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Dating of Liquefaction Features in the New Madrid Seismic Zone and Implications for Earthquake Hazard

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Prepared for
U.S. Nuclear Regulatory Commission

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ABSTRACT

Results of paleoseismological investigations of earthquake-induced liquefaction features at nine sites indicate that significant earthquakes struck the New Madrid region in A.D. 900 ± 100 yr and A.D. 1530 ± 130 yr. This finding is consistent with other paleoseismological studies in the region. The A.D. 900 event was probably similar to the 1811-1812 earthquake sequence. Less is known about the A.D. 1530 event, but it is likely to have been very large as well. These data suggest that very large earthquakes occurred in the New Madrid seismic zone every 200 to 900 yr during the past 1200 yr. In addition, liquefaction features along the Black and Current Rivers suggest an earthquake source, possibly associated with the Commerce geophysical lineament, in the western Lowlands. Much work remains to refine estimates of the timing, magnitude, and source areas of prehistoric earthquakes in the New Madrid region and to determine if the recent high rate of seismicity reflects the long-term hazard.

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EXECUTIVE SUMMARY

This project and related paleoseismological studies indicate that very large prehistoric earthquakes occurred in the New Madrid seismic zone in A.D. 900 ± 100 yr and A.D. 1530 ± 130 yr, suggesting a high rate of seismicity for at least the past 1200 yr. Additional study is underway to test these results and to determine if the recent high rate of seismicity reflects the long-term rate by further defining the age and size distribution of liquefaction features. We are able to resolve the ages of liquefaction features resulting from closely timed earthquakes by employing archeological, botanical, and paleoseismological techniques in combination with radiocarbon dating. Precise dating of liquefaction features is necessary to correlate similar-age features across the region and accurately estimate the source areas, magnitudes, and recurrence intervals of prehistoric earthquakes.

A repeat of a very large New Madrid earthquake would devastate the region encompassing the New Madrid seismic zone, severely impact the major urban areas of St. Louis, Memphis, and Little Rock, and could have an economic impact on the nation as a whole. Buildings, bridges, lifelines, and other critical facilities in the New Madrid region may be at considerable risk. This ongoing project increases our understanding of the earthquake potential of the New Madrid seismic zone and contributes to the regulatory mission of the Nuclear Regulatory Commission by reducing the uncertainty associated with seismic hazard in the central and eastern United States. In addition, our findings will have a direct impact on the Recommended Provisions for the Development of Seismic Regulations for New Buildings.

ACKNOWLEDGMENTS

This research was sponsored by the Nuclear Regulatory Commission, 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. This research would not have been possible without the cooperation of the property owners who permitted us to work on their land despite disruption to farming and their peace of mind. This report is dedicated to those property owners including Leara Barnard, Laverne Dodd and family (especially Mary Bess Taylor, and Ben and Dale Dodd), Mr. and Mrs. Tommie German, Jerry Daniels, Charles Richard Haynes, Glenn Hillhouse, Ben Young, Carl Johnson, and Sandra Tucker. Special thanks to Marion Haynes and Carl Johnson who provided information pertaining to the location of sand blows and archeological sites in the vicinity of Blytheville, Arkansas, and Steele, Missouri, respectively. Jim Vaughn graciously shared information pertaining to the locations of liquefaction features in the Western Lowlands, including features along the Current River. The achievements of this project were accomplished with the hard work and talents of Noel Barstow, Robert Cande, Jonathan Collier, Kathleen Dyer-Williams, Marion Haynes, Pedro Alfaro Garcia, Luis Pena, Mary Evelyn Star, and Ernst Zurflueh. Arch Johnston, Neal Lopinot, John Sims, Roy Van Arsdale, and Ann Wylie reviewed this report and made valuable suggestions for its improvement.

1. INTRODUCTION

1. 1. The New Madrid Seismic Zone

In 1811 and 1812, three very large to great earthquakes of moment magnitude **M** ~ 7.8 to 8.1 (Johnston, 1996) were generated by the New Madrid seismic zone (NMSZ) in the central United States. These three earthquakes are inferred to be among the largest known historic intraplate earthquakes anywhere (Johnston and Kanter, 1990) and caused widespread and severe liquefaction in the northern portion of the Mississippi embayment in southeastern Missouri, northeastern Arkansas, northwestern Tennessee, southeastern Kentucky, and southern Illinois (Fuller, 1912; Obermeier, 1989; Fig. 1.1). Should a repeat of a very large or great New Madrid earthquake occur today, the major urban areas of St. Louis, Memphis, and Little Rock would be severely impacted, as would numerous important agricultural and port communities. Buildings, bridges, lifelines, and other critical facilities may be at considerable risk.

During paleoseismological studies in the NMSZ, we discovered prehistoric liquefaction features in the northern, central, and southern parts of the region (Figs. 1.1 and 1.2; Li et al., 1998; Tuttle and Schweig, 1995, 1998; Tuttle et al., 1996). Native American occupation horizons or middens containing artifacts, as well as soil characteristics indicative of pre-1811 ages, are key factors in recognizing prehistoric liquefaction features. Dating of prehistoric liquefaction features indicates that at least three prehistoric earthquakes induced liquefaction during the eighteen-hundred years preceding the devastating New Madrid, Missouri, earthquakes of 1811 and 1812. Furthermore, the large size and broad distribution of similar-age features suggests that two of the prehistoric earthquakes were very large in magnitude. Our findings suggest a recurrence interval of 200 to 900 years for large to great earthquakes during the past 2 ka, similar to the results of paleoseismological studies by Russ (1982), Saucier (1991), and Kelson et al. (1996). These recurrence rates are also consistent with several seismological and geodetic studies of the region (e.g., Johnston and Nava, 1985; Liu et al., 1992; Schweig et al., 1996). There is now a large and growing body of evidence that large, and possibly great, earthquakes occurred fairly frequently in the region during the late Holocene.

This project involves detailed investigations of liquefaction features at sites with good opportunity for dating prehistoric earthquakes in the New Madrid region. The goals of this project are (1) toprovide well-constrained age estimates of additional liquefaction features in order to establish an earthquake chronology and occurrence rates of large magnitude earthquakes, and (2) to correlate paleoliquefaction features across the region for the purpose of estimating source areas and magnitudes of prehistoric earthquakes.

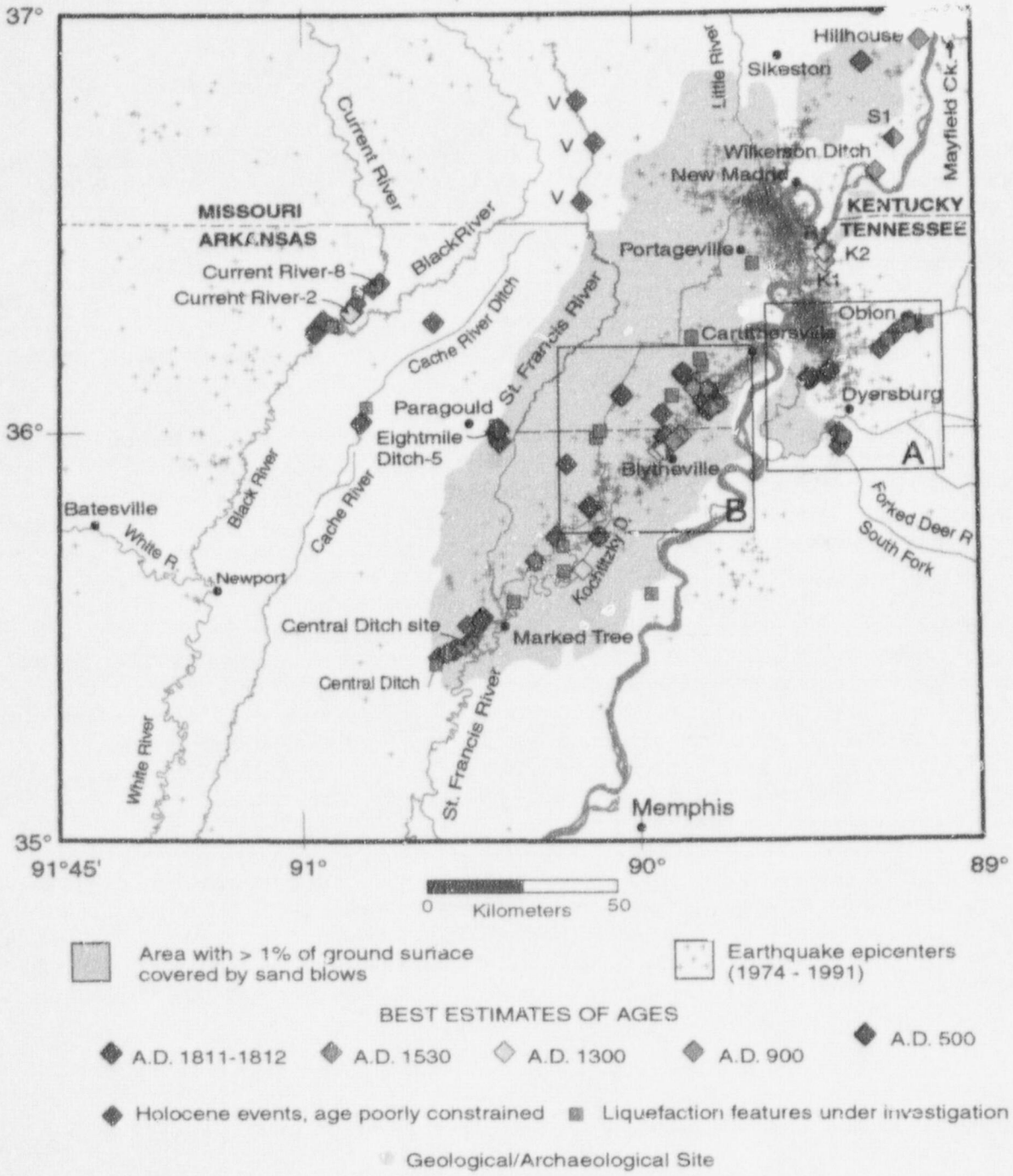


Figure 1.1. Map of New Madrid seismic zone. Boxes A and B are enlarged in Fig. 1.2. Liquefaction features whose ages have been estimated shown by colored diamonds. Age data of liquefaction features attributed to A.D. 1300 event are being reevaluated to determine if features could have formed instead in A.D. 900 or A.D. 1530. Central Ditch, Current River-8 and-2, Eightmile Mile Ditch-5, Hillhouse sites described in this report. Sites of other paleoseismological studies: R1, Russ (1982); S1, Saucier (1991); K1 and K2, Kelson et al. (1996); V, Vaughn (1994). Area of sand blow deposits from Obermeier (1989).

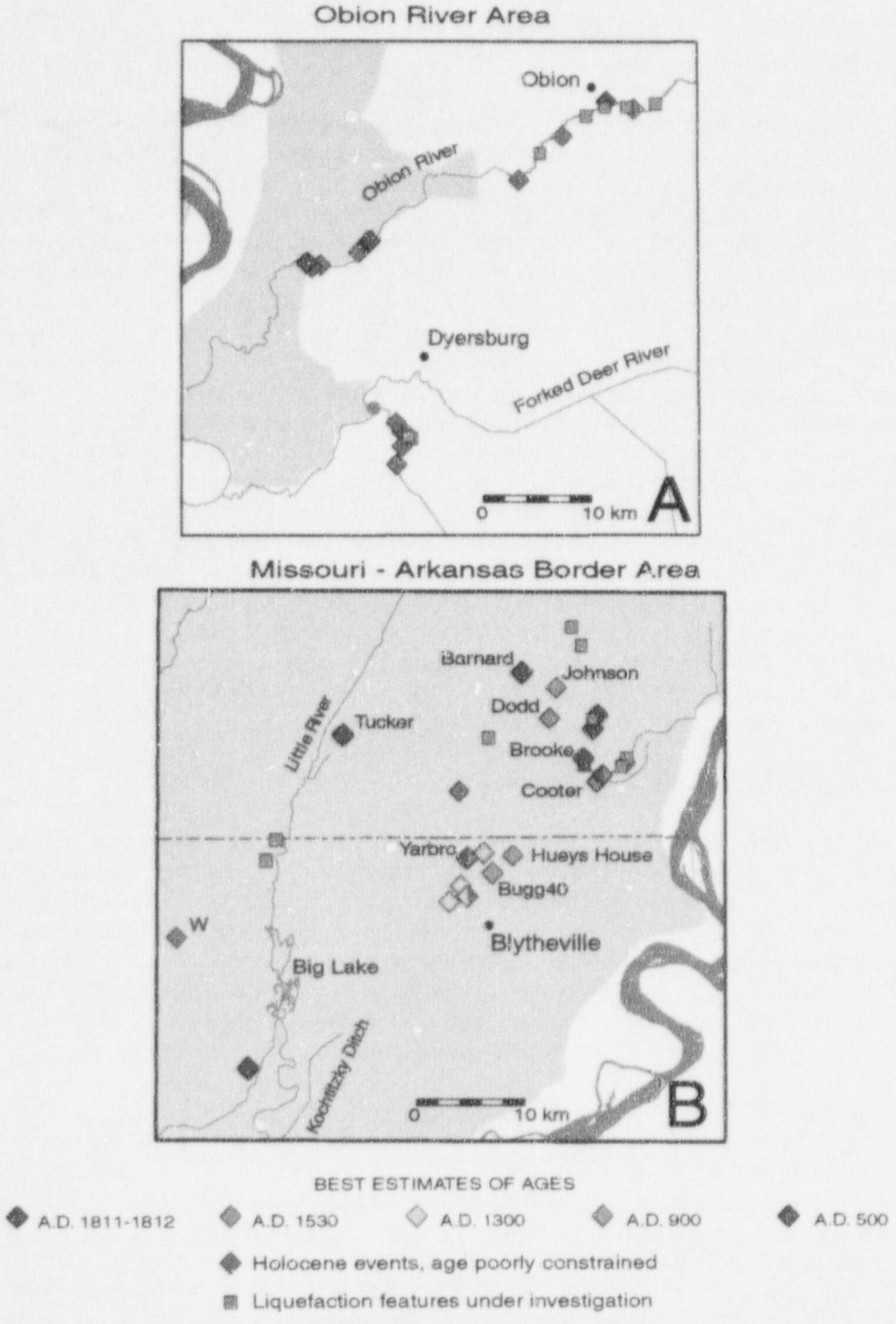


Figure 1.2. Blow-ups of areas A and B outlined on Fig. 1.1. Area A shows locations of liquefaction features found during reconnaissance on Obion and Forked Deer Rivers in Tennessee. Area B shows locations of liquefaction sites in Missouri-Arkansas border area. Barnard, Brooke, Bugg 40, Dodd, Hueys House, Johnson, and Tucker sites described in this report. Study site of Wesnousky and Johnson (1996) denoted by W. Age estimate of liquefaction features attributed to A.D. 1300 event currently under review.

1.2. Selection of Study Sites

During reconnaissance sponsored by the U.S. Geological Survey, National Earthquake Hazard Reduction Program, we found liquefaction features at hundreds of sites across the New Madrid region and documented features at more than 110 sites that appeared favorable for paleoseismological investigation (Figs. 1.1 and 1.2). From these, we selected 11 sites for further study as part of this project. At four of the sites, sand blows appeared young enough to have formed during the 1811-1812 earthquake sequence (see Figs. 1.1 and 1.2; Barnard, Brooke, Eightmile Ditch-5, and Tucker sites). We excavated sand blows at these four sites to determine calibration criteria for prehistoric liquefaction features. We found suitable material for radiocarbon dating at the Brooke and Eightmile Ditch-5 sites, and therefore, carried out detailed investigations of sand blows at these two sites. Liquefaction features at the seven other sites (Bugg 40, Central Ditch, Current River-8, Dodd, Hillhouse, Hueys House, and Johnson) appeared to be prehistoric in age based on soil characteristics or stratigraphic relations. The Current River site, located about 80 km west of the trend of the NMSZ, was chosen for study because it contains evidence of multiple liquefaction events and occurs in an area where little is known about earthquake-induced liquefaction (Fig. 1.1). The other six sites were chosen for their promise in dating prehistoric earthquakes due to the presence of archeological horizons and features. At one site (Hillhouse), a large sand dike and related graben disrupts a Native American occupation horizon and is overlain by a subsequent occupation horizon. At the other five archeological sites, sand blows overlie, and therefore apparently buried, Native American horizons. At three of these sites (Central Ditch, Dodd, and Hueys House), sand blows are overlain by Native American horizons and features, indicating occupation subsequent to the liquefaction event.

1.3. Archeological Periods and Artifacts

For over a century, archeological investigations have been carried out in northeast Arkansas, and southeastern Missouri. During the 19th century, the Smithsonian Institution conducted major excavations in some of the largest mound groups of the region (Thomas, 1894). This work demonstrated that the American Indians were the principal architects of these monumental structures, a topic of major debate during the previous century (Kennedy, 1994). In 1903, Holmes first defined pottery of the Mississippian tradition and presented detailed technological and artistic description of what are now the recognized major forms (Table 1.1). Pottery of the Woodland tradition was not noticed by Holmes in this analysis of Mississippi Valley ceramics.

During the first two decades of the twentieth century, C. B. Moore (1910, 1911) made several excursions into the region. He excavated and described pottery from many of the major sites within the region. Beginning in the 1940s, modern archeological investigations commenced in the central Mississippi Valley with the Lower Mississippi Valley Survey. This joint effort between Harvard University, the University of Michigan, and the Louisiana Geological Survey resulted in the first description of the major pottery types and wares in the region (Phillips, 1970). This work formed the basis for later 20th century investigations. Most important for the present discussion is Williams' (1954) definition of Barnes ceramics and Phillips' (1970) massive study of the ceramics in the Yazoo Basin. A major impetus of the Lower Mississippi Valley Survey was to establish a chronology of ceramic types. The survey was largely successful in this, particularly in the Yazoo Basin, where much of the effort was based on the principles of stratigraphy (Phillips et al., 1951; Phillips, 1970).

In the 1950s, radiocarbon dating became important in the development of the archeological chronology of the Lower Mississippi Valley (Crane and Griffin, 1958). Since then, over 200 radiocarbon analyses have been run on archeological materials in the central Mississippi Valley between Cairo, Illinois, and the Arkansas River. These dates provide the temporal basis for the archeological sequence of the past two millennia. Only a few dates from this area along with dates from other regions form the temporal basis for the archeological sequence prior to 2000 yr B.P. The archeological chronology presented in Table 1.1 and Figure 1.3 is modified specifically for northeastern Arkansas, and southeastern Missouri, from Morse and Morse (1983, 1996), who synthesized much of the radiocarbon data for the region. In Figure 1.3, we have indicated where there are questions regarding the temporal and geographical ranges of artifacts.

The earliest ceramics in the region are baked clay objects (Table 1.1). These have been dated to 5000 yr B.P. in adjacent areas and their use may have continued into the Mississippian period. About 2000 to 3000 yr B.P., two different Woodland ceramic traditions developed. East of Blytheville, Arkansas (Fig. 1.1), was the grog-tempered (usually ground up pot sherds or fired clay) Baytown tradition, while to the west was the sand-tempered Barnes tradition. Different tribes may have developed these two ceramic traditions (Morse and Morse, 1983). The geographical areas where the two traditions developed seem to have changed over time. In addition, ceramic assemblages suggest an overlap of traditions in the study area. Radiocarbon dating for this study indicates that the Woodland ceramic technology was employed until about A.D. 1000, two hundred to three hundred years later than previously thought. Mississippian shell-tempered pottery appears during the 9th century and becomes dominant after A.D. 1000 (Fig. 1.3). A number of marker types (formally defined artifact types) have been well dated, but their total temporal and geographical ranges are not well defined. For example, Varney Red Filmed pottery has been dated to A.D. 900 to 1000 at the Zebree site just west of Big Lake, Arkansas, but there are few data on how late this technique of waterproofing ceramics was used. Radiocarbon dates from the Hoecake site in southeast Missouri and from the eastern edge of the Ozarks suggest that Varney Red Filmed pottery begins as early as A.D. 600. Thus, we have the main sequence of ceramic types identified; however, the details of the temporal and geographical ranges of types need additional work. The projectile point chronology is similar (Fig. 1.3). We know that Scallorn points are early, Madison points are medial, and Nodena points are late in the development of point technology during the Mississippian period. We are not certain, however, when these forms began or ended. On Figure 1.3, the names of major ceramic types are placed near their estimated midpoints.

Investigations of liquefaction features and the analysis of artifacts conducted for this project provide age constraints on earthquakes in the New Madrid region. In addition, this project provides the first radiocarbon dates for several types of pottery and points, including those associated with the Late Mississippian Nodena Phase, and therefore contributes to the development of the archeological chronology in the Lower Mississippi Valley. This project also raises questions concerning the effect of major earthquakes on settlement patterns of aboriginal peoples.

1.4. Methodology of Paleoseismological and Archeological Investigations

We conducted paleoseismological investigations at nine liquefaction sites in the New Madrid region. We scraped and logged cutbank exposures and trench walls, noting structural,

Table 1.1. Cultures present in the study area, their approximate ages and associated diagnostic artifacts and plant remains.

Culture	Years (B.C./A.D.)	Diagnostic Artifacts and Plant Remains
Historic	A.D. 1673[1] - present	iron, glass, glazed pottery, plastic
Late Mississippian	A.D. 1400-1673	shell-tempered pottery - Parkin Punctate, Campbell Applique, Matthews Incised, Bell Plain, and Memphis rim mode; Nodena points
Middle Mississippian	A.D.1000-1400	shell-tempered pottery - Parkin Punctate and Old Town Red (shell tempered, exterior slipped); Madison points; 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) and mixed temper wares
Late Woodland	A.D. 400-800[2]	cordmarked and plain, sand- (Barnes) and grog- (Baytown, Mulberry Creek) tempered pottery; Table Rock Stemmed points
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

[1] Dougan, 1995

[2] Morse and Morse (1983 and 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 Late Woodland. Radiocarbon dating for this project suggests that Late Woodland extends to A.D. 1000.

sedimentological, and stratigraphic characteristics of liquefaction features and photographed important features and relationships. We described characteristics of soil horizons and collected soil samples in plastic bags for laboratory analysis. We also collected samples for radiocarbon dating. We placed samples for radiocarbon dating in aluminum foil packets in plastic bags and labeled both foil packets and plastic bags with site name, sample number, sample context, and date

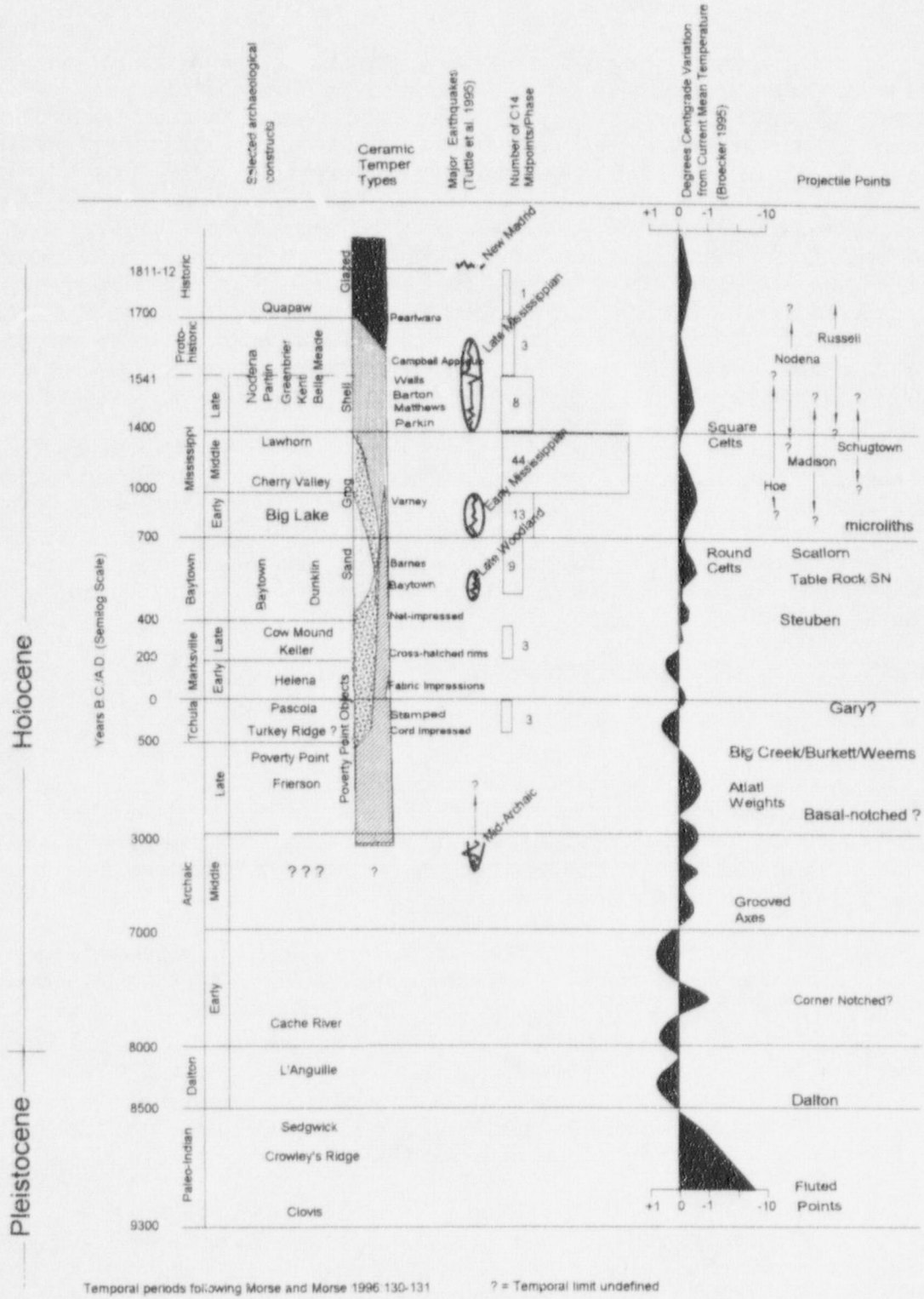


Figure 1.3 Archeological time line and major diagnostic types from northeast Arkansas/ southeast Missouri. Age range of earthquakes (cracked oval) is our current best estimates.

of collection. The stratigraphic position of samples were noted on site logs. Upon return to the University of Maryland, samples for radiocarbon dating were dried to discourage microbial activity that might contaminate the sample with young carbon. We reviewed the suite of samples collected at each site and selected samples for dating most likely to constrain the age of liquefaction features. Beta Analytic, Inc. performed radiocarbon dating on the samples.

We conducted archeological investigations at seven of the liquefaction sites (Brooke, Bugg 40, Central Ditch, Dodd, Hillhouse, Hueys House, and Johnson). At these sites, we excavated both natural and cultural deposits and collected material for flotation of archeological and plant remains. We made decisions in the field regarding the specific locations and sizes of the archeological excavations based on relationships between cultural and liquefaction features. We screened excavated material through 1/4 inch mesh and bagged recovered artifacts by provenience. In addition, we photographed and logged important relationships and levels of the excavations.

Archeological processing and analysis of samples was carried out by Mid-Continental Research Associates. Excavated material was processed by flotation to recover small artifacts and plant remains. Artifacts were cleaned, sorted, catalogued, weighed, counted, and evaluated in terms of sherd sizes and types (using standard archeological typologies), lithic types and sources, and tool types. Plant remains recovered by flotation were sent to Dr. Neal Lopinot who performed botanical analysis. Results of archeological and botanical analyses as well as radiocarbon dating are summarized in Table 1.2.

2. RESULTS OF SITE INVESTIGATIONS

2.1 Brooke Site

The Brooke site, located north-northeast of Blytheville, Arkansas (Fig. 1.2B), was surveyed by Martitia Tuttle and Marion Haynes because it is a well-known archeological site (23PM56) and sand blows are evident on aerial photographs of the area. During our survey, a large sand blow was found in association with a rich cultural horizon. Woodland and Mississippian potsherds were found on the surface of the sand blow.

Archeological investigation of this site included a surface collection, excavation of two test units (small excavations designed to gain knowledge about an archeological site), and recovery of artifacts from the profiles of two backhoe trenches. The surface collection was conducted in 14 areas or units. Each collection unit was a 4-m-diameter circle covering an area of 12.5 m^2. Figure 2.1 shows the density of artifacts recovered in the surface collection. The highest density of artifacts, more than 12 artifacts/m^2, occurs towards the southwestern portion of the site and the lowest density occurs towards the eastern portion (Table 2.1). Tests units were excavated in the area of intermediate density in the vicinity of the sand blow.

Test Unit 1 was begun as a 1 m x 0.5 m excavation and was later expanded to 1 m x 1m to make it possible to extend the excavation to 170 cm below the surface. In the excavation, the plow zone, a 25-30 cm thick loamy sand, was underlain by sand blow deposit containing lignite and only a few artifacts (Fig. 2.2). The sand blow overlies a buried A horizon of silt loam containing many artifacts that is an occupation horizon (Table 2.2). A second buried A horizon with fewer artifacts was encountered at 100 cm below the surface. An A horizon containing charcoal, bone, shell-tempered pottery, and flakes was encountered at 140 cm below the surface. Test Unit 2 was

Table 1.2. Radiocarbon ages, calibrated calendar years, and archaeologic ages associated with earthquake-induced liquefaction features in the New Madrid region. Calibrated calendar years were provided by Beta Analytic Radiocarbon Dating Laboratory (Vogel et al, 1993; Talma and Vogel, 1993; and Stuiver et al, 1993).

Site Name	Lab # Figure & Sample #	Material	Dating Method	Time Relationship to Liquefaction	Conventional Radiocarbon Age (BP)	Calibrated Age Intercept	Calibrated Age 2 sigma (95% Probability)	Age Estimate based on Ceramics and Lithics (AD)	Age Estimate based on Plant Remains (AD)	Maximum Age Range (Preferred Guess AD) for Liquefaction Events
Brooke	B-102497 F. 2.4	organic sediment	AMS	pre-liquefaction	1960 ± 40	AD 65	40 BC-AD 130	1400-1670 (Late Miss)	NA	AD 1811-1812
Brooke	B-102498 F. 2.4	charcoal	AMS	pre-liquefaction	370 ± 50	AD 1495	AD 1440-1650	1400-1670 (Late Miss)	NA	
Bugg 40	B-108883	charcoal	AMS	post-liquefaction	130 ± 4	AD 1695 AD 1725 AD 1815 AD 1920	AD 1670-1950	700-1000 (L Wood-E Miss)	NA	AD 800-1000 (900 ± 100 yr)
Bugg 40	NA[1]	potsherd	NA	pre-liquefaction	NA	NA	NA	800-1000 (Early Miss)	NA	
Central Ditch	B-108869 F. 2.11-C1	charcoal	AMS	post-liquefaction	70 ± 40	NA	AD 1690-1740 AD 1810-1930	700-1000 (Late Wood)	NA	AD 790-1000 (900 ± 100 yr)
Central Ditch	B-81308 F. 2.11-S4	organic sediment	radio-metric	post-liquefaction	940 ± 60	AD 1045 AD 1105 AD 1115	AD 1000-1240	700-1000 (Late Wood)	NA	
Central Ditch	B-81309 F. 2.11-S6	organic sediment	radio-metric	pre-liquefaction	1120 ± 60	AD 960	AD 790-1020	700-1000 (Late Wood)	NA	
Current River-8	B-110227	plant material	AMS	post-liquefacton	modern	NA	NA	NA	NA	2 earthquakes 3490 BC-AD 1812
Current River-8	B-110226 F. 2.14	plant material	AMS	pre-liquefacton	4560 ± 50	3340 BC	3490-3470 BC 3380-3090 BC	NA	NA	

Table 1.2. Continued.

Site Name	Lab # Figure & Sample #	Material	Dating Method	Time Relationship to Liquefaction	Conventional Radiocarbon Age (BP)	Calibrated Age Intercept	Calibrated Age 2 sigma (95% probability)	Age Estimate based on Ceramics and Lithics (AD)	Age Estimate based on Plant Remains (AD)	Maximum Age Range (Preferred Guess) for Liquefaction Events
Current River-2	B-110225	charcoal	radiometric	post-liquefaction	570 ± 60	AD 1405	AD 1300-1450	NA	NA	AD 1310-1450 (1380 ± 70 yr)
Current River-2	B-110223	wood	radiometric	pre-liquefaction	510 ± 60	AD 1425	AD 1310-1360 AD 1385-1480	NA	NA	
Current River-2	B-110224	charcoal	radiometric	pre-liquefaction	640 ± 90	AD 1310 AD 1365 Ad 1375	AD 1240-1440	NA	NA	
Dodd	B-102503 F. 2.19	charcoal	AMS	post-liquefaction	110 ± 50	AD 1825 AD 1835 AD 1880 AD 1915	AD 1670-1950	1400-1670 (Late Miss)	NA	AD 1400-1670 (1530 ± 130 yr)
Dodd	B-102502 F. 2.19	charcoal	AMS	pre-liquefaction	770 ± 40	AD1270	AD 1220-1300	1400-1670 (Late Miss)	NA	
Eight Mile-5	B-108867 F. 2.27	organic sediment	radiometric	post-liquefaction	4870 ± 110	3655 BC	3940-3850 BC 3830-3370 BC	NA	NA	AD 1811-1812
Eight Mile-5	B-108866 F. 2.27	plant material	AMS	pre-liquefaction	modern	NA	NA	NA	NA	
Hill-house	B-102500 F. 2.28	charcoal	AMS	post-liquefaction	1150 ± 50	AD 890	AD 780-1000	700-1000 (Late Wood)	NA	AD 790-1000 (900 ± 100 yr)
Hill-house	B-105142[2]	charcoal	radio metric	post-liquefaction	1130 ± 80	AD 910 AD 920 AD 950	AD 710-1040	700-1000 (Late Wood)	NA	
Hill-house	B-105141[2]	charcoal	AMS	post-liquefaction	1020 ± 50	AD 1020	AD 960-1070 AD 1080-1160	700-1000 (Late Wood)	NA	

Table 1.2. Continued.

Site Name	Lab # Figure & Sample #	Material	Dating Method	Time Relationship to Liquefaction	Conventional Radiocarbon Age (BP)	Calibrated Age Intercept	Calibrated Age 2 sigma (95% probability)	Age Estimate based on Ceramics and Lithics (AD)	Age Estimate based on Plant Remains (AD)	Maximum Age Range (Preferred Guess) for Liquefaction Events
Hill-house	B-102499 F. 2.28	charcoal	AMS	pre-liquefaction	1140 ± 50	AD 900	AD 790-1010	700-1000 (Late Wood)	NA	
Hill-house	B-102501 F. 2.28	organic sediment	AMS	pre-liquefaction	4880 ± 60	3660 BC	3780-3620 BC 3580-3530 BC	NA	NA	
Hueys House	B-91642 F. 2.31	charcoal-hearth	AMS	post-liquefaction	280 ± 60	AD 1650	AD 1470-1680 AD 1750-1810 AD 1940-1950	700-1000 (L Wood-E Miss)	Post-1000	AD 880-1000 (900 ± 100 yr)
Hueys House	B108939 F. 2.31	charcoal-maize	AMS	post-liquefaction	630 ± 50	AD 1310 AD 1360 AD 1390	AD 1290-1420	700-1000 (L Wood-E Miss)	Post-1000	
Hueys House	B-91641 F. 2.31	charcoal	AMS	pre-liquefaction	1090 ± 50	AD 980	AD 880-1030	700-1000 (L Wood-E Miss)	Pre-1050	
Hueys House	B-91643 F. 2.31	charcoal	AMS	pre-liquefaction	1280 ± 60	AD 720 AD 740 AD 760	AD 650-890	NA	NA	
Johnson	B-102504 F. 2.40	charcoal	AMS	post-liquefaction	220 ± 50	AD 1670	AD 1540-1550 AD 1640-1700 AD 1720-1820 AD 1855-1860 AD 1920-1950	NA	NA	AD 770-1200 (900 ± 100 yr)
Johnson	B-102505 F. 2.40	organic sediment	radiometric	pre-liquefaction	1110 ± 80	AD 970	AD 770-1040	700-1000 (L Wood-E Miss)	NA	

[1] NA means not applicable.
[2] C13/C12 value was estimated, not measured, based on material type.

