NUREG/GR-0018

Dating of Liquefaction Features in the New Madrid Seismic Zone

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Manuscript Completed: July 2000
Date Published: August 2000

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Prepared for
Division of Engineering Technology
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
NRC Job Code G6903

For sale by the U.S. Government Printing Office
Superintendent of Documents, Mail Stop: SSOP, Washington, DC 20402-9328

ISBN 0-16-050471-6

ABSTRACT

Investigations at six liquefaction sites in Arkansas and Missouri provide new data regarding sedimentary characteristics of historic sand blows and the distribution of liquefaction features generated by earthquake sequences circa A.D. 900 and A.D. 1450. These results support earlier findings that the New Madrid seismic zone has produced earthquake sequences that include at least one very large (**M** > 7.5) earthquake on average every 450 years over the past 1200 years. In addition, a relation between A horizon thickness and years of soil development is presented that may be a useful tool for estimating ages of sand blows in the New Madrid region.

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EXECUTIVE SUMMARY

During this study, we investigated and dated liquefaction features at six sites to further define the age and size distribution of liquefaction features in the New Madrid region. This type of information is needed to constrain estimates of the timing, magnitude, and recurrence intervals of New Madrid earthquakes.

A sand blow at the Lowrance site near Wilson, Arkansas, ranges up to 1.1 m in thickness and is composed of four fining-upward sedimentary units. All four units of the sand blow exhibit loose consistence and little evidence of soil development. Charcoal collected from a cultural feature 43 cm below the sand blow yielded a calibrated date of A.D. 1450-1660. A sand blow at the Archway site near Blytheville, Arkansas, is even larger, ranging up to 1.5 m, composed of four fining upward units, and exhibits similar soil characteristics to the Lowrance sand blow. The Archway sand blow overlies an occupation horizon that contains Early to Late Woodland artifacts. Wood collected 5 cm below the sand blow, however, yielded a calibrated date of A.D. 1660-1960. At the R. P. Haynes site also near Blytheville, Arkansas, a sand blow ranging up to 1 m in thickness is composed of three fining upward sedimentary units. The sand blows overlies a Native American occupation horizon containing predominantly Woodland artifacts and a few Early Mississippian artifacts. Radiocarbon dating of charcoal collected from the occupation horizon about 40 cm below the sand blow yielded a calibrated date of AD 1000-1170. Radiocarbon dating, stratigraphic relations, and soil characteristics suggest that the sand blows at the three sites formed during the 1811-1812 earthquake sequence. These sand blows are similar in thickness and sedimentary characteristics to other historic sand blows in the region.

A sand blow at the Upper Nodena archeological site near Wilson, Arkansas, overlies a Native American occupation horizon containing artifacts of the Late Mississippian period. Several ceramic artifacts and a large amount of baked clay were found less than 10 cm below the sand blow. The sand blow is up to 0.6 m thick and composed of two fining-upward sedimentary units. Radiocarbon dating of charcoal collected 1 cm below the sand blow provides a close maximum age of A.D. 1450. Two sand blows at the Walker site, adjacent to a Mississippian mound near Marked Tree, Arkansas, overlie a Native American horizon containing artifacts of the Middle and Late Mississippian periods. Radiocarbon dating of charcoal from the horizon and within a centimeter of the base of the sand blow indicates that the sand blows formed after A.D. 1420. Liquefaction features at the Amanda site, located southeast of Portageville, Missouri, and adjacent to a Mississippian mound, include two generations of sand dikes and related sand blows. The upper and lower sand blows are about 0.3 m and 0.2 m thick, respectively. Both generations of sand dikes crosscut soil horizons that contain artifacts of the Early to Middle Mississippian periods. Most of the artifacts are concentrated from 17 to 20 cm below the lower sand blow. Charcoal collected 19 cm below the sand blow yielded a date of A.D. 1020-1210. Another piece of charcoal collected in the upper part of the lower sand blow yielded a date of A.D. 1520-1950. Stratigraphic relations, soil characteristics, and radiocarbon dating indicate that the sand blows probably formed at least several hundred years after A.D. 1020 as a result of two events separated in time and that the upper sand blow formed after A.D. 1520. It is likely that the sand blows at the Upper Nodena and Walker sites formed during an event in A.D. 1450 $\pm$ 150 yr. It is possible that the lower sand blow at the Amanda site formed during this event. The

upper sand blow at the Amanda site, however, probably formed during the 1811-1812 earthquakes.

