Use of Archaeology to Date Liquefaction Features and Seismic Events in the New Madrid Seismic Zone, Central United States*

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Prehistoric earthquake-induced liquefaction features occur in association with Native American occupation horizons in the New Madrid seismic zone. Age control of these liquefaction features, including sand-blow deposits, sand-blow craters, and sand dikes, can be accomplished by extensive sampling and flotation processing of datable materials as well as archaeobotanical analysis of associated archaeological horizons and pits. This approach increases both the amount of carbon for radiocarbon dating and the precision dating of artifact assemblages. Using this approach, we dated liquefaction features at four sites northwest of Blytheville, Arkansas, and found that at least one significant earthquake occurred in the New Madrid seismic zone between A.D. 1180 and 1400, probably about A.D. 1300 ± 100 yr. In addition, we found three buried sand blows that formed between 3340 B.C. and A.D. 780. In this region where very large to great earthquakes appear to be closely timed, archaeology is helping to develop a paleoearthquake chronology for the New Madrid seismic zone.

INTRODUCTION

The New Madrid seismic zone (NMSZ) is the most seismically active region east of the Rocky Mountains and has generated three very large to great

* This article had been presented as part of the Archaeological Geology Symposium of the Geological Society of America Annual meeting held in Seattle, WA in November 1994. Dr. Margaret Guccione was guest editor.

Geoarchaeology: An International Journal, Vol. 11, No. 6, 451–480 (1996)
 CCC 0883-6353/96/060451-30

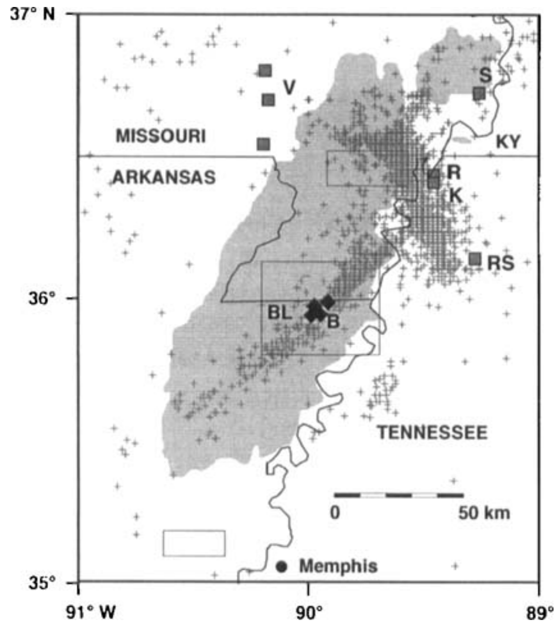

Figure 1. Map of the New Madrid seismic zone (excluding southern Illinois). Crosses are epicenters of recent earthquakes (1974–1991). Gray shading represents area where >1% of the surface is covered by sand-blow deposits (Obermeier, 1989). Study sites described in this article are denoted by black diamonds. B and BL indicate the locations of Blytheville, Arkansas, and Big Lake, respectively. Sites of other paleoseismic studies indicated by gray squares and labeled R = Russ (1982), S = Saucier (1991), V = Vaughn (1991), RS = Rodbell and Schweig (1993), and K = Kelson et al. (1996). Study areas of Wesnousky and Leffler (1992) outlined in black boxes.

earthquakes during the winter of 1811 and 1812 (Figure 1; Johnston, 1995). These earthquakes had extensive felt areas (Nuttli, 1982) and induced intense and widespread soil liquefaction (Fuller, 1912; Obermeier, 1989), in which saturated granular soil was transformed into a fluid state because of the passage of earthquake shear waves. Seismicity in the region is probably due to reactivation of structures associated with the Reelfoot rift by east-northeast directed compression (Zoback and Zoback, 1989). The great New Madrid earthquakes of 1811 and 1812 and continuing seismicity in the region have led to considerable concern about seismic hazards in the central United States. A repeat of a great New Madrid earthquake today would be devastating, and even a large earthquake is likely to cause significant damage because the infrastructure of the region is not designed to withstand strong ground shaking or ground displacements resulting from liquefaction.

Several studies evaluating the earthquake potential of the NMSZ have provided estimates of recurrence intervals of large-magnitude earthquakes. These estimates range from several hundred years to more than 10,000 years. Johnston and Nava (1985) estimated that events of moment magnitude, M, >8.0

should occur every 550–1100 yr based on the frequency and magnitude of modern seismicity. Most paleoseismic studies agree with this estimate. Russ (1982) excavated trenches across the Reelfoot scarp in the central portion of the seismic zone and found deformation features including normal faults, a monoclinal fold, and liquefaction features in Holocene sediment, indicative of two prehistoric events in the past 2 ka (Figure 1). The minimum magnitude event likely to cause liquefaction in the moderately susceptible sediments of the region is M 6.4 (Obermeier, 1989). Therefore, Russ' observations suggest that earthquakes of M $\geq$ 6.4 recur in this area every 600 yr, on average. Re-excavating the Reelfoot scarp, Kelson et al. (1996) found liquefaction features and other deformation structures. They interpreted the deformation structures as evidence of three episodes (including 1811–1812) in the past 2400 yr and a 400–500 yr average recurrence interval. In the northern portion of the NMSZ and about 30 km to the northeast of Reelfoot scarp, Saucier (1991) found liquefaction features at the Towosahgy archaeological site. He interpreted these features as evidence of two large prehistoric earthquakes between A.D. 400 and 900. Vaughn (1991) has found liquefaction features near the northwestern limit of the NMSZ and attributes these features to three prehistoric events, the timing of which is not well constrained.

Although liquefaction features are abundant throughout the NMSZ, previous studies in the southern part of the zone attributed liquefaction features to only the 1811–1812 earthquakes (Fig. 1; Wesnousky and Leffler, 1992; Rodbell and Schweig, 1993). Wesnousky and Leffler (1992) concluded that the recurrence interval of great New Madrid-type earthquakes may be more than 5–10 ka. Recently, we distinguished prehistoric from historic liquefaction features in this same part of the zone and dated several prehistoric sand blows and dikes in northeastern Arkansas, and southeastern Missouri (Lafferty et al., 1994; Tuttle et al., 1994; Tuttle and Schweig, 1995). We interpreted our findings to indicate a recurrence interval of hundreds of years for very large to great earthquakes in the region. Subsequently, Wesnousky and Johnson (1996) identified a prehistoric sand blow west of Big Lake that formed within the past 1000 radiocarbon yr B.P.

Archaeology is playing an important role in identifying and dating prehistoric earthquake-induced features in the NMSZ. Artifact assemblages and botanical remains of cultural horizons and features found in association with five liquefaction features in northeastern Arkansas are examined in this article. In addition, liquefaction features are described, and results of radiocarbon dating are presented. This article demonstrates how detailed archaeological excavation and analysis can be used in paleoseismology to help constrain the ages of prehistoric earthquakes.

GEOLOGIC SETTING

The study area is located in the Eastern Lowlands of the Mississippi alluvial valley (Figure 2). In the vicinity of the NMSZ, the Eastern Lowlands is 125 km wide and is characterized by approximately 30–35 m of Quaternary sedi-

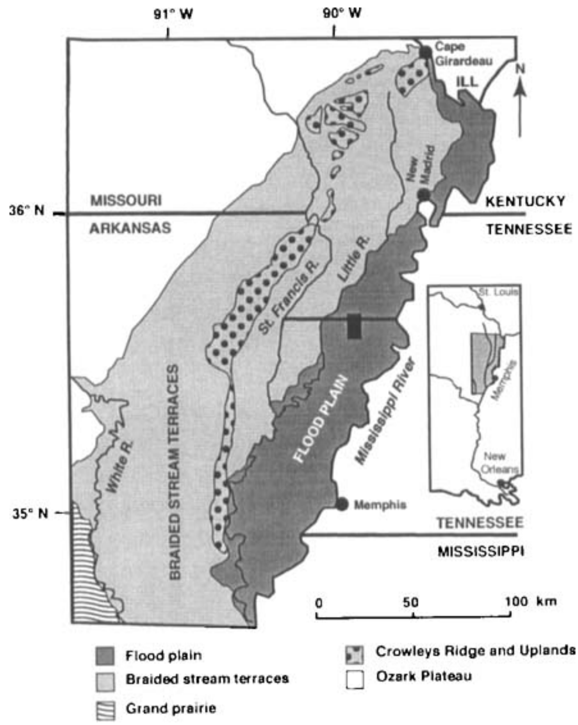

Figure 2. Geomorphic map of the northern portion of the Mississippi alluvial valley (modified from Saucier and Snead, 1989). Study area shown by black rectangle in the Mississippi River flood plain.

ment. The western half of the Eastern Lowlands is composed of terraces underlain by fluvial sediment deposited by Pleistocene glacial meltwater (Guccione, 1987). These fluvial deposits are sandy and have braided-channel patterns preserved where they are present at the surface. Small remnants of older terraces have a veneer of one or more loess deposits that mask paleochannels (Saucier and Snead, 1989; Kendall et al., 1995). The eastern portion of the lowlands is composed of the Holocene flood plain of the meandering Mississippi River, which includes meander belt to the east and backswamp to the west (Guccione, 1987). Within the 32-km-wide meander belt, channel and pointbar deposits are coarse-grained (sand), and abandoned channel deposits are fine-grained (silt and clay). In the 16-km-wide backswamp, deposits are also fine-grained and meander-channel deposits appear to be absent. Natural-levee deposits, which typically consist of thinly bedded fine sand and massive sandy silt to clayey silt, occur at the transition between the meander belt and the backswamp. The study area is located in the transition zone between the meander belt and the backswamp.