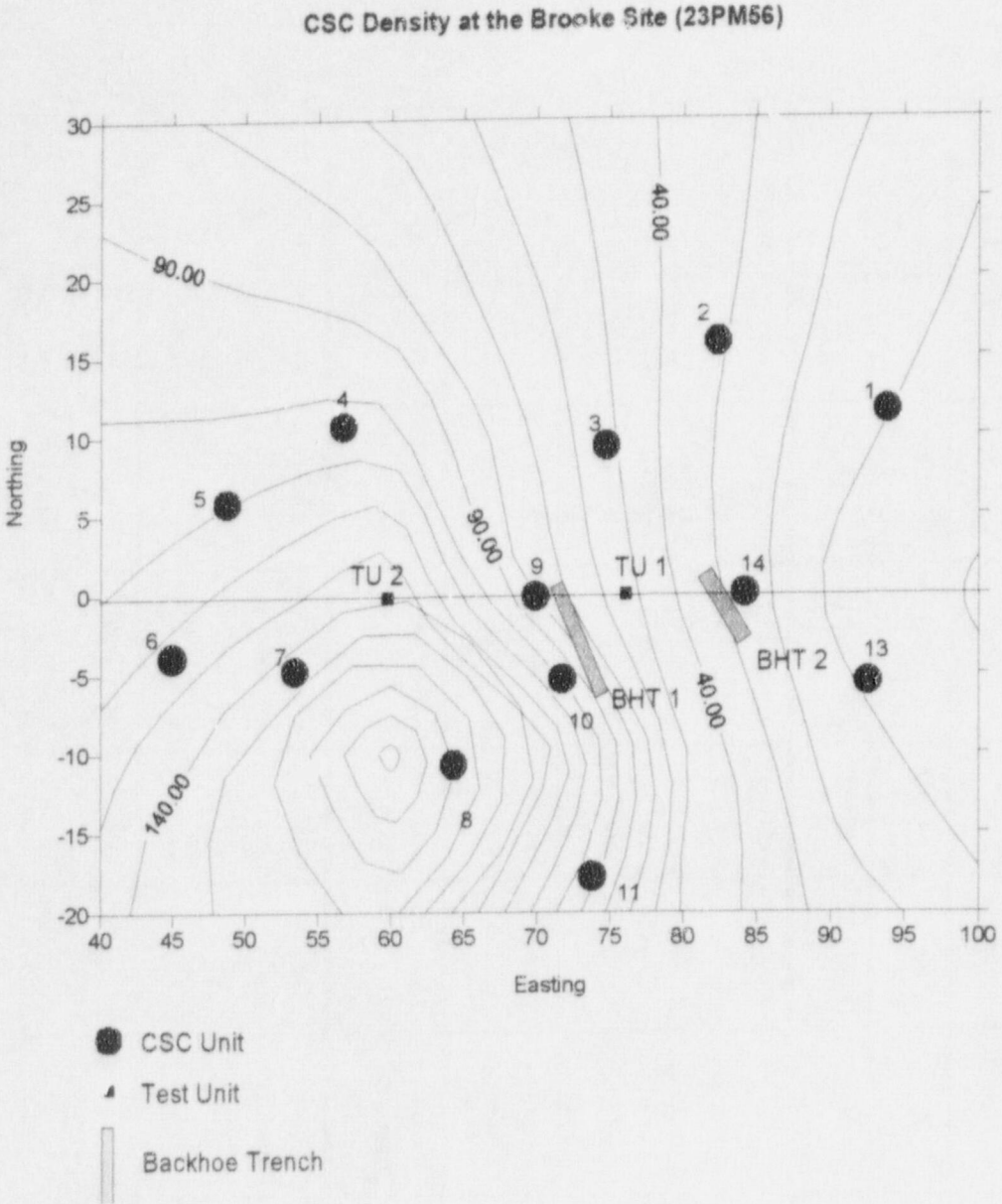


Figure 2.1. Results of controlled surface collection (CSC) of artifacts at Brooke site. CSC unit #8 produced 210 artifacts in 12.5m² (16 artifacts/m²). Contours are artifacts per collection unit. Test Unit 2 was placed in this area of high artifact density and Test Unit 1 in lower density area to the east.

Table 2.1. Location and artifacts recovered in the controlled surface collections, Brooke site.

CSC[1] Unit no.	Location Distance		Prehistoric Artifacts		Lignite	
	East[2]	North/South[3]	ct.[4]	wt.[5]	ct.	wt.
1	95	12	9	33.1	22	1.0
2	83	18.5	18	50.4	0	0
3	75	10.5N	49	338.8	1	0.1
4	61	10N	103	1318.5	0	0
5	52.5	6N	109	507.1	0	0
6	47	5S	116	180.0	0	0
7	56	6S	180	331.3	0	0
8	65.5	11.5S	210	359.7	0	0
9	70	0	78	1334.8	1	0.2
10	74.5	6.5S	85	101.9	2	1.1
11	74	17S	64	451.5	0	0
12	82	12.5S	43	320.8	5	0.5
13	95	6S	2	2.4	3	1.1
14	85	0	16	37.0	0	0
Totals			1082	5367.3	34	4

[1] controlled surface collection
[2] meters east of road
[3] meters north or south of base line, see Fig. 4
[4] count
[5] weight in grams

located in an area with a high concentration of daub (baked clay associated with Native American home sites). This test unit was excavated to 75 cm below the surface. A pot digger's hole had disturbed sediment in the southwestern part of this unit (Fig. 2.3). The northeastern two-thirds of the unit had intact deposits and intersected at least one burned floor with post molds evident in plan view and profile (Appendix A; Table A.1).

Two backhoe trenches were excavated at the site, however, the sand blow deposit was exposed only in Trench 2. As seen in the trench, the sand blow is more than 10 m across and up to 1.2 m thick (Fig. 2.4). It is composed of two, and possibly three, fining-upward sequences of medium to fine sand. Pieces of lignite are commonly associated with the layers of finer-grained sand. The feeder dike is subvertical, oriented N-S, and 7 to 10 cm wide. Medium sand and some fine sand fill the dike. A thick plow zone is present above the sand blow and no remnant of a pre-agricultural A horizon was found. The sand blow is probably young and may have formed in 1811-1812.

The sand blow was found to overlie a Native American occupation horizon. This horizon contains potsherds of the Late Mississippian period, a large quantity of daub suggestive of a burned house floor, and preserved antler and human bones. The assemblage of ceramics includes Parkin Punctate, Campbell Appliqué, and Bell Plain types (Figs. 2.5 and 2.6). Recovered Woodland-type sherds are rare and small. Several Nodena projectile points were recovered (Fig. 2.7). The

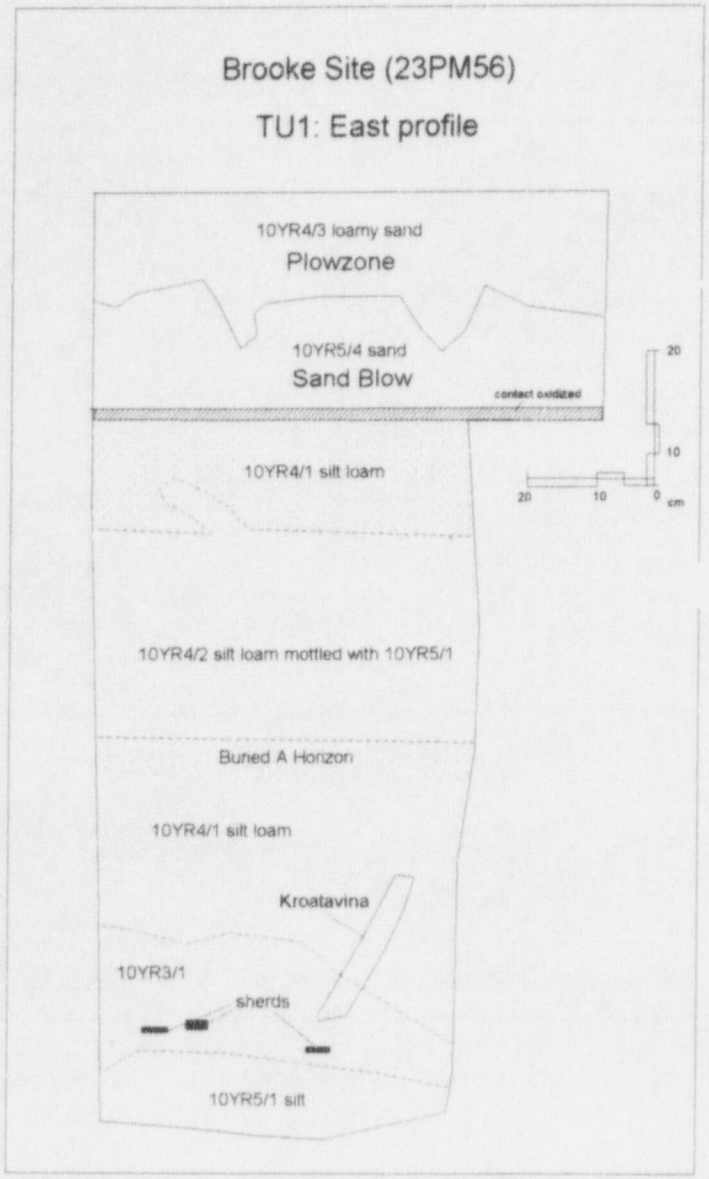


Figure 2.2 Profile of Test Unit 1 at Brooke site shows sand blow overlying the midden. Shading at bottom of the unit is mass of solid carbon.

human bones were disarticulated and did not appear to be part of a burial. However, further excavation of the site was halted due to the sensitive nature of human burials.

A soil sample collected from the A horizon immediately below the sand blow and a charcoal sample collected 45 cm below the sand blow from the B horizon have been radiocarbon dated (Fig. 2.4). The charcoal sample (B-102498) yielded a 2σ calibrated date of A.D. 1440 to 1650 (Table 1.2), which is consistent with the estimated age of the Late Mississippian artifacts recovered from this

Table 2.2. Artifacts from Test Unit 1, Brooke site by earthquake context.

Artifact Description	Post Earthquake		In Sandblow		Pre Earthquake	
	ct.[1]	wt.[2]	ct.	wt.	ct.	wt.
Chipped lithics						
core					1	18.2
flake	23	11.1	8	5.6	21	22.7
flake, polished					1	0.6
flake, decortication					3	11.4
shatter	4	8.9	1	7.2	2	7.2
Punctated shell-tempered body ceramics	2	1.6				
Notched and appliqued ceramics						
shell-tempered rim					1	10.5
Plain ceramics						
grog-tempered body	1	1.4			1	5.4
grog-tempered rim	1	0.4				
grog & shell-tempered rim					1	4.2
sand-tempered body	1	1.8				
sand-tempered rim	2	1.4			1	0.2
shell-tempered body	5	5.6	13	61.6	25	141.3
shell-tempered rim					2	16.2
Red-filmed ceramics						
shell-tempered plain body					1	0.3
Miscellaneous ceramics						
fired clay	nc[3]	130.8	nc	5.0	nc	38.1
poverty point object					1	13.4
daub	6	41.1				
sherds <¼"	18	6.0	7	1.6	39	14.2
Charcoal	13	7.8	9	6.8	1	1.7
Bone			1	8.0	2	3.5
Fire-cracked sandstone					1	1.2
Totals	76	217.9	39	95.8	101	310.3

[1] count
[2] weight
[3] no count

horizon. The overlying A horizon, is 15 to 20 cm thick, which takes about 300 to 500 yr to form in this region (Tuttle and Schweig, 1996). Given the date of the charcoal sample and the thickness of the buried A horizon, we conclude that the overlying sand blow formed during the 1811-1812 earthquake sequence. The soil sample (B-102497) yielded a 2σ calibrated date of B.C. 40 to 130 (Table 1.2) which is much older than the stratigraphically lower charcoal sample.

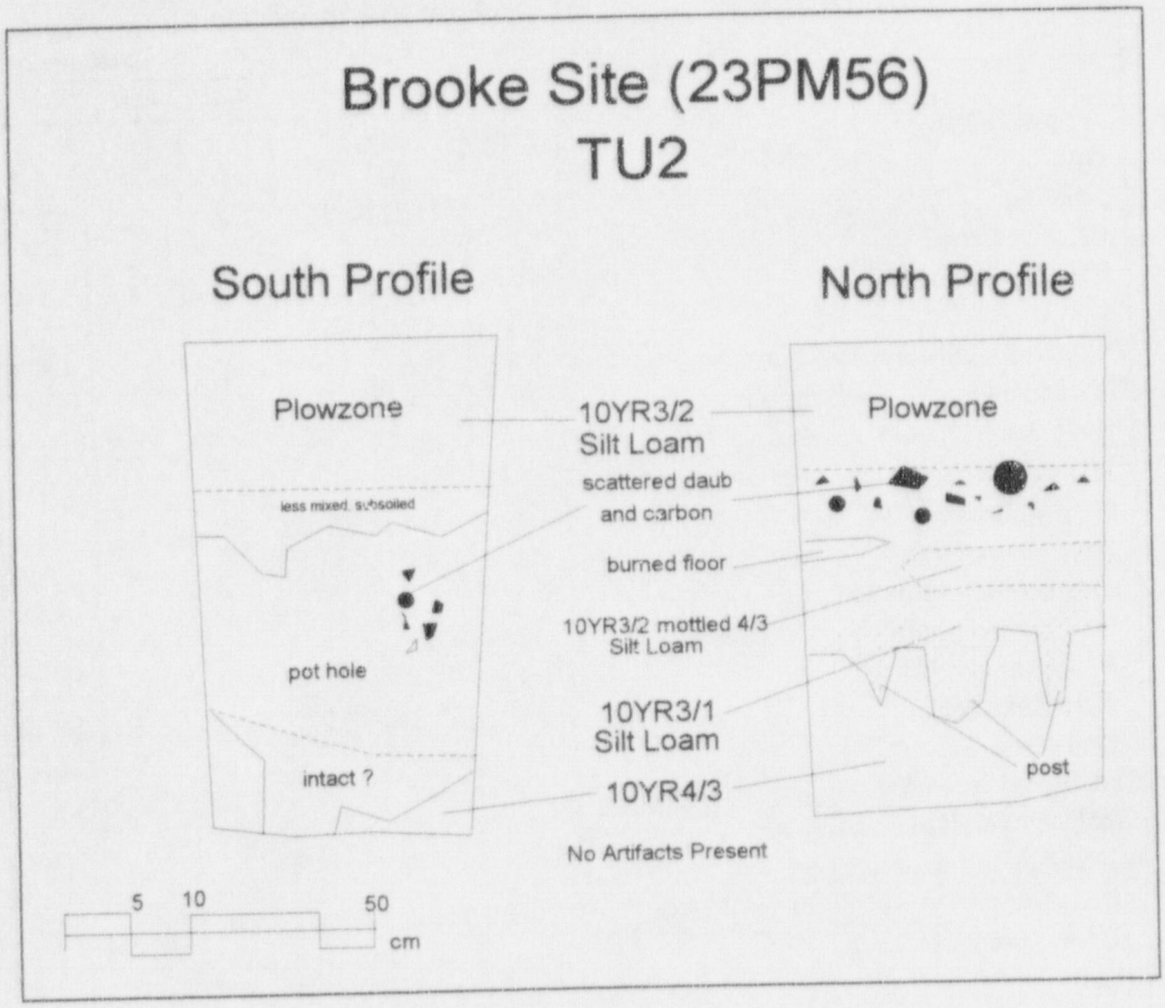


Figure 2.3. Profiles of Test Unit 2 at Brooke site shows pot hole in south profile and intact features and posts in north profile.

The date suggests that the soil sample contained some old carbon which is not surprising given that soil dates reflect the mean residence time of carbon in the sample (Trumbore, 1989).

2.2. Bugg 40 Site

The Bugg 40 site, located north of Blytheville, Arkansas (Fig. 1.2B), was brought to our attention by Mr. Marion Haynes, who is knowledgeable about archeological sites and sand blows in northeastern Arkansas. Bugg 40 is a well-known archeological site (3MS307). Haynes reported finding potsherd in association with several sand blows at this site. Sand blows at this site are visible on aerial photographs and on the ground surface. During the initial site survey conducted by Martitia Tuttle and Marion Haynes, artifacts of the Woodland and Mississippian cultural periods were found on the surface of a large sand blow about 90 m long and 30 m wide (Table 2.3). Test pits revealed a remnant A horizon (~10-cm thick) below the plow zone and in the top of the sand

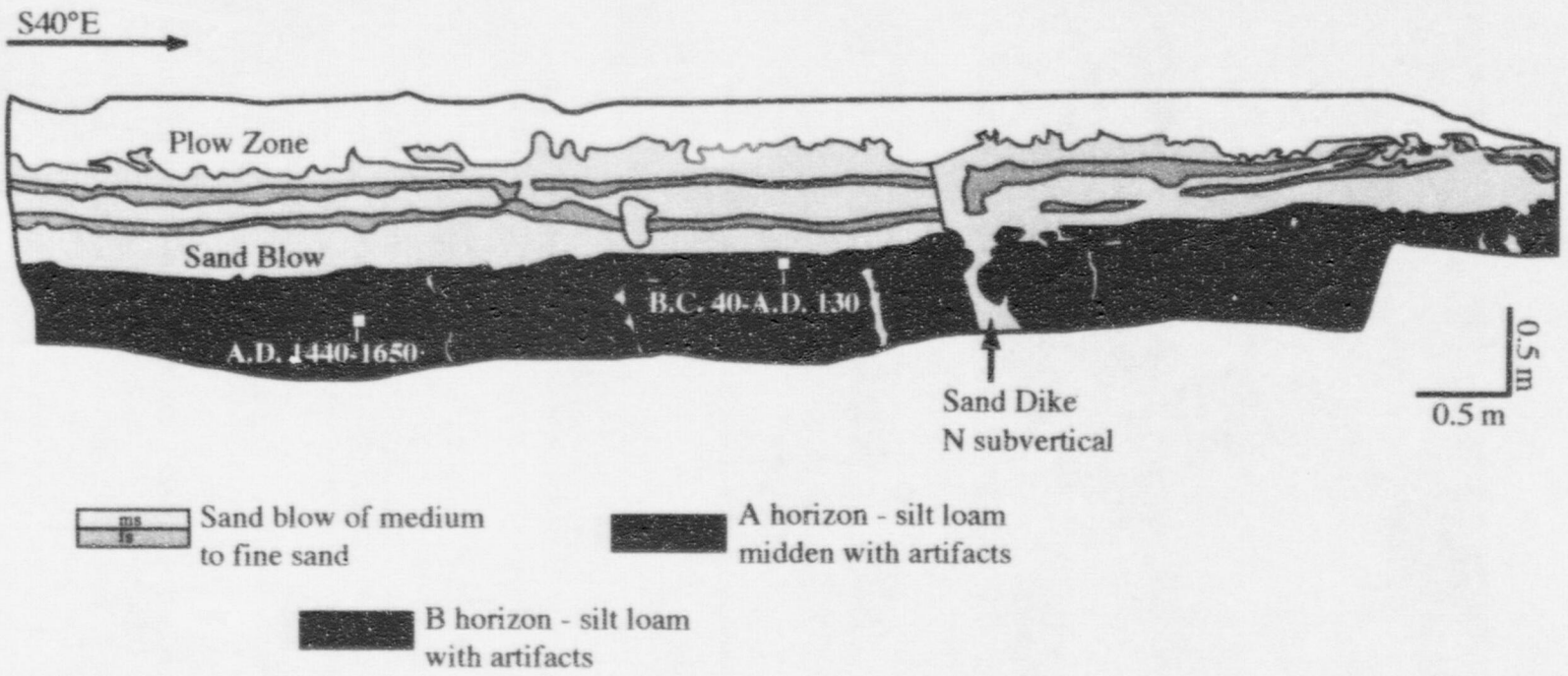


Figure 2.4. Trench log of sand blow and related sand dikes at Brooke site northeast of Blytheville, Arkansas. Sand blow buried Late Mississippian midden and probably formed during historic earthquakes of 1811-1812. Notice late phase sand dike cross-cuts early phases of sand blow deposit.

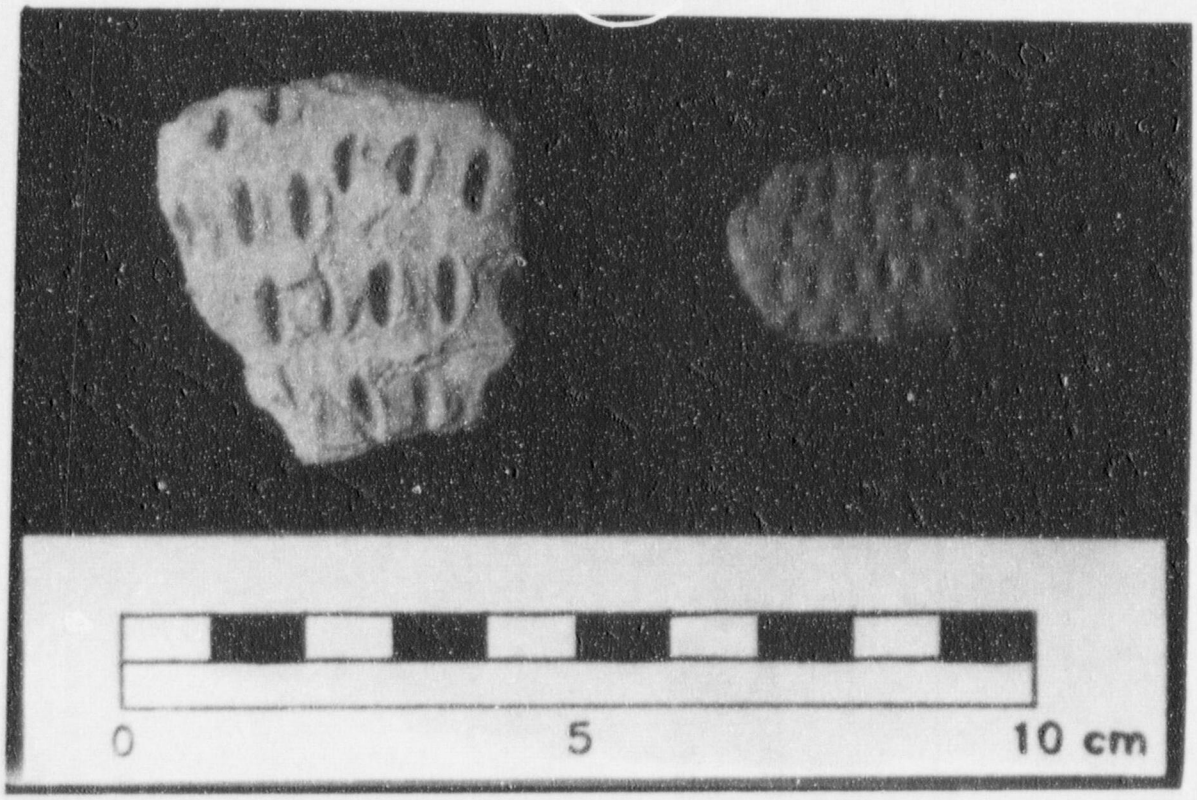


Figure 2.5. Parkin Punctate pottery from Brooke site begins in Middle Mississippian and increases in prevalence throughout Mississippian period (UM Catalogue # 8-3 and 1-32).

blow. The site was selected for subsurface investigation because the degree of soil development in the sand blow suggests that it is prehistoric in age and the presence of cultural material would help to date the sand blow. Prior to excavation, Lorraine Wolf and Jonathan Collier of Auburn University and Paul Bodin of University of Memphis conducted electrical resistivity and conductivity surveys at the site (Wolf et al., 1996). The goal of the geophysical study was to develop techniques that can both image liquefaction features and define their geologic setting. Upon excavation of the sand blow, sand dikes $\geq$ 20 cm in width were found to correspond with peaks in the resistivity profiles.

Two backhoe trenches were excavated at this site. The sand blow and six related sand dikes were exposed only in Trench 1 (Figs. 2.8 and 2.9). As exposed in the trench, a 10- to 15-cm-thick plow zone overlies a 10-cm-thick A horizon that had developed in the top of the sand blow. The sand blow deposit, ranging up to 1 m in thickness, is composed of fine-grained sand at the base overlain by two fining upward sequences of predominantly medium-grained sand. Clasts derived from the underlying soil occur within the sand blow and are concentrated above the largest feeder

Figure 2.6. Campbell Appliqué pottery from Brooke site comes in an amazing variety and represents an artistic technical peak achieved in Late Mississippian period (UM Catalogue # 6-8, 8-5, 8-5, and 9-8).

dike. The largest feeder dike is 70 cm wide and has a strike and dip of N50°E, 78°SE. The other sand dikes range from 1 to 50 cm in width and have similar orientations to the main dike. The sand blow was deposited on a Native American occupation horizon, containing abundant ceramic artifacts.

The archeological investigation at this site included a general surface collection and excavation of four 50 cm^2 test units in or adjacent to the backhoe trenches (Fig. 2.8). The few artifacts recovered above the sand blow come from the ground surface, the plow zone, and the soil developed in the top of the sand blow (Table 2.3). Diagnostic artifacts include a small sand-tempered sherd and a large grog- and shell-tempered sherd characteristic of the Late Woodland and Early Mississippian cultural periods.

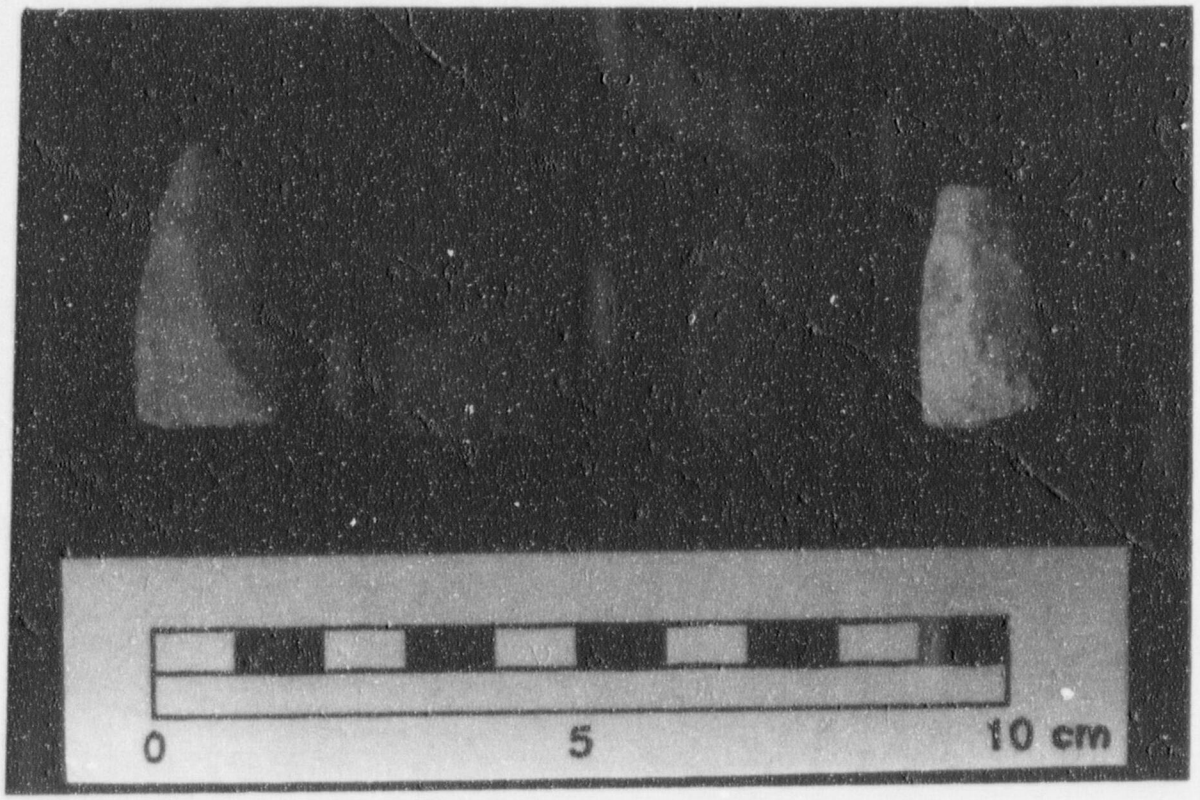


Figure 2.7. Nodena points from Brooke site of earlier Banks variety (UM Catalogue # 1-28 and 1-30).

We excavated three archeological test units in Trench 1 and a fourth test unit in Trench 2 (Appendix A; Table A.2). Test Units 1 and 2 sampled the occupation horizon immediately below the sand blow in Trench 1. The artifact assemblage from this horizon is composed of mixed tempered ceramics with Varney Red Filmed as the dominant decorated type (Fig. 1.3). This assemblage is representative of the Early Mississippian cultural period (A.D. 800 to 1000). Test Unit 3 was excavated adjacent to Trench 1 and below the sand blow deposit. Ceramics recovered from this unit reflect a gradual up-section replacement of Barnes sand-tempered pottery with pottery of mixed tempers followed by pottery of shell temper. This sequence suggests a continuous deposition of cultural material during the Late Woodland and Early Mississippian periods (Fig. 2.10; Table 2.4).

The thickness of the plow zone and remnant A horizon above the sand blow suggests that it is prehistoric in age. The A horizon was clearly more than 10 cm thick prior to cultivation. A 25-cm-thick A horizon would reflect about 560 ± 60 yr of soil development (Tuttle and Schweig, 1996). Given its archeological assemblage and abundance of artifacts in its upper 10 cm, the Native

Table 2.3. General surface artifacts from above the Trench 1 sand blow at the Bugg 40 site.

Artifact Description	ct.[1]	wt.[2]
Chipped lithics		
flake	1	1.0
flake, decortication	4	2.8
shatter	3	0.7
Plain ceramics		
grog & shell-tempered body	1	15.7
sand-tempered body (Barnes)	1	3.5
Miscellaneous ceramics		
fired clay	nc[3]	14.6
sherds <¼"	6	7.4
Totals	16	45.7

[1] count
[2] weight in grams
[3] no count

American occupation horizon probably was buried by the sand blow during the Early Mississippian period (A.D. 800-1000). To date, only one organic sample from the site has been dated. The sample was a piece of charcoal recovered by flotation from a root cast extending into the top of the sand blow. The sample (B-108883) yielded a 2σ calibrated date of A.D. 1670 to 1950 (Table 1.2). This result provides a minimum age of the sand blow. The evidence presently available suggests that the sand blow formed about A.D. 900 ± 100 yr. However, additional dating is warranted.

2.3. Central Ditch Site

This liquefaction site, located southwest of Marked Tree, Arkansas, was found by Martitia Tuttle during reconnaissance along Central Ditch several years ago (Fig. 1.1). This site occurs near the southern end of the NMSZ. During reconnaissance in 1997, we found additional historic and prehistoric sand blow deposits near this site.

At the Central Ditch site, a sand blow and related sand dikes are exposed in the cutbank (Fig. 2.11). The sand dikes are shallowly dipping, discontinuous, en echelon, and range up to 8 cm wide. The sand blow is about 20 to 25 cm thick, more than 6 m in diameter, and composed of medium-grained sand. The sand blow deposit is thickest (~30 cm) above the feeder dike that cross-cuts a Native American occupation horizon containing potsherds and lithic fragments. The dike is widest subjacent to the base of the sand blow. The sand blow was deposited directly on top of the occupation horizon. A soil, 10 to 20 cm in thickness, had formed in the top of the sand blow. The soil is a very dark grayish brown (Munsell color 10YR 3/2) sandy loam. We found artifacts including flakes, daub (baked clay), and very small potsherds within this soil. Several

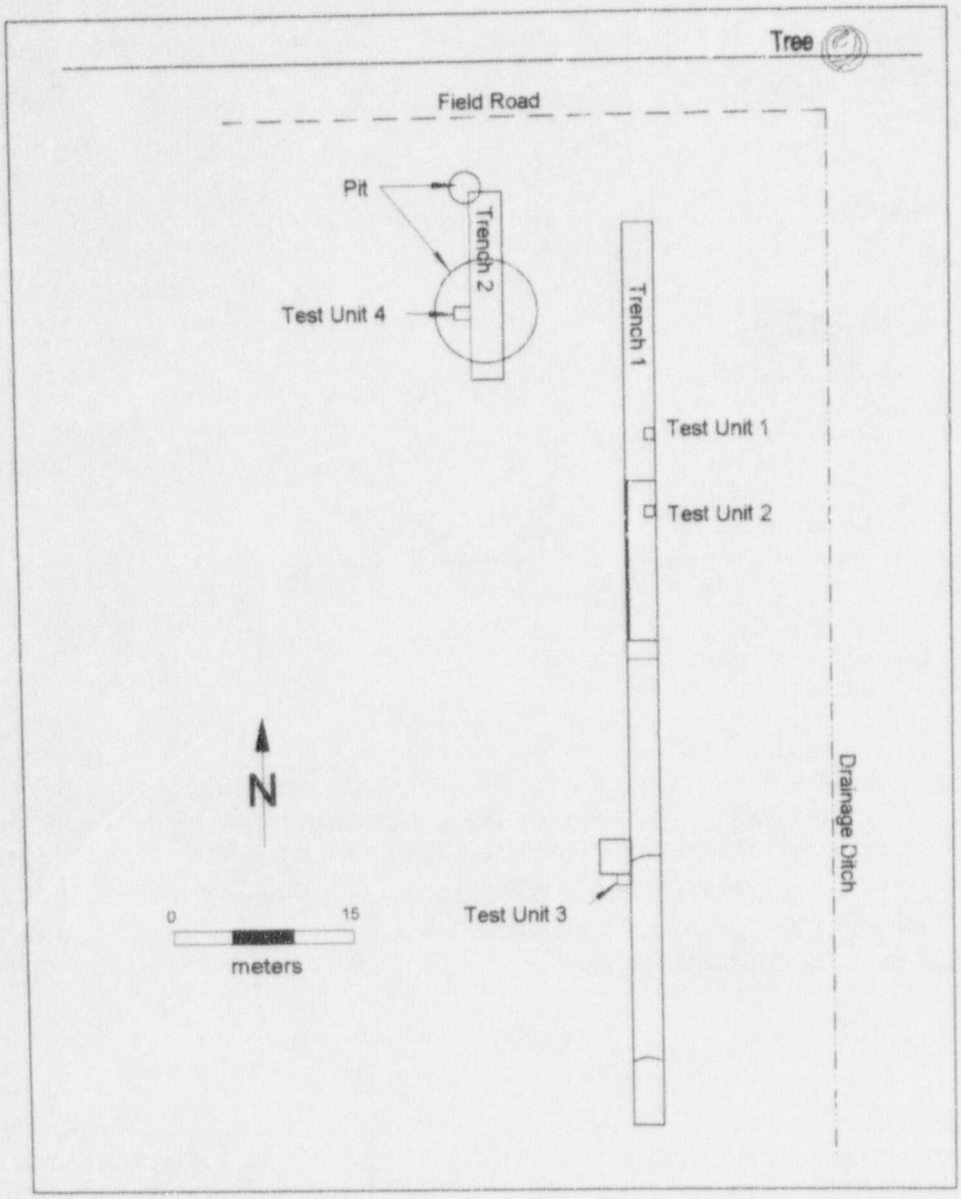


Figure 2.8. Plan of excavation units at Bugg 40 site. Test Units 1 and 2 were positioned to sample intact deposits exposed in trenches.

root casts extend from the base of the sandy loam into the sand blow and into the buried occupation horizon below. We found much charcoal associated with these root casts.

