, Petroleum traps associated with wrench faults. Am. Assoc. Pet. Geol. Bull., v. 58, p. 1290-1304.

Hildenbrand, T.G., 1985, Rift structure of the northern Mississippi embayment from the analysis of gravity and magnetic data. J. Geoph. Res., v. 90, n. B14, p. 12,607-12,622.

Johnson, P.R., Zietz, I., and Thomas, W.A., 1994, Possible Neoproterozoic-early Paleozoic grabens in Mississippi, Alabama, and Tennessee. Geology, v. 22, n. 1, p. 11-14.

Lowell, J.D., 1985, Structural styles in petroleum exploration, OGCI Publications, Oil & Gas Consultants Inc., Tulsa, 460 p.

Luzietti, E.A., Kanter, L.R., Schweig, E.S., Shedlock, K.M., and Van Arsdale, R.B., 1992, Shallow deformation along the Crittenden County fault zone near the southeastern boundary of the Reelfoot rift, northeast Arkansas. Seism. Res. Letters, v. 63, n. 3, p. 263-275.

Mihills, R.K., 1998, A structural analysis of the New Madrid seismic zone from structure contour maps and a three-dimensional model. MS Thesis, University of Memphis, 82 p.

Van Arsdale, R.B., Broughton, A.T., and Broughton, J.H., 1998, Liquefaction susceptibility mapping in Memphis and Shelby County, Tennessee (abs.). Assoc. Eng. Geol. 41st Annual Meeting, Seattle, Washington, p. 132.

Van Arsdale, R.B., Cox, R.T., and Harris, J.H., 2003, Investigation of faulting beneath the city of Memphis and Shelby County, Tennessee. USGS NEHRP grant 02HQGR0053 final report, 33 p.

Van Arsdale, R.B., and TenBrink, R.K., 2000, Late Cretaceous and Cenozoic geology of the New Madrid seismic zone. Seism. Soc. Am. Bull., v. 90, n. 2, p. 345-356.

Velasco, M.S., 2002, Investigation of possible Quaternary faulting beneath the cities of Memphs and Germantown, Shelby County, Tennessee. MS thesis, University of Memphis, 77 p.

Wells, D.L, and Coppersmith, K.J., 1994, New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement. Seism. Soc. Am. Bull., v. 84, p. 974-1002.

Williams, R.A., Luzietti, E.A., and Carver, D.L., 1995, High-resolution seismic imaging of Quaternary faulting on the Crittenden County fault zone, New Madrid seismic zone, northeastern Arkansas. Seism. Res. Letters, v. 66, n. 3, p. 42-57.

Williams, R., Stephenson, W., Odum, J., and Worley, D., 2001, Seismic-reflection imaging of Tertiary faulting and related post-Eocene deformation 20 km north of Memphis, Tennessee. Eng. Geol., v. 62/1-3, p. 79-90.