Three major geologic-geomorphic mapping units are present in the study

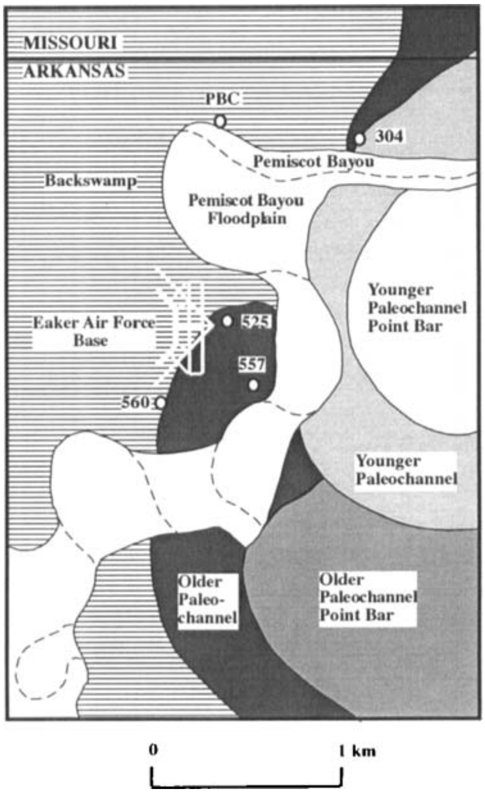

Figure 3. Geomorphic map of study area with the location of the four archaeological sites examined in this report and Pemiscot Bayou Core (PBC).

area. They include two paleochannels of the Mississippi River and a crevasse channel of the Mississippi River, known as the Pemiscot Bayou. As evident in Figure 3, the crevasse channel cross-cuts both paleochannels. Liquefaction features are present in all three geomorphic areas. The older paleochannel of the Mississippi River (Figure 3) is most easily identified just south of the study area by its lower topographic position and darker tone on aerial photographs. Within the study area, this older channel fill has been partially eroded by a younger Mississippi River paleochannel and the Pemiscot Bayou. Where the older paleochannel is preserved in the western portion of the study area, the channel fill is buried by overbank deposits derived from the younger paleochannel. This makes it difficult to identify the boundaries of the older paleochannel. The younger Mississippi River paleochannel (Figure 3) occurs in the eastern portion of the study area. This paleochannel truncates the older paleochannel and is truncated by the Pemiscot Bayou crevasse channel. With the exception of site 3MS304, the archeological sites and liquefaction features examined in this paper occur within the overbank deposits related to the younger paleochannel (Figure 3).

Liquefaction features are very common in the study area. Within the meander belt, sand blows, deposits of sand resulting from venting of water and sand due to earthquake shaking, commonly form above buried linear sand bodies, such as point bars and channels (Obermeier, 1989; Guccione, unpubl. data, 1995), and along the margins of thick cohesive deposits, such as channel-fills of the Mississippi River and crevasse splays (Tuttle and Barstow, 1996). Sand blows are abundant along Pemiscot Bayou, but most are buried by subseqeunt flood deposits and therefore are not apparent on aerial photography or satellite imagery. Within the backswamp region west of Eaker Air Force Base, sand blows have a more random pattern as compared to that in the meander belt.

ARCHAEOLOGIC SETTING

People have occupied the Mississippi alluvial valley since the Paleo-Indian Period, or 11,500 yr B.P. (Morse and Morse, 1983). Due to the young age of the landforms and deposits, however, only the past 2.2 ka of occupation are represented in the study area. The chronology of human artifacts from this time period is based on 200 radiocarbon dates of associated organic materials from sites between Memphis, Tennessee, and Cairo, Illinois (Table I). Within

Table I. Cultures represented in the study area, their approximate ages and the associated diagnostic artifacts and floral remains.

Culture	Years (B.C./A.D.)	Diagnostic Artifacts and Floral Remains
Historic	A.D. 1673[a]–present	Iron, glass, glazed pottery, plastic
Late Mississippian	A.D. 1400–1673	Shell-tempered pottery, ornate pottery
Middle Mississippian	A.D. 1000–1400	Shell-tempered pottery, Old Town Red pottery, (shell tempered, exterior slipped), Madison point, Maize becomes important by A.D. 1000–1050
Early Mississippian	A.D. 800–1000	Pottery transition: shell-tempered pottery, Varney Red Filmed pottery (shell tempered, interior slipped)
Late Woodland	A.D. 400–800[b]	Sand- and grog-tempered pottery
Middle Woodland	200 B.C.–A.D. 400	Sand- and grog-tempered pottery dentate, stamped, and fabric-marked pottery
Early Woodland	500–200 B.C.	Punctated pottery, baked clay objects
Late Archaic	3000–500 B.C.	Stemmed projectile points, baked clay objects

[a] Dougan (1995).
[b] Morse and Morse (1983, 1990) use A.D. 400–700 and do not assign A.D. 700–800 as either Late Woodland or Early Mississippian. To avoid a century that has no cultural designation, we have assigned this interval to the Late Woodland.

the region, the earliest ceramics, dating back to about 500 B.C., include both sand- and/or grog-tempered pottery, which are both plain and cordmarked. In the study area, the earliest documented ceramics are Middle Woodland (200 B.C.–A.D. 400) dentate-stamped pottery (see description of site 3MS525). There are reported occurrences of Archaic points and clay balls at site 3MS308, which is in the vicinity of the study area.

Shell-tempered pottery, representing the development of a new technology, appeared in southeastern Missouri by about A.D. 700. Most, if not all, of the pottery being made in northeastern Arkansas was shell-tempered by about A.D. 800 (Morse and Morse, 1983, 1990; Benn, 1990). This technology continued into the Historic period and is indicative of the Mississippian culture. Although most of the pottery made by the prehistoric Native Americans was plain or cordmarked, finer distinctions in the chronology are based on rare decorated pottery types that occur at rates of 0.1–10% of ceramic assemblages. These include dentate-stamped pottery (a Middle Woodland marker), interior-slipped (paint on interior of vessel) Varney Red Filmed pottery (a marker for Early Mississippian), and exterior-slipped (paint on exterior of vessel) Old Town Red pottery (a Middle Mississippian marker) (Phillips, 1970; Perino, 1985).

Projectile point styles also change through time, some diffusing geographically from north to south. However, projectile points occur in lower densities than pot sherds, typically < 1% of sherds. Because of their scarcity, projectiles have a more limited use in developing the chronology of human artifacts during the last 2.5 ka and were not used extensively in this study. A single Madison arrow point, a diagnostic type for the Middle Mississippian (Perino, 1985), was found at one of the study sites (3MS560).

METHODS

Mapping of surficial geology in the study area is based on interpretation of aerial photographs, topographic quadrangle maps, and borehole data, as well as observations of backhoe trench exposures that were logged and described. Graphical logs of the exposures were made based on 0.5 × 0.5 m grids. Descriptions of soil profiles use standard soil terminology (Soil Survey Staff, 1981) except for the textural designations, which are those of Folk (1974). Locations of samples collected for radiocarbon dating, archaeological analysis, and soil testing were designated on the logs. Beta Analytic and Geochron performed the radiocarbon analyses of organic samples, and Beta Analytic calibrated the radiocarbon ages using the Pretoria calibration curve (Vogel et al., 1993). When estimating the minimum and maximum ages of liquefaction features, we used maximum ranges based on 2 sigma calibrated ages in every case.

Test units (or exploratory pits), archaeological features, and prehistoric occupation horizons were excavated using standard archaeological methods. Techniques utilized at all sites are described in this section. At sites where archaeological material was present at the surface, the upper plow zone was skimmed with a flat shovel or a modified backhoe blade until plowscars could be identified. The zone containing the plowscars was removed by 1-cm-thick intervals down to undisturbed material. Below the plow zone material was excavated in 10-cm-thick levels and sieved through a 6.25 mm screen. All objects retained on the screen were bagged and labeled with a provenance and field specimen number. In the section, "Site Descriptions," additional techniques are described for the sites where they were employed.

Where archaeological features were excavated, all or systematic samples of the feature fill were collected and later processed by flotation using a modified symap machine (Struever, 1968; Watson, 1976; Pearsall, 1989). During this process, the material was suspended in water and centrifuged. The light fraction (carbon) was retained on a 0.78 mm screen and the heavy fraction fell to the bottom of the tank where it was retained on a 1.6 mm screen for later identification and analysis. The heavy fraction was further separated with 12.5 and 6.25 mm screens. Therefore, three sizes, >12.5 mm, 12.5–6.25 mm, and 6.25–1.6 mm, of the heavy-fraction and a light fraction, <0.78 mm, were obtained. All sherds >6.25 mm were identified for site 3MS304, and sherds >12.5 mm were identified for the remaining sites. The light fraction was identified for only one site, 3MS557.

SITE DESCRIPTIONS

Liquefaction features at sites 3MS304 (Yarbro-304) and 3MS560 (Eaker-560) have been described briefly in Tuttle and Schweig (1995); and sites 3MS557 (E-557) and 3MS525 (E-525) were used to illustrate means of identifying and dating prehistoric liquefaction features in Tuttle and Schweig (1996). In this article, artifacts assemblages and radiocarbon dating of organic-rich samples collected at four sites north of Blytheville, Arkansas are compared with other documented archaeological sites in the region. Ceramic artifacts at these sites represent both Woodland and Mississippian occupations. Occupations at three of the sites (3MS304, 3MS557, and 3MS560) spanned the transition from the Woodland to the Mississippian culture, whereas occupation at the fourth site (3MS525) was during the Middle and Late Woodland periods. 3MS525 is one of only a few well-dated Woodland sites in northeast Arkansas. It compares with dated Woodland components farther north in southeast Missouri (Morse and Morse, 1990).

The Zebree archaeological site (Morse and Morse, 1980), located 32 km west of the study area, is the type locality for the Early Mississippian in northeast Arkansas. Middle Mississippian components were dated at the Priestly site near Trumann, Arkansas, 75 km southwest of the study area, and in southeast Missouri (Morse and Morse, 1990). Dated Late Mississippian archaeological sites in northeast Arkansas include Nodena and Parkin, 60 km south and 95 km southwest of the study area, respectively (Morse and Morse, 1990).