Evidence for two subsequent episodes of liquefaction may be present at the site. A sandy deposit, exhibiting characteristics typical of sand blows (clasts of underlying deposits and sedimentary structure indicative of turbulent flow), overlies the sand blow described above (Fig. 2.11). However, no feeder dike related to this sandy deposit was observed in the exposure. The upper contact of the sandy deposit had been eroded. The absence of the upper part of the deposit

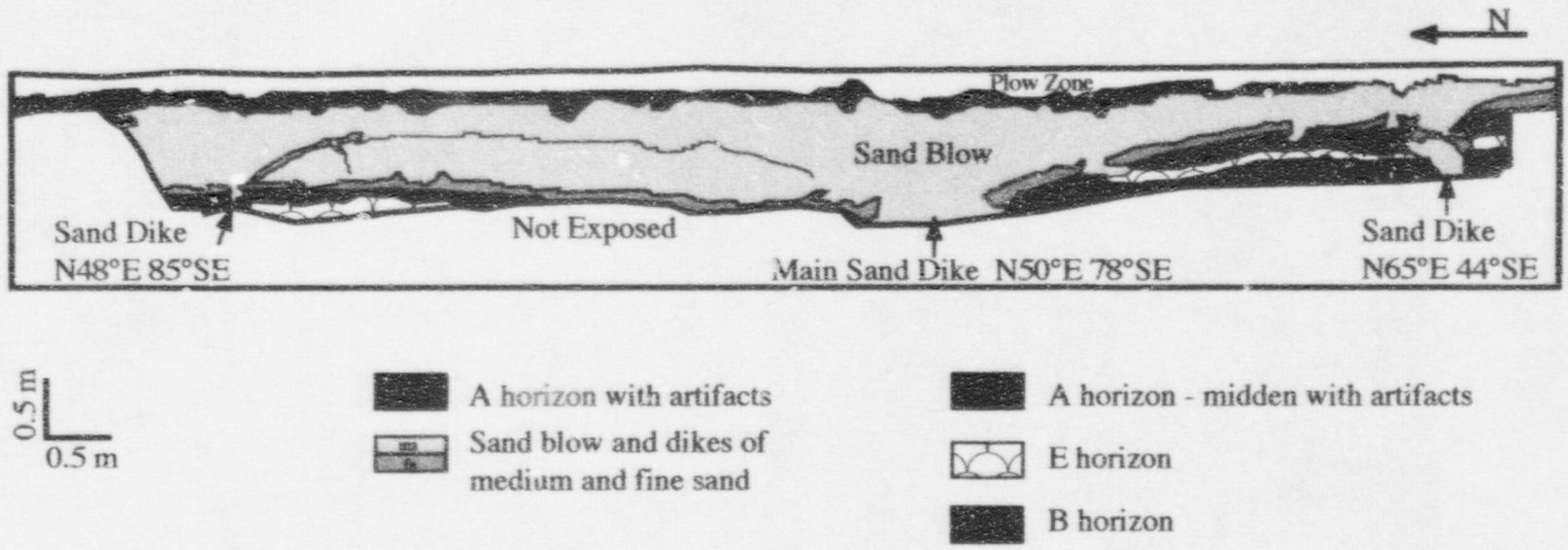


Figure 2.9. Log of Trench 1 sand blow and related feeder dikes at Bugg 40 site north of Blytheville, Arkansas. Sand blow deposits bury an Early Mississippian midden and probably formed about A.D. 900 +/- 100 yr.

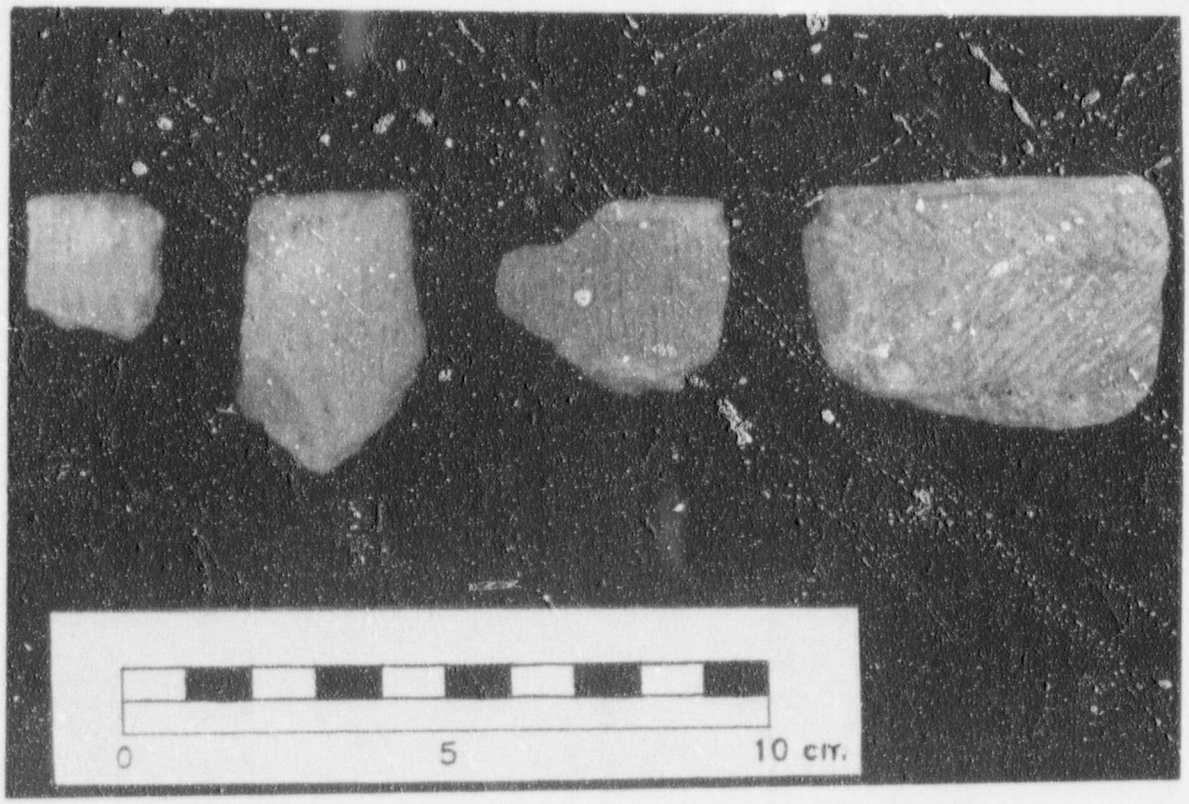


Figure 2.10. Barnes cordmarked rims from Bugg 40 site are sometimes cord notched but most often plain and rounded (AAS Catalogue #96-817: 17-3, 18-2, 19-4 and 20-4).

contributes to the difficulty in interpreting the origin of the deposit and in estimating its age. The sandy deposit is overlain by parallel, cross-bedded sands interpreted as recent fluvial deposits. In addition, it appears that the sandy deposit was intruded by a sand dike that also contains clasts of underlying deposits. However, the intruding dike was only observed within the sandy deposit. The sandy deposit may be a portion of a sand blow and the intruding dike may be related to a subsequent liquefaction event. However, the origin of both these features remains equivocal.

The archeological investigation of this site (archeological site designation 3PO588) focused on artifact assemblages collected above and below the sand blow deposit. Recovered artifacts are plotted on the log of the exposure and include potsherds and a few lithics (Fig. 2.11; Table 2.5). Artifacts recovered from the occupation horizon below the sand blow constrain the maximum age of the liquefaction features. Most of the ceramics from this horizon are sand-tempered Barnes pottery of the Late Woodland period (Fig. 2.12). Five sand-tempered sherds large enough to be typed include three Barnes Cord Marked sherds and two Barnes Plain sherds. The rest of the sherds are too small to be referred to conventional types. Seven sherds from this horizon have

Table 2.4. Pre and post earthquake artifacts from Bugg 40 site.

Artifact Description	Pre-Earthquake		Post-Earthquake		Totals	
	ct.[1]	wt.[2]	ct.	wt.	ct.	wt.
Chipped lithics						
flake	3	5.7	7	20.2	10	25.9
shatter		0	6	2.5	6	2.5
Plain ceramics						
sand-tempered body	19	37.4	2	6	21	43.4
sand & grog-tempered body	1	30.3			1	30.3
grog-tempered body	1	5.8			1	5.8
sand & ghell-tempered body	2	5.5		0	2	5.5
grog & ghell-tempered body	20	110.7	1	15.7	21	126.4
grog & shell-tempered rim	2	27.3			2	27.3
shell-tempered body	17	51.5			17	51.5
Cord-marked ceramics						
sand-tempered body	10	50.4			10	50.4
sand-tempered rim	2	8.4			2	8.4
Incised ceramics						
sand-tempered body	1	18.1			1	18.1
sand & grog-tempered body	1	8.9			1	8.9
Red-filmed ceramics						
sand & grog-tempered body	2	4.2			2	4.2
grog & Shell-tempered body	13	35.7			13	35.7
shell-tempered body	6	22.4			6	22.4
Miscellaneous ceramics						
fired clay	nc[3]	380.6	nc	27.4	nc	408
sherds <¼"	33	44.6	6	7.4	39	52
Totals	133	415.4	16	49.3	132	464.7

[1] count
[2] weight in grams
[3] no count

platy voids suggestive of leached shell-tempering typical of the Early Mississippian culture. These sherds, however, are predominately sand-tempered, with pastes otherwise indistinguishable from the rest of the assemblage. These and other sherds in the assemblage are relatively thin, a characteristic of Late Woodland assemblages. Potsherds recovered from the A horizon developed in the top of the sand blow are predominately sand-tempered indicating that they are also Woodland in age. The small size of these sherds may be due to mechanical weathering related to bioturbation and forest fires. Artifacts above and below the sand blow suggest that it formed during the Late Woodland period.

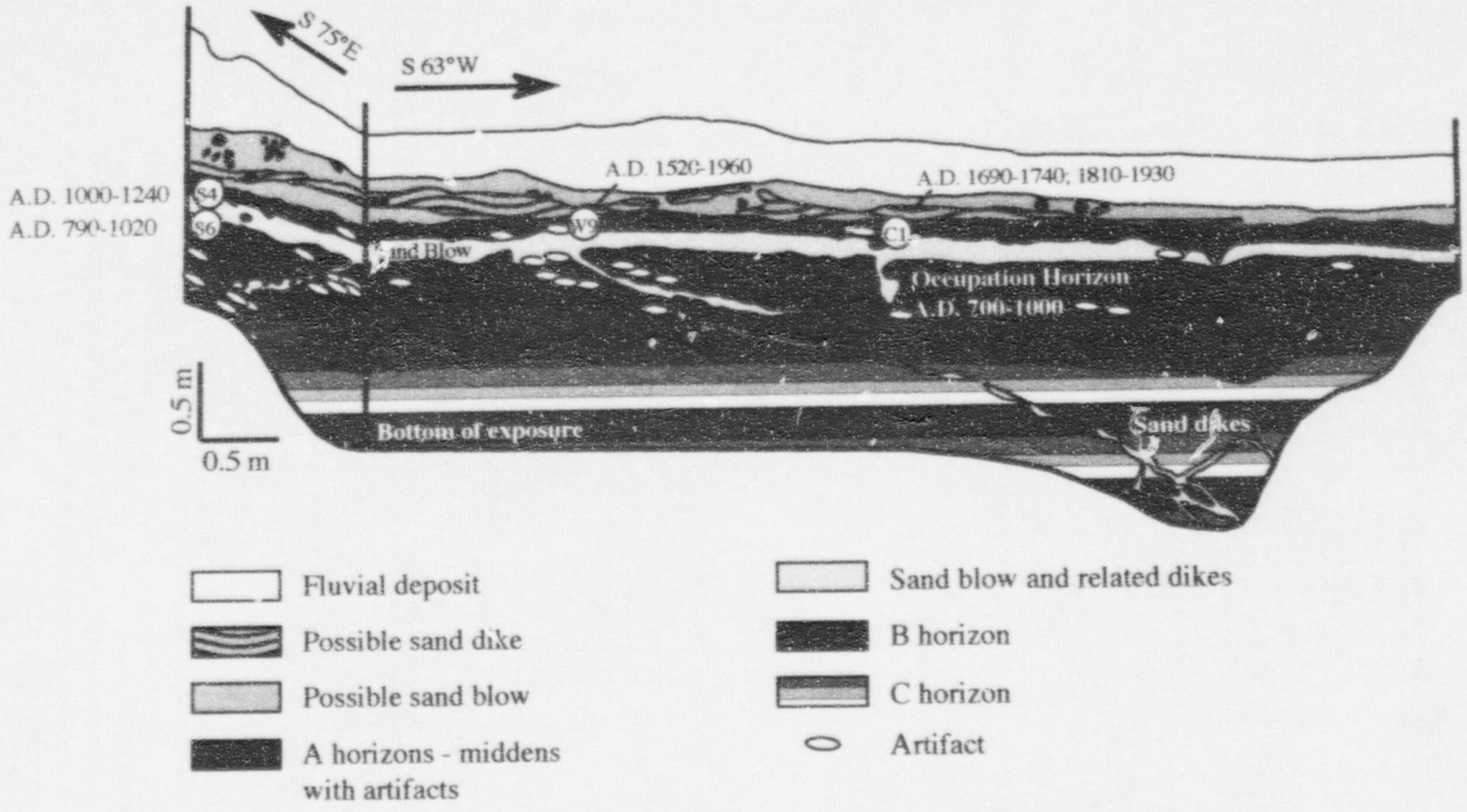


Figure 2.11. Logs of two nearly perpendicular exposures of cutbank along Central Ditch southwest of Marked Tree, Arkansas. Sand blow buried Late Woodland midden. A horizon (10 to 20 cm thick) containing Woodland potsherds developed in top of sand blow. This sand blow probably formed about A.D. 900 +/- 100 yr.

Table 2.5. Distribution of artifacts in pre and post earthquake contexts, Central Ditch site.

Artifacts Description	Pre-Earthquake Artifacts			Post-Earthquake Artifacts		
	ct.[1]	wt.[2]	average	ct.	wt.	average
Ceramics						
sand tempered	18	24.6	1.37	10	4.7	.47
Barnes plain	1	11.5	11.5			
rim, everted	1	11.6	11.6			
Barnes cord-marked	3	38.2	12.7			
sand/grog tempered	17	26.4	1.55	3	1.8	.6
sand/grog/quartzite/shell (?) tempered	7	10.7	1.53			
grog tempered	2	.2	.1			
Total Ceramics	49	123.2		13	6.5	
Lithics						
Crowley's Ridge chert						
flake	5	7.1	1.4	1	1.2	1.2
fire cracked	7	12.9	1.8			
adz	1	6.1	6.1			
quartzite, shatter	2	28.1	14.1			
Total Lithics	15	54.2		1	1.2	

[1] count
[2] weight in grams

We collected and submitted samples for radiocarbon dating from the occupation horizon buried by the sand blow and the sandy loam developed in the sand blow. A soil sample from the buried occupation horizon (B-81309) yielded a 2σ calibrated date of A.D. 790 to 1020 and a soil sample from the top of the sand blow (B-81308) yielded a 2σ calibrated date of A.D. 1000 to 1240 (Table 1.2). Radiocarbon ages of soils reflect the mean residence time of carbon in the samples and can give erroneous results if the samples have been contaminated. In this case, however, the dates are consistent with the archeological context of the samples. Charcoal sample B-108869 was collected from a root cast that extended into the top of the sand blow and yielded a 2σ calibrated date of A.D. 1670-1740 and A.D. 1810-1930 (Table 1.2). This samples provides a minimum age for the sand blow but does not help to further constrain its age. Radiocarbon dating of the soil samples indicates that the sand blow formed between A.D. 790 and 1240. Taking the archeological analysis into account, the sand blow probably formed about A.D. 900 ± 100 yr.

2.4. Current River-8

This site, as well as several others along the Current and Black Rivers northwest of Paragould, Arkansas, were found by M. Tuttle, M. Haynes, and Luis Pena during reconnaissance in 1997

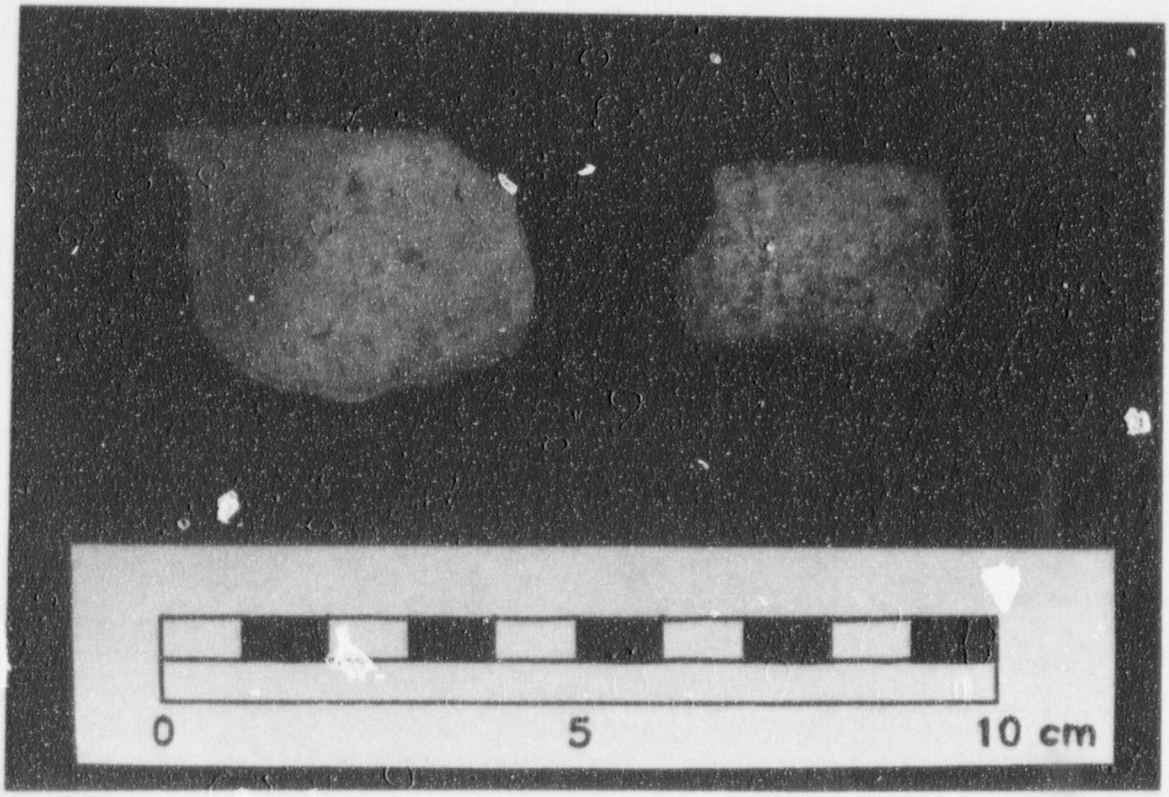
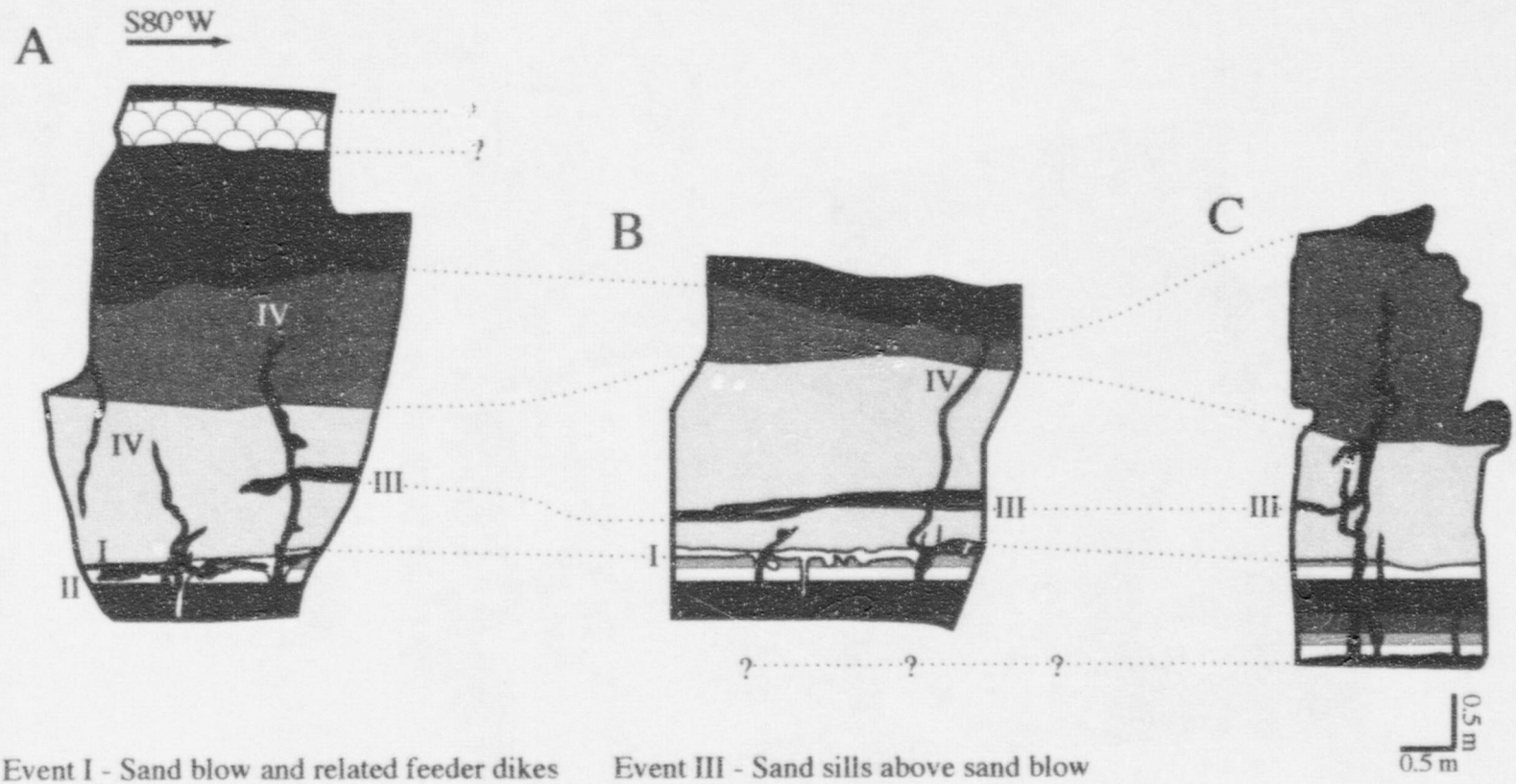


Figure 2.12. Everted Barnes Plain rim sherd from Central Ditch site. These rims are characteristic of Late Woodland. Curved rim strengthened orifice and occur on jars as large as thirty liters (AAS Catalogue # 96-818: 22-1 & 23-1).

(Fig. 1.1). The site, located near the trend of the Commerce geophysical lineament and about 80 km northwest of the New Madrid seismic zone, was selected for further study because of evidence of multiple episodes of liquefaction. Several years ago, Vaughn (1994) described liquefaction features in this area.

The site investigation was conducted in September when the river level was low. In preparation for logging, the southern cutbank of the Current River was cleared in three sections (Fig. 2.13). Laminated silt occurs near the bottom of the exposed sections (Figs. 2.14, 2.15, and 2.16). Bedding within the laminated silt is well-preserved. This deposit contains abundant organic material, some of which was collected for radiocarbon dating. The laminated silt is overlain by a 1.4- to 1.6-m-thick deposit of interbedded silt and sand. A paleosol caps this deposit and is overlain by cross-bedded, very fine sand with multiple paleosols. This deposit is in turn overlain by reddish, cemented silty sand and silt. A silt loam has formed in the silt deposit at the top of the section (Fig. 2.14).



Event I - Sand blow and related feeder dikes
Event II - Sand dikes and silts
Event III - Sand sills above sand blow
Event IV - Sand dikes that cut sills of event III

Figure 2.13. Spatial relationship of three logged sections (A, B, C) of southern cutbank at Current River-8 site. Detailed section of A shown in Fig. 2.14; B shown in Fig. 2.15; and C shown in Fig. 2.16.

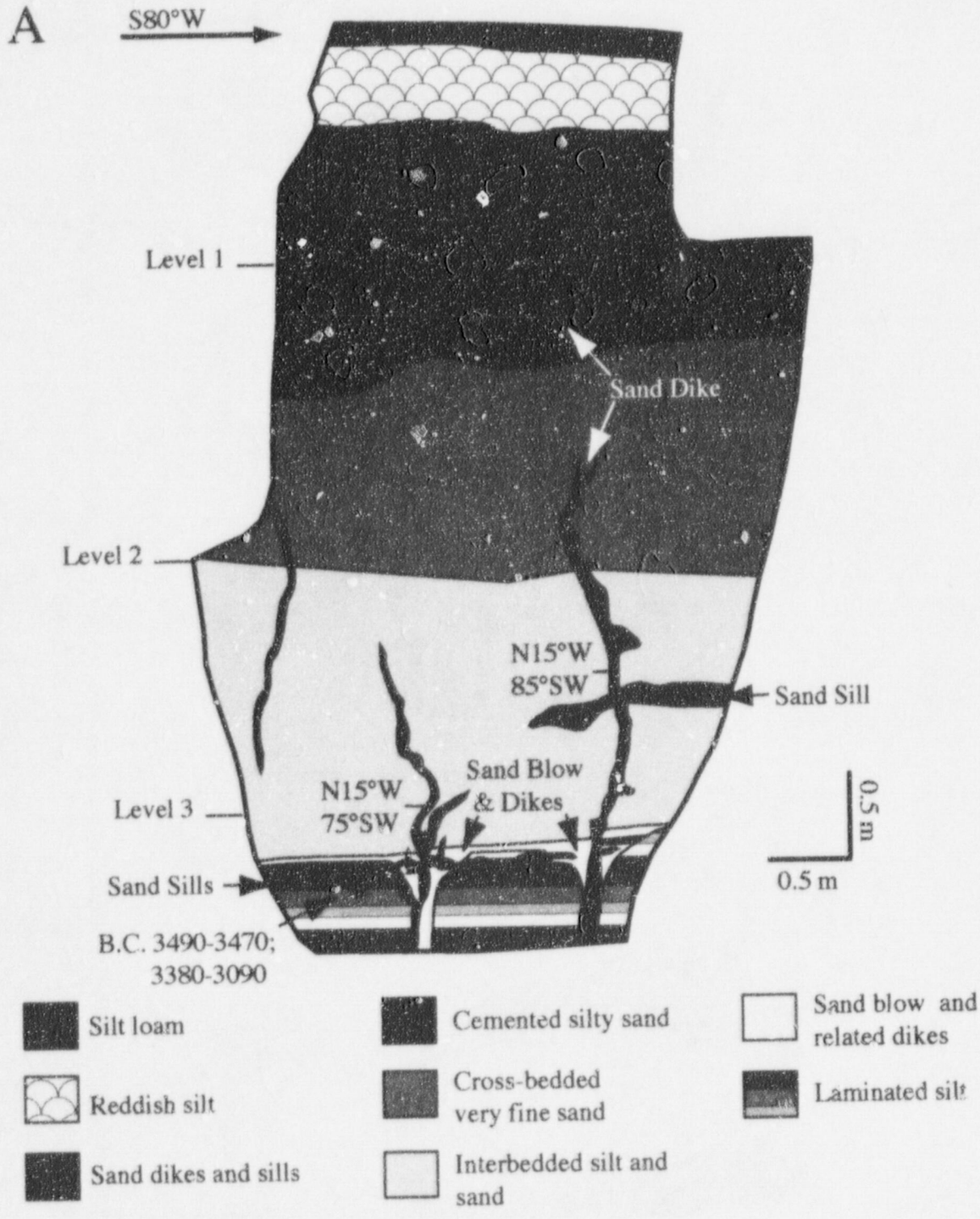


Figure 2.14. Log of section A of Current River-8 site. Sand blow, sand dikes, and sand sills in this section formed during at least two prehistoric earthquakes since 3490 B.C.

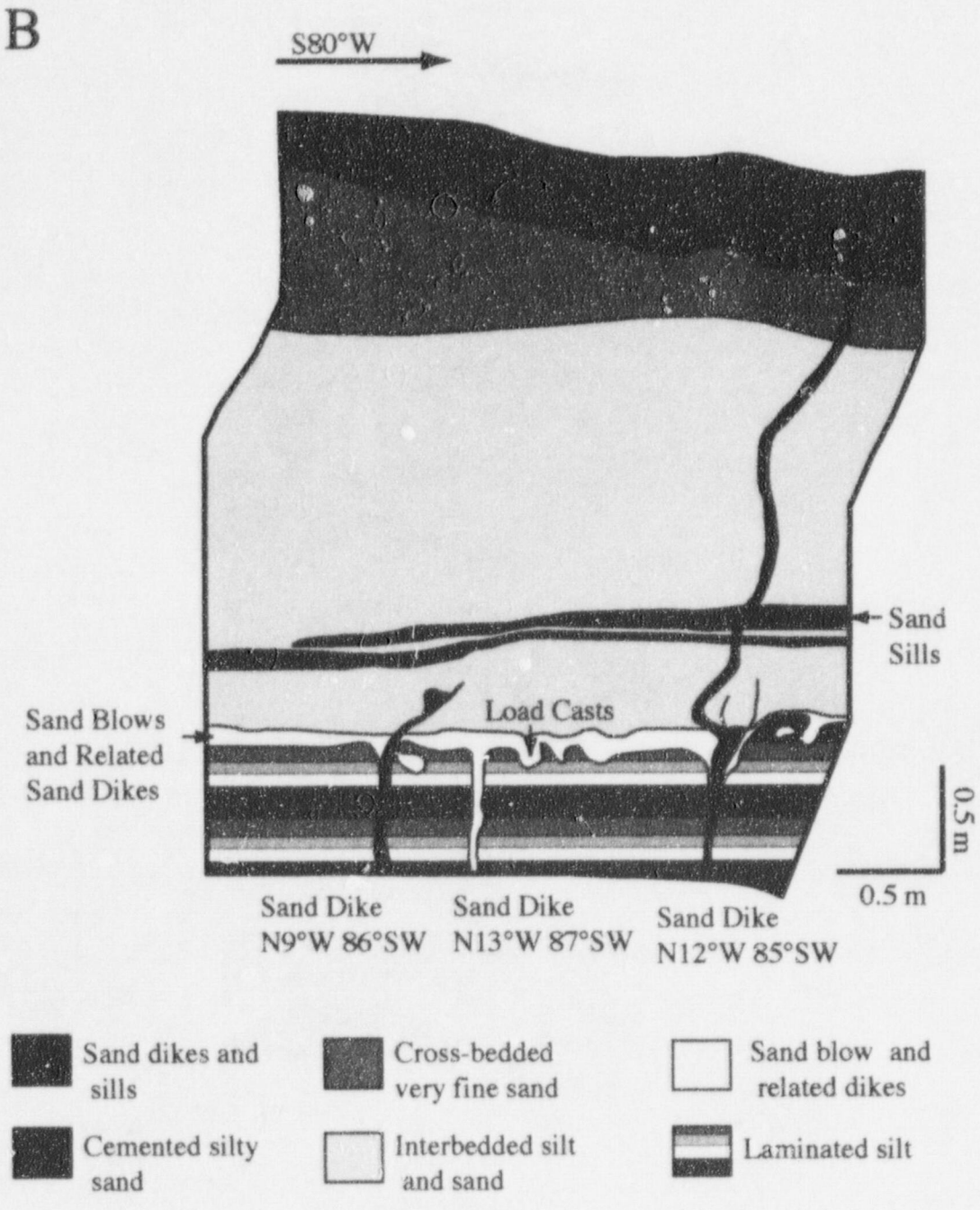


Figure 2.15. Log of section B of Current River-8 site. Sand blow, dikes, and sills in this section formed during at least two prehistoric earthquakes since 3490 B.C.

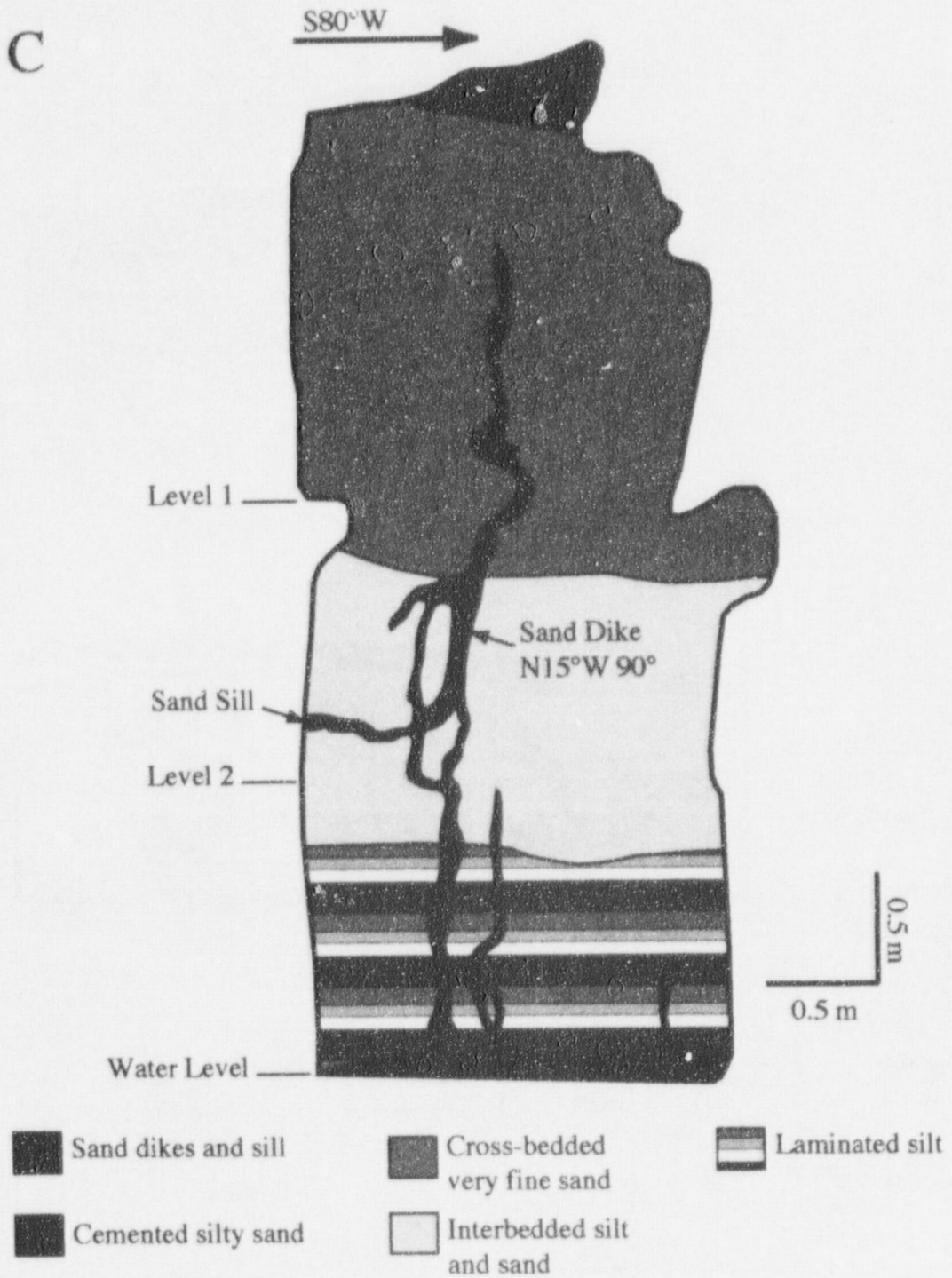


Figure 2.16. Log of section C of Current River-8 site. Sand dikes in this section fed sand sills observed in sections A and B. Also, source of sand dikes is exposed at base of this section.

Structural relations of liquefaction features at this site proved to be quite complicated. Eight sand dikes cross-cut the laminated silt at the base of the exposures (Fig. 2.13). Strikes of the dikes range from N9 to 15°W and dips range from 75°SW to vertical. The sand dikes are from 3 to 10 cm wide, exhibit varying degrees of weathering, and represent multiple phases of intrusion. Five of the dikes appear to have fed a sand blow of very fine sand, only 8 cm in thickness and at least 8 m in diameter, deposited on the laminated silt (Figs. 2.13, 2.14, and 2.15). The portions of the dikes that appear related to sand blow deposition are extremely weathered and iron-cemented. Two sand dikes appear to have fed sand sills and dikelets within the laminated silt (Fig. 2.14). These sills and dikelets cross-cut contacts of the dikes and sand blow and are only slightly iron-stained. Portions of the sandy sills and the overlying sand blow formed load casts within the laminated silt.

