SEARCH FOR AND STUDY OF SAND BLOWS AT DISTANT SITES RESULTING FROM PREHISTORIC AND HISTORIC NEW MADRID EARTHQUAKES: Collaborative Research, M. Tuttle & Associates and Central Region Hazards Team, U.S. Geological Survey

Annual Project Summary

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USGS Internal Project, "Earthquake Risk Reduction in the Central and Eastern United States"

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Program Element II (Research on Earthquake Occurrence and Effects) and
Program Element I (Products for Earthquake Loss Reduction)

Key Words: Paleoseismology, Paleoliquefaction, Age Dating, Quaternary Fault Behavior

Investigations Undertaken

Preliminary conclusions regarding the earthquake potential of the New Madrid seismic zone (NMSZ) have been drawn from liquefaction features preserved in the geologic record (e.g., Tuttle, 1999; Tuttle et al., 2002). This study builds on previous findings and aims to reduce uncertainties regarding locations, magnitudes, and recurrence intervals of very large New Madrid earthquakes. The specific goals of this study are (1) to find, measure, date, and correlate sand blows beyond their currently known distributions, (2) to identify distal sites of liquefaction related to major New Madrid earthquakes, (3) to employ liquefaction potential analysis to help constrain locations and magnitudes of New Madrid earthquakes, and (4) to determine if mapped faults outside the currently active NMSZ have generated large earthquakes during the Holocene and Late Wisconsin.

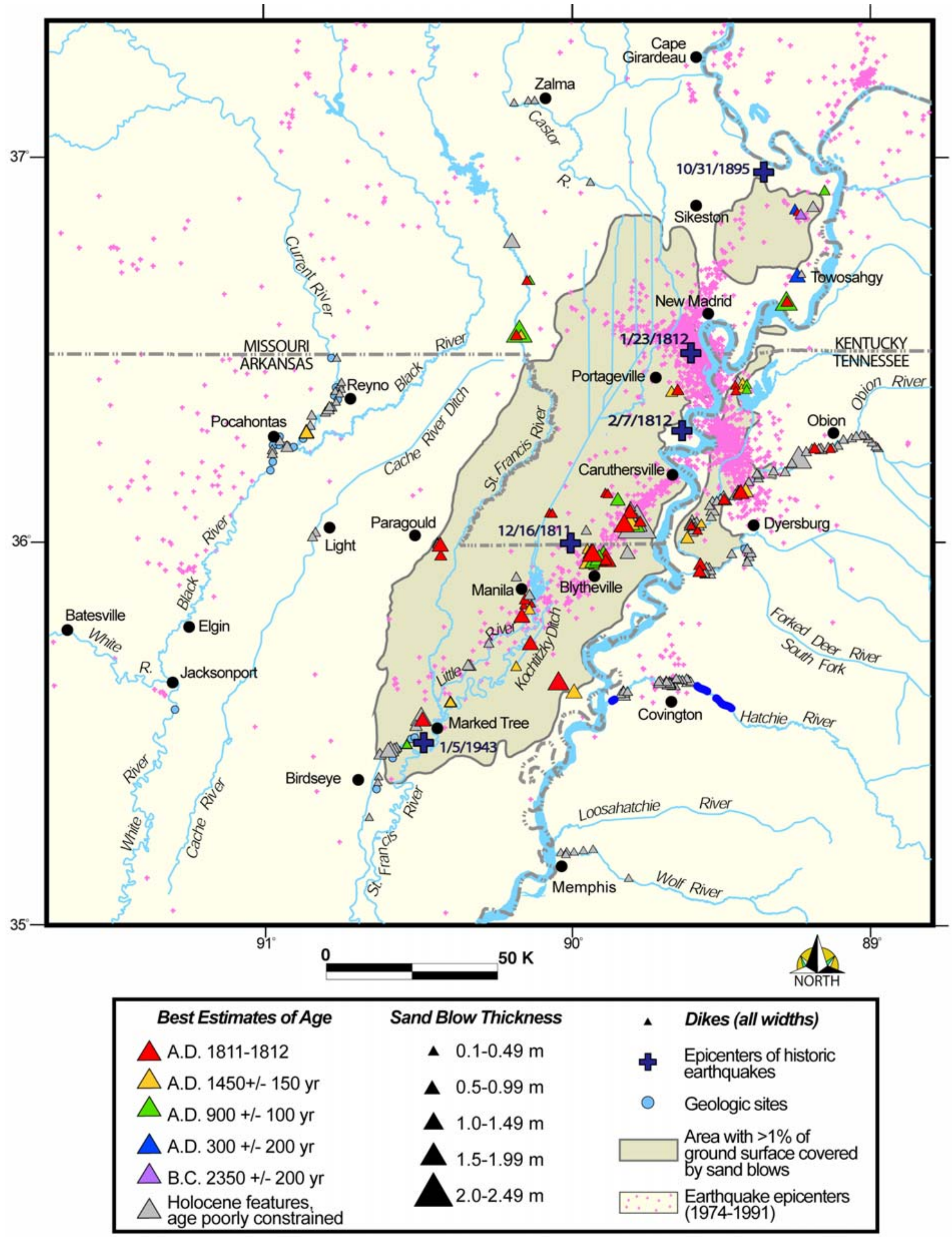
Tasks accomplished during the 2003 project period include (1) reconnaissance for and study of earthquake-induced liquefaction features along the Hatchie River in western Tennessee, and (2) evaluation of several scenario earthquakes using new information on the distribution of liquefaction features. Carol Prentice and Sarah Jane Kroupa of the U.S. Geological Survey helped with river reconnaissance and Kathleen Dyer-Williams performed liquefaction potential analysis.