Site 3MS304

Site 3MS304 is located near the margin of the younger Mississippi River paleochannel (Figure 3) and is underlain by sandy silt. This deposit is derived

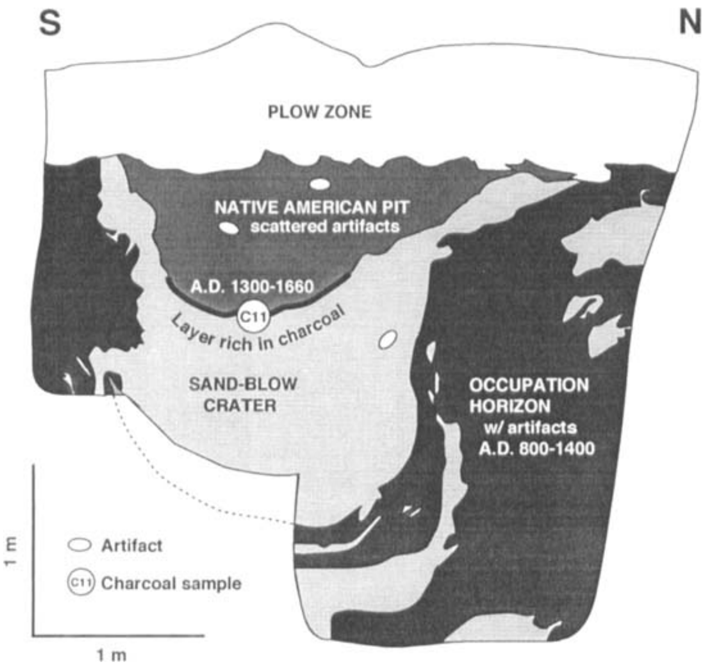

Figure 4. Log of western trench wall at site 3MS304. Analysis of ceramic artifacts within the occupation horizon and the Native American pit, as well as radiocarbon dating of charcoal lining the base of the pit, indicate that the sand-blow crater formed between A.D. 800 and 1400.

from a nearby channel, probably the Pemiscot Bayou, and may be overbank sediment or channel fill of a larger Pemiscot Bayou channel. A trench about 2.5m^3 was excavated across the margin of a large sand blow, exposing overbank sediment overlain by a thick (~1m) prehistoric occupation horizon that includes abundant carbon and artifacts (Figure 4, Tables II and III; Tuttle and Schweig, 1995). The occupation horizon is cross-cut by a 2-m-wide sand-blow crater and its associated 1-m-wide feeder dike. A prehistoric cultural pit, interpreted as a fire pit, extends into the top of the sand-blow crater and is filled with anthropogenically derived trash.

Several different archaeological sampling strategies were used at this site. As a result, sampling of the occupation horizon is not statistically equivalent to sampling of the fire pit above the sand blow. For the occupation horizon, exposed artifacts were point plotted and collected. To sample the prehistoric pit, a 1 × 1.5 m archaeological test unit was excavated followed by a 20-cm-wide trench excavated in 10-cm-thick intervals. Flotation samples from the pit and the underlying sand-blow crater were collected and analyzed.

Artifacts in the occupation horizon include abundant shell-tempered and Varney Red Filmed pottery of the Early Mississippian culture. Alternating artifact-rich and artifact-poor layers within the thick occupation horizon sug-

Table II. Artifacts >6.25 mm collected from occupation horizons/features at study sites. Relative age of occupation horizon is referenced to liquefied sand at the site. Weight percent of ceramic tempers is based on total weight of sherds with identifiable temper.

Ceramics							Lignite (g)	Faunal (g)	Floral (Includes Charcoal) (g)
Grog (g) (%)	Sand (g) (%)	Grog and Sand (g)(%)	Shell (g) (%)	Varney Red Filmed (g)	Old Town Red (g)	Fired Clay (g)			
3MS304—postliquefied sand (plow zone, 0–30 cm depth)									
11.5 23%	19.4 39%	6.2 13%	2.9 6%	9.3 19%	0 0%	70.1	3.1	0	0.2
3MS304—postliquefied sand (fire pit, 30–72 cm depth)									
7.9 18%	0.4 1%	0 0%	13.9 31%	16.2 37%	5.9 13%	7.2	2.5	0.5	91
3MS304—preliquefied sand									
0 0%	0 0%	0 0%	2.1 2%	99.9 98%	0 0%	0	NA[a]	NA[a]	NA[a]
3MS525—preliquefied sand									
87.7 39%	90.0 40%	46.8 21%	0 0%	0 0%	0 0%	0.3	25.4	0	5.4
3MS557—postliquefied sand dike (≤10 cm depth)									
12.0 4%	90.1 32%	43.6 15%	142.3 49%	0 0%	0 0%	24.6	0	0	See Table 4
3MS557—preliquefied sand dike (clasts within sand dike and >10 cm depth)									
12.8 11%	81.0 71%	8.7 8%	11.6 10%	0 0%	0 0%	30.2	0	0	0
3MS560—postliquefied sand (test unit, features, and control columns)									
15.7 2%	146.0 19%	12.9 2%	576.4 77%	0 0%	0 0%	283.4	0	0.1	1.5
3MS560—preliquefied sand (test unit)									
9.9 2%	198.8 49%	0 0%	196.2 49%	0 0%	0 0%	196.5	0	0	0

[a] NA = not available.
[b] Includes 1.8 g of grog- and shell-tempered pottery not listed in table.

gests that overbank sediment accumulated during periodic flood events while the site was occupied. The sand-blow crater and feeder dike cross-cut, and therefore post-date, the occupation horizon. The sand-blow crater contains a minor amount of lignite as well as a few artifacts and clasts of the disrupted occupation horizon. The cultural pit, probably a fire pit, extends into the top of the sand-blow crater, indicating that the site was reoccupied after the liquefaction event. The basal contact of the pit is abrupt and is blackened due to the presence of charcoal, with pieces ranging up to 3 cm in diameter (Figure 4). There is only a low density of artifacts (<25% by weight) within the sandy lower portion of the pit, where most of the recovered material is charcoal (Table II). The silty upper portion of the pit contains abundant ceramic artifacts and a low density (<3%) of carbon. The silty upper portion of the pit fill was probably derived from the surrounding host deposit and therefore may include some artifacts from the occupation horizon. In addition, anthropogenically derived trash, contemporaneous with the pit, was used to fill the pit. There are no siltation bands within the feature fill, which suggests that the pit was used only briefly as a fire pit and then was filled during a short time interval.

Artifacts within the fire pit include both Early and Middle Mississippian diagnostic pottery (Table II), which indicates that the pit is younger than the Early Mississippian occupation horizon. Virtually all of the >12.5 mm ceramics from the pit are red filmed on the interior and fired buff on the exterior, typical of Early Mississippian pottery. Although grog- and sand-tempered as well as shell-tempered Varney Red Filmed (interior slipped) pot sherds are present, the largest sherd is an Old Town Red (exterior slipped; Table II). This type sherd is a regional marker for the Middle Mississippian culture (Phillips, 1970) and indicates that the pit was dug during the Middle Mississippian period.

The age of the liquefaction event is constrained by the chronology of human artifacts in the occupation horizon and the fire pit as well as by radiocarbon dating of charcoal within the pit (Table III). The cross-cutting relationship between the sand-blow crater and the occupation horizon containing only Early Mississippian artifacts indicates the event occurred during or after the Early Mississippian. The Old Town Red pot sherd within the fire pit indicates that the pit was excavated before the close of the Middle Mississippian, or prior to A.D. 1400 (Table I). A calibrated radiocarbon age of A.D. 1300–1660 (Table III) was determined for charcoal collected from the base of the pit. Therefore, archaeology and radiocarbon dating indicate that the sand-blow crater formed between A.D. 800 and 1400. The thickness (~1 m) of the occupation horizon cross-cut by the sand-blow crater and related feeder dike suggests that the event did not occur at the beginning of the Early Mississippian period and therefore may have occurred closer to A.D. 1400 than to A.D. 800.

Site 3MS525

Site 3MS525 is located within the older paleochannel and near the margin of the younger paleochannel of the Mississippi River. This site is underlain by silty overbank sediment, probably derived from the younger paleochannel to the east (Figure 3). Two 2-m-deep trenches, 11 m and 26 m long, were excavated perpendicular to one another. Exposed in the trenches, overbank sediment is capped by an occupation horizon which is overlain by a sand blow. The sand blow is up to 0.75 m thick and was fed by a sand dike that is at least 0.25 m wide.

In one of the trench walls, a large root cast containing large pieces of charcoal occurs above the sand blow. The root cast extends through the sand blow and into the underlying occupation horizon (Figure 5). Within the buried occupation horizon, the root cast has the form of a nearly vertical tap root. In addition, a lateral root cast extends along the top of the buried horizon. Sedimentary structures within the sand blow suggest that the tree was present at the time

Table III. Radiocarbon ages, calibrated calendar years, and archaeologic ages associated with earthquake-induced liquefaction features near Blytheville, Arkansas. Calibrated calendar years were provided by Beta Analytic Radiocarbon Dating Laboratory (Vogel et al., 1993; Talma and Vogel, 1993; Stuiver et al., 1993).