Five sand dikes extend up-section and cross-cut the overlying deposit of interbedded silt and sand; four of these dikes continue upward into the deposit of cross-bedded, very fine sand; and two of these dikes extend into the cemented, silty sand where they pinch out (Figs. 2.13-2.16). Sand in these dikes is relatively unweathered, except in the upper 30 to 50 cm of the dikes. Here, the dikes are iron-stained and cemented suggesting that they are prehistoric in age. Sills, 10-cm-thick, of unweathered, loose, very fine sand containing clasts of silt intrude along bedding of the interbedded silt and sand deposit. In a few places, the sills cut across bedding. One of the sand dikes apparently fed these sills (Fig. 2.16). A second dike broadens into a vent-like structure below the sills and may have been a second feeder dike (Fig. 2.15). The sills are clearly cross-cut by two of the dikes that extend higher in the section.

Cross-cutting relations of the liquefaction features and their varying degrees of weathering indicate at least two, and possibly as many as four, events (Fig. 2.13). The very weathered sand dikes and related sand blow represent the oldest event (I). The lower sills (II) post-date the sand blow, and therefore, the oldest event. The upper sills (III) occur in deposits overlying the sand blow and therefore post-date the sand blow. The sand dikes that extend high in the section and are weathered only in their uppermost 30 to 50 cm represent the youngest event (IV). These dikes cross-cut, and therefore post-date, the sand blow and upper and lower sills. Cross-cutting relationships of liquefaction features indicate four episodes of emplacement. These episodes may represent four different liquefaction events. It is also possible that the later three episodes of emplacement occurred during the same earthquake or earthquake sequence. There are no structural relationships or sedimentary characteristics that require that each of these features formed at different times.

The formation of load casts from portions of the sand blow and sills suggests a density instability between the sandy and silty materials near a water-sediment interface and possibly reliquefaction during a subsequent earthquake. These mechanisms require that features be below the water table at the time of deformation. Preservation of bedding within the upper part of the laminated silt suggests that it was not subject to subaerial exposure prior to the oldest liquefaction episode (I) and was rapidly buried by overlying deposits following that event. Rapid burial is supported by lack of soil development in the sand blow. Perhaps the sand blow was deposited in a subacqueous environment.

Vertical offsets of depositional contacts (including the laminated silt and overlying sand blow) on the order of 2 to 6 cm are documented across three of the dikes that extend high in the section (Figs. 2.14 and 2.15). In addition, several other very small (< 1 cm) offsets were noted across soft-sediment faults within stratigraphic units. All of the offsets indicate vertical displacements

down towards the east. All of the sand dikes at this Current River site are oriented north-northwest, similar in trend to the western margin of a nearby abandoned channel. Small offsets of depositional contacts across three of the sand dikes indicate vertical displacement down to the northeast or towards the abandoned channel during both the oldest and youngest events. These characteristics suggest that the sand dikes formed as a result of lateral spreading towards the abandoned channel that would have formed a free face. The sand blow overlies a laminated silt deposit and in turn is ovelain by a deposit of interbedded silt and sand. This facies change suggests that the environment of deposition changed immediately following and possibly because of the earthquake. Liquefaction-related ground failure may have contributed to a change in the environment of deposition at this site. Similar changes along Pemiscot Bayou near Blytheville, Arkansas, have been related to earthquake-induced liquefaction and ground failure (Guccione et al., 1996).

We collected a number of charcoal, wood, and soil samples at this site for radiocarbon dating. Two wood samples collected above and below the sand blow have been dated. Sample B-110226 collected from the laminated silt about 15 cm below the sand blow yielded a 2σ calibrated date of B.C. 3490 to 3470 and 3380-3090 (Fig. 2.14; Table 1.2). Sample B-110227 collected from a root cast above the sand blow yielded a modern age. The root cast disturbed, and therefore post-dates, the sand dike that extends high in the section. However, the modern date is not helpful in constraining the minimum age of any of the liquefaction features. Radiocarbon dating, structural relationships, and weathering characteristics of liquefaction features indicate that at least of two prehistoric earthquakes affected the area along the Current River since B.C. 3490 or in the past 5,500 yrs. Additional dating may help to further constrain the timing of the events and is planned during the continuation of this project.

2.5. Dodd Site

The Dodd site, located north-northeast of Blytheville, Arkansas (Fig. 1.2B), was discovered by Martitia Tuttle employing techniques developed over a 5-yr period working in the NMSZ (Tuttle and Schweig, 1996). On topographic maps, the site appears to be on relatively high ground adjacent to the Pemiscot Bayou, an ideal location for Native American sites. Aerial photographs show elliptical gray and white patches, typical of sand blows, near the bayou. During reconnaissance near the bayou, a northwestern-southeastern trending sand blow deposit with intact A horizon below the plow zone was found. Numerous potsherds of the Woodland and Mississippian periods were found on the ground surface above the sand blow. The site was selected for excavation because the sand blow appeared to be prehistoric in age and associated with cultural material. Reference check with the Missouri Archeological Survey found this to be a registered archeological site (23PM46). Prior to excavation, Lorraine Wolf and Jonathan Collier of Auburn University conducted electrical resistivity and conductivity surveys at the site (Fig. 2.17; Collier et al., 1997). A northwest-southeast trending zone of high resistivity was found to correspond with the location and orientation of the sand blow.

A surface collection of artifacts was made prior to excavation of a backhoe trench across the sand blow. The surface collection was made in forty-one 5 m^2 areas arranged diagonally along the length of the sand blow (Fig. 2.18). The collected artifacts were analyzed and artifact density contoured. A high density of artifacts (16 artifacts/5 m^2) was found overlying the sand blow. A trench was then excavated across the sand blow and adjacent to the area of high artifact density.

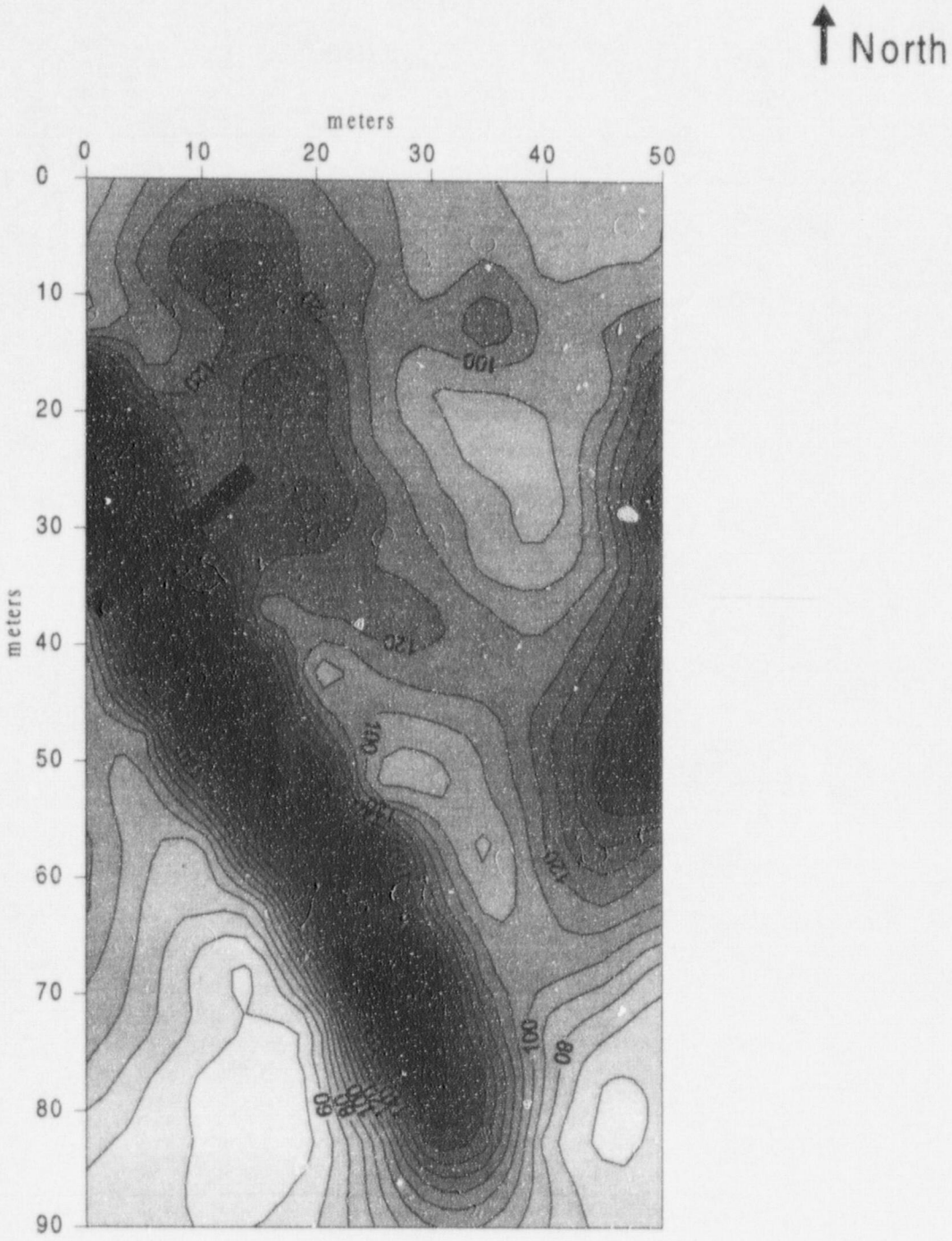


Figure 2.17. Resistivity survey of Dodd site provided by Wolf and Collier of Auburn University. Linear zone of high resistivity values corresponds with subsurface sand dikes and related sand blow. Location of the excavation shown by the black bar.

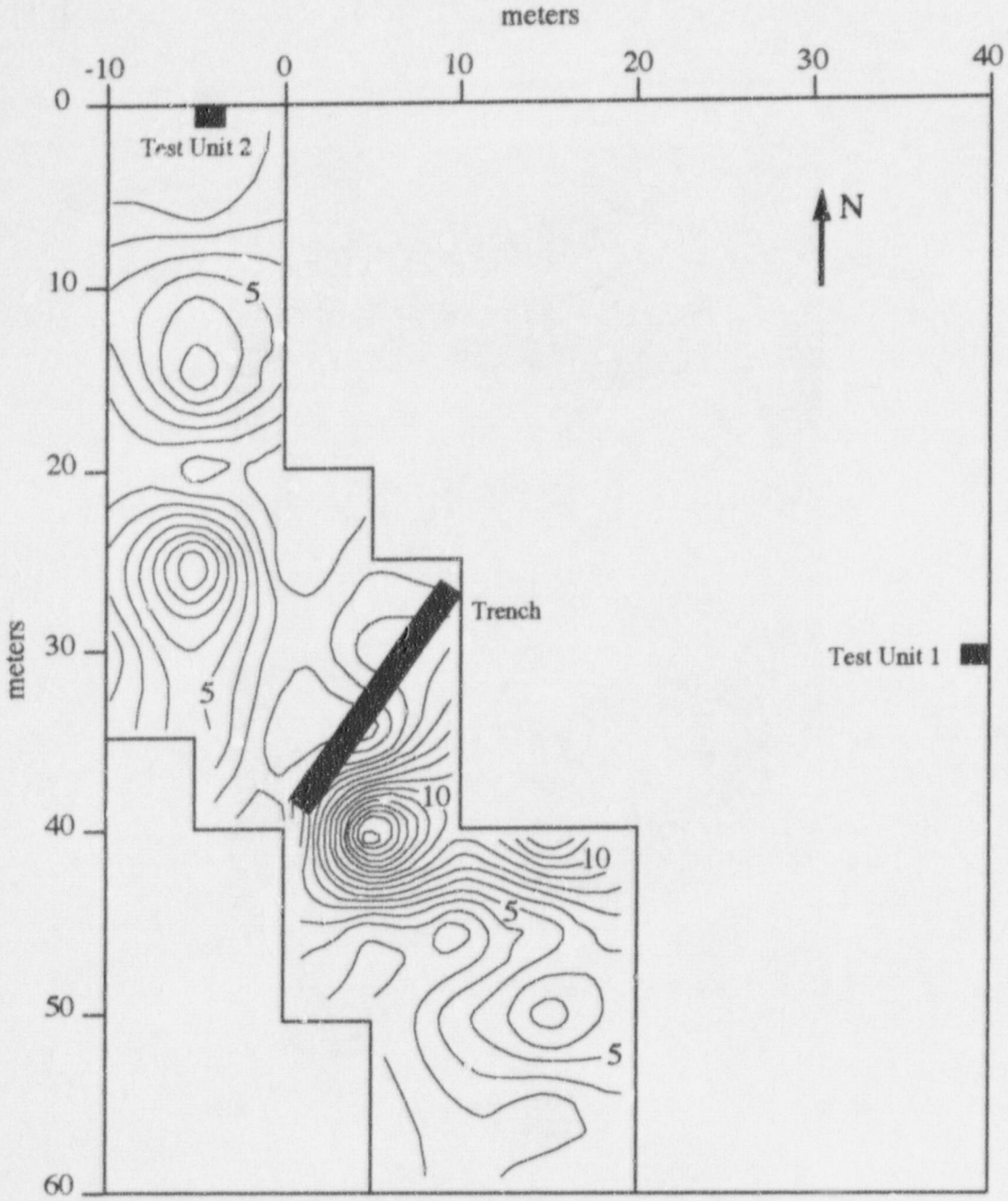


Figure 2.18. Contoured artifact density (# artifact/5 sq. m) at Dodd site based on controlled surface collection conducted along length of sand blow deposit. Locations of trench and test units shown.

Two feeder dikes, as well as the sand blow deposit, were exposed in the trench (Fig. 2.19). Both feeder dikes strike N35 to 45°W and dip from 70°NE to 81°SW. One of the feeder dikes (below the clast zone of the sand blow) is about 5 m wide and the other is about 1 m wide. The two dikes are separated by about 4 m. The sand blow deposit is more than 12 m across and up to 1 m thick. Subvertical flow structure and clasts were observed in the sand blow deposit above the feeder dikes. Most of the sand blow lies between the northeast margin of the smaller dike and the southwest margin of the larger dike, where the pre-event ground surface was displaced downward by 70 to 80 cm. Beyond the margins of the dikes, the pre-event surface is higher in the section and overlain by a relatively thin (~25 to 50 cm) deposit of vented sand. An 8- to 15-cm-thick A horizon had developed in the top of the sand blow, which is overlain by a silt deposit that had also been subjected to soil development.

Two archeological test units were excavated to establish the cultural context of the site. Test Unit 1 was located about 30 meters east of the sand blow (Figs. 2.18 and 2.20). As exposed in the excavation, the plow zone overlies a very dark grayish brown, fine sandy loam, carbon-rich occupation horizon or midden. Subsoiling of the site had disturbed portions of the underlying midden. The plow zone contained 300 artifacts/m^3 (Appendix A; Table A.3). Artifacts were present to a depth of 65 cm below the surface, where a brown silt loam was encountered. Diagnostic artifacts in the test unit, including a Campbell Appliqué/notched sherd from the base of the plow zone and six sherds of highly burnished Bell paste from 25 to 45 cm below the surface, are indicative of Late Mississippian occupation (Table 1.1). A Madison point was recovered from 35 to 45 cm below the surface. In this region, Madison points are thought to appear during the Middle Mississippian and continue into the Late Mississippian (Table 1.1; Fig. 1.3).

Test Unit 2 was excavated about 7 meters northeast of the sand blow (Figs. 2.18 and 2.21). The plow zone is a dark grayish brown sandy loam to a depth of 25 cm. Eight shell-tempered Neeley's Ferry sherds were recovered from the plow zone of the test unit (Appendix A; Table A.3). The plow zone is underlain by a very dark grayish brown, clayey fine sandy loam and is dominantly sandy to a depth of about 70 cm. No artifacts were recovered below the plow zone.

During excavation of the trench, the plow zone was first removed to look for cultural features and artifacts. We found a Native American pit (Feature 1) at 35 cm below the surface towards the northeast end of the trench (Figs 2.19 and 2.22). The northwestern half of the pit was excavated and the fill was reserved for flotation processing. The material in the pit was yellowish brown silt that contained abundant charcoal and carbonized corn. The pit had been dug into a pale brown soil that had developed in the top of the sand blow (Fig. 2.22). The northeast end of the trench was excavated to 65 cm below the surface (Fig. 2.23). At this level, a thin occupation horizon of silt loam with abundant daub and charcoal was encountered (Figs. 2.19 and 2.24). Sand immediately overlying the occupation horizon appeared to have been burned. The trench was later deepened to 1.3 m below the surface.

Artifacts from the Native American pit, which post-dates the sand blow, include shell-tempered plain ceramics and Varney Red Filmed sherds. Varney Red Filmed sherds are diagnostic of the Early Mississippian period (Table 1.1). Artifacts from the buried occupation horizon, which pre-dates the sand blow, include two Nodena points and shell-tempered pottery (Fig. 2.25; Table 2.6). Nodena points are diagnostic of the Late Mississippian and are thought to occur after A.D. 1400 (Table 1.1; Fig. 1.3). Another Nodena point was recovered during the surface collection. There

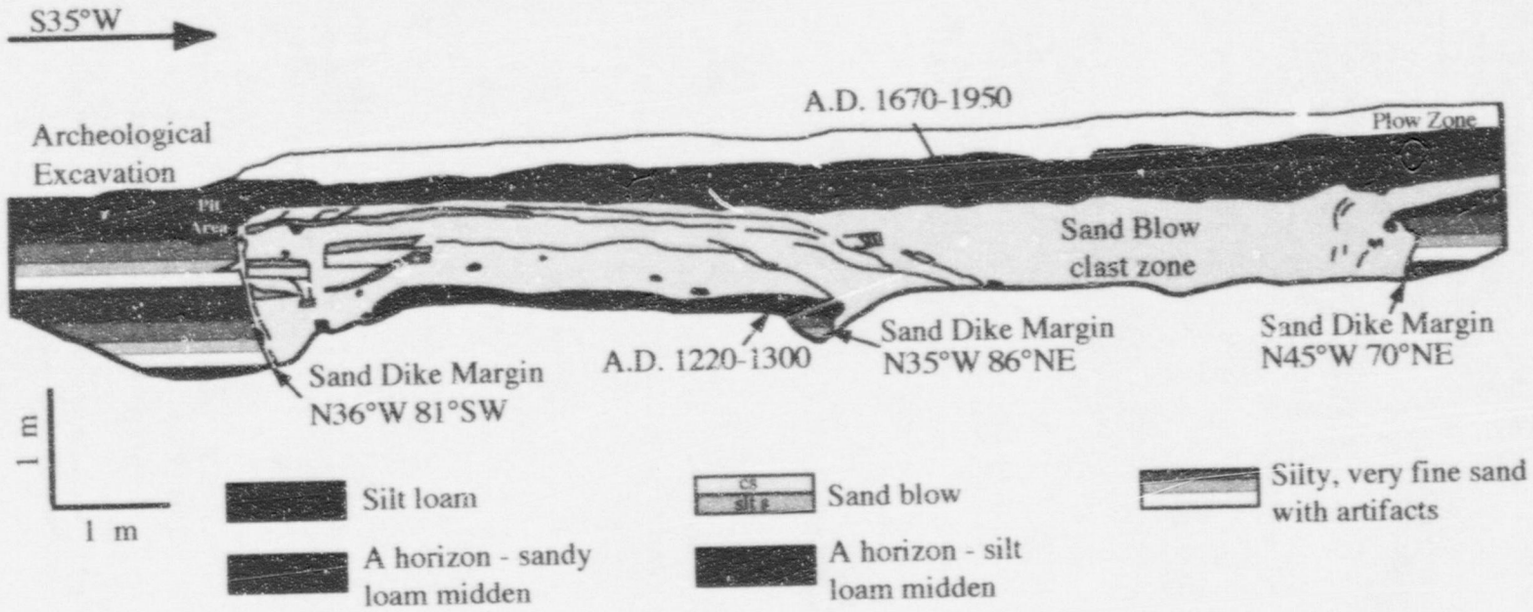


Figure 2.19. Trench log of sand blow and related sand dikes at Dodd site located north-northeast of Blytheville, Arkansas. Sand blow buried Late Mississippian midden and was reoccupied by aboriginals soon after the event. This sand blow probably formed about A.D. 1540 +/- 130 yr. Archeological excavation shown in Figs. 2.22, 2.23, and 2.24 was conducted in northeast end of trench.

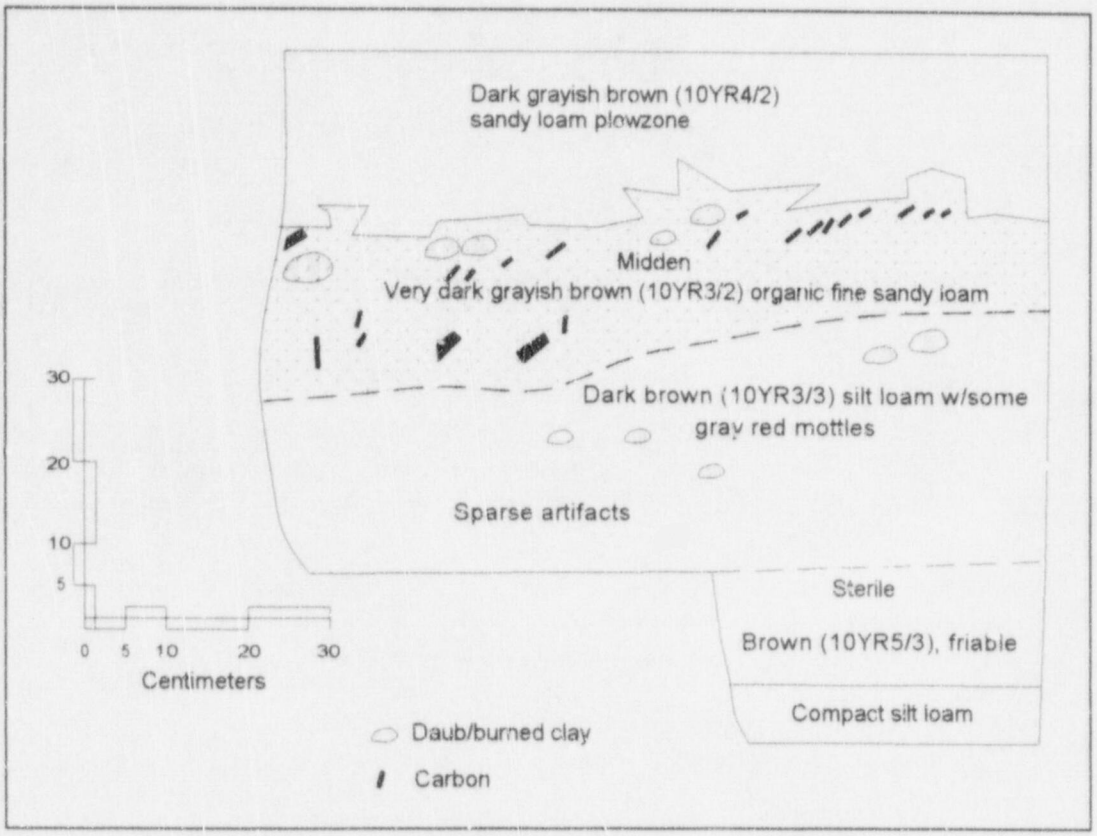


Figure 2.20. Test Unit 1 profile at Dodd site. There was intact, well-preserved midden below plow zone that produced several Late Mississippian sherds.

are also relatively high densities of Mill Creek chert and Dover sharpening flakes, which are also representative of the Middle to Late Mississippian period (Table 2.6).

At this site, the ceramics are overwhelmingly Middle to Late Mississippian forms of shell-tempered pottery (Table 2.7; Appendix A, Table A.4). There is a high percentage of burnished Bell paste sherds and rim sherds, including Campbell Appliqué and rims with notched fillets (Fig. 2.26) and Memphis rim mode. The presence of Varney Red Filmed potsherds in the cultural pit (Feature 1) was a surprise. These sherds are very small and probably were reworked from an earlier buried component. The liquefaction features cross-cut and bury a patently Late Mississippian occupation horizon, that appears to have been occupied at the time of the event. In fact, the burned basal portion of the sand blow suggests that deposition of the sand blow extinguished a small fire. Furthermore, it appears that the sand blow was re-occupied soon after the event (Table 2.6). This would place the timing of the event between A.D. 1400 and 1670.

Numerous charcoal and soil samples have been collected at this site. So far, two charcoal samples collected above and below the sand blow have been dated. Sample B-102502, collected 20 cm below the sand blow, yielded a 2σ calibrated date of A.D. 1220 to 1300 and sample B-102503, collected from the sandy loam developed in the top of the sand blow, yielded a 2σ calibrated date

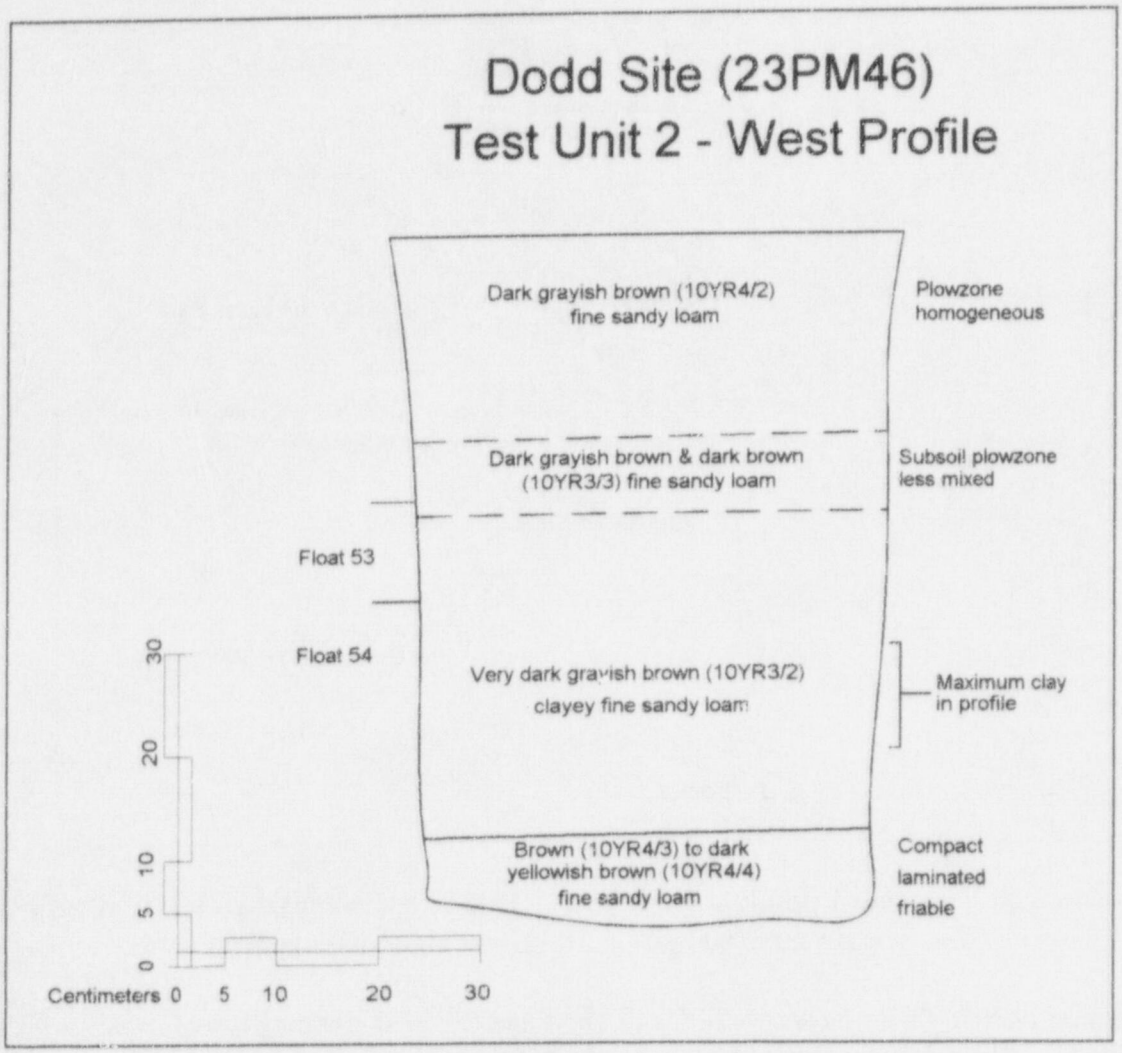


Figure 2.21 Test Unit 2 profile at the Dodd site. This unit was in a low artifact density area. Intact lower portion of the A horizon is one munsell lighter than that in Test Unit 1.

of A.D. 1670 to 1950 (Table 1.2). Although they do not constrain the timing of the event as well as the archeology, these radiocarbon dates are consistent with the results of the archeological investigation. Due to the promise this site holds for constraining the age of a Late Mississippian earthquake, additional study is planned during the continuation of this project. Preliminary results of additional excavation conducted in November 1997 support the finding that the sand blow formed, and its causative earthquake occurred, during the Late Mississippian period.

2.6. Eightmile Ditch-5

This site, along with several other sites east of Paragould, Arkansas, was discovered by M. Tuttle and M. Haynes during reconnaissance of Eightmile Ditch in 1997 (Fig. 1.1). The site was selected

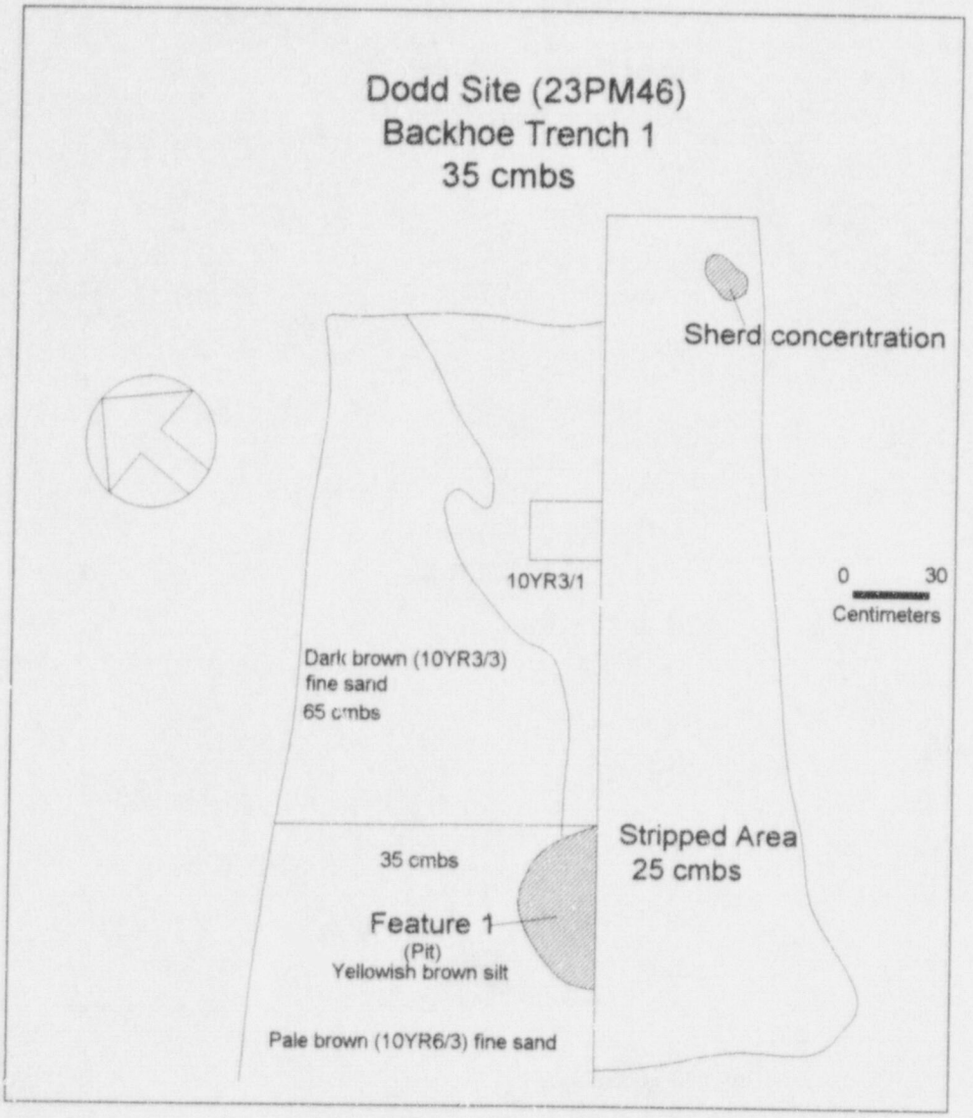


Figure 2.22. Plan view of archeological excavation at upper level of Trench 1 at the Dodd site. Trenching was stopped at 35 cmbs when Feature 1 was encountered. Feature 1 was excavated, then the surrounding unit was shovel skimmed.

for further study because of its clear structural and stratigraphic relations and its location about 30 km northwest of the Blytheville arch and its associated seismicity. No liquefaction features had previously been found or studied in this area.