Results of Investigations

During the 2003 project period, we discovered and studied forty-three earthquake-induced liquefaction features, including seven sand blows, along the Hatchie River in western Tennessee (Figure 1; Table 1). In addition, we evaluated whether or not earthquakes like the three major shocks of the 1811-1812 New Madrid sequence and a moderate to large local event would be likely to induce liquefaction at the Route 51 crossing of the Hatchie River northeast of Covington, TN.

Reconnaissance

Continuing reconnaissance begun in 2000, we surveyed three additional portions of the Hatchie River (Figure 1). The westernmost portion is about 3 km long and is located about 6-7 km east of the confluence of the Hatchie River with the Mississippi River; the middle portion is 6 km long and is located from 25-28 km east of the Mississippi River; and the eastern-most portion is 13 km long and occurs 36- 42 km east of the Mississppi. There are many excellent exposures along all three sections of the river. Mostly Holocene deposits are exposed along the western and middle sections; whereas, Holocene and Late Wisconsin deposits are exposed along the eastern section.



Cape Girardeau
Zalma
Castor R.
37°
10/31/1895
Sikeston
Current River
Towosahgy
New Madrid
MISSOURI
ARKANSAS
Black River
1/23/1812
KENTUCKY
TENNESSEE
Reyno
Portageville
Obion River
Pocahontas
Cache River Ditch
St. Francis River
2/7/1812
Obion
Caruthersville
Black River
Paragould
Light
12/16/1811
Dyersburg
36°
Manila
Blytheville
Batesville
Elgin
Black
White
R.
Jacksonport
Little River
Kochitzky Ditch
Forked Deer River
South Fork
Marked Tree
Covington
Hatchie River
1/5/1943
Birdseye
White River
Cache River
St. Francis River
Loosahatchie River
Memphis
Wolf River
35°
91°
90°
89°
0
50 K
NORTH
Best Estimates of Age
A.D. 1811-1812
A.D. 1450+/- 150 yr
A.D. 900 +/- 100 yr
A.D. 300 +/- 200 yr
B.C. 2350 +/- 200 yr
Holocene features, age poorly constrained
Sand Blow Thickness
0.1-0.49 m
0.5-0.99 m
1.0-1.49 m
1.5-1.99 m
2.0-2.49 m
Dikes (all widths)
Epicenters of historic earthquakes
Geologic sites
Area with >1% of ground surface covered by sand blows
Earthquake epicenters (1974-1991)

Figure 1. Map of NMSZ showing portions of Hatchie River in blue recently surveyed for earthquake-induced liquefaction features as well as estimated ages and sizes of sand blows across the New Madrid region (modified from Tuttle et al., 2002).