Location	Lab No. Figure and Sample No.	Material	Method	Time Relationship to Liquefaction	Conventional Radiocarbon Age (B.P.)	Calibrated Age Intercept	Calibrated Age 2 sigma (95% Probability)	Age Estimate Based on Ceramics and Lithics (A.D.)	Age Estimate Based on Botanical Remains (A.D.)	Maximum Age Range (Preferred Guess) for Liquefaction Events
3MS304	G-19080 Fig. 4-C11	Charcoal	Radiometric	Postliquefaction	455 ± 110	A.D. 1440	A.D. 1300–1660	NA	NA	A.D. 800–1400 (1300 ± 100 yr)
3MS304	NA[a]	NA	NA	Postliquefaction	NA	NA	NA	1000–1400 (Mid. Miss.)	NA	
3MS304	NA	NA	NA	Preliquefaction	NA	NA	NA	800–1000 (Early Miss.)	NA	
3MS525	B-75326 Fig. 5-C6	Charcoal	AMS	Postliquefaction	170 ± 60	A.D. 1680 A.D. 1760 A.D. 1810 A.D. 1940	A.D. 1650–1950	NA	NA	A.D. 1180–1630 (1300 + 100
3MS525	B-75325[c] Fig. 5-W2	Organic material	AMS	Postliquefaction	450 ± 60	A.D. 1450	A.D. 1410–1530 A.D. 1560–1630	NA	NA	
3MS525	B-65729[b,c] Fig. 5-CL	Charcoal	Radiometric	Preliquefaction	740 ± 100	A.D. 1280	A.D. 1050–1110 A.D. 1120–1420	NA	NA	
3MS525	B-81313 Fig. 5-S14	Organic sediment	Radiometric	Preliquefaction	740 ± 70	A.D. 1280	A.D. 1180–1400	NA	NA	
3MS525	NA	NA	NA	Preliquefaction	NA	NA	NA	Post-400 (Mid Wood.)	NA	
3MS557	NA	NA	NA	Postliquefaction	NA	NA	NA	800–1670 (Miss.)	NA	A.D. 1000–1420 (1300 ± 100 yr) (L1)
3MS557	B-86810	Charcoal	Radiometric	Postliquefaction	460 ± 60	A.D. 1440	A.D. 1400–1520 A.D. 1570–1630	NA	NA	
3MS557	B-86811 Fig. 6D-C3	Charcoal	Radiometric	Postliquefaction	510 ± 60	A.D. 1425	A.D. 1310–1360 A.D. 1390–1480	NA	NA	
3MS557	B-77450 Fig. 6D-C4	Charcoal	Radiometric	Postliquefaction	660 ± 60	A.D. 1300	A.D. 1270–1420	NA	NA	
3MS557	B-86190 Fig. 6C-S4	Organic sediment	Radiometric	Postliquefaction	770 ± 60	A.D. 1270	A.D. 1180–1310	NA	NA	

3MS557	B-86816 Fig. 6C-S3	Organic sediment	Radiometric	Preliquefaction	1420 ± 80	A.D. 645	A.D. 470–480 A.D. 520–780	NA	NA	
3MS557	NA Fig. 6A	NA	NA	Preliquefaction	NA	NA	NA	~800 (terminal Late Wood.)	Post-1000	
3MS557	B-86814 Fig. 6C-S1	Organic sediment	Radiometric	Postliquefaction	1420 ± 80	A.D. 645	A.D. 470–480 A.D. 520–780	NA	NA	800 B.C.–A.D. 780 (L2)
3MS557	B-86814 Fig. 6C-S1	Organic sediment	Radiometric	Preliquefaction	2410 ± 80	415 B.C.	800–360 B.C. 290–230 B.C.	NA	NA	
3MS557	B-86814 Fig. 6C-S1	Organic sediment	Radiometric	Postliquefaction	2410 ± 80	415 B.C.	800–360 B.C. 290–230 B.C.	NA	NA	1430–800 B.C. (L3)
3MS557	B-81311 Fig. 6B-S1	Organic sediment	Radiometric	Preliquefaction	2970 ± 100	1170 B.C.	1430–910 B.C.	NA	NA	
3MS557	B-86815 Fig. 6C-S2	Organic sediment	Radiometric	Preliquefaction	3020 ± 80	1265 B.C.	1430–1010 B.C.	NA	NA	
3MS557	B-86812 Fig. 6D-S1	Organic sediment	Radiometric	Preliquefaction	3200 ± 100	1440 B.C.	1690–1250 B.C.	NA	NA	
3MS557	B-86812 Fig. 6D-S1	Organic sediment	Radiometric	Postliquefaction	3200 ± 100	1440 B.C.	1690–1250 B.C.	NA	NA	3340–1690 B.C. (L4)
3MS557	B-86813 Fig. 6D-S2	Organic sediment	Radiometric	Preliquefaction	4180 ± 190	2870 B.C. 2800 B.C. 2760 B.C.	3340–2210 B.C.	NA	NA	
3MS560	B-69618 Fig. 7	Charcoal	AMS	Postliquefaction	300 ± 60	A.D. 1640	A.D. 1460–1680 A.D. 1770–1800 A.D. 1940–1950	NA	NA	Two earthquakes A.D. 800–1400 (1300 ± 100 yr)
3MS560	NA Fig. 7	NA	NA	Postliquefaction	NA	NA	NA	Lithics = pre-1400 (Mid. Miss.)	NA	
3MS560	NA Fig. 7	NA	NA	Preliquefaction	NA	NA	NA	Ceramics = post-800 (Early Miss.)	NA	

[a] NA means not applicable.
[b] Small sample given extended counting time.
[c] Carbon 13 not measured; adjusted age normalized to −25 per mil Carbon 13.

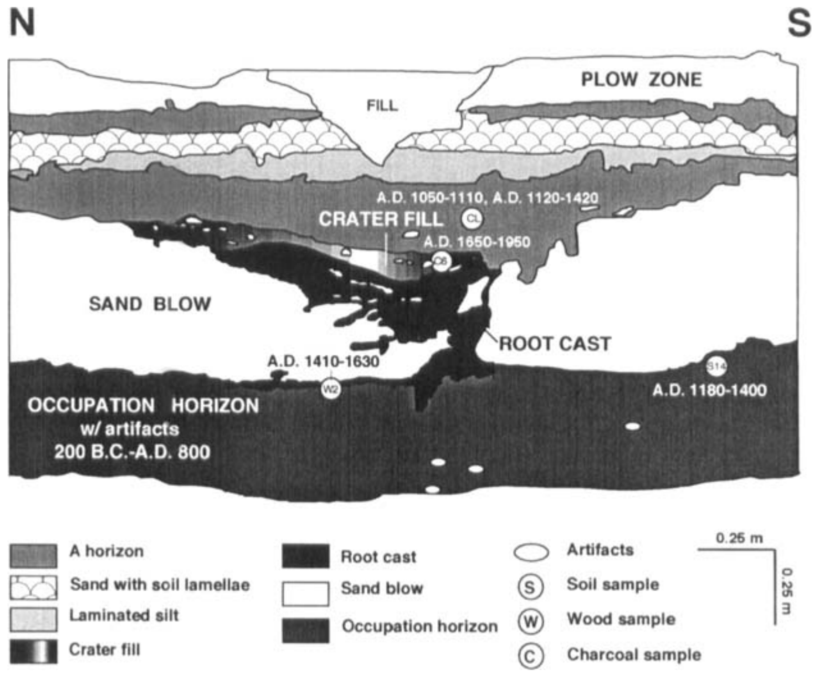

Figure 5. A portion of the log of the eastern trench wall at site 3MS525. Analysis of artifacts within the occupation horizon buried by the sand blow as well as radiocarbon dating of the occupation horizon, the lateral tree root, and the crater fill, indicate that the sand blow formed between A.D. 1180 and 1630.

of the event; however, casts of rootlets in the top of the sand blow and of the lateral root along the base of the sand blow clearly indicate that the tree continued to grow after the event. The root cast is overlain sequentially by a filled tree-throw crater and a buried soil characterized by a 10 cm-thick A horizon (Figure 5).

On the southern end of the excavation, the sand blow is overlain by a laminated silt deposit, which contains a few prehistoric artifacts. Eight- to 15-cm-thick fine-grained sand deposit overlies the laminated silt (Figure 5), and where the silt is absent, the sand deposit directly overlies the sand blow. Curiously, small sand dikes (≤3 cm in width and interpreted as reliquefaction features) originating from the top of the sand-blow deposit extend into the overlying fine-grained sand deposit. The fine-grained sand deposit is characterized by lamellae, however, the lamellae do not occur within the sand dikes. The fine-grained sand is overlain by a 20-cm-thick loamy A horizon. The upper 12–15 cm of the A horizon is an olive brown (2.5Y 4/3 moist), sandy loam and has been plowed. Some of the material comprising the A horizon may be reworked sand vented along the nearby Pemiscot Bayou during the 1811–1812 earthquakes (Guccione et al., 1996). The lower 5–8 cm of the A horizon is a very dark grayish brown (2.5Y 3/2 moist), silt loam and is relatively undisturbed by plowing.

Two-hundred thirty-seven artifacts were recovered from site 3MS525. Most of the sherds were recovered from a 2 × 0.5 m test unit in which all of the material >6.25 mm was recorded (Table II). All but five of the sherds were recovered from the occupation horizon buried by the sand blow, so that the artifacts only constrain the maximum age of the sand blow. Pot sherds typical of the Middle and Late Woodland cultural periods (Table II) were found between 15 and 65 cm below the sand blow. One dentate-stamped pot sherd, diagnostic of the Middle Woodland (Table I), was found about 60 cm below the sand blow.

Several samples were collected for radiocarbon dating. A whole-soil sample (S14 in Figure 5) taken from the top of the buried occupation horizon yielded a calibrated radiocarbon age of A.D. 1180–1400 (Table III). This age is younger than that estimated for the occupation horizon based on its ceramic artifacts, suggesting that the site was abandoned for at least several centuries prior to burial by the sand blow. The soil sample predates the sand blow and therefore provides a maximum age of its formation. A sample of the decomposed lateral root at the contact of the occupation horizon and overlying sand blow (W2 on Figure 5), yielded a calibrated radiocarbon age of A.D. 1410–1530 and 1560–1630. The lateral root is thought to have grown after the sand blow was deposited and thus provides a minimum age of formation for the sand blow. A sample of charred wood (C6 on Figure 5) collected from the sandy fill within the tree-throw crater yielded a calibrated radiocarbon age of A.D. 1650–1950. As expected, this date is younger than that of the lateral tree root. Charcoal from the soil overlying the crater fill (CL in Figure 5) yielded a calibrated age of A.D. 1050–1110 and 1220–1420. This age is nearly the same as that of the soil buried by the sand blow; this suggests that the piece of charcoal that originated from the buried soil horizon was transported up section during either the liquefaction or tree-throw event, and became part of the soil horizon developed above the sand blow.