The investigation was conducted in September when the water-level was low. A moderate-size sand blow, up to 70 cm thick and more than 8.5 m in diameter, was exposed in the western cutbank of Eightmile Ditch (Fig. 2.27). The sand blow is composed of predominantly fine sand with few lenses of silty, very fine sand and small pieces of lignite. The sand blow buries a silty loam. Clasts of silt and soil are concentrated in the sand blow above the feeder dike. The dike

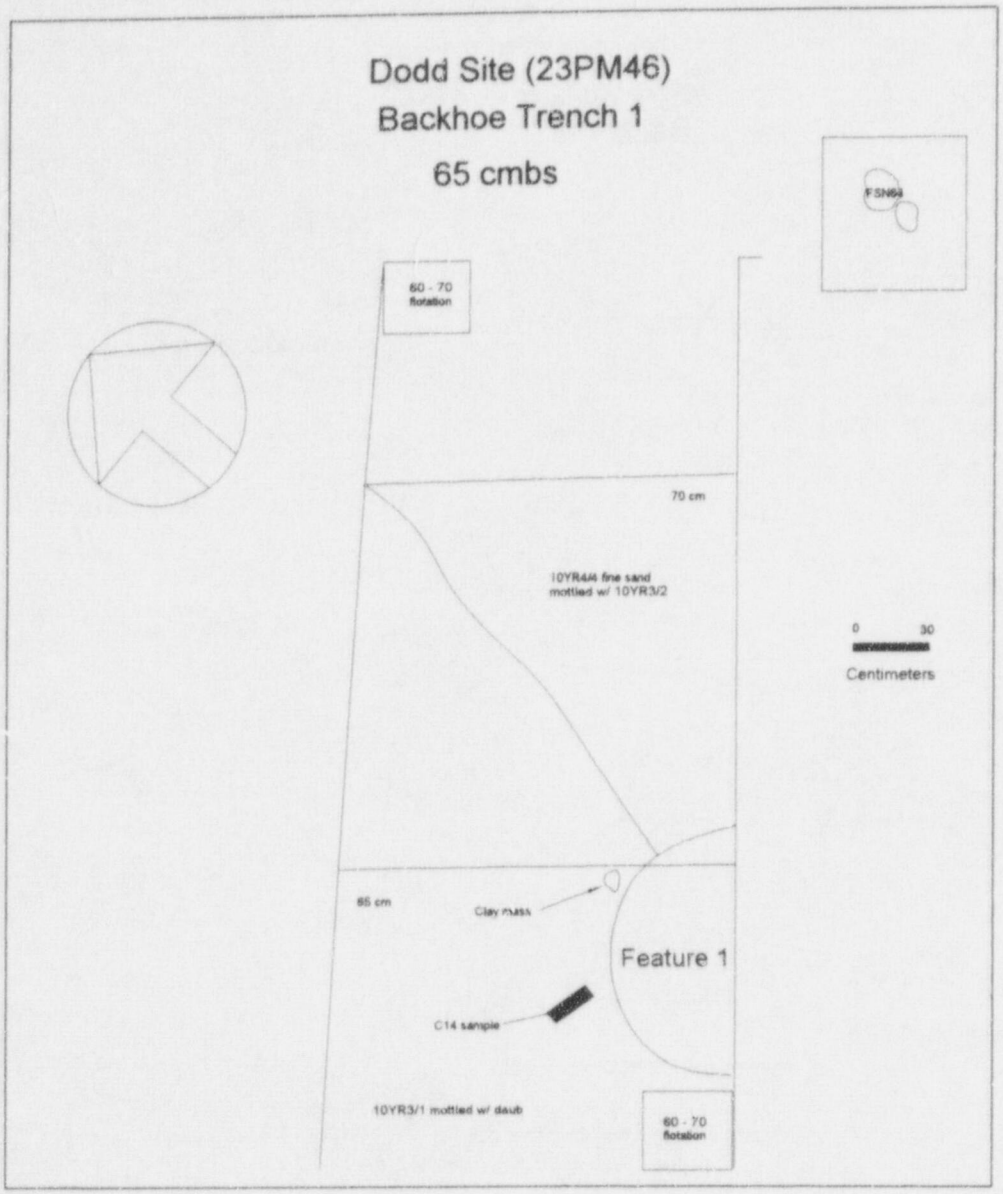


Figure 2.23. Plan view of archeological excavation at 65cmbs, Dodd site. Two Nodena points came from this level.

strikes N33 to 42°E and dips 28°E and contains many clasts of silt. The dike is 55 cm wide at the base of the exposure and broadens upward to a width of 1.1 m just below what would have been the ground surface at the time of the event. In the section examined, a small dike, only 5 to 10 cm wide, extends upward from the broad portion of the dike to form the feeder dike of the sand blow. In other sections, the broad portion of the sand dike probably forms the main vent area of the sand blow. A 5- to 10-cm thick loamy sand had developed in the top of the sand blow. A chaotic deposit of silt and sand, interpreted as ditch spoil, overlies the soil developed in the sand blow. The chaotic deposit is in turn overlain by laminated silt, interpreted as overbank deposits. White

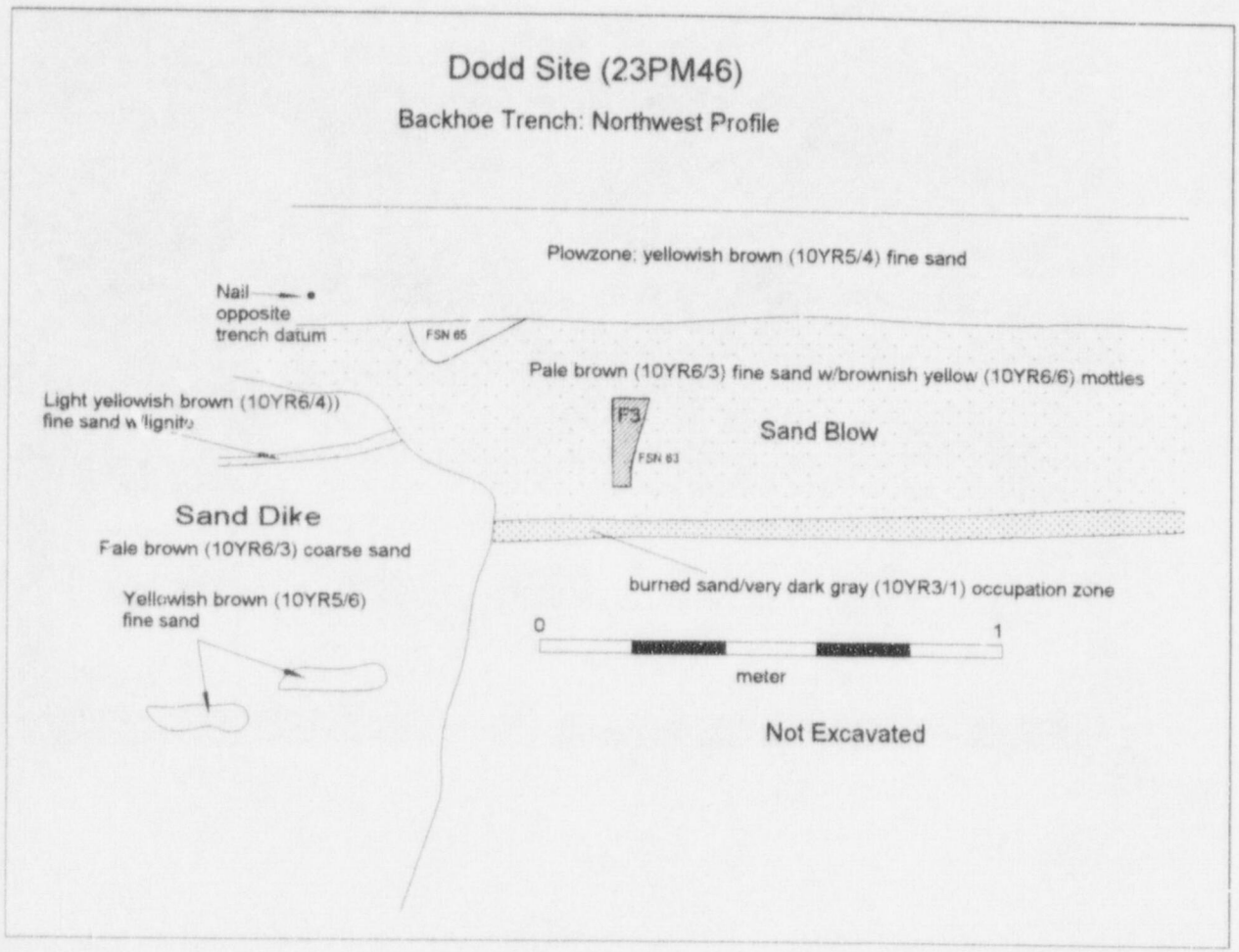


Figure 2.24. Northwest profile of archeological excavation at the Dodd site. Dark gray occupation horizon at base of excavation produced Bell plain sherds and two Nodena points.

zones had formed along the contacts of the sand blow with silty spoil above and silt loam below. These white zones may be related to leaching by ground water suggesting preferential flow within the sand blow.

The texture and thickness of the soil developed in the sand blow reflect a young age and suggest that the sand blow formed during the 1811-1812 earthquake sequence. Radiocarbon dating of soil sample B-108867, collected from the loamy sand developed in the sand blow, yielded a 2σ calibrated date of B.C. 3940-3845 and 3830-3370 (Table 1.2). Even though soil dates reflect the mean residence time of carbon in the soil, this date seems much too old given the characteristics of the soil. The date may reflect contamination by old carbon introduced by ground water or vented

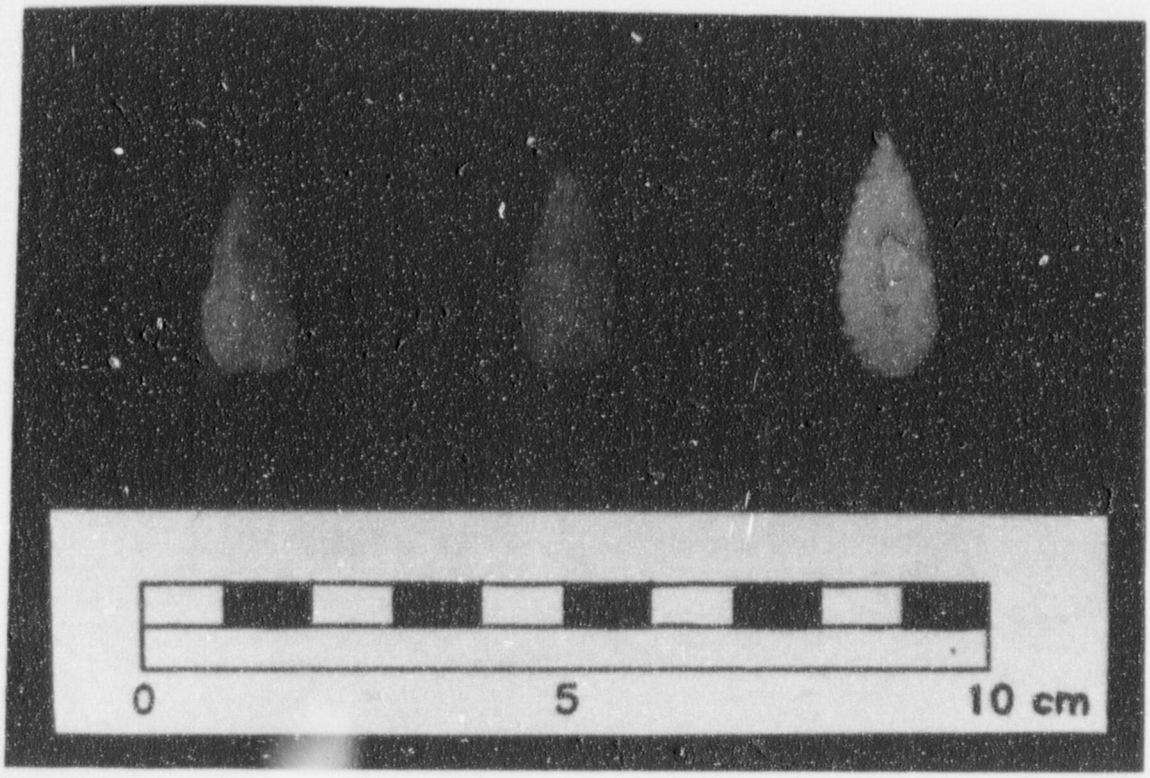


Figure 2.25. Nodena (left two) and Madison points from Dodd site. Nodena points represent technological peak of efficiency. By placing widest part of point in front of haft, shaft could pierce skin with less drag (UM Catalogue # 37-3, 56-12, 56-11 and 5-12).

during the earthquake and incorporated into the soil. A charcoal sample (B-108866) collected from the leached portion of the silt loam buried by the sand blow yielded a modern age. This sample may have been derived from a modern root grown into the horizon. Although these features probably formed in 1811-1812, additional dating is warranted to verify this result.

2.7. Hillhouse Site

The Hillhouse site, located east-northeast of Sikeston, Missouri, was discovered by Mid-Continental Research Associates during an archeological survey of the New Madrid floodway for the Memphis District, U.S. Army Corps of Engineers (Fig. 1.1). Archeological investigation of this large Bayto n site (23MI699) began in the summer of 1996. Dr. Robert Lafferty was the Principal Archeologist on the project. The investigation included making a controlled surface collection over 6 hectares with 2 x 2 meter collection units. The plow zone was stripped from approximately 2000 square meters, exposing many cultural and a few geological features. These included two building foundations, a sweat lodge, many post molds, earth ovens, and several sand

Table 2.6. Artifacts from Backhoe Trench 1 at Dodd site by pre and post earthquake context.

Artifact Description	Post earthquake		Pre earthquake	
	ct.[1]	wt.[2]	ct.	wt.
Chipped lithics				
arrow point - Nodena			2	1.4
biface	1	3.3		
flake	32	13.3	26	18.8
cobble tool	1	7.8		
shatter	11	1.0	24	44.6
Decorated ceramics shell-tempered body			1	3.1
Notched ceramics				
shell-tempered body - Bell Plain			1	14.2
Plain ceramics				
grog-tempered rim			1	1.3
grog & sand-tempered body			17	112.4
grog & sand-tempered rim			1	1.5
grog & shell-tempered body	13	20.4	3	15.2
shell-tempered body			81	144.6
shell-tempered body - Bell Plain	10	62.9	1	0.1
shell-tempered rim			5	12.5
Burnished ceramics				
shell-tempered body - Bell Plain	4	5.3		
Miscellaneous ceramics				
fired clay	nc[3]	67.1	128	228.9
modeled object			2	4.0
daub	39	239.6	17	210.9
sherds <¼"	11	2.6	30	16.2
Bone			1	0.4
Fire-cracked sandstone	2	1.0		
Totals	124	424.3	341	828.7

[1] count
[2] weight
[3] no count

dikes. Recognizing that the sand dikes were probably earthquake-induced liquefaction features, Lafferty contacted Tuttle, who visited the site in October, 1996. We decided that further investigation of liquefaction features and associated cultural features was warranted as part of this

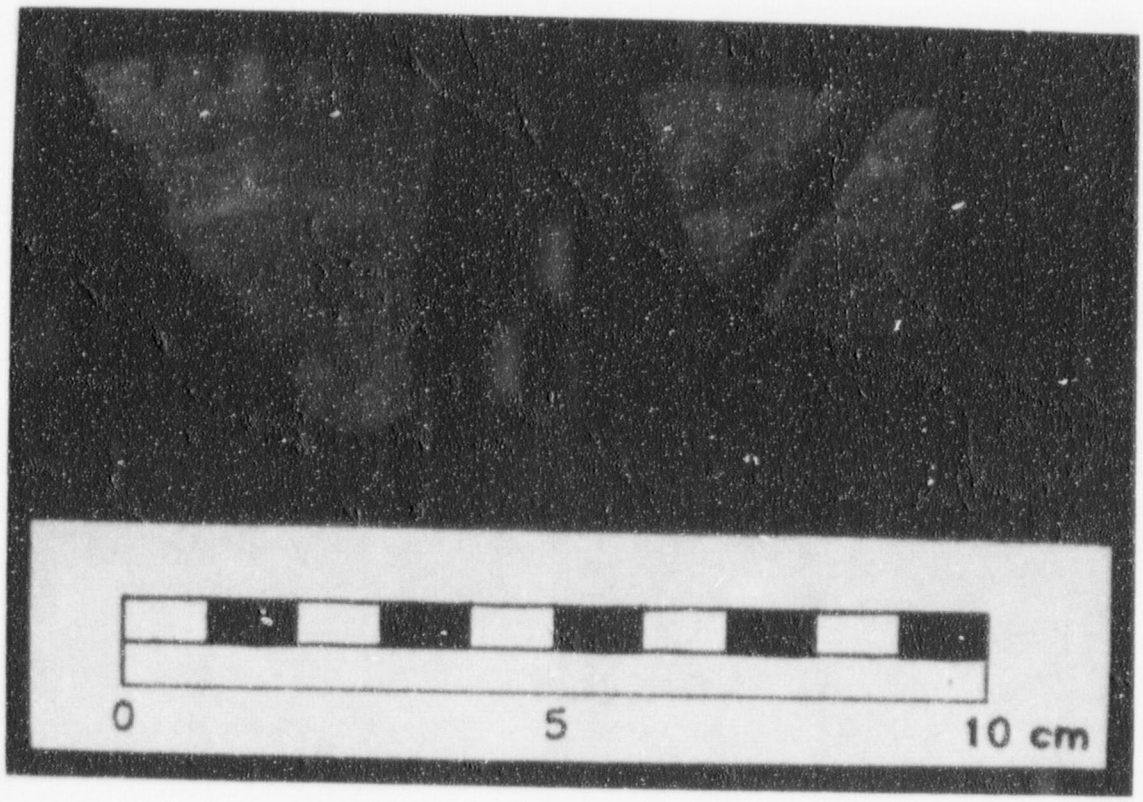
Table 2.7. Average sherd size from excavations and controlled surface collection context from the Dodd site.

Artifact Description	Excavated Material		Controlled Surface Collection	
	ct.[1]	wt.[2]	ct.	wt.
Decorated ceramics				
grog-tempered body			2	4.5
shell-tempered body	1	3.1		
Notched ceramics				
grog-tempered rim			1	1.1
shell-tempered rim	1	17.2		
shell-tempered rim - Bell Plain	1	14.2		
Plain ceramics				
grog-tempered body	3	8.0	52	114.9
grog-tempered body - Baytown Plain	4	10.2		
grog-tempered rim	2	5.5	3	3.3
grog & sand-tempered body	26	149.6	14	22.5
grog & sand-tempered rim	1	1.5	1	0.9
shell-tempered body	31	151.6	5	12.0
shell-tempered body - Bell Plain	5	18.5		
shell-tempered body - Mississippi Plain	108	248.5		
shell-tempered rim	5	17.9		
shell-tempered rim - Mississippi Plain	3	3.9		
Burnished ceramics				
grog & shell-tempered body - Bell Plain	6	18.5		
shell-tempered body - Bell Plain	10	62.9		
sherds <¼" - grog-tempered			2	107
Red-filmed ceramics				
shell-tempered body - Varney Red	2	2.2		
shell-tempered rim			1	1.4
Totals	209	733.3	81	267.6

[1] count
[2] weight in grams

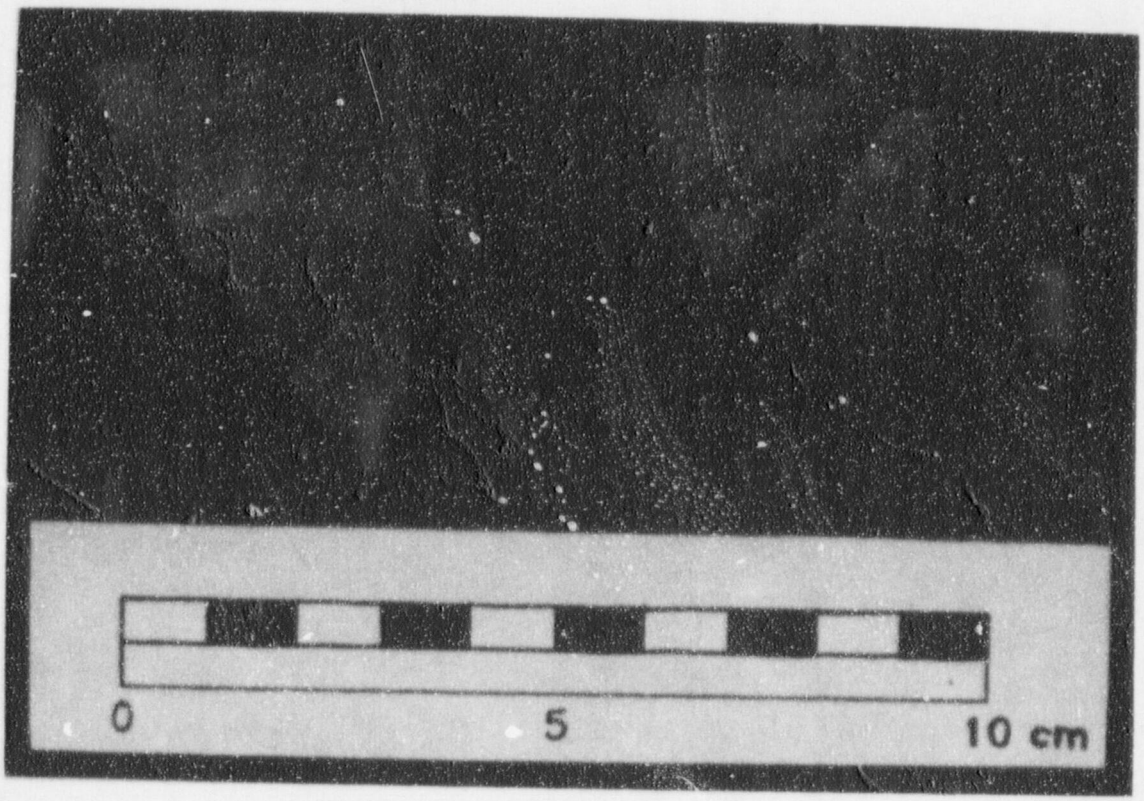
NRC project. During the course of the investigation, a large quantity of cultural material was recovered, making precise dating of the liquefaction features likely.

Four sand dikes, with widths of 1 m, 0.25 m, 0.15 m, and 0.05 m, were exposed in trenches excavated at this site. Three dikes, exposed in two trenches dug perpendicular to and within 20 m of a topographic break, were studied in detail. The topographic break, with 2.6 m of relief, forms the southwestern margin of an abandoned channel of the Mississippi River. The largest and Figure



2.26. Campbell Appliqué pottery from Dodd site. This pottery type often has notched rims. It usually has highly fired Bell paste (UM Catalogue # 59-3 & 42-1).

smallest of the three dikes occur within 0.8 m of one another (Fig. 2.28). The intermediate-size dike occurs about 10 m northeast of the largest dike (Fig. 2.29). The largest and intermediate-size dikes are subvertical and oriented N85°W and N75°W, respectively. The top of the largest dike occurs at 1.25 m below the scraped surface (plow zone removed). The intermediate and smallest dikes extends to within 35 to 25 cm of the scraped surface. No evidence of soil development was noted within the largest dike. However, soil development is evident within the other two dikes. The contact between these dikes and the overlying occupation horizon is bioturbated. The upper portions (~40 cm) of these dikes are composed of very dark grayish brown (Munsell color 10YR 3/2) fine sand with fines in the matrix. Below that, for an additional 55 cm, the dikes are composed of olive brown (Munsell color 2.5 Y 4/4) fine sand with fines accumulated only along the dike margins. Clasts of occupation horizon occur within all three dikes. In the largest and intermediate-size dikes, clasts were found up to 1.8 m below the surface. No sand blow deposit was found in association with the intermediate or smallest dike and only a small amount of vented sand is associated with the largest dike (Figs. 2.28 and 2.29). Vertical displacements of 40 and 15 cm, northeast side down, were measured across the largest and intermediate dikes, respectively. An 8- to 10-cm thick, clayey silt layer was found immediately overlying the top of the largest dike



2.26. Campbell Appliqué pottery from Dodd site. This pottery type often has notched rims. It usually has highly fired Bell paste (UM Catalogue # 59-3 & 42-1).

smallest of the three dikes occur within 0.8 m of one another (Fig. 2.28). The intermediate-size dike occurs about 10 m northeast of the largest dike (Fig. 2.29). The largest and intermediate-size dikes are subvertical and oriented N85°W and N75°W, respectively. The top of the largest dike occurs at 1.25 m below the scraped surface (plow zone removed). The intermediate and smallest dikes extends to within 35 to 25 cm of the scraped surface. No evidence of soil development was noted within the largest dike. However, soil development is evident within the other two dikes. The contact between these dikes and the overlying occupation horizon is bioturbated. The upper portions (~40 cm) of these dikes are composed of very dark grayish brown (Munsell color 10YR 3/2) fine sand with fines in the matrix. Below that, for an additional 55 cm, the dikes are composed of olive brown (Munsell color 2.5 Y 4/4) fine sand with fines accumulated only along the dike margins. Clasts of occupation horizon occur within all three dikes. In the largest and intermediate-size dikes, clasts were found up to 1.8 m below the surface. No sand blow deposit was found in association with the intermediate or smallest dike and only a small amount of vented sand is associated with the largest dike (Figs. 2.28 and 2.29). Vertical displacements of 40 and 15 cm, northeast side down, were measured across the largest and intermediate dikes, respectively. An 8- to 10-cm thick, clayey silt layer was found immediately overlying the top of the largest dike

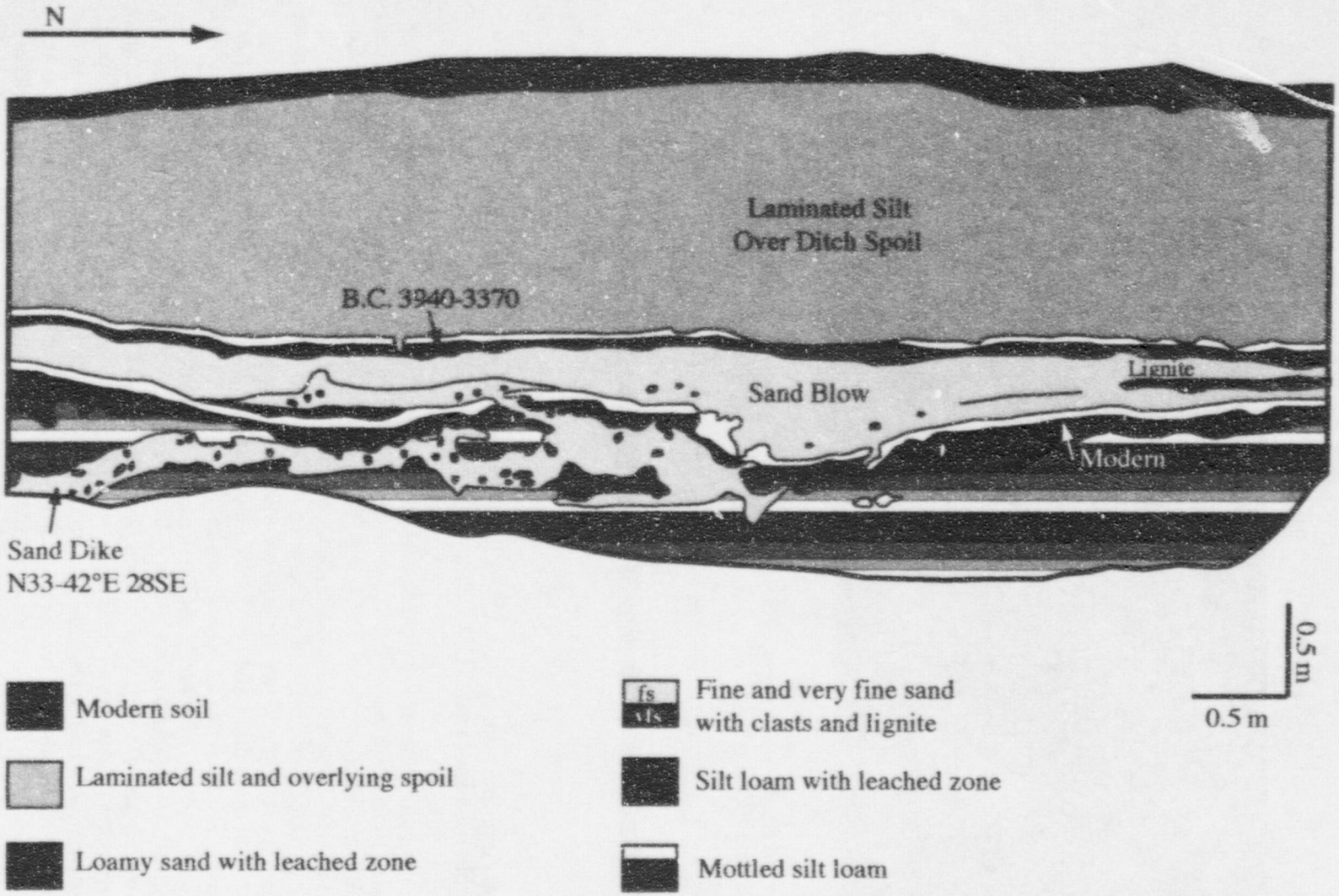


Figure 2.27. Trench log of sand blow and related sand dikes at Eightmile Ditch-5 site east of Paragould, Arkansas. Sand blow is characterized by minimal soil development and is immediately overlain by spoil from excavation of Eightmile Ditch. This sand blow probably formed during historic earthquakes of 1811-1812.

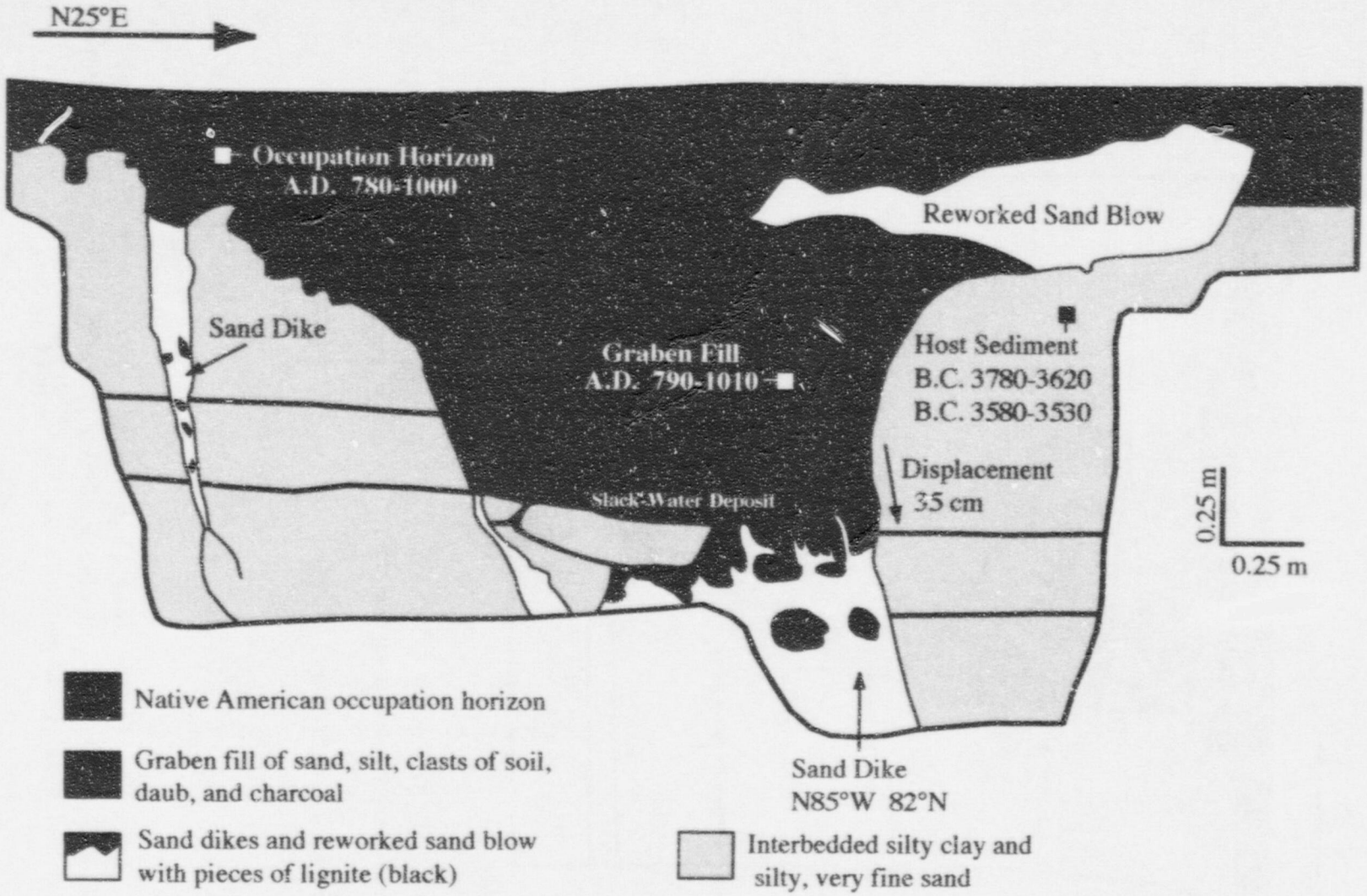


Figure 2.28. Trench log of sand dikes and portion of reworked sand blow at Hillhouse site. These sand dikes cross-cut and are overlain by Late Woodland midden. Clasts of midden occur in sand dike near base of trench. Liquefaction features formed and lateral spreading occurred about A.D. 900 +/- 100 yr.

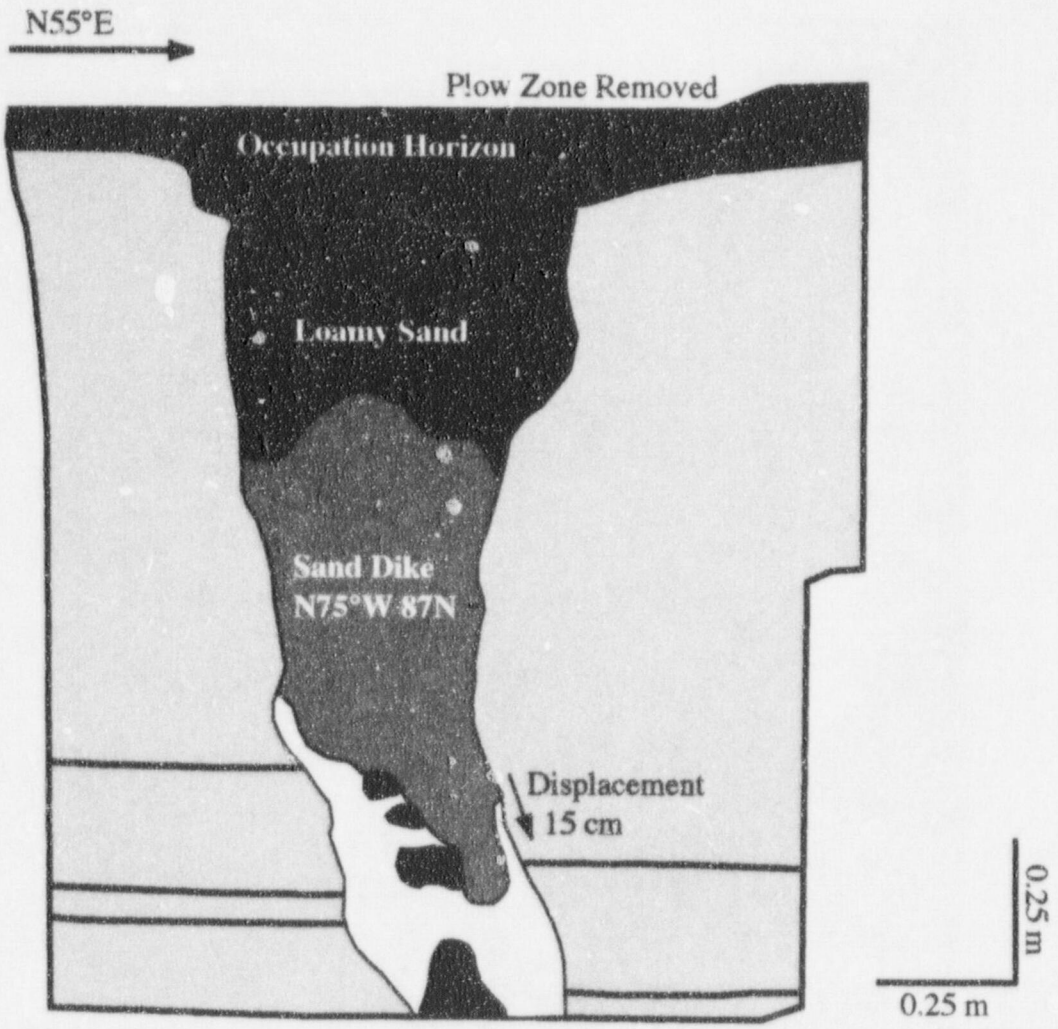


Figure 2.29. Trench log of a sand dike at Hillhouse site. A 40-cm-thick soil had formed in the top of the dike. Like the liquefaction features in Fig. 2.28, this sand dike probably formed as result of lateral spreading about A.D. 900 +/- 100 yr.

(Fig. 2.28). The clayey silt layer is overlain by an 0.8 m-thick deposit of a chaotic mixture of sand, burned clay (often found in association with Native American home sites), and clasts of soil and host sediment. This chaotic deposit, as well as the adjacent sand blow, is overlain by a Native American occupation horizon rich in potsherds and lithic fragments.

The chaotic deposit above the largest dike is interpreted as a graben fill. Sand in the deposit was probably washed into the graben from the nearby sand blow deposit following the event. The clasts of soil, host sediment, and burned clay may have washed or fallen into the graben. Alternatively, these materials may have been used by the natives, who lived on the site at the time of the earthquake, to fill the graben that formed through their village. The graben would be a convenient place to discard debris. The clayey silt layer, between the top of the dike and the chaotic deposit, is interpreted as a slack-water deposit (Fig. 2.28). Typically, large volumes of water are vented to the ground surface during liquefaction events. At this site, it is likely that muddy water would have been standing in depressions, such as the graben, following the event. The silt and clay suspended in the water would settle to the bottom of the graben over a period of minutes to hours.

The clasts of host deposits and occupation horizon within the large sand dike indicate that collapse was associated with the formation of the graben. In addition, the paucity of vented sand indicates that the dikes did not form as the result of explosive venting of water and sand to the surface. More likely, the sand dikes and the graben associated with the largest dike formed as the result of lateral spreading. The dikes are subparallel to a nearby topographic break, which would reduce lateral earth support during ground shaking and may have contributed to ground failure.

Two archeological test units, 2 m^2, were excavated above the largest sand dike and related graben. Excavations were conducted in 5 cm levels to a depth of 87 cm below the surface. Concentrations of large sherds, bone, flakes, and charcoal were mapped in each level. Preservation quality increased with depth, with almost-solid animal bone being recovered below 60 cm. The ceramics in the midden overlying the graben were grog-tempered Baytown plain and Mulberry Creek cord-marked (Table 2.8). Both these pottery types are characteristic of the Late Woodland period between A.D. 700 to 1000 (Table 1.1; Morse and Morse, 1983). This suggests that the liquefaction features formed during the Late Woodland period.