During the past year, we discovered liquefaction features at nine new sites, HR 25-33, along the western portion of the Hatchie River. The liquefaction features include 4 sand blows and 20 sand dikes. The sand blows range from 7 to 65 cm thick and the sand dikes from 1.2 to 80 cm wide. Along the middle portion of the river, we found liquefaction features at three new sites, HR 34-36. These features include sand dikes ranging from 1 to 22 cm wide and a sand blow ranging up to 6 cm thick. At one of these sites, there appears to be multiple stratified sand blows that warrant further investigation. Along the eastern portion of the river, we documented features at seven new sites, HR 37-45. The features include three sand blows ranging from 0.5 to 16 cm thick and ten sand dikes ranging from 1 to 12 cm wide. Several of the sand blows, both historic and prehistoric, are compound in nature, suggesting that they formed as the result of multiple large earthquakes in a sequence, similar to the 1811-1812 New Madrid event. To date, we have found liquefaction features up to 55 km from the southwestern branch of the NMSZ or 70 km southeast of the inferred epicenter of the December 16, 1811 earthquake. We have not yet found the eastern limit of sand blows along the Hatchie River. Liquefaction features at several of the newly discovered sites are shown below and discussed in the accompanying captions (see Figures 2-8).

Similar to earlier findings on the Hatchie River (Tuttle, 2001), there appears to be at least two generations of liquefaction features along the Hatchie River. On the basis of their stratigraphic positions and weathering characteristics, some of the liquefaction features are probably historic in age while others appear to be prehistoric. Differences in the degree of weathering, such as depth of bioturbation and iron-staining as well as coating of sand grains by fines and formation of manganese nodules, suggest that the prehistoric liquefaction features formed during more than one event separated in time. During the next few months, radiocarbon dating of samples collected at several of the liquefaction sites will be completed. These results will help to constrain the age of some of the liquefaction features and to correlate them, or not, with other liquefaction features across the region.

Click here for link to Table-1.htm

Figure 2. Sand dikes and probable sand blow at site HR 29 along Hatchie River. Only upper 4 cm of 11-cm-thick sand blow is iron-stained and bioturbated suggesting that liquefaction features at this site are fairly young.