Given the calibrated radiocarbon ages of the samples from site 3MS525, the liquefaction event occurred between A.D. 1180 and 1630. The maximum age estimate is consistent with the Woodland artifacts found in the occupation horizon below the sand blow. The minimum age is based on a sample collected from the lateral root that probably grew along the basal contact of the sand blow after its deposition. If, instead, the lateral root had grown prior to the formation of the sand blow, and therefore was exposed at the ground surface at the time of the event, then the earthquake occurred after A.D. 1630.

We prefer the interpretation that the sand blow formed prior to A.D. 1630 for several reasons. Tree roots typically grow along contacts between permeable and less permeable material where ground water tends to collect. Tree roots are not commonly present at the ground surface unless erosion exposes the root ball, which is unlikely in this low-relief terrain. Therefore, we think that it is more likely that the lateral root grew after rather than before the sand blow formed. In addition, some of the roots associated with the root cast clearly grew into the top of the sand blow. Secondly, a substantial amount of time must have passed since the sand blow formed to account for the formation of the tree-throw crater, filling of the crater, soil development within the crater-fill, deposition of the overlying laminated sandy silt and the fine-grained sand, and finally development of an A horizon and lamellae. A horizons can form in decades, but lamellae require centuries. Thirdly, sand dikes interpreted as reliquefaction features extend from the top of the sand blow into the overlying fine-grained sand deposit and do not exhibit lamellae as does the host deposit. This indicates that an earthquake large enough to liquefy the sand-blow deposit occurred after the lamellae had begun to form in the overlying sand deposit. Soil lamellae are thought to form in more than two but less than six centuries in this region (Guccione, unpubl. data, 1995). Therefore, the reliquefaction features probably formed fairly recently, most likely during the 1811 and 1812 earthquake sequence, and the fine-grained sand deposit was subjected to soil-forming processes for 200–600 yr prior to the reliquefaction event. In this scenario, the sand blow could have formed between A.D. 1200 and 1600. This would be consistent with radiocarbon dating of the sand blow and would allow enough time for the depositional events and pedogenic development evident at the site.

Site 3MS557

This site occurs within the older paleochannel of the Mississippi River and is adjacent to both the margin of the younger paleochannel and the present floodplain of Pemiscot Bayou (Figure 3). It is located on a ridge oriented parallel to the younger paleochannel to the east, with fan-shaped lobes to the west. We interpret the ridge to be a natural levee and the lobes to be associated with crevasse splays. Deposits at this site consist of sandy silt derived from the younger Mississippi River paleochannel. The upper 0.5 m of sediment at this location is probably derived from the nearby Pemiscot Bayou. It is unlikely that flooding of Pemiscot Bayou was capable of depositing appreciable sediment at the site because it is located on the highest surface in the area and on a landform that conforms to the Mississippi River paleochannel orientation.

When the plow zone was stripped from an area depicted in Figure 6A, a linear feature (>12 m in length) thought to represent a prehistoric palisade wall was uncovered. The linear feature was later discovered to be a sand dike when three trenches, about 2.5 m deep and 5–11 m long, were excavated across it (Figures 6A, 6B, 6C, and 6D). The sand dike is at least 60 cm wide and 12 m long and cross-cuts overbank sediment, several paleosols, three sand-blow deposits, and a Native American occupation horizon. In all three trenches, numerous clasts of the occupation horizon occur within the dike. In trench 1, a portion of the occupation horizon that predates the liquefaction event dips into the top of the sand dike (L1 in Figure 6B). Another portion of the occupation horizon, thought to post-date the liquefaction event, overlies the dike. During archaeological excavation, it was observed that sand separating the two portions of the occupation horizon had vented through small (<2 cm wide), round (plan view) holes in the disturbed portion of the occupation horizon. In trench 2, the top of the sand dike occurs at a greater depth below the surface than in the other two trenches (Figure 6C). Immediately above the dike, lenses of sand are interbedded with organic-rich material typical of the occupation horizon. Higher in the section, the occupation horizon becomes homogeneous and contains a burned area, comprised mostly of charcoal, which is interpreted as a fire pit. In trench 3, the disturbed portion of the occupation horizon dips into the top of the dike and is overlain by vented sand, which, in turn, is overlain by the plow zone (Figure 6D).

Deformation of the Native American occupation horizon indicates that the horizon was disturbed during formation of the sand dike (L1). In addition, collapse of the occupation horizon into the dike and absence of an associated sand-blow deposit suggest that the sand dike formed as a result of lateral spreading toward the nearby Pemiscot Bayou. In trench 2, the observed relations suggest that the occupation horizon collapsed into the dike and broke up into clasts, that a fissure formed above the dike and was filled first with sediment washed from the fissure walls and later with new cultural material. The upper part of the occupation horizon filling the fissure is contemporaneous with the occupation horizon overlying the sand dike in trench 1. In trench 3, plowing appears to have removed post-event occupation horizon that developed above the dike; a Native American pit, however, cross-cuts, and therefore post-dates, the vented sand overlying the disturbed occupation horizon. In all three trenches there is evidence that Native Americans reoccupied this site following the liquefaction event (L1).

Archaeological samples were collected over a 2-year span during two different field seasons from three test units. One test unit was excavated in the sand dike (L1); a second unit was excavated in the occupation horizon; and a third test unit was excavated in selected cultural features (Figure 6A). Fine-textured clasts of the disturbed occupation horizon within the dike were removed in levels and screened for artifacts. Flotation samples were also collected. All samples were categorized as pre-event based on their presence within the dike or at a depth greater than 10 cm below the occupation surface or as post-event if collected from a depth less than 10 cm.

Comparison of the ceramic assemblages classified as pre-event and post-event indicates that they differ in the stratigraphically predicted direction. The overlying unit has 49% shell-tempered ceramics, which is typical of the Mississippian on multicomponent sites. In contrast, the lower stratum has only 10% shell-tempered and 90% grog- and sand-tempered sherds. The very low abundance of shell tempered pottery suggests that the older occupation horizon represents the terminal Late Woodland culture (Table II). Flotation samples were taken from each of the stratum to recover charred botanical remains.

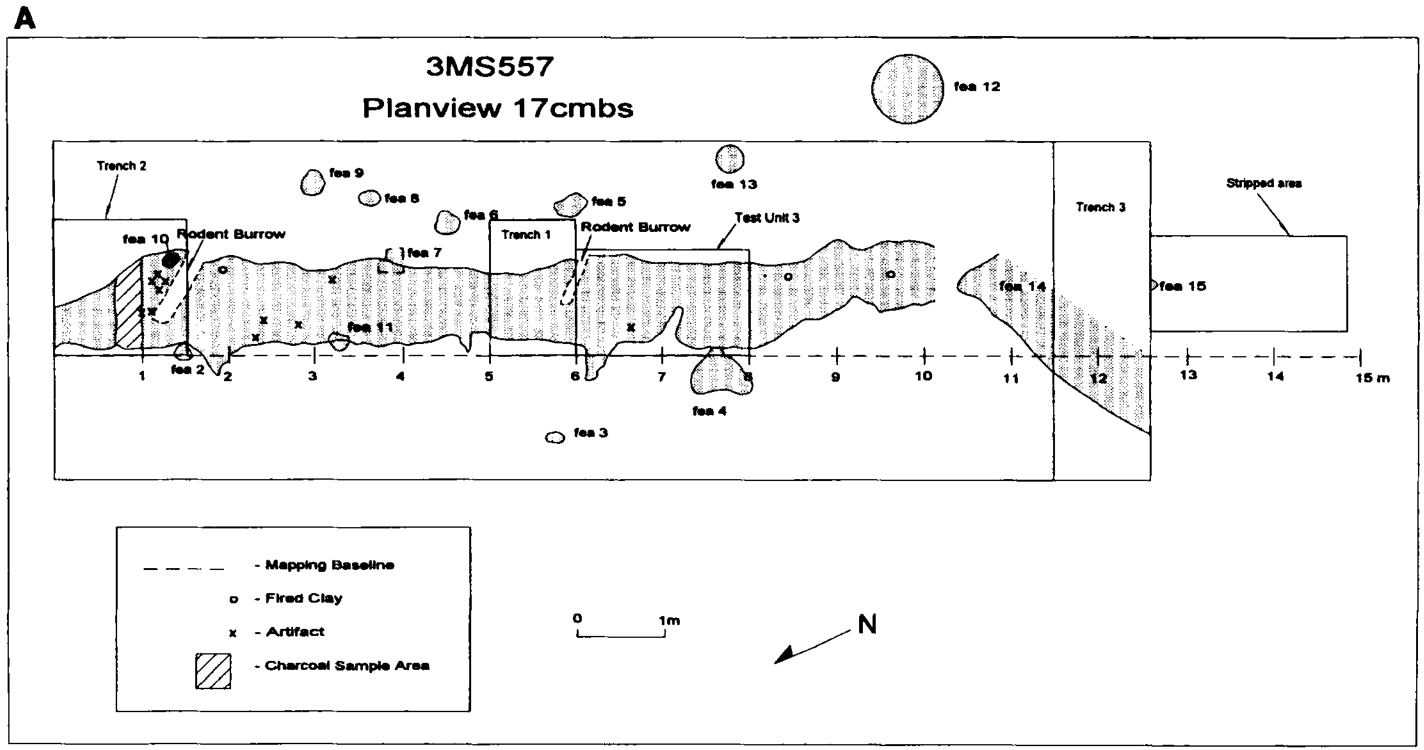

Figure 6. Site 3MS557. (A) Subplow-zone plan view at 17 cm below the ground surface. Features are shaded and location of trenches and test unit 3 are shown. The linear feature that spans almost the entire length of the figure is underlain by the sand dike.