Radiocarbon dating indicates that deposition of sediment, on which the archeological site developed and through which the liquefaction features intruded, occurred prior to B.C. 3000 (Fig. 2.28 and Table 1.2, sample B-102501). This finding is consistent with the interpretation of the ages of the Mississippi River meanders in this region by Porter and Guccione (1994). A piece of charcoal (B-102499) collected from the chaotic deposit filling the graben yielded a 2σ date of A.D. 790 to 1010, a maximum age of the liquefaction event (Fig. 2.28 and Table 1.2). Charcoal (B-102500) collected from the midden above the small dike and level with the top of the reworked sand blow yielded a 2σ date of A.D. 780 to 1000, which reflects the minimum age of the event. Two other pieces of charcoal (B-105142 and B-105141) collected from the midden above the graben were also dated. These samples were collected during archeological excavation of the midden and their exact stratigraphic positions are uncertain. The samples yielded 2σ calibrated dates of A.D. 710 to 1040 and A.D. 960 to 1070 and 1080 to 1160, which also constrain the maximum age of the liquefaction features. The radiocarbon results provide a well-constrained date

Table 2.8. Artifacts recovered above graben, post earthquake context, Hillhouse site.

Location	Grog-tempered plain		Incised /Punctated		Grog-tempered cord-marked	
	ct.[1]	wt.[2]	ct.	wt.	ct.	wt.
124N/278E[3]						
30-35 cmbs[4]	28	419.5			47	1043.6
56-41 cmbs	102	736.4	9	79.1	121	890.7
61-66 cmbs	58	365.3	4	36.5	36	60.9
126N/276E						
58-65 cmbs	75	459.1	5	86.9	51	335.0
67-70 cmbs	13	91.8	4	26.3	11	68.6
70-77 cmbs	6	39.3	1	2.4	11	75.6
77-82 cmbs	3	5.3			6	69.9
82-87 cmbs	31	155.7	1	5.9	30	268.7
Totals	316	2272.4	24	3	313	2813

Table 2.8 continued.

Location	Sand-tempered		Poverty Point Objects		Totals	
	ct.	wt.	ct.	wt.	ct.	wt.
124N/278E						
30-35 cmbs	1	3			76	1466.1
56-41 cmbs			1	19.9	233	1726.1
61-66 cmbs					98	1002.7
126N/276E						
58-65 cmbs			1	109	132	990
67-70 cmbs					28	186.7
70-77 cmbs					18	117.3
77-82 cmbs					9	75.2
82-87 cmbs					62	430.3
Totals	1	3	2	128.9	656	5994.4

[1] count

[2] weight in grams

[3] The site was grided. This unit is 124 meters north and 278 meters east of the site origin. The center of the logged trench was at 132N/274E.

[4] centimeters below surface

of the earthquake that induced liquefaction and led to lateral spreading at this site of about A.D. 900 ± 100 yr.

2.8. Hueys House Site

This site, located north-northeast of Blytheville, Arkansas (Fig. 1.2B), was brought to our attention by Mr. Marion Haynes. Hueys House is a well-known archeological site (3MS306) and Haynes reported finding potsherds in association with a sand blow at this site. During the initial site survey conducted by Martitia Tuttle and Marion Haynes, an elliptical (plan view) sand blow approximately 30 m long and 20 m wide was identified. Potsherds of the Woodland and Mississippian cultures occur on the surface of the sand blow, which is characterized by a well-developed A horizon despite cultivation. We excavated a backhoe trench across the southwestern end of the sand blow where cultural features that could help to date the sand blow were present (Fig. 2.30). Adjacent to the northeast side of the trench, the plow zone was stripped to expose the relationships between cultural features and the sand blow.

In the backhoe trench, a sand blow, sand-blow crater, and related sand dikes were exposed (Fig. 2.31). The feeder dike is small, about 1 to 2 cm wide. This is not surprising given that the trench was positioned across the end, as opposed to the central part, of the sand blow. The feeder dike has a strike and dip of N60°E, 80°NW. The sand-blow crater is about 1 m wide and formed in a Native American occupation horizon, containing artifacts of both Woodland and Early Mississippian periods. The crater is filled with very fine to coarse sand, containing clasts of the occupation horizon. The sand blow was deposited over the occupation horizon that subsided about 10 to 20 cm on the southeast side of the sand-blow crater. No sand appeared to have vented on the ground surface on the northwest side of the crater. Clay layers, with a Native American hearth near the upper contact of the upper layer, are directly overlying the sand blow deposit. A cultural pit, filled with numerous potsherds, occurs close to the northwest margin of the clay layer. Characteristic of cultural pits, artifacts were concentrated in the center of the feature. The pit extended into the upper corner of the sand-blow crater. The contact between the two features was disturbed by a root cast.

The upper clay layer with hearth is thought to be a floor of a Native American dwelling that was built on the sand blow and would, therefore, post-date the liquefaction event. The clay layer had been reddened by firing adjacent to the hearth; however, the firing had not been intense enough to allow for archeomagnetic analysis. The cultural pit appears to intrude the top of the sand blow and would also post-date the event. No sand dike intrudes the clayey house floor or cultural pit, supporting their post-earthquake origin. The occupation horizon buried by the sand blow clearly pre-dates the event. Sand dikes do occur in the midden below the sand blow.

Archeological investigation of the site consisted of a controlled surface collection and excavation of a 1 m^2 test unit through the midden below the sand blow (Test Unit 1; Figs. 2.30 and 2.32) and a 0.5 m x 2 m test unit through the clayey house floor, cultural pit, sand blow, and into the buried midden below (Test Units 2 and 3; Figs. 2.30, 2.33, and 2.34). The surface collection was conducted in a 10 m^2 area adjacent to the southwestern margin of the backhoe trench (Fig. 2.30). Eighty-seven artifacts, mainly sand-tempered, Barnes cord-marked sherds, were recovered (Appendix A; Table A.5). No shell-tempered pottery was recovered adjacent to the southwestern side of the trench. However, large sherds of shell-tempered pottery were collected from the ground surface elsewhere at the site.

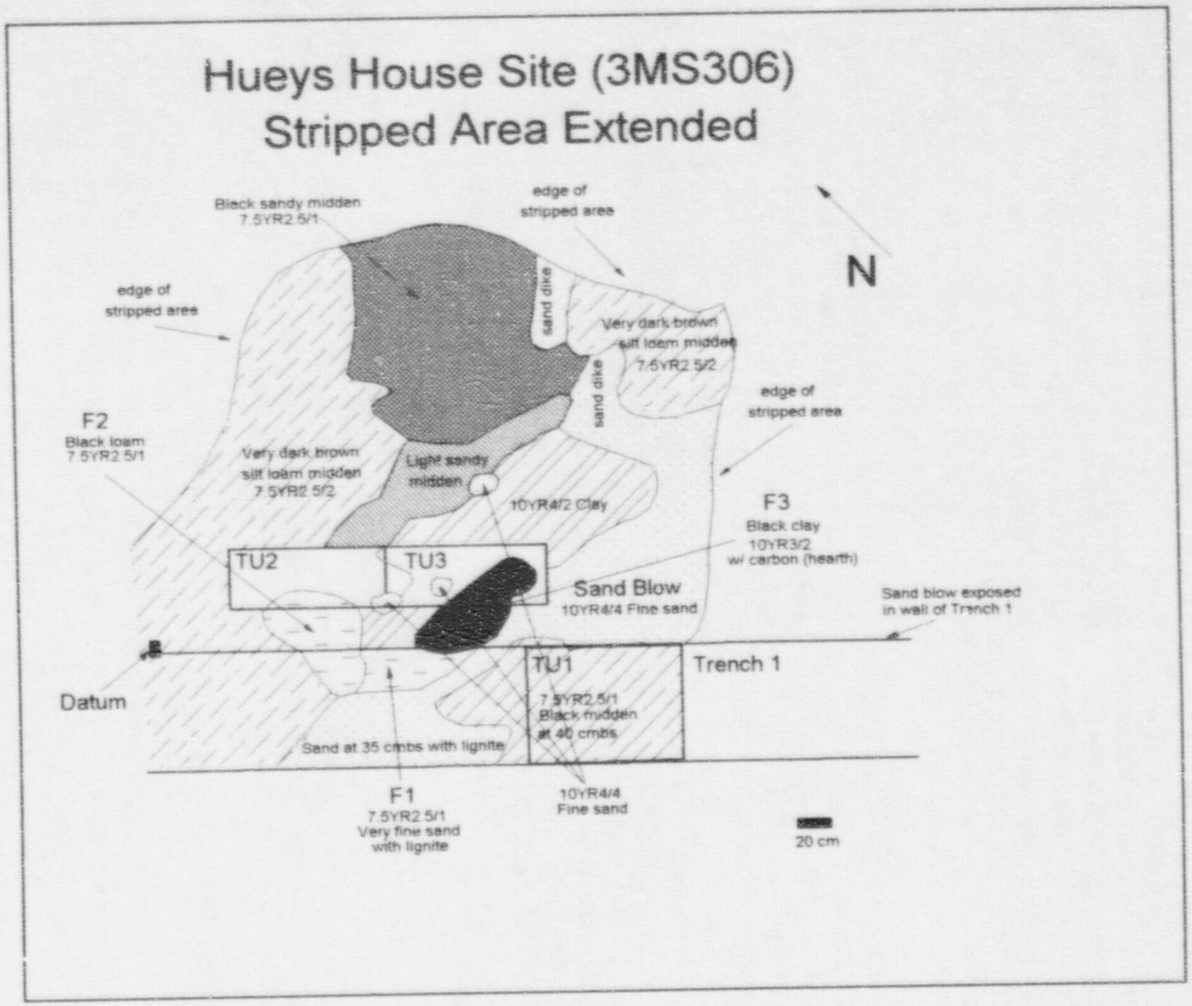


Figure 2.30. Plan view of stripped area, Hueys House site (plow zone removed) northeast of Blytheville, Arkansas. Excavation of Trench 1 stopped at midden. Test Unit 1 was excavated into underlying midden. Test Units 2 and 3 were excavated to sample overlying deposits.

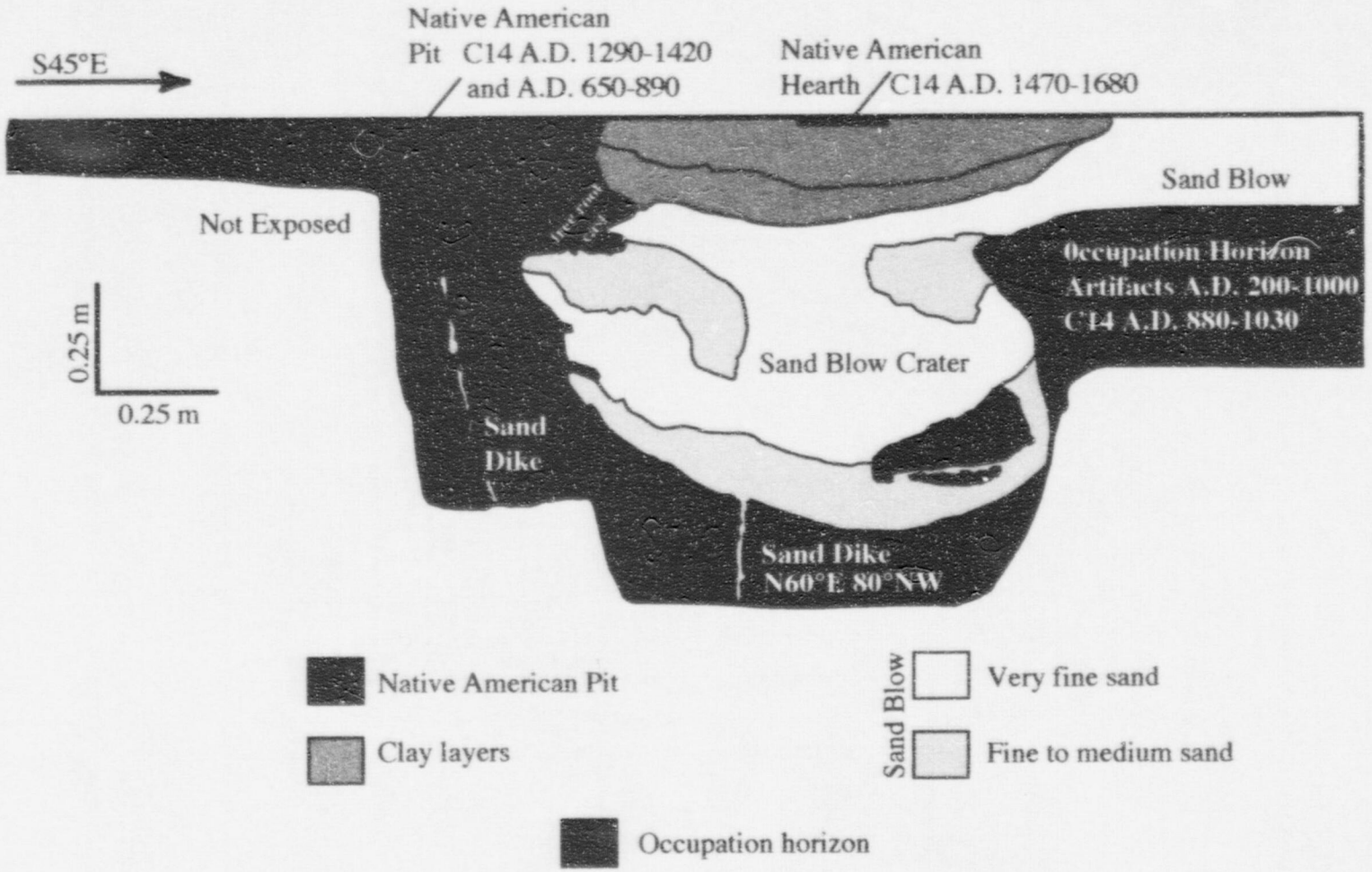


Figure 2.31. Trench log of sand-blow crater, sand blow, and related sand dikes at Hueys House site. Sand-blow crater and sand blow cross-cut and overlie Late Woodland to Early Mississippian midden. Clayey layers with hearth overlie and cultural pit intrudes sand-blow crater. Artifacts in these features are also Late Woodland to Early Mississippian. Liquefaction features probably formed about A.D. 900 +/- 100 yr.

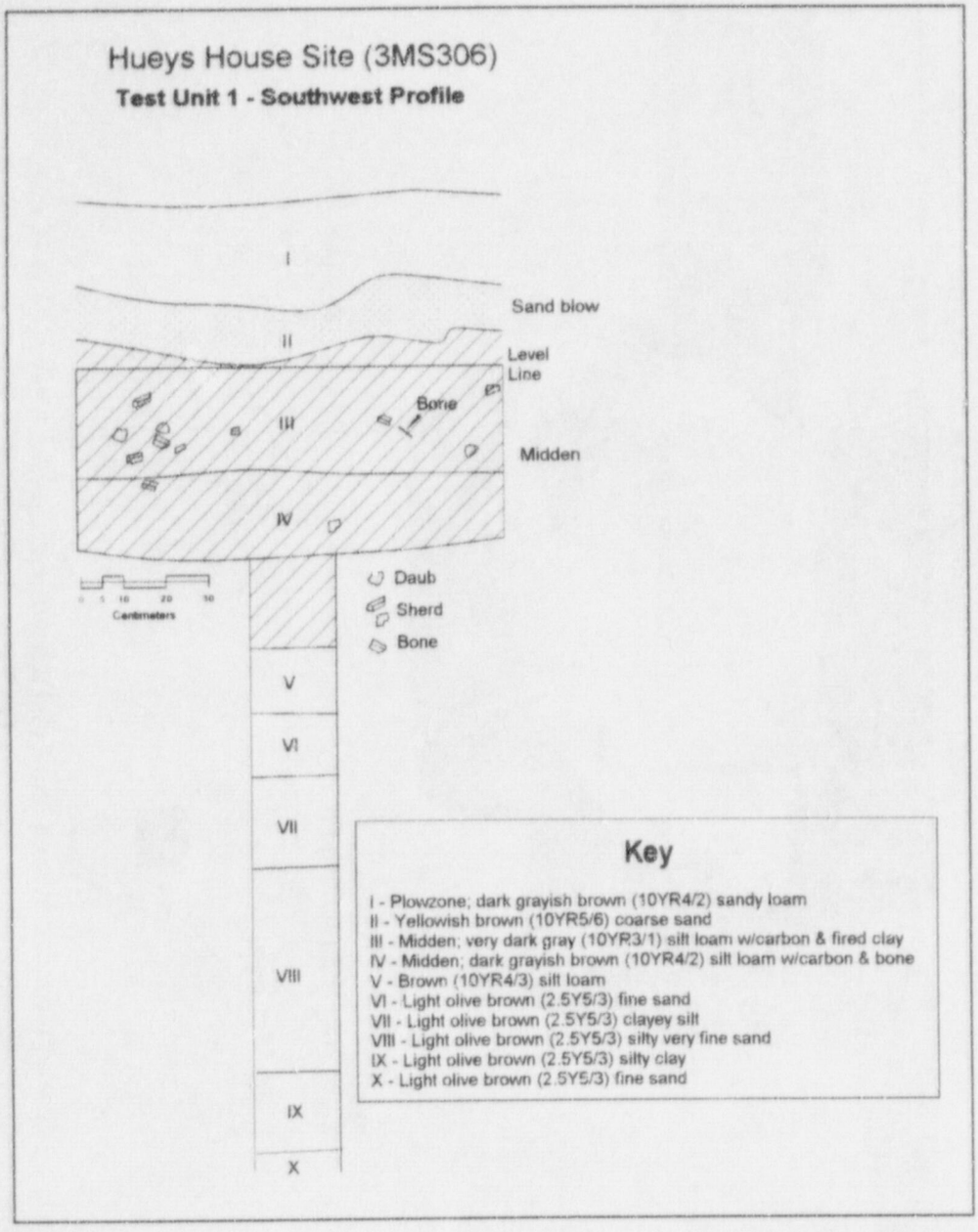


Figure 2.32. Test Unit 1 profile, Hueys House site. Radiocarbon sample B-91641 (Table1.2) came from zone III, which also produced one Table Rock Stemmed points.

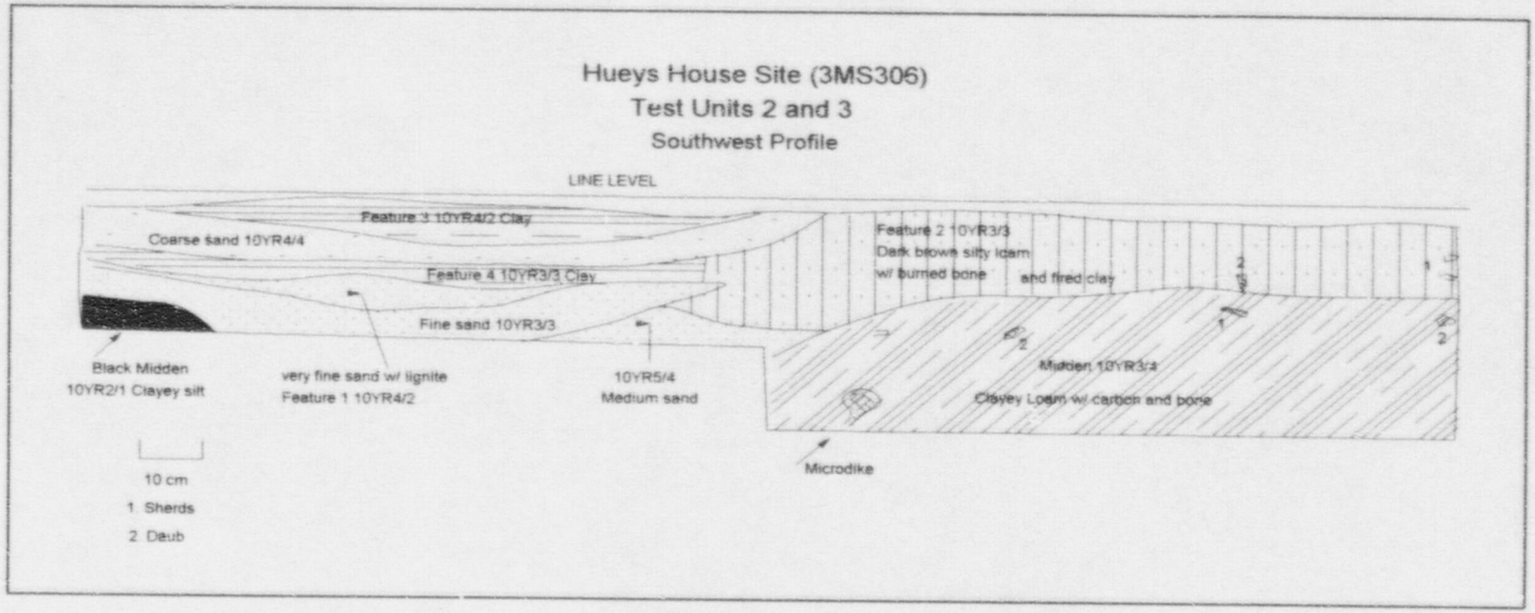


Figure 2.33. Hueys House site; southwest profile of Test Units 2 and 3 clearly overlies sand blow.

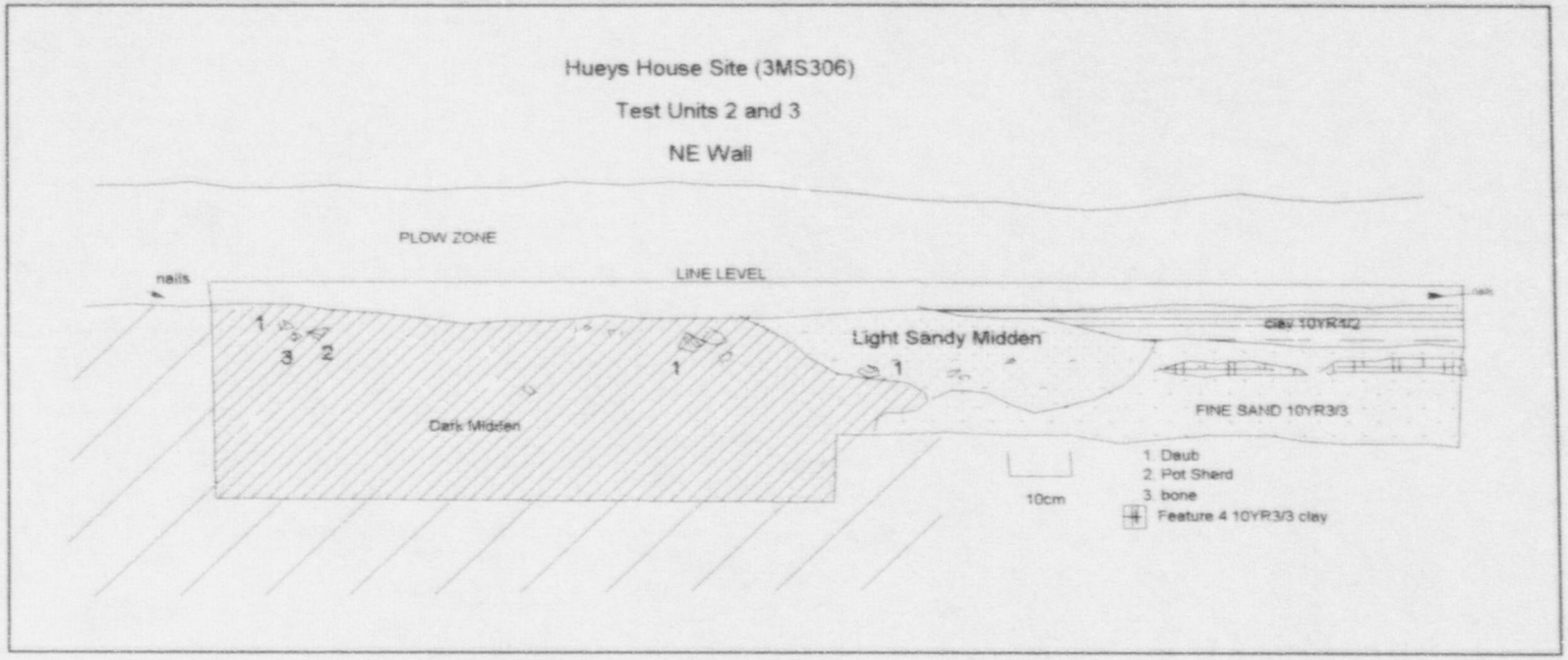


Figure 2.34. Northeast profile of Test units 2 and 3, Hueys House site.

Test Unit 1 was located in the bottom of the trench with the first excavation level in the base of the sand blow (Figs. 2.30 and 2.32). The test unit was excavated to 85 cm below surface followed by a control column to over 2 m. We recovered many artifacts, from 40-80 cm below the surface, concentrated in the dark grayish brown, silty loam midden beneath the sand blow (Appendix A; Table A.6). We found few artifacts below the depth of 80 cm. Test Units 2 and 3 were laid out 20 cm northeast of the trench (Fig. 2.30). Test Unit 2 sampled the cultural pit (Feature 2), the root cast (Feature 1) and the same black midden as Test Unit 1 (Figs. 2.33 and 2.34). In both Test Units 1 and 2, the greatest concentration of artifacts in the midden occurred in the third excavation level. Test Unit 3 sampled the clayey house floor with hearth (Feature 3), a second clay layer (Feature 4), and the sand blow below (Appendix A; Tables A.7 and A.8).

The assemblage of artifacts recovered from the buried midden is typical of the Late Woodland-Early Mississippian transitional period (Table 2.9). The assemblage is dominated by sand-tempered Barnes cord-marked pottery (Table 1.1). Mixed-tempered wares comprise over 10% of the ceramics. Shell-tempering increases in the upper levels of Test Unit 1 (Table 2.10, mixed-tempered sherds with shell are counted as Mississippian), at the expense of sand-tempered Barnes pottery, and pottery of mixed tempers. The shell-tempered pottery is leached of shell and is very friable. Only two sherds of Varney Red Filmed pottery were recovered. One projectile point, a Table Rock Stemmed, a Late Woodland type, was recovered in the third excavation level. The presence of a mud dauber nest and baked clay in the upper levels of the test unit suggests that a Native American building once stood on the horizon that now lies below the sand blow.

The artifacts recovered at this site indicate that the earthquake responsible for the formation of the liquefaction features occurred during the transition from Late Woodland to Early Mississippian period (Figs. 2.35-2.38; Tables 2.11 and 2.12). All of the red-filmed pottery is interior slip, indicative of Varney Red Filmed. The mixed-temper ceramics have sparse shell, which contrasts with Mississippian wares that have much more shell and, until the Late Mississippian, have virtually no grog added. The mixed temper ceramics, occur in the middle levels of the buried occupation horizon and is exactly what one expects at the cusp of this technological transformation. The two point types, diminutive dart point and very large arrow point, are also characteristic of this transitional period. We plotted the percentages of Woodland and Mississippian pottery for the assemblage of artifacts from the buried midden as well as for similar assemblages from other sites in the region (Fig. 2.39) . Comparison of the assemblages suggests that this midden was last occupied about A.D. 900-950. This would reflect the time of burial of the occupation horizon by the sand blow.

Dr. Neal Lopinot conducted an archeobotanical analysis of samples collected at this site and found much higher densities of plant remains within the clayey house floor and adjacent pit overlying the sand blow than in the buried occupation horizon. The plant remains from the house floor and pit included large amounts of *Zea maize* or corn and *Hordeum pusillum* or little barley (Appendix B; Table B.1). The occupation horizon buried by the sand blow contained virtually no corn or other seeds, which is characteristic of Late Woodland horizons. In the study area, maize became dominant in the Native American diet about A.D. 1000 to 1050. Therefore, the archeobotanical analysis suggests that the sand blow formed prior to A.D. 1050.

Charcoal (B-91641) from the occupation horizon buried by the sand blow yielded a 2σ calibrated date of A.D. 880 to 1030 (Fig. 2.31 and Table 1.2). This is consistent with the age of the midden

Table 2.9. Summary of Woodland and Misssissippian ceramics by depth, Test Unit 1, the Huey's House site.

	Woodland		Mississippi		TOTAL	%
Depth in cmbs[1]	ct.[2]	% by depth	ct.	% by depth	ct.	%
40 - 50	40	65.6%	21	34.4%	61	100.0%
50 - 60	86	66.7%	43	33.3%	129	100.0%
60 - 70	116	89.2%	14	10.8%	130	100.0%
70 - 80	90	93.7%	6	6.3%	96	100.0%
80 - 105	1	100.0%	0	0.0%	1	100.0%
TOTAL	333	80.0%	84	20.0%	417	100.0%

[1] centimeters below surface
[2] count

based on its artifact assemblage. We also dated a piece of charcoal and kernels of maize collected from the pit (Feature 2). The maize (B-108939) yielded a 2σ calibrated date of A.D. 1290-1420. The charcoal (B-91643) gave a 2σ calibrated date of A.D. 650 to 890. Given the results of the archeobotanical analysis, the age of the pit is more likely reflected by the maize than the charcoal sample which may have been reworked from the underlying, older midden. Charcoal from the hearth (B-91642) within the clay layer overlying the sand blow yielded a 2σ calibrated date of A.D. 1470-1680, 1750-1810, 1940-1950. The latter two ranges can be disregarded because the Native American population was decimated by 1670. The earlier range is in line with radiocarbon date of the corn kernel from the pit and suggests that occupation of the site continued into the Late Mississippian. Results of radiocarbon dating of materials that pre- and post-date the sand blow indicate that the sand blow formed between A.D. 880 and 1420. The archeological and archeobotanical analyses further constrain the timing of the liquefaction event to A.D. 900 ± 100 yr.

2.9. Johnson Site

This site located north-northeast of Blytheville, Arkansas (Fig. 1.2B), was brought to our attention by the property owner, Mr. Carl Johnson, who is knowledgeable about archeological sites and sand blows in southeastern Missouri. He reported finding a Late Woodland or Early Mississippian arrow point near a sand blow at this archeological site (23PM60). During our initial site visit, a large sand blow was found with Woodland and Mississippian potsherds on the ground surface. In test pits dug at the site, we found an intact A horizon below the plow zone. Based on the depth and thickness of the remnant A horizon developed in the sand blow and the presence of ceramic artifacts that could help to date the sand blow, the site was selected for subsurface investigation.

Table 2.10. Summary of ceramics by temper type, Test Unit 1 the Huey's House site.

		Sand		Shell		Grog	
Depth in cmbs	ct.	%	ct.	%	ct.	%	ct.
40 - 50	40	13.6%	21	33.3%	0	0.0%	0
50 - 60	73	24.8%	39	61.9%	2	50.0%	11
60 - 70	114	38.8%	1	1.6%	0	0.0%	2
70 - 80	66	22.4%	2	3.2%	2	50.0%	22
80 - 105	1	0.3%	0	0.0%	0	0.0%	0
Total	294	100.0%	63	100.0%	4	100.0%	35

Table 2.10 continued.

	Grog & Sand		Shell & Sand		Shell & Grog		Total
Depth in cmbs	%	ct.	%	ct.	%	ct.	%
40 - 50	0.0%	0	0.0%	0	0.0%	61	14.6%
50 - 60	31.4%	4	36.4%	0	0.0%	129	30.9%
60 - 70	5.7%	3	27.3%	10	100.0%	130	31.2%
70 - 80	62.9%	4	36.4%	0	0.0%	96	23.0%
80 - 105	0.0%	0	0.0%	0	0.0%	1	0.2%
Total	100.0%	11	100.0%	10	100.0%	417	100.0%

We excavated two perpendicular and intersecting trenches oriented roughly E-W and N-S. The N-S trench intersected the E-W trench at its western termination. Large coalesced sand blows and their related feeder dikes were exposed in the trenches. The plow zone is about 25 cm thick. The base of an A horizon developed in the top of the sand blow remains intact in a few places below the plow zone. This remnant A horizon is thickest (about 15 cm) above the feeder dikes. Obviously, the A horizon had been thicker prior to plowing. Charcoal is abundant in the remnant A horizon and several samples were collected for radiocarbon dating. Several root casts extend downward from the horizon into the sand blow and soil lamellae had formed along textural boundaries within the sand blow as deep as 75 cm below the present surface.

Two feeder dikes were exposed in the E-W oriented trench (Fig. 2.40) and a third feeder dike was exposed in both the western end of the E-W trench (not shown in Fig. 2.40) and in the N-S oriented trench (Fig. 2.41). The large feeder dike in the E-W trench is about 47 cm wide, steeply dipping (subvertical), and oriented N 55-57°W. This feeder dike is characterized by irregularly shaped domains of medium to fine sand and very fine sand. Adjacent to this dike, the sand blow is about 25 cm thick and composed of medium to fine sand. A smaller sand dike, exposed in the same trench about 3.5 m west of the large dike, is 5 cm wide and has a strike and dip of N48°W 70°SW. The third dike exposed in the N-S trench is 32 cm wide and has a strike and dip of N52-

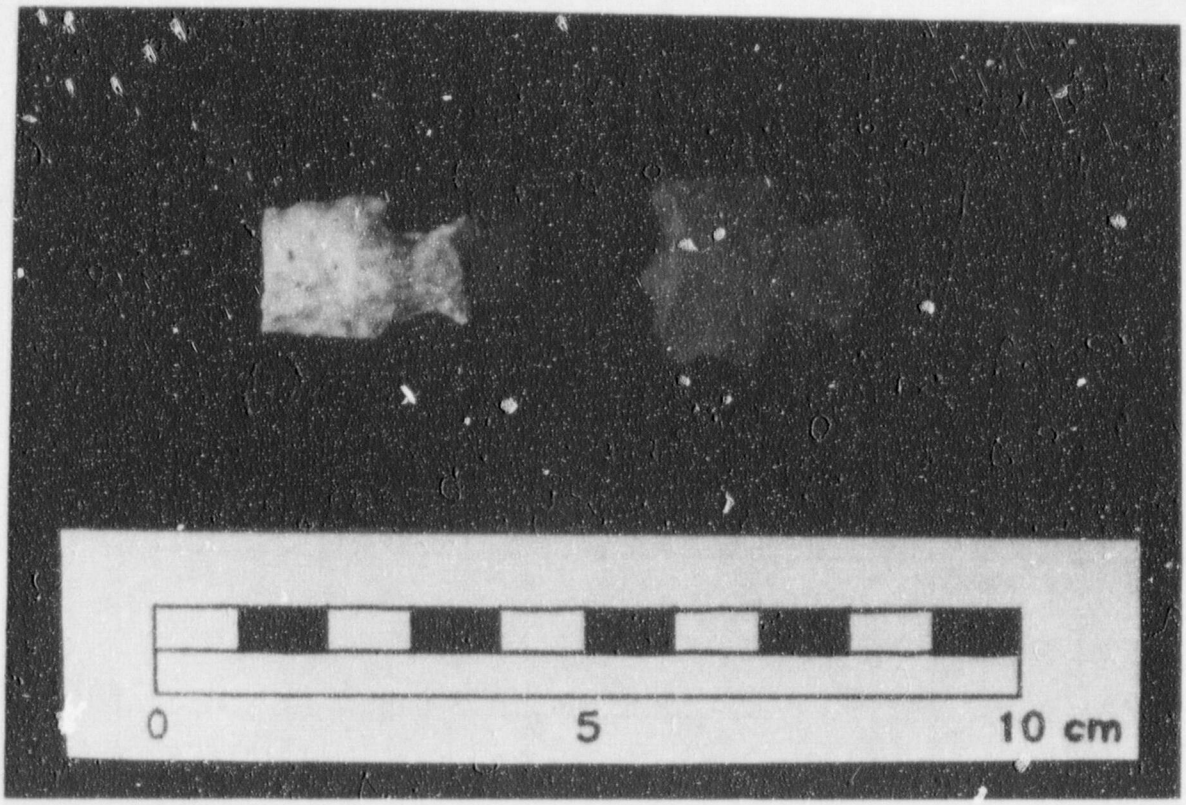


Figure 2.35. Projectile points from Hueys House site generally classified as Table Rock Stemmed, are transitional in size indicating the diffusion of the bow and arrow from north during Late Woodland (AAS Catalogue # 96-816: 39-9 & 7-1).

55°W 86°NW. The coalesced sand blows reach a thickness of about 1 m above this feeder dike. Here, the sand blow is composed of silty very fine sand overlain by medium to coarse sand. Silty very fine sand occurs within the dike and makes up that portion of the sand blow immediately above the dike. As seen in oblique section along the western end of the E-W trench, there is considerable variability in the grain-size of the sand blow along the strike of the dike.

During the archeological investigation, a surface collection was made of the site. Most of the cultural material, including large sherds and debitage (debris resulting from manufacture of stone tools) was found north of the trenches. More than half of the assemblage recovered is composed of lithics, predominantly Crowley's Ridge chert (Table 2.13). Recovered sherds include Baytown plain, Mulberry Creek cordmarked (grog-tempered), and Barnes cordmarked (sand-tempered), all characteristic of the Late Woodland period. One shell-tempered plain sherd was also recovered.