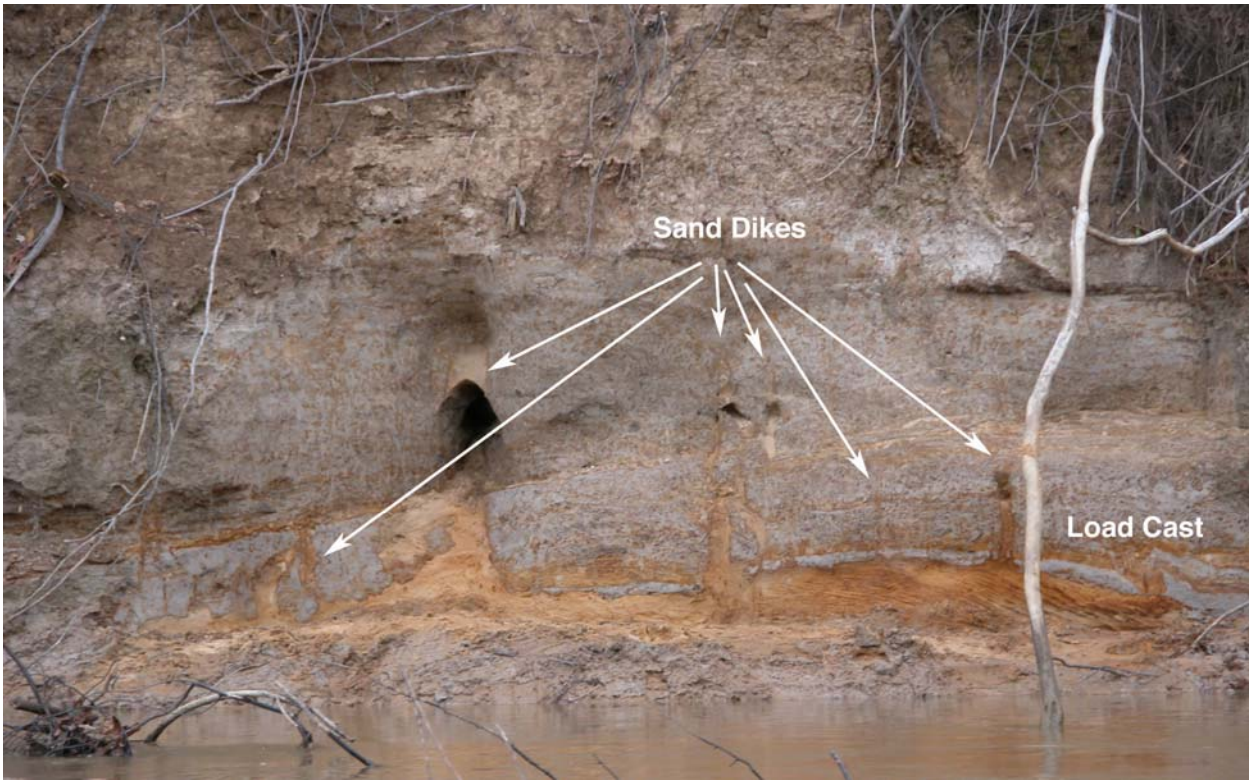


Figure 3. At HR 30, several sand dikes, ranging from 3 to 42 cm wide, intrude mottled silt containing thin interbeds of cross-bedded fine sand. Sand dikes originate in cross-bedded fine to medium sand at base of exposure. No related sand blow was observed in overlying deposits indicating that water and sand did not vent to ground surface at this location.