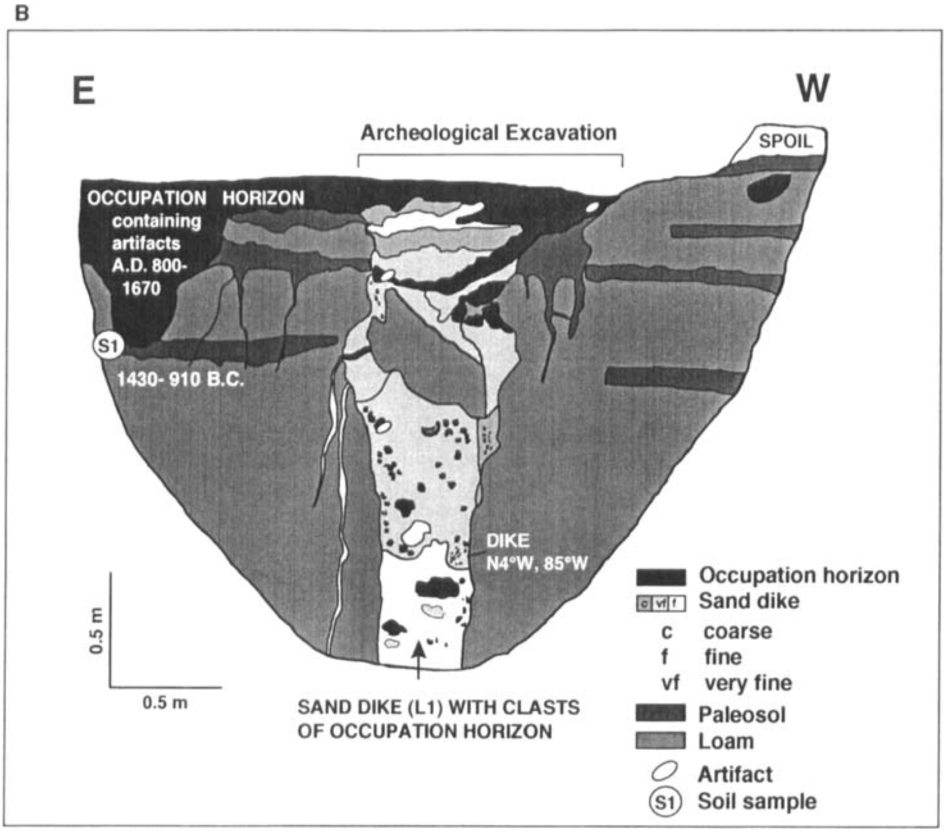

Figure 6. (B) Log of south wall of trench 1. Analyses of artifacts and botanical remains in the disturbed (preliquefaction) and undisturbed (postliquefaction) portions of the occupation horizon indicate that the sand dike (L1) formed between A.D. 1000 and 1670. Two paleo-sand blows (L2 and L3) were present in the north wall of the trench, the lower of which was overlying the paleosol (S1) that formed between 1430 and 910 B.C.

Four-hundred and forty-five specimens larger than 2 mm in size were analyzed (Table IV). Maize cob and kernel fragments were abundant in the samples. In the disturbed occupation horizon, which predates liquefaction, maize fragments accounted for 41% of the recovered botanical material. In the occupation horizon developed above the sand dike, they comprise 17% of the samples. In the study area, the use of maize became dominant in Native American diets about A.D. 1000–1050. Therefore, the abundance of maize in the occupation horizons and features at the site suggests that the dike (L1) formed after A.D. 1000.

In trench 2, a sample of the occupation horizon filling the fissure above the dike yielded a calibrated age of A.D. 1180–1310 (Table III). Radiocarbon dating of the fissure fill suggests that the event occurred prior to A.D. 1310. Also, a

C

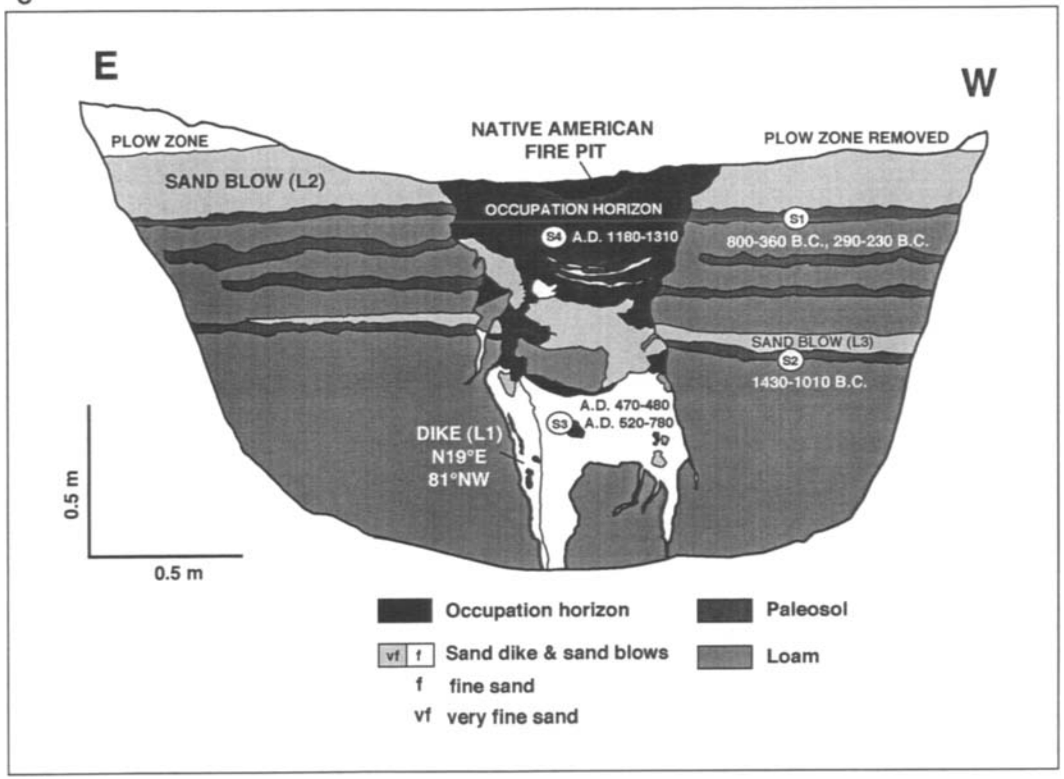

Figure 6. (C) Log of south wall of trench 2. Radiocarbon dating of a clast (S3) of the occupation horizon within the dike and of the occupation horizon (S4) above the dike helps to constrain the age of the sand dike. Dating of the clast (S3) within the dike and the paleosol (S1) buried by the youngest sand-blow deposit indicates that the sand blow (L2) formed between 800 B.C. and A.D. 780. Dating of the two paleosols buried by sand blows indicates that the intermediate-age sand blow (L3) formed between 1430 and 800 B.C.

D

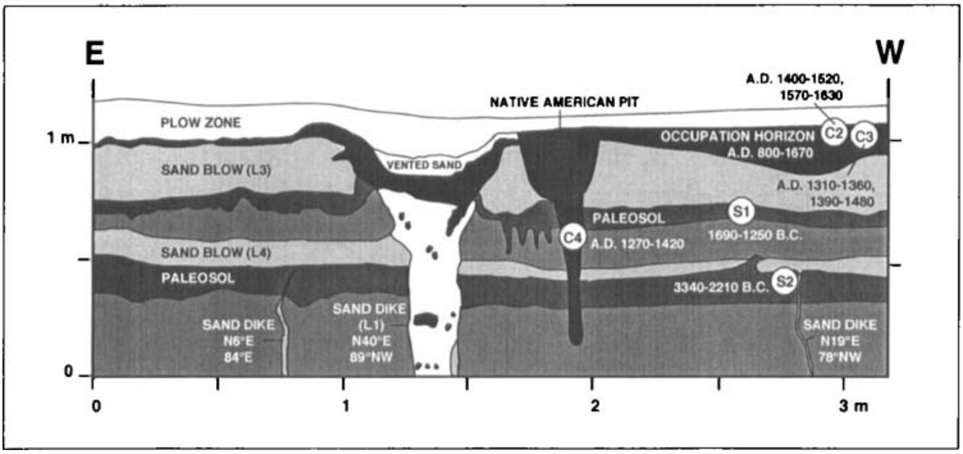

Figure 6. (D) Log of south wall of trench 3. Radiocarbon dating of charcoal collected from the root cast (C4) which grew through the Native American pit that cross-cuts, and therefore postdates, the vented sand indicates that the sand dike (L1) formed prior to A.D. 1420. This is supported by dating of charcoal collected from the upper part of the occupation horizon (C2 and C3). Dating of the two paleosols buried by sand blows indicates that the oldest sand blow (L4) formed between 3340 and 1690 B.C.

clast of the disrupted occupation horizon within the dike yielded a calibrated age of A.D. 470–480 and 520–780, indicating that the dike (L1) formed after A.D. 470. In trench 3, the cultural pit that cross-cuts the disturbed occupation horizon as well as the overlying vented sand was penetrated by a root (Figure 6D). Radiocarbon dating of charcoal (C4) from the root cast indicates that the dike formed prior to A.D. 1420 (Table III). This is supported by dating of charcoal samples collected from the upper part of the occupation horizon west of the dike (C2 and C3 in Figure 6D), which yielded calibrated ages of A.D. 1400–1520 and 1570–1630 and A.D. 1310–1360 and 1570–1630. This part of

Table IV. Floral content of flotation samples taken from 3MS557.