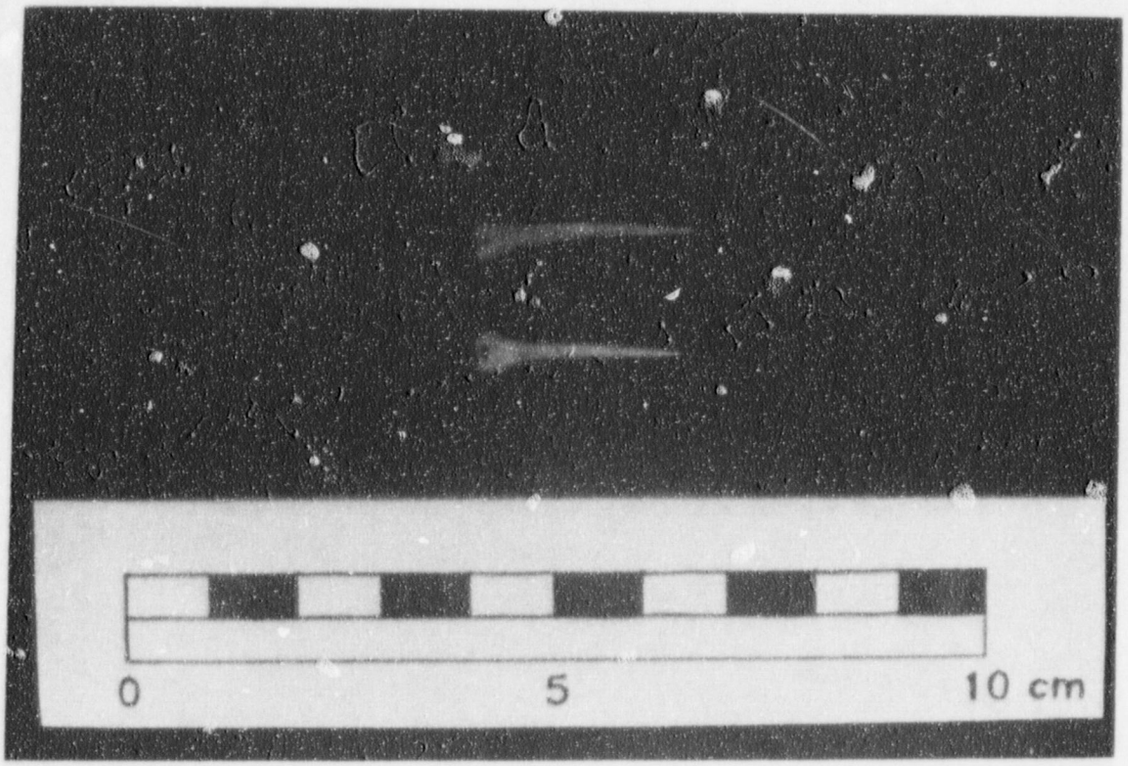


Figure 2.36. Bone needles from Hueys House site have highly polished tips that aided in their preservation (AAS Catalogue # 96-816: 29-1 & 29-13).

An archeological test unit (0.5 m^2) was excavated in the occupation horizon buried by the sand blow and adjacent to the large dike in the south wall of the trench (Fig. 2.40). Artifacts were also recovered from the buried horizon in the trench profile. Recovered artifacts are from a pre-sand blow context and include Varney Red Filmed, Barnes Plain and mixed-temper (grog and sand) sherds (Table 2.13). These types are characteristic of the Late Woodland to Early Mississippian periods. Artifacts recovered from this site suggest that the sand blow formed during or soon after the transitional period from the Late Woodland to the Early Mississippian.

The presence of a 15-cm thick remnant A horizon below the 25-cm-thick plow zone, as well as the development of soil lamellae within the sand blow, indicate that the sand blow is prehistoric in age. If the A horizon were 40 cm thick prior to cultivation, the sand blow would have been exposed to soil forming processes for 800 to 1000 yr. We dated a charcoal sample (B-102504) collected from the remnant A horizon overlying the sand blow and a soil sample (B-102505) collected immediately below the sand blow. The soil sample, which predates the sand blow, yielded a 2σ calibrated date of A.D. 770-1040 (Fig. 2.40 and Table 1.2). This age estimate for the buried

Figure 2.37. Grog-tempered miniature bowl from Hueys House site has rounded bottom, a style that persisted for over a millennium in this part of Mississippi Valley (AAS Catalogue #96-816-26-1).

horizon is similar to that based on the archeological analysis. The charcoal sample, which postdates the sand blow, yielded a 2σ calibrated date of A.D. 1540-1950. The maximum age of the sand blow is well-constrained, however, its minimum age is somewhat uncertain. Soil characteristics of the sand blow combined with archeological and radiocarbon analyses of the buried occupation horizon suggest that the sand blow formed between A.D. 770 and 1200. Additional dating of samples collected from the remnant A horizon is warranted to further constrain the minimum age of the sand blow. Our best guess at this time is that the sand blow formed during the A.D. 900 ± 100 yr event.

3. DISCUSSION OF RESULTS

The sand blows documented at the Brooke and Eightmile Ditch-5 sites probably formed during the 1811-1812 earthquakes. Very few sand blows known to have formed during the historic New Madrid earthquake sequence have been studied in the same detail as prehistoric features. Therefore, these historic features serve as reference sand blows for interpreting prehistoric

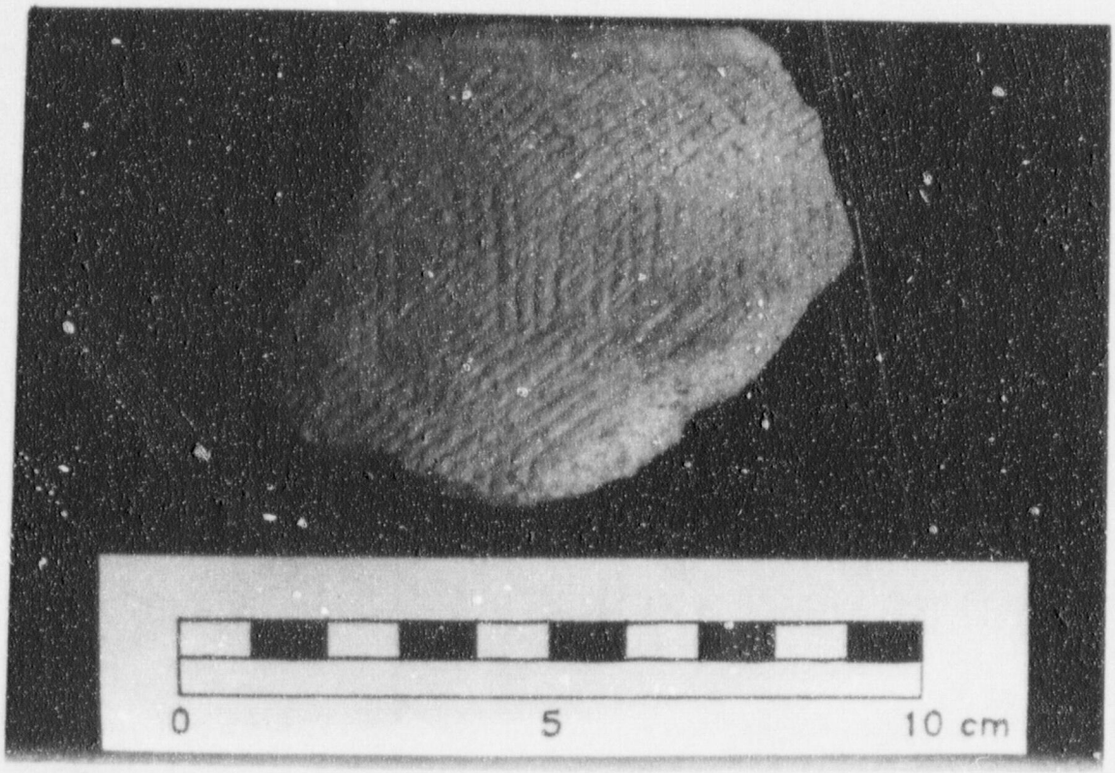


Figure 2.38. Barnes cordmarked sherd from Hueys House site shows overstamping of cord wrapped paddle. Rough surface helped keep pot from breaking from thermal shock (AAS Catalogue # 96-816-29-1).

liquefaction features. After more historic sand blows have been documented across the region, it will be possible to develop regional empirical relationships between liquefaction and various earthquake parameters. Ideally, this would include geotechnical testing at sites of historic liquefaction.

Our investigation at the Dodd site suggests that a large earthquake occurred in the NMSZ about A.D. 1530 ± 130 yr (Table 1.2). Additional field work conducted at this site in November 1997 supports this finding. Sand blows documented at three other sites, located 9 km southeast, 12 km southwest (Cooter and Yarbro on Fig. 1.2B; Craven, 1995; Tuttle, 1996) and 70 km northeast (Wilkerson Ditch on Fig. 1.1; Li et al., 1998) of the Dodd site, as well as deformation associated with the Reelfoot fault that occurred between A.D. 1260 and 1650 (Kelson et al., 1996; Fig. 1.1), may be related to this event. The sand blows at the three sites in the vicinity of the Arkansas-Missouri border are large, suggesting that the causative earthquake may have been centered nearby. If so, and the similar-age sand blow located at the Wilkerson Ditch site formed as a result of the same event, that earthquake would have been at least of **M** 7.2. Our estimates of earthquake magnitude are based on the relationship between moment magnitude and maximum distance from

Table 2.11. Aboriginal ceramics recovered from pre-quake contexts, Huey's House site.

Temper and Decoration	Body		Rim or Base		Total		
	ct.[1]	wt.[2]	ct.	wt.	ct.	wt.	%
sand - plain	22	85.6	4	37.8	26	123.4	0.0
sand - cordmarked	392	3176.8	6	196.6	398	3373.4	54.7%
sand - incised	1	3.8			1	3.8	0.1%
sand and shell-cordmarked	40	382.9	4	83.4	44	466.3	6.1%
sand and shell-plain	15	108.4			15	108.4	2.1%
grog - plain	3	19.1	3	67.9	6	87.0	0.8%
grog - cordmarked	8	42.6	1	39.5	9	82.1	1.2%
grog - redfilmed	1	10.1			1	10.1	0.1%
grog and sand - plain	13	100.3			13	100.3	1.8%
grog and sand - cordmarked	105	702.2	2	39.6	107	741.8	14.7%
grog and shell - plain	21	90.2			22	105.9	3.0%
grog and shell - cordmarked	1	8.8			1	8.8	0.1%
shell - plain	80	350.1			80	350.1	11.0%
shell - Bell Plain	1	11.7			1	11.7	0.1%
shell - red slipped	3	5.0			3	5.0	0.4%
miscellaneous sherds<1/4"		129.5				129.5	0.0%
Totals	706	5227.1	18	440.9	727	5707.6	100.0%

[1] count
[2] weight in grams

an inferred earthquake epicenter to surface evidence of liquefaction for central U.S. earthquakes (Ambraseys, 1988; Obermeier et al., 1993; and Pond, 1996). Since the actual limits of liquefaction for the prehistoric events have yet to be determined, these magnitude estimates represent minimum values. Alternatively, the sand blows may have formed as a result of an earthquake generated by the Reelfoot fault, or earthquakes generated by the Reelfoot fault and the southern branch of the NMSZ. At this time, there are too few sites to draw definitive conclusions about the timing, size, and location of A.D. 1530 ± 130 yr event. Additional reconnaissance and site investigations are needed to further define size distribution of liquefaction features that formed during this event.

Could a very large New Madrid earthquake have occurred between A.D. 1600 and 1670 and not been recognized in the historic record? During this period, European settlements were established at Quebec along the St. Lawrence River, in the Georgian Bay area of Lake Huron, in coastal areas of Massachusetts, New Hampshire, and Rhode Island, and along the Connecticut River in Connecticut, the Hudson River in New York, the lower reaches of the Delaware River, the Potomac River in Maryland, and the James River in Virginia (Garraty, 1966). The December 16, 1811 earthquake was felt and reported in Charlestown, New Hampshire, Washington, D.C., and Norfolk, Virginia, and assigned Modified Mercalli (MM) intensities of II-III, IV-V, and V,

Table 2.12. Ceramic artifacts recovered from post earthqauke cultural features 1 and 2, Huey's House site.

Temper and Decoration	Body		Rim		Total		
	ct.[1]	wt.[2]	ct.	wt.	ct.	wt.	%
sand - plain	9	17.9	1	0.3	10	18.2	11.2%
sand - cordmarked	56	345.7			56	345.7	62.9%
sand - incised			1	2.9	1	2.9	1.1%
grog - plain	5	12.5	1	6.8	6	19.3	6.7%
grog - redfilmed	1	1.6			1	1.6	1.1%
grog and sand - plain	6	12.3			6	12.3	6.7%
grog and sand - cordmarked	4	10.7	1	1.3	5	12.0	5.6%
grog and shell - cordmarked	1	5.1			1	5.1	1.1%
shell - plain	3	8.9			3	8.9	3.4%
miscellaneous sherds<1/4"		67.9				67.9	0.0%
Totals	85	482.6	4	11.3	89	493.9	100.0%

[1] count
[2] weight

respectively (Nuttli, 1973). Ground shaking for the January 23, 1812 earthquake was of MM intensity IV in Toronto, Canada, Jamaica, New York (Long Island), and Annapolis, Maryland, III-IV in Alexandria, Virginia, and III in Baltimore, Maryland (Nuttli, 1973). Ground shaking for the February 7, 1988 earthquake was of MM intensity V in Washington, D.C., and IV-V in New York, New York, Baltimore, and Alexandria (Nuttli, 1973). It seems possible, especially during the early 1600s, that low levels of ground shaking related to a very large New Madrid earthquake may not have been reported at all these localities and may not have been recognized as a New Madrid earthquake. It is important to address this issue. A review of the historic record between A.D. 1600 and 1670 seems warranted.

Liquefaction features at most of the study sites, including Bugg 40, Central Ditch, Hillhouse, Hueys House, and Johnson, formed about A.D. 900 ± 100 yr (Table 1.2). The Central Ditch site is spatially associated with the southern branch of the NMSZ and occurs close to its southern terminus (Fig. 1.1). This site represents the southernmost expression of this event to date. Bugg 40, Hueys House, and Johnson sites occur from 70 to 90 km northeast of the Central Ditch site and are also associated with the southern branch of the NMSZ (Fig. 1.1 and 1.2B). The Hillhouse site occurs about 100 km northeast of the Johnson site, northeast of the northern branch of the NMSZ, and near the northern limit of surficial sand blows mapped by Obermeier (1989). To date, the Hillhouse site represents the northernmost expression of liquefaction induced by the A.D. 900 ± 100 yr earthquake. Sand blows of this age are documented at Towosahgy archeological site (S1 on Fig. 1.1; Saucier, 1991) and Wilkerson Ditch (Fig. 1.1; Li et al., 1998) located 25 km and 38

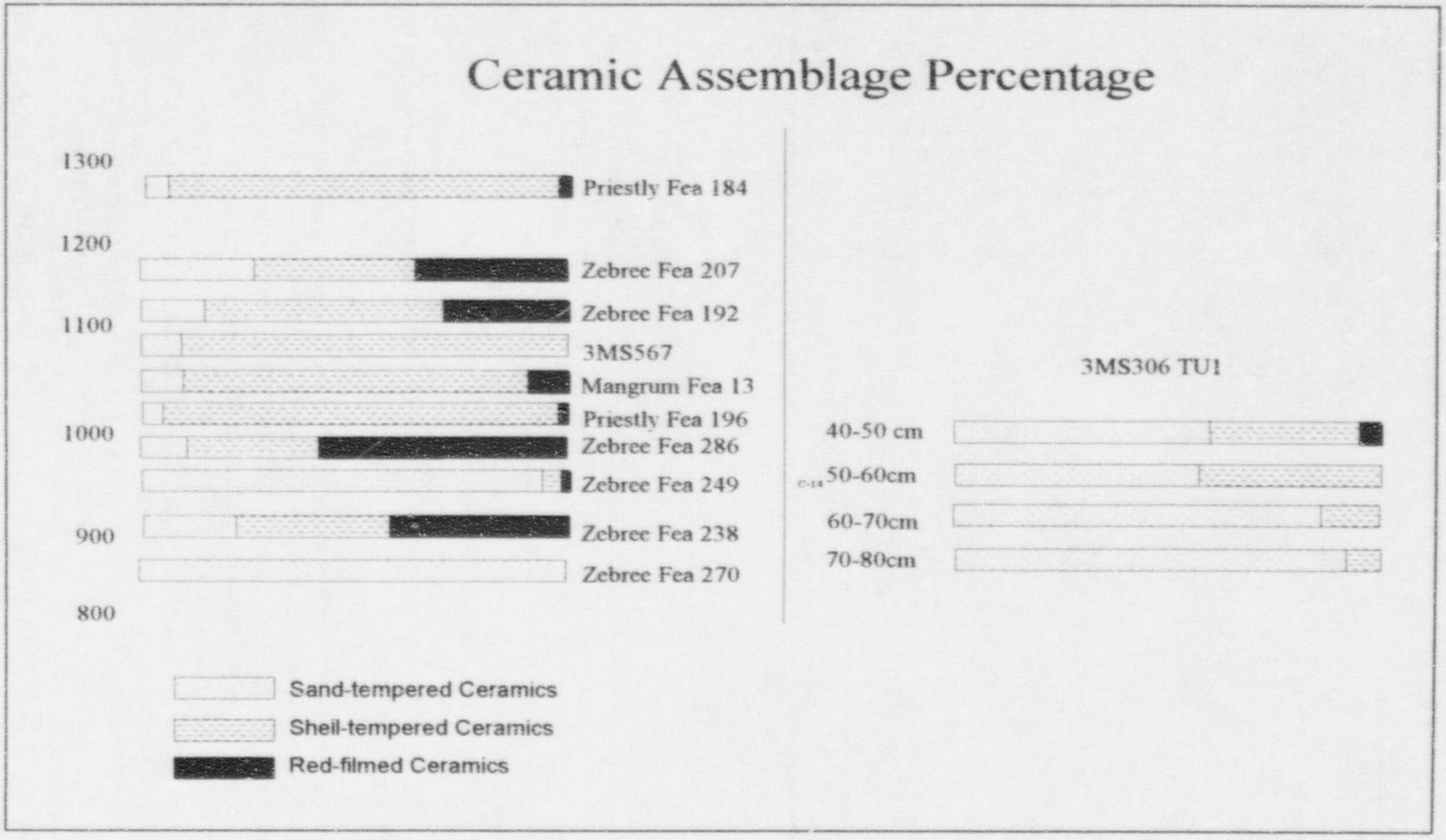


Figure 2.39. Temper percentages from dated contexts arranged by calibrated radiocarbon age. After A.D. 1000 shell-tempered pottery predominates in this locality.

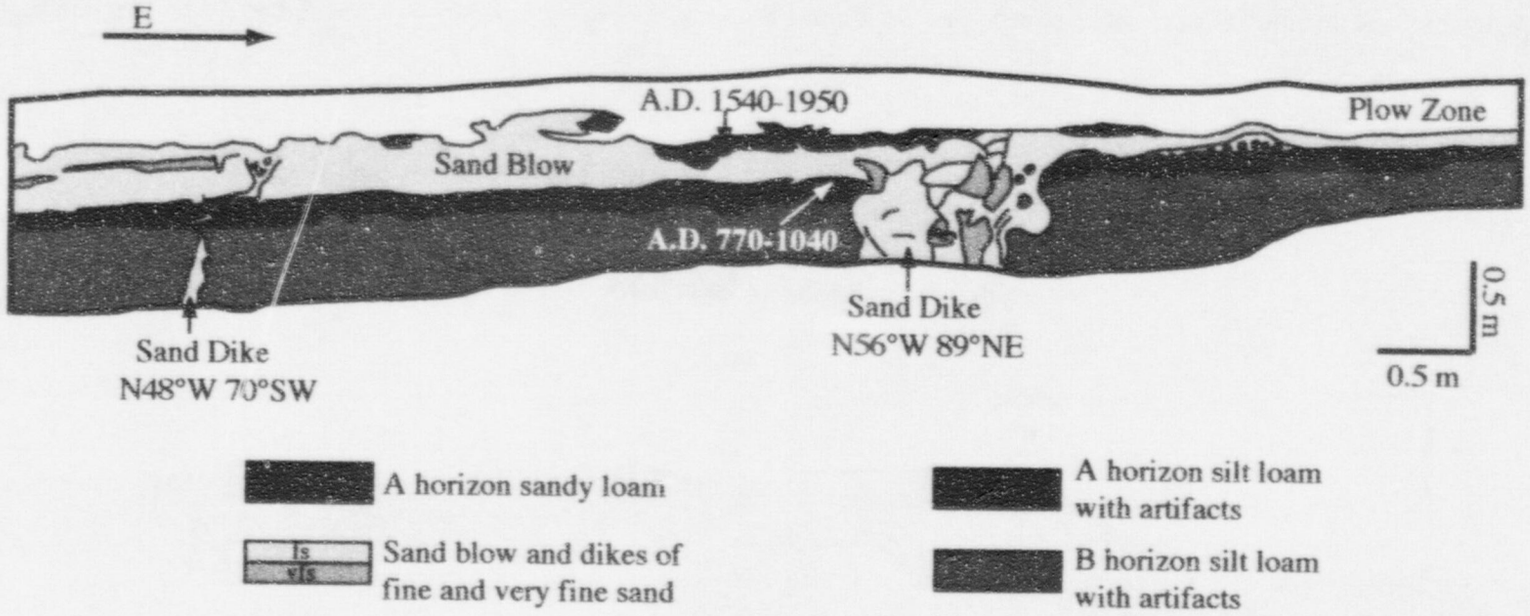


Figure 2.40. Log of eastern portion of E-W oriented trench showing sand blow and related sand dikes at Johnson site located north-northeast of Blytheville, Arkansas. Larger sand dike is composed of irregularly shaped domains of sand that may represent different injection phases. This sand blow buried a Late Woodland to Early Mississippian midden. A remnant A horizon below the plow zone and soil lamellae within the sand blow deposit suggest that it has been subjected to soil development for as much as 1000 yr. This sand blow may have formed about A.D. 900 +/- 100 yr.

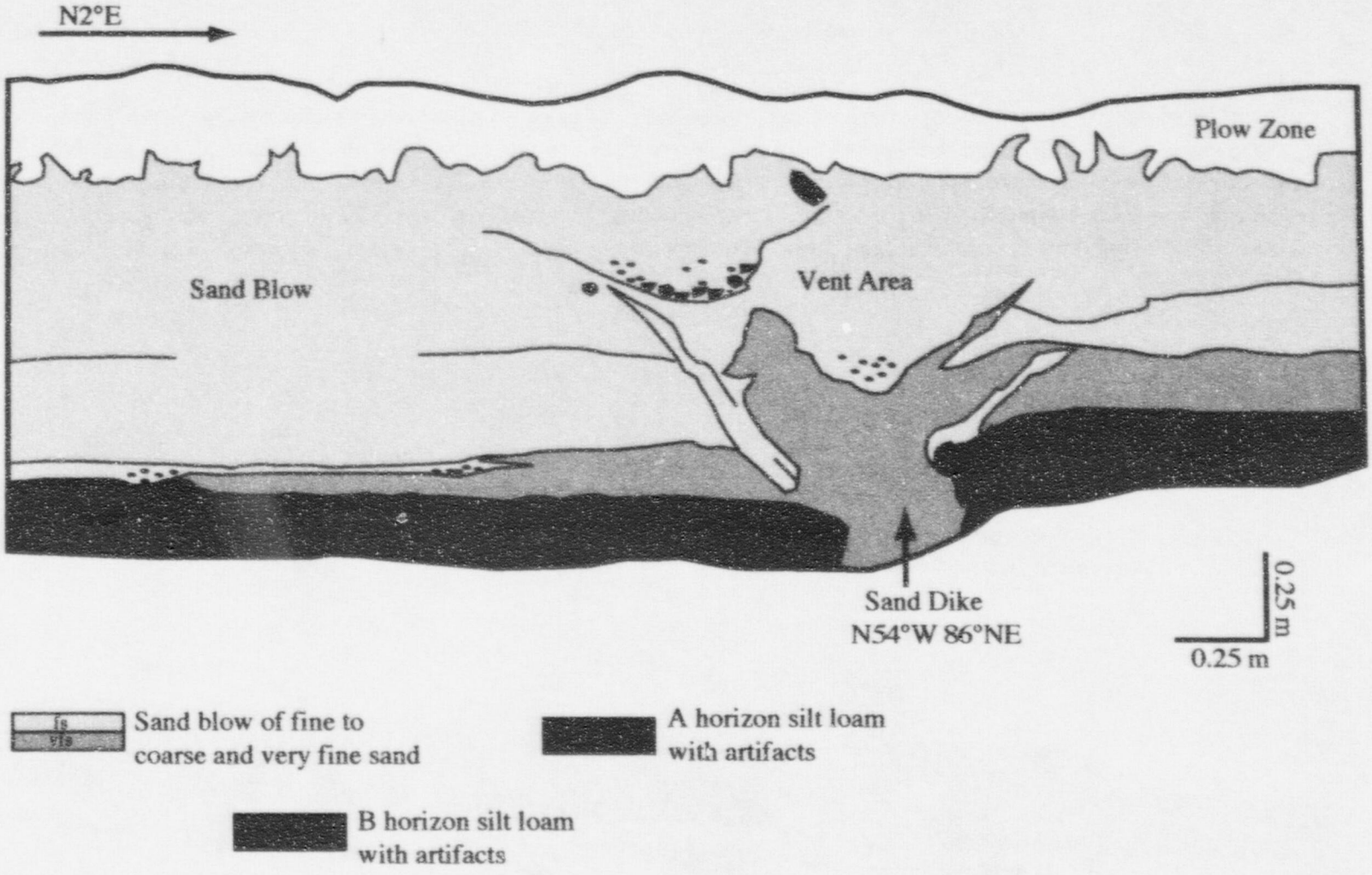


Figure 2.41. Log of portion of N-S oriented trench showing sand blow and related sand dikes at Johnson site located north-northeast of Blytheville, Arkansas. N-S trench intersected E-W trench at its western end. Notice cross-cutting relationships and subvertical flow structure typical of sand blow deposits above feeder dikes. Much lateral variability in grain-size of sand blow deposit occurs in vent area along strike of feeder dike.

Table 2.13. Artifacts from the Johnson site.

	Post-Earthquake		Pre-Earthquake			
	General surface		Test Unit 1		BHTR[1] 1	
Artifact Description	ct.[2]	wt.[3]	ct.	wt.	ct.	wt.
Chipped lithics						
biface	2	34.5				
core	10	421.4				
hammer	1	25.6				
flake	17	48.8	1	0.1	2	1.9
flake, retouched	46	6.8				
flake, decortication	3	8.2				
shatter	2	22.9			1	1.2
Plain ceramics						
grog tempered base (Baytown)	1	45.0				
grog tempered body	23	60.1				
grog & sand-tempered body			1	0.5		
grog & shell tempered body	1	4.0				
sand-tempered body (Barnes)	20	85.7			2	9.4
shell tempered	1	9.2			5	2.8
Red-filmed grog & shell tempered					1	3.4
Cord marked ceramics						
sand tempered body	4	7.8				
grog tempered body	1	1.6				
Miscellaneous ceramics						
daub	2	3.4				
fired clay			2	1.3		
sherds <¼"			4	1.2		
Totals	134	785.0	8	3.1	11	18.7

[1] backhoe trench
[2] count
[3] weight in grams

km to the south, respectively. Kelson et al. (1996) have recognized a similar age event in their trenches across the Reelfoot scarp (K1 on Fig. 1.1). The Reelfoot scarp is thought to reflect deformation above the Reelfoot fault which is spatially coincident with the middle branch of the NMSZ.

The largest liquefaction features that formed in the A.D. 900 ± 100 yr earthquake are those in the Blytheville, Arkansas, area (Bugg 40, Hueys House, and Johnson sites). If all the A.D. 900 features formed as the result of one earthquake, the size distribution of liquefaction features

suggests that the causative earthquake was centered near Blytheville. If this were the case and this event induced liquefaction 90 km to both the northeast and southwest, it would have been of $M \geq 7.3$. As explained above, this value reflects a minimum estimate of magnitude. As new sites are found and dated, the distance from an inferred epicenter to liquefaction features that formed during this earthquake are likely to increase, which would lead to greater magnitudes estimates.

With the exception of the northern part of the NMSZ, we have found liquefaction features that formed in 1811-1812 in the same areas where we have found features that formed in A.D. 900 ± 100 yr. Fuller (1912) did not map 1811-1812 sand blows much farther north than New Madrid, Missouri or in the Mississippi River floodway east of Sikeston's Ridge. Based primarily on aerial photograph interpretation, Obermeier (1989) recognized sand blows as far north as Sikeston, Missouri, both east and west of Sikeston's Ridge. As we conduct more field work in the northern part of the NMSZ, we will determine whether historic sand blows occur there. If so, the areal distribution of liquefaction features that formed in 1811-1812 and A.D. 900 ± 100 yr would be quite similar, suggesting that the two earthquake sequences also may have been similar. Recent modeling of the 1811-1812 sequence shows that the southern, middle, and northern branches of the New Madrid fault system would have had to rupture to generate the observed ground deformation and the seismic moment release implied by the observed far field ground motion intensities (Ellis et al., 1995; Johnston, 1996). Perhaps, all three branches of the fault system ruptured in A.D. 900 ± 100 yr, as they did in 1811-1812, generating three M ~8 earthquakes.

At least two prehistoric earthquakes large enough to induce liquefaction are recorded at the Current River-8 site. The earlier of the two events probably occurred soon after 3490 B.C. or about 5,490 yr B.P. The age of the later event is poorly constrained. However, this event could have been responsible for another sand blow located only 10 km to the southwest that formed in A.D. 1380 ± 70 yr (see Current River-2 on Fig. 1.1; Table 1.2). This sand blow is very large (1 m thick and at least 80 m in diameter) and much larger than sand blows documented at the Central and Wilkerson Ditch sites towards the southern and northern margins of the NMSZ, respectively. This suggests that the large sand blow along the Current River did not form as a result of a New Madrid earthquake at least 80 km away, but instead resulted from a more local earthquake.

We found numerous liquefaction features, mostly sand dikes, along portions of the Current and Black Rivers in the western Lowlands that formed during the past 5,500 yr. At this time, no young sand blows that could be related to the 1811-1812 earthquakes have been found in this area. Initial reconnaissance along these two rivers suggests that the size and frequency of liquefaction features increase in the vicinity of the Commerce geophysical lineament (Tuttle and Schweig, 1998). This suggests that a fault associated with the lineament may be an active earthquake source. The English Hills fault, also associated with the lineament and located 150 km to the northeast of Current River-8, has experienced strike- and dip-slip motion during the late Pleistocene and Holocene (Palmer et al., 1997). The liquefaction features along the Current and Black Rivers may indicate that faults associated with the lineament, such as the English Hills fault, are seismogenic as has been suspected. Additional reconnaissance of the Black and Current Rivers is planned in the near future.

4. CONCLUSIONS

Investigations of earthquake-induced liquefaction features at nine sites indicates that significant earthquakes struck the New Madrid region in A.D. 900 ± 100 yr and A.D. 1530 ± 130 yr and that

a distinct earthquake source, possibly associated with the Commerce geophysical lineament, may be present in the western Lowlands.

The A.D. 900 ± 100 yr earthquake(s) induced severe liquefaction over much the same area affected by the 1811-1812 earthquakes, and therefore, may have been similar to the historic sequence. The areal distribution of liquefaction features, which is likely to enlarge with additional reconnaissance, suggests that this event was of $\mathbf{M} \geq 7.3$.

The Dodd site, investigated for this project, suggests a significant earthquake about A.D. 1530 ± 130 yr. To date, there is evidence for this event at a few liquefaction sites and possibly three fault sites along the Reelfoot scarp (Kelson et al., 1996). The size distribution of liquefaction features suggests that this earthquake may have been centered near Blytheville, Arkansas, and been of $\mathbf{M} \geq 7.2$. This conclusion is supported by the similarity in size of the sand blows that formed about A.D. 1530 with those that formed in 1811-1812.

During previous studies, we have suggested that another significant earthquake struck the New Madrid region about 1300 ± 100 yr (Tuttle et al., 1996). Liquefaction features attributed to this event occur in the vicinity of Blytheville, Arkansas, and 35 km to the southwest along Kochtitzky Ditch (Fig. 1.1). The age ranges for several of these features are quite broad. Currently, we are reevaluating the age data for these features to determine if some of them could have formed during the A.D. 900 ± 100 yr or A.D. 1530 ± 130 yr event, rather than an event in A.D. 1300 ± 100 yr.

The age of the large sand blow at Current River-2 site overlaps with the liquefaction features in the NMSZ that formed about 1530 ± 130 yr. Although some of the sand dikes along the Current and Black Rivers may be related to New Madrid earthquakes, no young sand blows related to the 1811-1812 earthquakes have yet been found in this area. This suggests that the sand blow at Current River-2 site resulted from a local earthquake which occurred about A.D. 1380 ± 70 yr rather than from a prehistoric New Madrid earthquake. These observations raise the question whether there is an earthquake source in the western Lowlands, perhaps associated with the Commerce geophysical lineament, capable of generating large earthquakes. Additional reconnaissance and documentation of liquefaction features in the area will test this possibility.

Taken together, results of this project and other paleoseismological studies indicate that very large prehistoric earthquakes were centered in the New Madrid seismic zone in A.D. 900 ± 100 yr and A.D. 1530 ± 130 yr. The A.D. 900 event(s) was probably similar to the 1811-1812 earthquake sequence. Less is known about the A.D. 1530 event(s), but it is likely to have been very large as well. These data suggest that very large earthquakes occurred in the NMSZ every 200 to 900 yr during the past 1200 yr.

More work is necessary to better quantify the magnitude of the seismic hazard in the New Madrid region. It is critical for structural design in the region to know whether the high seismicity rate that we see today is ephemeral or indicative of the long-term hazard. This ongoing project will contribute towards this end by further defining the age and size distribution of liquefaction features, the source areas and magnitudes of prehistoric earthquakes, and thus the occurrence rates of damaging earthquakes in the NMSZ.

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Appendix A
Artifact Tables

Table A1. Artifacts recovered from test units at the Brooke site (23PM56)

Artifact Description	Test Unit 1					
	0-25 cmbs[1]		33 cmbs		25-36 cmbs	
	ct.[2]	wt.[3]	ct.	wt.	ct.	wt.
Chipped lithics						
flake	23	11.1	6	4.3	2	1.3
shatter	4	8.9	1	7.2		
Punctated shell-tempered body ceramics	2	1.6				
Plain ceramics						
grog-tempered body	1	1.4				
grog-tempered rim	1	0.4				
sand-tempered body	1	1.8				
sand-tempered rim	2	1.4				
shell-tempered body	5	5.6	13	61.6		
Miscellaneous ceramics						
fired clay	nc[4]	130.8	nc	3.8	nc	1.2
daub	6	41.1				
sherds <¼"	18	6.0	7	1.6		
Charcoal	13	7.8			9	6.8
Bone			nc	7.9	1	0.1
Totals	76	217.9	27	86.4	12	9.4

[1] centimeters below surface
[2] count
[3] weight in grams
[4] no count

Table A1 continued

Artifact Description	Test Unit 1							
	35-52cmbs		40-50 cmbs		63 cmbs		52-72 cmbs	
	ct.	wt.	ct.	wt.	ct.	wt.	ct.	wt.
Chipped lithics								
core							1	18.2
flake	6	4.1	2	0.9			7	3.2
Notched and appliqued ceramics								
shell-tempered rim							1	10.5
Plain ceramics								
sand-tempered rim							1	0.2
shell-tempered body	4	3.7	2	0.7	1	4.6	5	6.6
shell-tempered rim			1	3.2				
Red-filmed ceramics								
shell-tempered plain body							1	0.3
Miscellaneous ceramics								
fired clay	nc	6.4	nc	1.9			nc	6.3
poverty point object	1	13.4						
sherds <¼"	8	2.7					9	2.4
Charcoal							1	0.1
Bone	1	0.2					1	0.1
Totals	20	30.5	5	6.7	1	4.6	27	47.9

Table A1 continued.