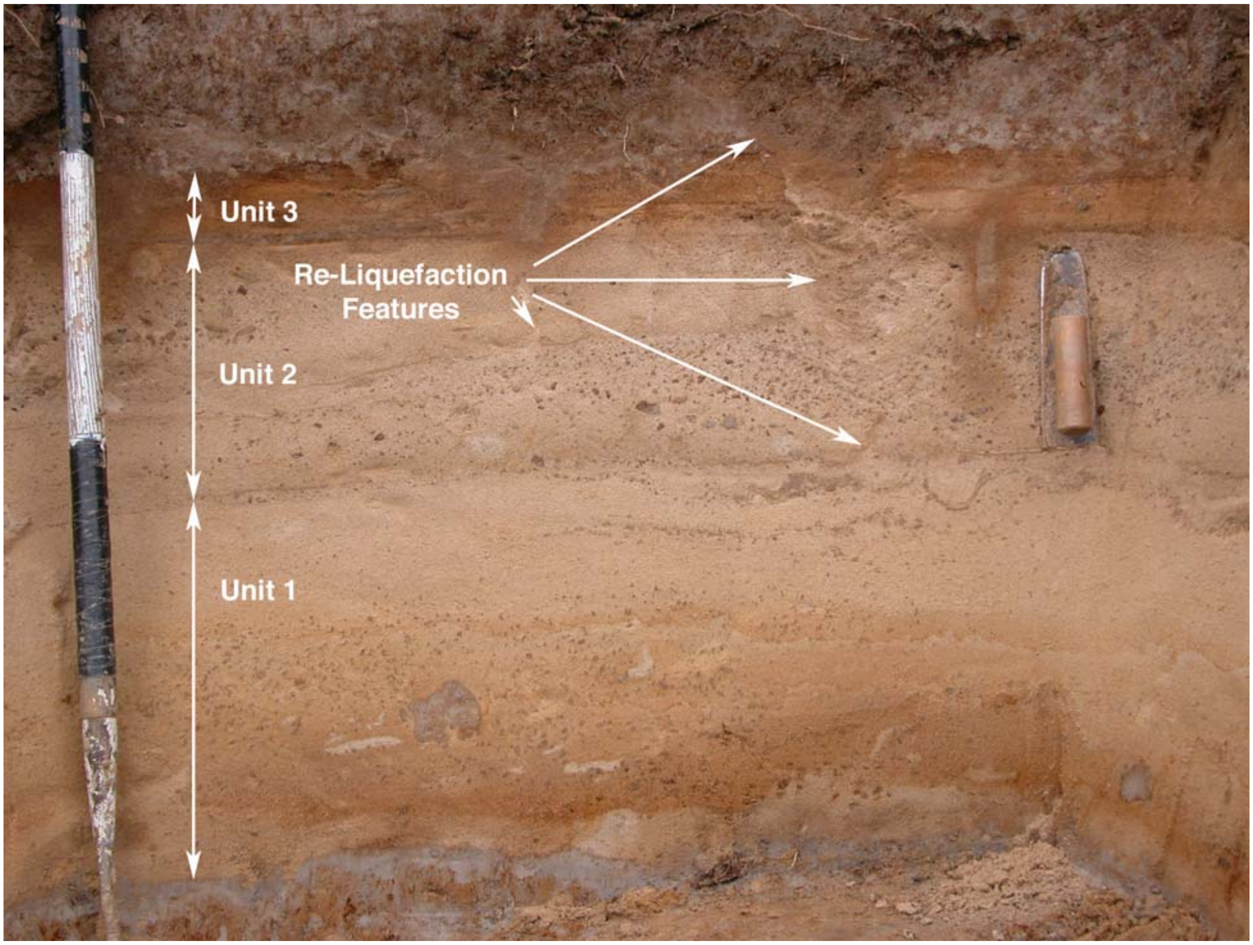


Figure 4. At site HR 31, 65-cm-thick sand blow is composed of three major sedimentary units each made up of multiple subunits and capped by thin silt layer. Three major units may represent different events within earthquake sequence; whereas, subunits may reflect changes in water flow and sediment deposition during each venting episode. Upper 8-cm-thick unit of sand blow is bioturbated and iron-stained and overlain by mottled silt suggesting that sand blow is prehistoric in age. Load casts and sand diapers, one of which extends into overlying mottled silt, indicate that sand blow deposit reliquefied during later earthquake. Radiocarbon dating of organic samples collected above and below sand blow should help to constrain age of liquefaction features and thus causative earthquakes.

Figure 5. Large, 80-cm-wide sand dike at site HR 33 exposed along Hatchie River. Weathering of sand dike is especially pronounced in upper 15 cm of sand dike and extends down dike for another 70 cm. Weathering characteristics of sand dike suggest it is probably prehistoric in age. Hoe is 1 m long with each color band representing 25 cm.

Figure 6. Below sand dike shown in Figure 5, diapir and disturbed bedding in sand layer that liquefied at site HR 33. Scraper is 20 cm in length.

Figure 7. Very small liquefaction features, including 1.5-cm-wide sand dike and 0.5-cm-thick sand blow or sill at site HR 38. Silt coatings on sand grains and manganese nodules within sand dike indicate that liquefaction features are prehistoric in age and could be thousands of years old.