Material Class	Preliquefaction		Postliquefaction	
	(Count)	(%)	(Count)	(%)
Fuel/construction	96	25	27	41
Nuts	89	24	22	34
Seeds	34	9	5	8
Maize	155	41	11	17
Coal	5	1	0	0
Indeterminate	1	P[a]	0	0
Total	380	100	65	100

[a] P = present in the residual fraction only.

the occupation horizon probably accumulated following the liquefaction event. Results of radiocarbon dating of the dike are consistent in both trenches. These results combined with those of the archaeological and botanical analyses indicate that the sand dike formed between A.D. 1000 and 1420.

Three paleo-sand blows that predate the formation of the sand dike and represent three other prehistoric liquefaction events (L2, L3, and L4) were observed at this site. These sand blows are associated with small (<3 cm wide) feeder dikes, and they directly overlie paleosols. In addition, the sand blows occur adjacent to the large dike, suggesting that it may have been utilized during the earlier liquefaction events. The youngest of the three sand blows (L2) was present in trenches 1 and 2, the oldest sand blow (L4) was observed in trench 3, and the intermediate-age sand blow (L3) occurred in all three trenches. In trench 2, radiocarbon dating of the paleosols buried by the upper and lower sand blows yielded calibrated ages of 800–360 and 290–230 B.C. and 1430–1010 B.C., respectively (Figure 6C). In trench 1, the calibrated age of a paleosol overlain by the lower of two discontinuous sand blows (observed in north wall but not south wall) is 1430–910 B.C. (Figure 6B). The paleosol overlain by the upper sand blow was not dated but is probably similar in age to the paleosol overlain by the upper sand blow in trench 2. In trench 3, radiocarbon dating of the paleosols buried by the upper and lower sand blows yielded calibrated ages of 1690–1250 B.C. and 3340–2210 B.C., respectively (Figure 6D).

The age of the youngest sand blow (L2; the upper sand blow in trenches 1 and 2) is constrained by the clast of the disturbed occupation horizon within the dike and the paleosol buried by the sand blow (Figure 6C). Therefore, this sand blow formed between 800 B.C. and A.D. 780. The ages of the intermediate and oldest sand blows are constrained by the overlying and underlying paleosols. Therefore, the intermediate sand blow formed between 1430 and 800 B.C. (L3; Figures 6C and 6D) and the oldest sand blow (L4; Figure 6D) formed between 3340 and 1430 B.C. The sand blows are probably closer in age to the paleosols they bury than to the disturbed occupation horizon and overlying paleosols used to constrain their minimum ages. The three sand blows and the large sand dike indicate that four different prehistoric earthquakes induced liquefaction in the area since 3340 B.C. Similarly, Tuttle and Schweig (1995) found evidence for four liquefaction events since 4040 B.C. at a site about 8 km to the north.

Site 3MS560

3MS560 is located near the margin of the older paleochannel of the Mississippi River and within the backswamp. Here the surface is underlain by sandy silt overbank deposit (Figure 3). The lower part of the overbank deposit is slightly coarser and is probably derived from the adjacent older paleochannel. The upper 0.4 m of the deposit contains slightly less sand and is probably derived from the more distant younger paleochannel.

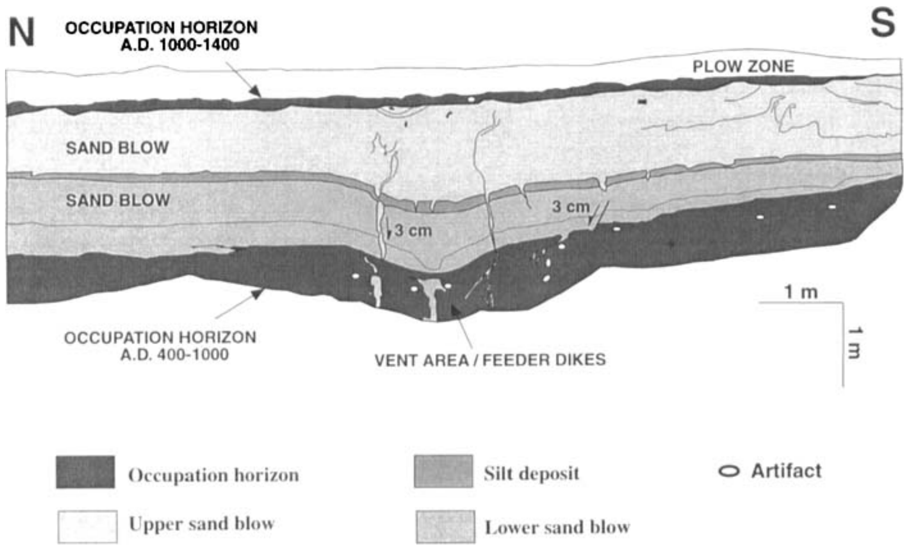

Figure 7. Log of a portion of the eastern trench wall at site 3MS560. Analysis of ceramic and lithic artifacts within the occupation horizons above and below the sand blows indicates that the sand blows formed between A.D. 800 and 1400. Deposition and bioturbation of the silt deposit between the sand blows indicates that the sand blows formed during different earthquakes.

At 3MS560, a trench about 40 m long and 1.7 m deep revealed overbank sediment and an associated occupation horizon buried by two sand-blow deposits that were overlain by another occupation horizon (Figure 7). The surficial occupation horizon was developed in the upper sand blow. Cultural pits extended downward into the sand blow from the overlying occupation horizon. The upper and lower sand blows were up to 0.8 and 0.6 m thick, respectively. The lower sand blow was composed of two fining upward sequences and ranged from medium sand to very fine sandy, silt. The upper sand blow was predominately a fine sand, which exhibited single-grained to weak, very fine, angular blocky soil structure. The feeder dike of the upper sand blow (observed in the western trench wall and not shown on Figure 7) was at least 0.5 m wide.

A 10-cm-thick silt deposit stratigraphically separated the two sand blows. This deposit was thickest over the vent of the underlying sand blow, extended beyond the limits of the sand blow, and pinched out over the lower occupation horizon which dips toward the vent. These relations suggest that the silt deposit is the result of fines settling out of a pond of water that formed in a subsided area associated with the sand blow. In the NMSZ, subsidence is often associated with sand blows and has been attributed to the removal of subsurface material during the venting of sand-bearing water (Tuttle and Barstow, 1996). The silt deposit and the upper few, silty centimeters of the underlying sand blow exhibited few, very fine pores and roots as well as moderate, very fine, subangu-

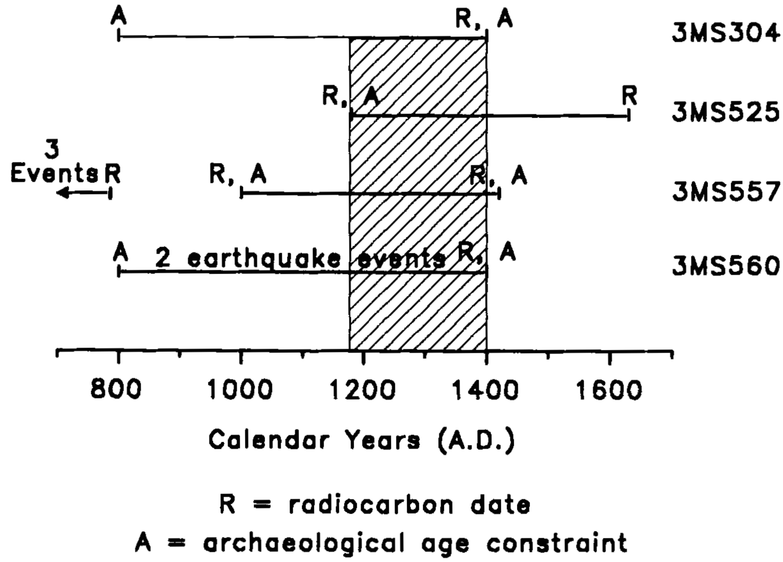

Figure 8. Age ranges for liquefaction features at the four sites examined in this article. The hachured area shows the intersection in the ages of the features.

lar to angular blocky soil structure, respectively. Also, the contact between the silt deposit and lower sand blow was bioturbated. Deposition of silt between the two sand blows, formation of roots and pores, and bioturbation of the basal contact of the silt indicate that the two sand blows formed during different earthquakes.

Ten control columns (post holes) were excavated up to 2 m deep. The material from the columns was screened. Six of the control columns were located adjacent to the sand blows and four were excavated through the sand blows. One of the cultural pits and a 0.5 × 2 m test unit were excavated in 10-cm levels. Eight hundred and twenty-nine artifacts were recovered from the two occupation horizons above and below the sand blows (Table II). Slightly less than 50% of the ceramics collected below the sand blows were shell-tempered. In contrast, more than 75% of the ceramics collected above the sand blows were shell-tempered.

The ceramic assemblages of the two occupation horizons suggest that these sand blows formed after the transition to the shell-tempered technology of the Early Mississippian culture which began circa A.D. 800 (Table I). Although no potsherds diagnostic of either Early or Middle Mississippian cultures were retrieved from either occupation horizon, the difference in the distribution of the ceramic percentages above and below the sand blows suggests that the two occupations occurred during different cultural periods. A Madison arrow point found above the sand blows indicates that the post-earthquake occupation occurred during the Middle Mississippian cultural period, or prior to A.D. 1400 (Table I). Charcoal from tree roots grown into one of the cultural pits that intruded the upper sand blow yielded a calibrated age of A.D. 1460–1955. This result is consistent with the estimated minimum age of the sand blows based on human artifacts retrieved from the upper occupation horizon.