Artifact Description	Test Unit 1							
	30-90 cmbs		72-93 cmbs		100-115 cmbs		140 cmbs	
	ct.	wt.	ct.	wt.	ct.	wt.	ct.	wt.
Chipped lithics								
flake			1	0.1			5	14.4
flake, polished	1	0.6						
flake, decortication					1	4.2	2	7.2
shatter							2	7.2
Plain ceramics								
grog-tempered body	1	5.4						
grog & shell-tempered rim			1	4.2				
shell-tempered body			3	1.4	5	6.7	5	117.6
shell-tempered rim	1	13.0						
Miscellaneous ceramics								
fired clay	nc	7.4	nc	1.7			nc	14.4
sherds <¼"							22	9.1
Charcoal							nc	1.6
Bone							nc	3.2
Fire-cracked sandstone			1	1.2				
Totals	3	26.4	6	8.6	6	10.9	36	174.7

Table A1 continued

Artifact Description	Test Unit 2					
	0- 20 cmbs		20-30 cmbs		30-40 cmbs	
	ct.	wt.	ct.	wt.	ct.	wt.
Chipped lithics						
biface	1	2.1				
flake	41	10.8	56	16.7	6	1.3
flake, decortication	8	12.0	4	4.8		
pebble, tested			1	36.9		
Punctated ceramics						
shell-tempered body			2	2.6	1	2.6
Notched and appliqued ceramics						
grog-tempered rim			1	4.1		
Plain ceramics						
grog-tempered body			1	2.9	1	5.0
grog & shell-tempered body	1	1.7				
grog & shell-tempered rim					1	1.1
shell-tempered body	3	6.8	6	7.8	12	67.6
shell-tempered rim			13	8.8	2	7.9
Burnished ceramics						
shell-tempered body					1	3.6
Miscellaneous ceramics						
fired clay	nc	278.3	nc	323.6	nc	76.8
daub	6	50.4	17	297.7	4	55.4
sherds <¼"	37	12.0	3	1.2	14	5.6
Charcoal					5	0.1
Bone	1	0.1	4	0.7	9	1.0
Fire-cracked sandstone	1	1.2				
Totals	99	375.1	108	707.8	56	228.3

Table A1 continued.

Artifact Description	Test Unit 2					
	40-55 cmbs		50-60 cmbs		60-70 cmbs	
	ct.	wt.	ct.	wt.	ct.	wt.
Chipped lithics						
flake	5	2.3			2	0.3
Plain ceramics						
shell-tempered body	1	0.9	2	5.7	2	11.2
shell-tempered rim	1	1.9	1	5.1		
Miscellaneous ceramics						
fired clay	nc	37.2	nc	5.1		
daub	11	46.8				
sherds <¼"	11	4.8	1	0.2		
Charcoal	3	0.1				
Bone	14	2.6				
Totals	46	96.6	4	16.1	4	11.5

Table A1 continued.

Artifact Description	Test Unit 2			
	50-75 cmbs		80-90 cmbs	
	ct.	wt.	ct.	wt.
Chipped lithics				
flake	1	2.1		
flake, decortication	1	6.5		
Plain ceramics				
shell-tempered body	2	4.6		
Miscellaneous ceramics				
fired clay	nc	26.0	nc	0.6
sherds <¼"	6	2.3		
Bone	12	2.4		
Totals	22	43.9	nc	0.6

Table A2. Artifacts recovered from test units at the Bugg 40 site (3MS307).

Artifact Description	Test Unit 1			
	20-30 cmbs[1]		30-40 cmbs	
	ct.[2]	wt.[3]	ct.	wt.
Plain ceramics				
grog & shell-tempered body	1	3.3		
shell & sand-tempered body			1	3.1
Red-filmed ceramics				
shell-tempered plain body			1	3.7
Miscellaneous ceramics				
fired clay	nc[4]	1.8		
modeled object, grog & shell-tempered	1	5.7		
Totals	2	10.8	2	6.8

Table A2 continued.

Artifact Description	Test Unit 2			
	101-111 cmbs		111-121 cmbs	
	ct.	wt.	ct.	wt.
Plain ceramics				
shell-tempered body	1	1.9	2	6.4
Red-filmed ceramics				
shell-tempered plain body	2	2.7		
Miscellaneous ceramics				
fired clay	nc	13.5	nc	3.6
Historic material				
plastic	1	1.0		
Totals	4	19.1	2	10.0

[1] centimeters below surface
[2] count
[3] weight in grams
[4] no count

Table A2 continued.

Artifact Description	Test Unit 3							
	22-39 cmbs		39-47 cmbs		47-57 cmbs		57-67 cmbs	
	ct.	wt.	ct.	wt.	ct.	wt.	ct.	wt.
Chipped lithics								
flake	1	1.9						
Cord marked ceramics								
sand-tempered body					1	3.8	1	3.4
sand-tempered rim	1	4.4						
Incised ceramics								
sand-tempered body			1	18.1				
sand & grog-tempered body					1	8.9		
Plain ceramics								
grog-tempered body	1	5.8						
grog & shell-tempered body			2	4.7	7	57.0		
grog & shell-tempered rim							1	12.6
sand-tempered body							2	9.9
sand & shell-tempered body			1	3.0			1	2.5
shell-tempered body	8	29.1						
Red-filmed ceramics								
sand & shell-tempered plain body			1	2.9				
shell-tempered plain body					2	12.5		
Miscellaneous ceramics								
fired clay	nc	14.3	nc	42.1	nc	19.6	nc	0.4
sherds <¼"	5	5.1			2	5.1	2	3.3
Charcoal							nc	0.2
Totals	16	60.6	5	70.8	13	106.9	7	32.3

Table A2 continued

Artifact Description	Test Unit 4					
	0-10 cmbs		10-20 cmbs		20-30 cmbs	
	ct.	wt.	ct.	wt.	ct.	wt.
Chipped lithics						
shatter					2	0.4
Cord marked ceramics						
sand-tempered body					1	7.0
Miscellaneous ceramics						
fired clay	nc	3.7			nc	5.3
sherds <¼"			nc	1.9		
Historic material						
glass bottle, modern colored	2	1.8				
Charcoal					nc	0.3
Totals	2	5.5	nc	1.9	3	13.0

Table A3. Artifacts recovered from test units at the Dodd site (23PM46).

	Test Unit 1					
Artifact Description	0-25 cmbs[1]		25-35cmbs		25-45[2] cmbs	
	ct[3]	wt[4].	ct.	wt.	ct.	wt.
Chipped Lithics						
flake	7	3.6			4	1.3
flake, decortication	2	7			1	0.6
shatter			11	15.1		
Organic Remains						
bone					1	0.4
charcoal			4	0.1		
Historic Materials						
glass			1	1.1		
Plain Ceramics						
grog-tempered body (Baytown)	2	4.7			3	8.8
grog & sand-tempered body	6	10.1	9	37.2		
shell-tempered body (Neeley's Ferry)	15	30.1			22	38.0
shell-tempered burnished body (Bell)					6	18.5
Miscellaneous Ceramics						
fired clay	31	12.3	10	6.6	22	15.6
sherds <¼"	9	4.1	5	1.8	27	10.2
Decorated Ceramics						
notched applique rim	2	7.1				
Totals	74	79.0	40	61.9	86	93.4

[1] centimeters below surface
[2] flotation sample heavy fraction
[3] count
[4]. weight in grams

Table A3 continued.

Artifact Description	Test Unit 1					
	35-45 cmbs		45-55 cmbs		55-65 cmbs	
	ct.	wt.	ct.	wt.	ct.	wt.
Chipped Lithics						
pebble, tested			1	7.1		
debitage			4	0.1		
flake	16	15.2	1	0.1	51	19.6
flake, decortication	3	2.5			6	5.7
shatter	18	5.3	3	0.9		
arrow point, Madison	1	1.5				
biface, polished					1	1.2
Organic Remains						
bone	2	0.6			1	1.2
charcoal	6	0.9				
Plain Ceramics						
grog-tempered body (Baytown)					2	2.1
shell-tempered body (Bell)	2	5.0				
shell-tempered body (Neeley's Ferry)	7	15.6			26	59.7
Miscellaneous Ceramics						
fired clay			3	0.8	nc[5]	11.3
sherds <¼"					24	7.8
Decorated Ceramics						
shell-tempered notched rim	1	17.2				
Totals	56	63.8	12	9.0	111	108.6

[5] no count

Table A3 continued

Artifact Description	Test Unit 2 0-30 cmbs		Totals	
	ct.	wt	ct.	wt.
Chipped Lithics				
pebble, tested			1	7.1
debitage			4	0.1
flake			79	39.7
flake, decortication			12	15.8
shatter			32	21.3
arrow point, Madison			1	1.5
biface, polished			1	1.2
Organic Remains				
bone			4	2.2
charcoal			10	1.0
Historic Materials				
glass			1	1.1
Plain Ceramics				
grog-tempered body (Baytown)			7	15.6
grog & sand-tempered body			15	47.3
shell-tempered body (Bell)			2	5.0
shell-tempered body (Neeley's Ferry)	8	35.2	79	178.6
shell-tempered burnished body (Bell)			6	18.5
Miscellaneous Ceramics				
fired clay			66	46.6
sherds <¼"	8	6.3	73	30.2
Decorated Ceramics				
shell-tempered notched rim			1	17.2
notched applique rim			2	7.1
Totals	16	41.5	395	457.1

Table A4. Artifacts recovered from backhoe trench 1 at the Dodd site (23PM46).

	0-2.2m[1] NE[2]				Feature 1	
Artifact Description	20-25 cmbs[3]		44.0 cmbs		48-80 cmbs	
	ct.[4]	wt.[5]	ct.	wt.	ct.	wt.
Chipped lithics						
biface					1	3.3
flake	8	6.0	2	1.4	24	7.3
cobble tool					1	7.8
shatter			3	11.9	11	1.0
Decorated ceramics shell-tempered body			1	3.1		
Plain ceramics						
grog & sand-tempered body			10	97.6		
grog & shell-tempered body	3	6.2	3	15.2	10	14.2
shell-tempered body - Bell Plain	10	62.9				
Burnished ceramics						
shell-tempered body - Bell Plain	2	3.1			2	2.2
Miscellaneous ceramics						
fired clay					nc[6]	67.1
daub					39	239.6
sherds <¼"	7	1.7	1	0.1	4	0.9
Fire-cracked sandstone					2	1.0
Totals	30	79.9	20	209.2	94	344.4

[1] meters
[2] northeast
[3] centimeters below surface
[4] count
[5] weight
[6] no count

Table A4 continued.

Artifact Description	0-1m NE 50-70 cmbs		1-2.2m NE 44-64cmbs		1-2.2m NE 64-70 cmbs	
	ct.	wt.	ct.	wt.	ct.	wt.
Chipped lithics						
arrow point - Nodena			2	1.4		
flake	8	3.4	16	14.0		
shatter	12	22.3	9	10.4		
Notched ceramics						
shell-tempered body - Bell Plain	1	14.2				
Plain ceramics						
grog-tempered rim			1	1.3		
grog & sand-tempered body			7	14.8		
grog & sand-tempered rim			1	1.5		
shell-tempered body	54	75.3	26	68.1	1	1.2
shell-tempered body - Bell Plain	1	0.1				
shell-tempered rim	1	0.8	4	11.7		
Miscellaneous ceramics						
fired clay	40	83.3	88	142.1	nc	3.5
modeled object			2	4.0		
daub			17	210.9		
sherds <¼"			29	16.1		
Bone					1	0.4
Totals	117	199.4	202	496.5	2	5.0

Table A5. Artifacts recovered from the surface of Huey's House site (3MS306).

Artifact Description	10 x 10 m[1] CSC[2]		General Surface		Pipeline Surface		Total	
	ct.[3]	wt.[4]	ct.	wt.	ct.	wt.	ct.	wt.
Chipped Lithics								
shatter	4	5.8					4	5.8
Unmodified Lithics								
sandstone						45.2		45.2
fire cracked chert	nc[5]	21.8						21.8
basalt						21.4		21.4
chert		89.3						89.3
Cord-marked ceramics								
sand tempered	74	177.8	5	84.4	16	161.2	95	423.4
grog & shell tempered					1	9.5	1	9.5
grog & sand tempered			1	42.7	4	23.5	5	66.2
gand & shell tempered					5	43.3	5	43.3
Plain ceramics								
grog tempered rim	3	10.7					3	10.7
sand tempered body	2	7.5			1	17.2	3	24.7
shell tempered body					5	44.1	5	44.1
grog & sand tempered	3	11.3					3	11.3
grog & shell tempered					1	3.4	1	3.4
sand & shell tempered			1	12.5	1	14.1	2	26.6
Shell tempered								
red filmed incised					1	3.8	1	3.8
red filmed			2	20.3	1	10.8	3	31.1
Miscellaneous ceramics								
fired clay	nc	46.9					nc	46.9
sherds <¼"	nc	30.6			2	3.7	2	34.3
Historic material								
glass, modern colored	1	2.5					1	2.5
brick	1	2.8					1	2.8
Total	87	407.0	9	159.9	38	401.2	134	968.1

[1] meter
[2] controlled surface collection
[3] count
[4] weight in grams
[5] no count

Table A6. Artifacts recovered from Test Unit 1 at the Hueys house site (3MS306).

Artifact Description	40-50 cmbs[1]		50-60 cmbs		60-70 cmbs	
	ct.[2]	wt.[3]	ct.	wt.	ct.	wt.
Chipped lithics						
core	1	8.8				
flake, modified	1	5.1				
dart point, tablerock stemmed					1	3.3
Unmodified lithics, quartzite					1	79.0
Unmodified raw material, chert	1	13.5				
Fire cracked chert	1	16.4	1	24.7		
Cord marked ceramics						
sand-tempered body	43	238.7	72	744.8	113	1145.5
sand-tempered rim, everted flat					3	116.6
sand-tempered rim, everted	1	9.5			2	70.5
grog & shell-tempered body					1	8.8
grog & sand-tempered body					2	19.2
Plain ceramics						
grog-tempered body	1	0.9	1	16.8		
grog-tempered rim, everted flat			1	35.6		
sand-tempered body			6	7.5	10	44.7
sand-tempered rim, everted flat			2	32.3		
sand-tempered rim					1	3.4
shell-tempered body	19	58.6	39	230.2	1	4.6
grog & sand-tempered body			11	87.0		
grog & shell-tempered body					9	40.6
sand & shell-tempered body			4	22.9	3	47.8
Decorated ceramics						
red filmed shell-tempered body	2	3.3				
sand-tempered incised body	1	3.8				

[1] centimeters below surface
[2] count
[3] weight in grams

Table A6 continued.

Artifact Description	Test Unit 1					
	40-50 cmbs		50-60 cmbs		60-70 cmbs	
	ct.	wt.	ct.	wt.	ct.	wt.
Miscellaneous ceramics						
daub		96.7		269.0	10	282.1
fired clay		35.7		20.7	83	24.9
modeled object, grog tempered	1	2.8	2	69.9		
baked clay ball fragment					2	4.4
sherds <¼"		22.7		41.4	16	47.4
Organic remains						
bone			22	27.1	10	8.0
mud dauber nest	1	8.9				
Total	72	525.4	160	1629.9	268	1950.8

Table A6 continued.

Artifact Description	Test Unit 1					
	70-80 cmbs		85-105 cmbs		Total	
	ct.	wt.	ct.	wt.	ct.	wt.
Chipped lithics						
core					1	8.8
flake, modified					1	5.1
dart point, tablerock stemmed					1	3.3
Unmodified lithics, quartzite					1	79.0
Unmodified raw material, chert					1	13.5
Fire cracked chert					2	41.1
Cord marked ceramics						
grog-tempered body	2	20.3			2	20.3
sand-tempered body	63	470.8	1	2.5	292	2602.3
sand-tempered rim, everted flat					3	116.6
sand-tempered rim, everted					3	80.0
grog & shell-tempered body					1	8.8
grog & sand-tempered body	22	167.1			24	186.3
sand & shell-tempered body	4	37.2			4	37.2
Plain ceramics						
grog-tempered body					2	17.7
grog-tempered rim, everted flat					1	35.6
grog-tempered rim, flat					2	32.3
sand-tempered body	2	7.5			18	59.7
sand-tempered rim, everted flat	1	2.1			3	34.4
sand-tempered rim					1	3.4
shell-tempered body	2	4.9			61	298.3
grog & sand-tempered body					11	87.0
grog & shell-tempered body					9	40.6
sand & shell-tempered body					7	70.7
Decorated ceramics						
red filmed shell-tempered body					2	3.3
sand-tempered incised body					1	3.8

Table A6 continued.

Artifact Description	Test Unit 1					
	70-80 cmbs		85-105 cmbs		Total	
	ct.	wt.	ct.	wt.	ct.	wt.
Miscellaneous ceramics						
daub		97.5			10	745.3
fired clay					83	81.3
modeled object, grog tempered					3	72.7
baked clay ball fragment					2	4.4
sherds <¼"		7.3			16	118.8
Organic remains						
bone	29	10.8			61	45.9
mud dauber nest					1	8.9
shell		18.5				18.5
charcoal	1	0.1			1	0.1
Total	126	844.1	1	2.5	627	4985.0

Table A7. Artifacts recovered from Test Unit 2 at the Huey's house site (3MS306).

Artifact Description	Test Unit 2							
	20-30 cmbs[1]		30-40 cmbs		44 cmbs		40-50 cmbs	
	ct.[2]	wt.[3]	ct.	wt.	ct.	wt.	ct.	wt.
Chipped lithics								
potlid w/cortex			1	0.6				
shatter	1	2.1						
Burnishing stone, granite			1	16.9				
Unmodified quartzite	nc[4]	7.7						
Cord marked ceramics								
grog-tempered body			1	5.4				
grog-tempered vessel, cup					1	39.5		
sand-tempered body	53	290.4	7	19.8			11	117.6
grog & shell-tempered body			1	9.7				
grog & sand-tempered body	1	5.3	38	46.7			34	418.8
sand & shell-tempered body							15	138.3
sand & shell-tempered rim, everted flat							1	20.4
sand & shell-tempered rim, flat							1	27.1
Plain ceramics								
grog-tempered body			1	1.4				
sand-tempered body			1	11.1			2	12.7
shell-tempered body	10	25.8	1	6.7			1	2.9
shell-tempered Bell Plain body			1	11.7				
grog & sand-tempered body			2	13.3				
grog & shell-tempered body			5	19.4			1	7.4
sand & shell-tempered body							7	35.3

[1] centimeters below surface
[2] count
[3] weight in grams
[4] no count

Table A7 continued.

Artifact Description	Test Unit 2							
	20-30 cmbs		30-40 cmbs		44 cmbs		40-50 cmbs	
	ct.	wt.	ct.	wt.	ct.	wt.	ct.	wt.
Decorated ceramics								
redfilmed grog-tempered body			1	10.1				
redfilmed shell-tempered body	1	1.7						
Miscellaneous ceramics								
daub		99.9	1	33.6			1	3.0
fired clay		39.5		416.8			52	118.7
sherds <¼"		18.2	10	13.6			20	15.3
Organic remains								
bone	2	0.3	16	8.9			19	5.9
shell			nc	10.0			nc	183.3
fish scale							2	0.1
Total	68	490.9	88	655.7	1	39.5	165	1106.7

Table A7 continued.

Artifact Description	Test Unit 2						NE[5] of TU[6]2	
	50-60 cm		60- 70cm		Total		top of midden	
	ct.	wt.	ct.	wt.	ct.	wt.	ct.	wt.
Chipped lithics								
potlid w/cortex					1	0.6		
shatter					1	2.1		
Burnishing stone, granite					1	16.9		
Uunmodified lithics			1	30.3	1	30.3		
Unmodified quartzite					nc	7.7		
Cord marked ceramics								
grog-tempered body	5	16.9			6	22.3		
grog-tempered vessel, cup					1	39.5		
sand-tempered body	12	35.7			83	463.5	11	60.6
grog & shell-tempered body					1	9.7		
grog & sand-tempered base	1	38.3	1	1.3	2	39.6		
grog & sand-tempered body	3	14.6			76	485.4		
sand & shell-tempered body	12	122.6	5	25.6	32	286.5		
sand & shell-tempered rim, everted flanged	1	31.6			1	31.6		
sand & shell-tempered rim, everted flat					1	20.4		
sand & shell-tempered rim, flat					1	27.1		
Plain ceramics								
grog-tempered body					1	1.4		
sand-tempered body					3	23.8		
shell-tempered body					12	35.4		
shell-tempered Bell Plain body					1	11.7		
grog & sand-tempered body					2	13.3		
grog & shell-tempered body	1	1.3			7	28.1	4	17.4
sand & shell-tempered body	1	2.4			8	37.7		

[5] northeast
[6] test unit

Table A7 continued.

Artifact Description	Test Unit 2						NE of TU2	
	50-60 cm		60- 70cm		Total		top of midden	
	ct.	wt.	ct.	wt.	ct	wt.	ct.	wt.
Decorated ceramics								
redfilmed grog-tempered body					1	10.1		
redfilmed shell-tempered body					1	1.7		
Miscellaneous ceramics								
daub	1	9.5			3	146.0		
fired clay			8	9.0	60	584.0		
sherds <¼"	10	7.1	4	1.5	44	55.7		
Organic remains								
bone	15	1.5	5	0.7	57	17.3		
bone needle	2	0.1			2	0.1		
shell		48.1		7.0	nc	248.4		
fish scale	3	0.1						
Total	64	329.7	24	75.4	410	2697.9	15	78.0

Table A8. Artifacts recovered from Test Unit 3, Huey's House site (3MS306).

Artifact Description	20-25 cmbs[1]		25-35 cmbs		45-55 cmbs		Total	
	ct.[2]	wt.[3]	ct.	wt.	ct.	wt.	ct.	wt.
Cord Marked Ceramics								
sand tempered body			2	8.8			2	8.8
sand & shell tempered body					1	5.6	1	5.6
Plain Ceramics								
sand tempered body			1	2.1			1	2.1
shell tempered body					4	10.3	4	10.3
sherds <¼"	2	6.1			1	0.4	3	6.5
charcoal			nc[4]	7.7			nc	7.7
Total	2	6.1	3	18.6	6	16.3	11	41.0

[1] centimeters below surface
[2] count
[3] weight in grams
[4] no count

APPENDIX B, Table B.1. Archaeobotanical Contents of Flotation Samples, Hueys House Site (3MS306).

MATERIAL CLASS Plant Part	FSN 1 Feature 1 (31-35 cm) ct. wt.(g)	FSN 5 Test Unit 1 (50-60 cm) ct. vt.(g)	FSN 8 Test Unit 1 (60-70 cm) ct. wt.(g)	FSN 11 Feature 2 (35-42 cm) ct. wt.(g)	FSN 15 Feature 2 (20-40 cm) ct. wt.(g)	FSN 17 Test Unit 2 (20-30 cm) ct. wt.(g)	FSN 18 Test Unit 2 (30-40 cm) ct. wt.(g)
FUEL/CONSTRUCTION							
Wood Charcoal	45 .29	1 t	p	4 .04	9 .09	5 .04	155 1.60
Bark				1 .03	1 .01		12 .08
Twig Fragment							
Herb Stem							
Cane/Grass Stem							
Fungal Tissue	1 t						
NUTS							
Carya Nut Shell				p		p	7 .13
Carya Husk							
Juglans Nut Shell							
Juglandaceae Shell	1 t	1 .01	1 t		1 t	1 .01	18 .16
Quercus Shell			p	p	p	p	2 t
Quercus Nut Meats				7 .06	8 .09		
MAIZE							
Cob Fragments					p	2 t	p
Kernel Remains				p	p	p	p
MISCELLANEOUS							
Cucurbit Rind							
Fruit Flesh		4 .02				5 .02	
Coal	2,651 43.09						
Indeterminate				3 .02			5 .03
TOTALS	2,698 43.38	6 .03	1 t	15 .15	19 .19	13 .07	199 2.00
Residual Fraction Wt. (g)	47.24	.48	.22	.85	.59	.44	2.13
Sample Volume (liters)	7.5	5.0	5.0	8.0	7.5	3.5	6.0
Density (g/10 liters)	120.83	1.02	.44	1.25	1.04	1.46	6.88

t=trace weight or less than 0.005 g

APPENDIX B, Table B.1 (continued).

MATERIAL CLASS Plant Part	FSN 21 Feature 2 (40-48 cm) ct.	 wt.(g)	FSN 27 Test Unit 2 (40-50 cm) ct.	 wt.(g)	FSN 30 Test Unit 2 (50-60 cm) ct.	 wt.(g)	FSN 34 Test Unit 2 (60-70 cm) ct.	 wt.(g)	FSN 38 Feature 3 (20-25 cm) ct.	 wt.(g)	FSN 39 Feature 2 (25-40 cm) ct.	 wt.(g)	FSN 42 Test Unit 3 (25-35 cm) ct.	 wt.(g)
FUEL/CONSTRUCTION														
Wood Charcoal	396	4.49	33	.20	7	.03	11	.16	3	.02	6	.03	6	.03
Bark	29	.40	5	.03									1	.01
Twig Fragment														
Herb Stem		p											1	.01
Cane/Grass Stem	1	.01							2	.01				
Fungal Tissue														
NUTS														
Carya Nut Shell	28	.47	2	.11						p				p
Carya Husk	3	.05												
Juglans Nut Shell	3	.10												
Juglandaceae Shell	49	.44	1	t						p		p	1	.02
Quercus Shell	4	.01		p		p		p						
Quercus Nut Meats	13	.10	2	.03										
MAIZE														
Cob Fragments	7	.04												
Kernel Remains	4	.10												
MISCELLANEOUS														
Cucurbit Rind		p				p								
Fruit Flesh						p								
Coal									7	.04	2	.01	43	.45
Indeterminate	22	.19	2	.02	1	t	1	.01			1	t		
TOTALS	559	6.40	45	.39	8	.03	12	.17	12	.07	9	.04	52	.52
Residual Fraction Wt. (g)	43.41		2.69		.74		.56		20.67		1.96		16.63	
Sample Volume (liters)	13.0		7.5		7.0		7.0		20.0		12.0		6.0	
Density (g/10 liters)	38.32		4.11		1.10		1.04		10.37		1.67		28.58	

t=trace weight or less than 0.005 g

APPENDIX B, Table B.1 (continued).

MATERIAL CLASS Plant Part	FSN 43 Feature 4 (35-37 cm) ct.	wt.(g)	FSN 45 Feature 1 (35-47 cm) ct.	wt.(g)	FSN 48 Test Unit 1 (70-80 cm) ct.	wt.(g)	FSN 60 Feature 2 Top ct.	wt.(g)	FSN 61 Feature 2 Middle-Bottom ct.	wt.(g)	TOTALS ct.	wt.(g)	Ubiquity Index (% of Samples with Tissue)
FUEL/CONSTRUCTION													
Wood Charcoal	53	.38	64	.48	172	1.85	5	.07	156	.97	1,131	10.77	100.0
Bark	8	.10	9	.05			5	.04	14	.08	85	.83	52.6
Twig Fragment	1	t									1	t	5.3
Herb Stem											1	.01	10.5
Cane/Grass Stem											3	.02	10.5
Fungal Tissue	2	.01	p		1	t					4	.01	21.1
NUTS													
Carya Nut Shell	1	t			38	.70	1	t	29	.41	106	1.82	57.9
Carya Husk											3	.05	5.3
Juglans Nut Shell											3	.10	5.3
Juglandaceae Shell	1	t			99	.69			42	.24	216	1.57	73.7
Quercus Shell	1	t	p		3	t	p		4	t	14	.01	73.7
Quercus Nut Meats									4	.04	34	.32	26.3
MAIZE													
Cob Fragments	p						4	.05	3	.02	16	.11	36.8
Kernel Remains			p		1	t	p		23	.19	28	.29	47.4
MISCELLANEOUS													
Cucurbit Rind											p		10.5
Fruit Flesh											9	.04	15.8
Coal	155	1.68	33,837e	269.33	p						36,695	314.60	36.8
Indeterminate	6	.06			3	.01			20	.09	64	.43	52.6
TOTALS	228	2.23	33,910	269.86	317	3.25	15	.16	295	2.04	38,413	330.98	
Residual Fraction Wt. (g)	27.17		339.80		2.31		5.19		33.72		546.80		
Sample Volume (liters)	9.0		22.0		8.0		12.0		20.0		186.0		
Density (g/10 liters)	32.67		277.12		6.95		4.46		17.88		29.40		

t=trace weight or less than 0.005 g; e=estimated; p=present in residual fraction only

APPENDIX B, Table B.1 (continued).

SEED GROUP Seed Taxon	Common Name	FSN 8 Test Unit 1 (60-70 cm) SNE*	FSN 11 Feature 2 (35-42 cm) SNE	FSN 15 Feature 2 (20-40 cm) SNE	FSN 17 Test Unit 2 (20-30 cm) SNE	FSN 18 Test Unit 2 (30-40 cm) SNE	FSN 21 Feature 2 (40-48 cm) SNE	FSN 27 Test Unit 2 (40-50 cm) SNE
STARCHY SEEDS								
Chenopodium berlandieri	Chenopod		1	-	1		7	10
Hordeum pusillum	Little Barley					2		1
Phalaris caroliniana	Maygrass	1	2		2	2	8	15
Polygonum erectum	Erect Knotweed	2	3	3		1	24	1
OILY SEEDS								
Helianthus/Iva spp.	Sunflower/Marshelder							
FLESHY FRUITS								
Diospyros virginiana	Persimmon	1	1	1		2	2	
Rhus spp.	Sumac							
Solanum americanum	Nightshade						1	
Vitis sp.	Wild Grape							
POTHERBS/OTHER ECONOMIC								
Amaranthus sp.	Pigweed							
Panicum sp.	Panic Grass						1	
Portulaca oleracea	Purslane	1						
Strophostyles helvola	Wild Bean							
WEEDS/MISCELLANEOUS								
cf. *Andropogon* sp.	Beardgrass						1	
cf. *Elymus canadensis*	Wild Rye							
Galium sp.	Bedstraw					3	4	
cf. *Ipomoea* sp.	Morning Glory							
cf. *Paspalum* sp.	Bead Grass							
Phytolacca americana	Pokeweed	1						1
Poaceae	Grass Family							
Polygonum lapathifolium	Pale Smartweed							
Polygonum sp. (trigonal)	Knotweed					1		
Unidentified			1	2	1	2	13	4
TOTALS		6	8	8	4	13	61	32

*Seed Number Estimate, estimated total number of seeds represented by whole seeds and seed fragments (e.g., testae, kernel fragments, etc.).

APPENDIX B, Table B.1 (continued).

SEED GROUP Seed Taxon	Common Name	FSN 30 Test Unit 2 (50-60 cm) SNE*	FSN 38 Feature 3 (20-25 cm) SNE	FSN 39 Feature 2 (25-40 cm) SNE	FSN 42 Test Unit 3 (25-35 cm) SNE	FSN 43 Feature 4 (35-37 cm) SNE	FSN 48 Test Unit 1 (70-80 cm) SNE	FSN 60 Feature 2 Top SNE
STARCHY SEEDS								
Chenopodium berlandieri	Chenopod	4	1				1	
Hordeum pusillum	Little Barley	1	1	1	1	1		
Phalaris caroliniana	Maygrass	1	3	1			6	6
Polygonum erectum	Erect Knotweed	2		1			24	
OILY SEEDS								
Helianthus/Iva spp.	Sunflower/Marshelder			1				
FLESHY FRUITS								
Diospyros virginiana	Persimmon						1	1
Rhus spp.	Sumac							1
Solanum americanum	Nightshade							
Vitis sp.	Wild Grape			1				
POTHERBS/OTHER ECONOMIC								
Amaranthus sp.	Pigweed							1
Panicum sp.	Panic Grass							
Portulaca oleracea	Purslane							
Strophostyles helvola	Wild Bean							
WEEDS/MISCELLANEOUS								
cf. *Andropogon* sp.	Beardgrass							
cf. *Elymus canadensis*	Wild Rye						2	
Galium sp.	Bedstraw						2	
cf. *Ipomoea* sp.	Morning Glory	1						
cf. *Paspalum* sp.	Bead Grass					1		
Phytolacca americana	Pokeweed							
Poaceae	Grass Family						4	
Polygonum lapathifolium	Pale Smartweed							
Polygonum sp. (trigonal)	Knotweed						1	
Unidentified		2	2			2	4	2
TOTALS		11	7	5	1	4	45	11

*Seed Number Estimate, estimated total number of seeds represented by whole seeds and seed fragments (e.g., testae, kernel fragments, etc.).

APPENDIX B, Table B.1 (continued).

SEED GROUP Seed Taxon	Common Name	FSN 61 Feature 2 Mid-Bottom SNE*	TOTALS SNE	Ubiquity Index (% of Total No. of Samples†)
STARCHY SEEDS				
Chenopodium berlandieri	Chenopod	2	29	47.4
Hordeum pusillum	Little Barley	1	9	42.1
Phalaris caroliniana	Maygrass	6	53	63.2
Polygonum erectum	Erect Knotweed	2	63	52.6
OILY SEEDS				
Helianthus/Iva spp.	Sunflower/Marshelder		1	5.3
FLESHY FRUITS				
Diospyros virginiana	Persimmon	2	11	42.1
Rhus spp.	Sumac		1	5.3
Solanum americanum	Nightshade		1	5.3
Vitis sp.	Wild Grape		1	5.3
POTHERBS/OTHER ECONOMIC				
Amaranthus sp.	Pigweed		1	5.3
Panicum sp.	Panic Grass		1	5.3
Portulaca oleracea	Purslane		1	5.3
Strophostyles helvola	Wild Bean	1	1	5.3
WEEDS/MISCELLANEOUS				
cf. *Andropogon* sp.	Beardgrass		1	5.3
cf. *Elymus canadensis*	Wild Rye		2	15.8
Galium sp.	Bedstraw		9	5.3
cf. *Ipomoea* sp.	Morning Glory		1	5.3
cf. *Paspalum* sp.	Bead Grass		1	5.3
Phytolacca americana	Pokeweed		2	10.5
Poaceae	Grass Family		4	5.3
Polygonum lapathifolium	Pale Smartweed	1	1	5.3
Polygonum sp. (trigonal)	Knotweed		2	10.5
Unidentified		2	37	63.2
TOTALS		17	233	

*Seed Number Estimate, estimated total number of seeds represented by whole seeds and seed fragments (e.g., testae, kernel fragments, etc.).

†Based on 19 samples, rather than the 15 samples in which seeds were observed.

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Results of paleoseismological investigations of earthquake-induced liquefaction features at nine sites indicate that significant earthquakes struck the New Madrid region in A.D. 900 ± 100 yr and A.D. 1530 ± 130 yr. This finding is consistent with other paleoseismological studies in the region. The A.D. 900 event was probably similar to the 1811-1812 earthquake sequence. Less is known about the A.D. 1530 event, but it is likely to have been very large as well. These data suggest that very large earthquakes occurred in the New Madrid seismic zone every 200 to 900 yr during the past 1200 yr. In addition, liquefaction features along the Black and Current Rivers suggest an earthquake source, possibly associated with the Commerce geophysical lineament, in the western Lowlands. Much work remains to refine estimates of the timing, magnitude, and source areas of prehistoric earthquakes in the New Madrid region and to determine if the recent high rate of seismicity reflects the long-term hazard.

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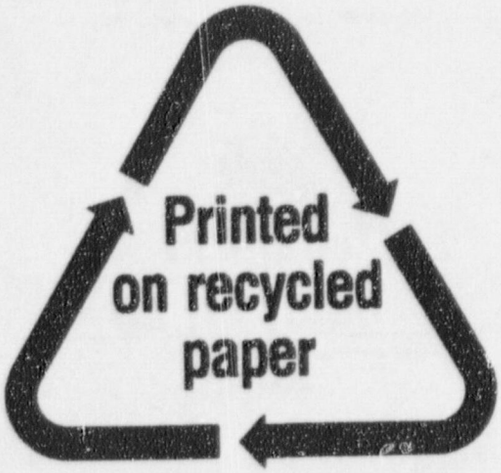

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