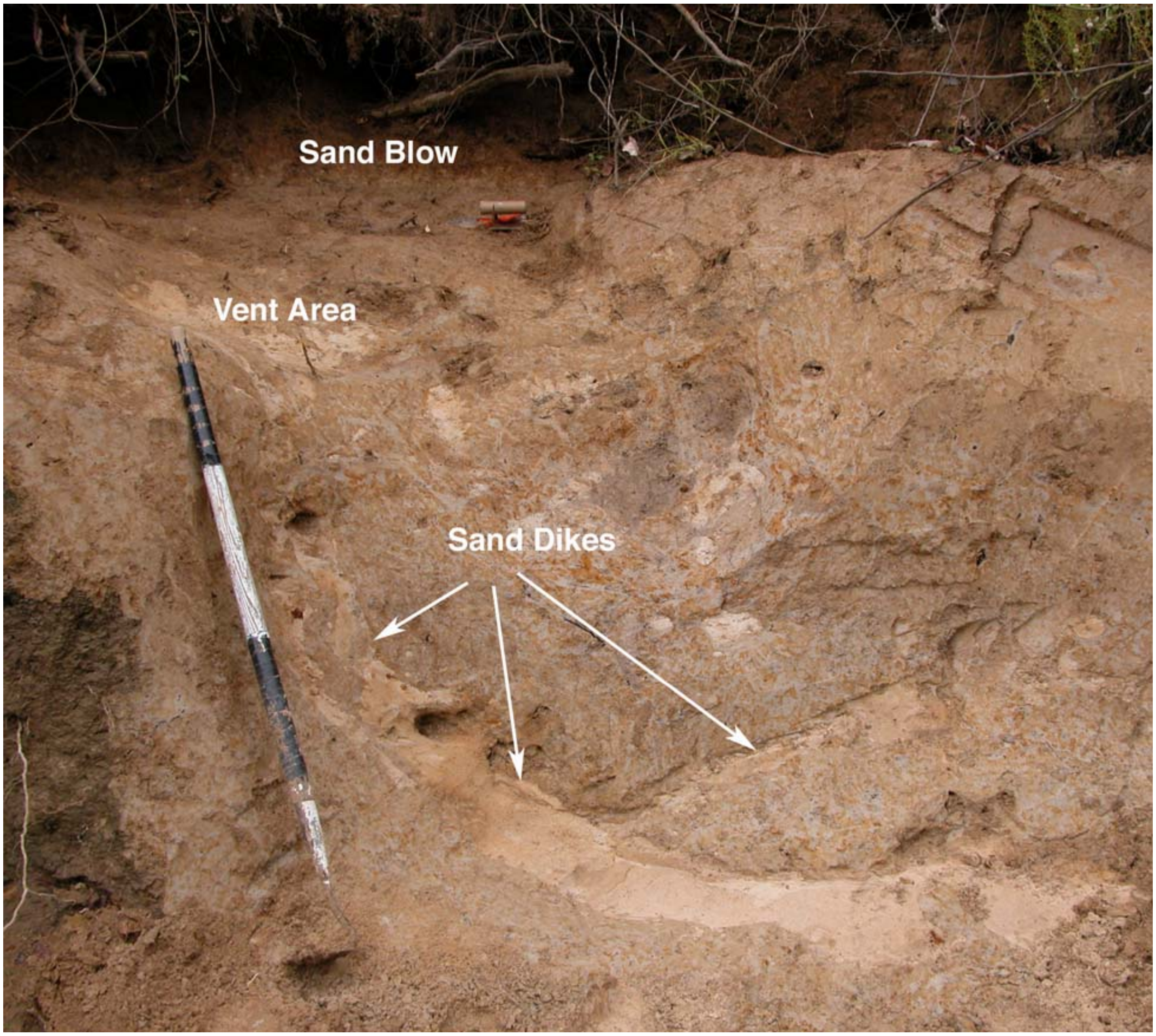


Figure 8. At site HR 44, liquefaction features, include 12-cm-wide sand dike, portion of vent area, and 15-cm-wide sand blow overlain by 36-cm-thick soil and associated roots. Thickness of overlying soil and bioturbation and iron-staining of sand blow suggest that liquefaction features at this site are also prehistoric in age. This site is located about 15 km east of Covington and 55 km southeast of the southwestern branch of the NMSZ.

Evaluation of Scenario Earthquakes

Prior to evaluating scenario earthquakes, we acquired borehole logs for the Route 51 crossing of the Hatchie River from the Tennessee Department of Transportation (Figure 1). We reviewed the logs, selected representative sandy layers below the water table, and compiled data for liquefaction potential analysis (Tables 2-5). Blow counts of the sandy layers range from 14 to 29, indicating that they are of moderate relative density and therefore not especially susceptible to liquefaction. It would be preferable to use geotechnical data collected at specific liquefaction sites along the river, but these data are not currently available.

We evaluated whether or not several scenario earthquakes would be likely to induce liquefaction in fluvial sediments at the Route 51 crossing of the Hatchie River. The analysis was performed with the revised simplified procedure of Seed and Idriss (1982) and Youd and Idriss (1997). Similarities in the size and distribution of historic and prehistoric liquefaction features across the New Madrid region suggest that prehistoric earthquakes were similar to the three largest events in the 1811-1812 New Madrid sequence (Tuttle et al., 2002). Therefore, the scenario earthquakes we evaluated include the December 16, 1811 (Table 2), January 23, 1812 (Table 3), and February 7, 1812 (Table 4) events. In addition, we considered an hypothetical local earthquake in the vicinity of the cluster of modern seismicity located north of Covington (Table 5). For the 1811-1812 events, we used the estimated magnitudes of three different studies (**M** 7.2, 7.0, and 7.4 from Hough et al., 2000; **M** 7.6, 7.5, and 7.8 from Bakun and Hopper, pers. comm., 2003; and **M** 8.1, 7.8, and 8.0 from Johnston, 1996). Distances were measured between inferred epicenters of the historic earthquakes and the Route 51 crossing of the Hatchie River. The December 16, January 23, and February 7 earthquakes are thought to have been centered near Blytheville, Arkansas, New Madrid, Missouri, and Caruthersville, Missouri, respectively (Figure 1). Peak ground accelerations for the earthquakes are derived from ground-motion relations developed for the central United States (Toro et al., 1997). For the hypothetical local event, we assume a distance of 10 km and evaluate three different magnitudes (**M** 5.25, 5.5, and 6.0).