The ages of the two sand blows are constrained between A.D. 800 and 1400 by radiocarbon dating and analysis of artifact assemblages of the two occupation horizons. Determining the time interval between the two events responsible for the formation of the two sand blows is problematic. The archaeology of the upper and lower occupation horizons would allow, but does not require, a maximum of 600 yr between events. If the parent material of the two sand blows was the same, their soil characteristics would suggest that they formed decades to centuries apart. In this case, however, the upper part of the lower sand blow, as well as the silt deposit above, are finer-grained than the upper sand blow. Soil structure develops more quickly in fine-grained material. Thus, it is unlikely that the lower sand blow is centuries older than the upper sand blow. It is possible that the lower sand blow is decades older than the upper sand blow, but more likely that the lower sand blow is only a few months older. In the latter case, the two sand blows may have resulted from the same earthquake sequence. If so, this would be reminiscent of the 1811–1812 earthquake sequence, during which three very large to great earthquakes occurred in a 3-month period.

PALEOSEISMOLOGY RECORD FOR NORTHEASTERN ARKANSAS

At the four sites described in this article, earthquake-induced liquefaction features occur in association with archaeological features. At site 3MS304, a sand blow-crater formed between A.D. 800 and 1400, probably closer to A.D. 1400 than A.D. 800; at 3MS525, a sand blow was deposited between A.D. 1180 and 1630; at 3MS557, a sand dike formed between A.D. 1000 and 1420; and at 3MS560, two sand blows were deposited between A.D. 800 and 1400 as the result of two significant events. One could interpret these liquefaction features as evidence for five earthquake sequences. However, until the age and size distributions of liquefaction features are better defined across the region, it seems more prudent to use the simpler interpretation that similar-age features formed as a result of the same earthquake sequence. In addition, it seems reasonable, given the large size of the liquefaction features, that they formed as a result of two very large earthquakes rather than five smaller events.

The intersection of the age ranges of the liquefaction features at the four sites is A.D. 1180–1400. Therefore, A.D. 1300 ± 100 yr is a reasonable estimate of the timing of the earthquake sequence and reflects the uncertainty of the estimate. This finding is similar to that of a paleoseismic study of deformation associated with the Reelfoot fault, where Kelson et al. (1996) found evidence for a significant event between A.D. 1260 and 1650.

Given the limited information at this time, it is difficult to estimate the magnitude of the prehistoric earthquakes. Because they induced liquefaction, however, these events were at least of M 6.4, which Obermeier (1989) estimates to be the liquefaction threshold in the moderately susceptible sediments of the region. These prehistoric liquefaction features are similar in size (e.g., 0.5- to 1-m thick sand blows and 0.5- to 1-m wide sand dikes) to features that formed during the 1811 and 1812 earthquake sequence, which suggests that the prehistoric events may have been very large to great earthquakes. If similar-age features across the region formed as a result of the same event, then a great earthquake is almost certainly required. A regional search for prehistoric liquefaction features is now underway. The age and size distribution of liquefaction features should help to resolve the timing, magnitude, and source areas of prehistoric earthquakes in the NMSZ.

SIGNIFICANCE OF GEOLOGY FOR THE PALEOSEISMOLOGICAL RECORD

Meander-belt deposits within the study area are late- to mid-Holocene in age and thus may have recorded seismic events during the past 6–7 ka. The younger Mississippi River paleochannel is estimated to have been active slightly more than 5.3 ka ago, based on radiocarbon dating of a paleosol at site 3MS557 and correlation with dated overbank deposits in the Pemiscot Bayou Core at the northwest edge of the study area (PBC on Figure 3; Guccione, 1987). Older liquefaction features are likely to be buried by natural levee deposits of the Pemiscot Bayou and the Mississippi River, and slackwater deposits filling the Pemiscot Bayou channel.

In the study area, the surficial deposits associated with the two oldest landforms (the Mississippi River paleochannels) are 1–6 ka old based on radiocarbon dating (Table I) and archaeological evidence. Although no archaeological sites older than Middle Woodland (200 B.C.–A.D. 400) were located during surveys of the southern portion of this study area (Lafferty et al., 1994b), Late Archaic (3000–500 B.C.) artifacts have been reported in the general vicinity. The presence of Middle and Late Woodland archaeological sites at the surface and immediately beneath sand-blow deposits indicates that overbank deposition had ceased or appreciably slowed in the central and southern portion of the study area by 200 B.C.

Sediments along Pemiscot Bayou are the youngest deposits in the area. Using relative age relations, the bayou is younger than both paleochannels of the Mississippi River. Based on radiocarbon dating, the Bayou is thought to have initially formed 3–4 ka ago (Guccione, unpubl. data; Saucier, 1994). A thick (~1 m) Early Mississippian (A.D. 800 and 1000) occupation horizon that accumulated at 3MS304, close to Pemiscot Bayou, suggests that it was still active by A.D. 800 (Figure 3). In support of this interpretation, the sand dike at 3MS557, which was emplaced between A.D. 1000 and 1420 (Table III), is thought to have formed as a result of lateral spreading towards Pemiscot Bayou.

The age and distribution of sediments are important factors in determining where liquefaction features of different ages can be found. In the study area, only sand blows that formed in the past 2.2 ka are likely to be present at the surface; older liquefaction features appear to be buried (e.g., buried sand blows at 3MS557). These older features are likely to be discovered in excavations of younger features and in drainage ditches and river cutbanks. The oldest liquefaction event documented in the study area, a buried sand blow at site 3MS557, formed between 3340 and 1690 B.C. The mid- to late-Holocene age of sediment will preclude determination of paleoseismological events prior to 6–7 ka B.P. in the study area. However, ongoing studies in the region that include older deposits are likely to extend the chronology of prehistoric earthquakes farther back in time.

IMPLICATIONS FOR ARCHAEOLOGY

The co-occurrence of archaeological sites and earthquake-induced liquefaction features may not be coincidental. As a result of liquefaction, water under high hydraulic pressure will flow upward, carrying sand and utilizing zones of weakness in the soil. For example, pre-existing crab burrows and soil fractures have been shown to serve as conduits to the surface (Audemard and de Santis, 1991). In the NMSZ, the Native Americans dug pits at their habitation sites for many purposes, including cooking and storage of food, disposal of trash, construction of pit houses, and burial of their dead. In the region, pits commonly 1–2 m deep and shaft graves up to 5 m deep are reported. Prehistorically dug pits may have provided yet another pathway for the escape of sand-bearing water to the surface. In addition, the prevalence of occupation horizons on top of sand blows suggest that they were favorable sites for occupation, especially in poorly drained settings.

The deposition of sand as the result of liquefaction has provided a unique opportunity for the preservation of archaeological sites. There are more than 10,000 known archaeological sites in the region (Arkansas and Missouri Archeological Surveys, unpublished site files). However, the upper 20–40 cm of virtually all of these sites have been disturbed by plowing. Archaeological sites fortuitously have been buried by sand blows. In 2 years, we have located 10 Woodland and Mississippian sites buried and protected by sand blows in the Blytheville, Arkansas area (Lafferty et al., 1994b). Two of these sites may date to the Middle Woodland period, which is rarely represented in this region. Many additional buried sites are likely to be present in the study area and in other portions of the NMSZ.

SUMMARY AND CONCLUSIONS

Native American occupation horizons and features, containing artifacts as well as botanical and charred material, have helped to identify and date prehistoric liquefaction features within the study area. These liquefaction features are interpreted as evidence for two significant earthquakes, probably during the same earthquake sequence, that occurred about A.D. 1300 ± 100 yr, and three earlier events between 3340 B.C. and A.D. 780.

The magnitude of the earthquakes that generated the paleoliquefaction features are difficult to determine at this time. Given that they induced liquefaction, the prehistoric earthquakes were at least of M 6.4 (Obermeier, 1989). The prehistoric liquefaction features that formed about A.D. 1300 ± 100 yr are similar in size to features that formed during the 1811 and 1812 earthquakes. This suggests that these prehistoric events may have been similar in size to the very large to great New Madrid earthquakes of 1811–1812 (Tuttle and Schweig, 1995).

Intermittent sedimentation at various localities forms land surfaces of different ages on the Mississippi River flood plain. Liquefaction features that can be used to develop an earthquake chronology are younger than their host sediment. Thus, the completeness of the earthquake record will vary across the region depending on the age of the surficial deposits. The landforms, deposits, and soils near Blytheville, Arkansas, located in the southern part of the NMSZ, are mid- to late-Holocene in age and occur in the transition zone between Mississippi River meanderbelt and backswamp deposits. Radiocarbon dating of a core in the study area and of buried paleosols at 3MS557 suggests that proximal overbank deposition of the Mississippi River paleochannels began about 6–7 ka ago. The oldest prehistoric artifacts found in the area suggest that the land surface is no older than 2.2–5 ka. The oldest sand blows in the area are buried and formed as much as 5.3 ka ago. Thus, the earthquake chronology for the study area may be limited to 6–7 ka. The record is likely to be longer in those areas where near surface sediments are older. Therefore, it is important to study prehistoric liquefaction features in other areas of the NMSZ characterized by older deposits.

Additional liquefaction features related to these and other seismic events are likely to be preserved in the region. With additional field work, including the careful and detailed study of liquefaction features and associated Native American occupation horizons, we will be able to develop an earthquake chronology for at least the past 6–7 ka. Documentation and dating of liquefaction features across the region will help to better define the number, timing, and magnitude of prehistoric earthquakes in the NMSZ.

This research was funded by the U.S. Geological Survey under Contract USGS-1434-93-G2352 as well as by the U.S. Air Force, Earth Technology Corporation, and the Memphis District of the Army Corps of Engineers through a subcontract with Mid-Continental Research Associates. Additional funding was provided by the Nuclear Regulatory Commission under Contract NRC-04-95-073. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies of the U.S. Government. We thank John Craven and Janine Savage for field assistance, Ed Hajic, Randy Jibson, and Dan Morse for helpful reviews of the original manuscript, and Marty Rabenhorst and Moye Rutledge for discussions concerning soil development.

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Received November 17, 1995
Accepted for publication June 3, 1996