Click here for link to Tables-2,3,4,5.htm

The liquefaction potential analysis suggests that the December 16, 1811 event, if it were of **M** 7.2 would induce liquefaction in about half of the layers of sediment we considered. If the December event were of **M** 7.6, however, almost all the layers would liquefy (Table 2). Therefore, the December event is much more likely to have produced liquefaction features in the area if it were on the order of **M** 7.6. The analysis also suggests that the January 23, 1812 event, whether of **M** 7.0, 7.5, or 7.8, was located too far away to induce liquefaction at the bridge site (Table 3). And the February 7, 1812 event probably would not have induced liquefaction at the bridge site unless it were on the order of **M** 7.8 (Table 4). In addition, the analysis suggests that a hypothetical local earthquake would only have to be about **M** 5.5 to induce liquefaction at the Route 51 crossing of the Hatchie River (Table 5).

A compound sand blow composed of two sedimentary units occurs at site HR 3 located less than 1 km from the Route 51 bridge crossing. The compound nature of the sand blow suggests that it formed as the result of liquefaction induced by two large events in an earthquake sequence. Liquefaction analysis suggests that such a sand blow could have formed during an earthquake sequence much like the one in 1811-1812 if the December 16 and February 7 events were on the order of **M** 7.6 and 7.8, respectively. The age of the sand blow at HR 3 is currently under investigation. Three other compound sand blows, one historic and two prehistoric in age, also occur along the middle section of the Hatchie River. Recent field observations along the Hatchie and liquefaction analysis are consistent with our earlier interpretation that New Madrid sequences have struck the region prior to 1811-1812 and have included earthquakes of **M** $\geq$ 7.6

(Tuttle et al., 2002). We hope to acquire borehole data for Hatchie River bridge crossings farther from the NMSZ and to extend our liquefaction analysis to more distant liquefaction sites east of Covington. Once radiocarbon dating is completed, it will be possible to compare the age of the Hatchie River features with the New Madrid earthquake chronology and to evaluate whether any of these features may be related to earthquakes generated by faults outside the currently active NMSZ.

Unanticipated Problems

In the fall of 2002, heavy rainfall led to flooding of most of the rivers in the New Madrid region, which prohibited us from continuing reconnaissance along the Hatchie River begun in 2000. In the fall of 2003, conditions were ideal for river reconnaissance and we surveyed an additional 22 kilometers of the Hatchie River. Due to flooding in 2002, however, this project remains behind schedule.

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Non-technical Summary

This collaborative research project is providing new liquefaction data that will help to reduce uncertainties regarding source areas, magnitudes, and recurrence intervals of major New Madrid earthquakes and to determine if faults outside the currently active NMSZ may have produced large earthquakes during the Holocene and Late Wisconsin. During the 2003 project period, we discovered liquefaction features, including sand blows and sand dikes, along the Hatchie River in western Tennessee up to 55 km southeast of the southwestern branch of the NMSZ and 70 km from the inferred epicenter of the December 16, 1811 mainshock. There appears to be several generations of the liquefaction features along the Hatchie River that formed during earthquake sequences similar to the 1811-1812 New Madrid event. Radiocarbon dating of organic material collected at several of the sites is currently underway and will help to constrain the ages of liquefaction features and to correlate them, or not, with other liquefaction features across the region. On the basis of liquefaction potential analysis, earthquakes like the December 16, 1811 and February 7, 1812 events, if they were on the order of **M** 7.6 and **M** 7.8, respectively, could produce liquefaction features similar to those observed along the Hatchie River.

Recent Publications

Atwater, B.F., Tuttle, M.P., Schweig, E., Rubin, C.M., Yamaguchi, D.K., and Hemphill-Haley, E., 2003, Earthquake history from paleoseismology, *in* Gillespie A., Atwater B.F., eds., The Quaternary of the United States, International Union of Quaternary Scientists (INQUA) review volume: Elsevier, p. 331-350.

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