The historic sand blows at the Archway and Lowrance sites are very thick and composed of three to four fining upward sequences. The historic sand blow at the R.P. Haynes site is composed of three fining upward sequences and is very thick, but not as thick as the sand blow at the nearby Archway site. Sand blows near Marked Tree, Portageville, and Wilson that formed about A.D. 1450 are composed of only one or two sedimentary units and are thinner than historic sand blows in the same areas. Each of the fining upward sedimentary units within the sand blows may be related to a large event within an earthquake sequence. If so, the historic sand blows may have formed during the three to four largest earthquakes in the 1811-1812 sequence. The sand blows that formed about A.D. 1450, however, may have formed during only one or two large earthquakes.

This project contributes to the Nuclear Regulatory Commission's regulatory mission by improving our understanding of the earthquake potential of the New Madrid seismic zone and reducing the uncertainty associated with seismic hazard assessments in the central and eastern United States. The results of this study 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 under contract NRC-04-97-065. Additional funds were provided by U.S. Geological Survey through grant 1434-HQ97-GR-03082. The views and conclusions contained in this report 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 property owners and farmers, including Mrs. Dillahunty, Charles Richard and Priscilla Haynes, Charles Lowrance, Chris Goble, Keohler Blankenship, Mary Ellen Ray, Sonny Turnage, and Toby Walker. We are grateful to Marion Haynes, Charles Lowrance, and Toby Walker who provided information pertaining to archeological sites in the vicinity of Blytheville, Wilson, and Marked Tree, Arkansas, respectively, and to Wayne Hendrix, Bobbie Hensley, and Floyd Jefferson who excavated trenches at the study sites. April Barnes and Lorraine Wolf of Auburn University, Sharon Diehl of the U.S. Geological Survey, Laurel Clark and William Hoyt of the University of Memphis, and Marion Haynes of the Arkansas Archeological Survey participated in the field program. Laurel Clark and William Hoyt also drafted site maps and ditch profiles. Kathy Tucker of University of Memphis assisted by developing a GIS database of liquefaction sites in the New Madrid region and producing Figure 1.1 for this report. Many thanks to Ernst Zurflueh who provided valuable guidance and support throughout the project.

1. INTRODUCTION

1. 1. The New Madrid Seismic Zone

The New Madrid seismic zone (NMSZ) is recognized as the most seismically active region in the eastern United States (Johnston and Kanter, 1990) and the source of a significant earthquake sequence during the winter of 1811 and 1812 (Fig. 1.1; Fuller, 1912; Johnston, 1996). The largest of the 1811-1812 earthquakes generated strong ground shaking of modified Mercalli intensity (MMI) X in the New Madrid region and MMI VI to VII as far away as Cincinnati, Ohio (Nuttli, 1973). The historic sequence induced intense liquefaction in the meizoseismal area that led to vertical and lateral ground displacements of several meters (Wesnousky and Leffler, 1992; Tuttle and Barstow, 1996) as well as less severe liquefaction and ground failure up to 250-275 km from the epicentral area (Johnston, 1996). Therefore, a repeat of the 1811-1812 sequence during modern times would probably cause considerable damage to the urban areas of Memphis, Little Rock, and St. Louis as well as to lifelines and other critical facilities in the New Madrid region.

Previous liquefaction studies indicate that the NMSZ generated significant earthquakes in A.D. 900 $\pm$ 100 years and A.D. 1450 $\pm$ 150 years (e.g., Tuttle et al., 1998; Tuttle, 1999). These events appear to have induced liquefaction over a broad region encompassing the NMSZ and to have led to the formation of large, compound sand blows. Sand blows that formed during the A.D. 900 event are composed of three to four fining-upward sedimentary units, similar to sand blows that formed during the 1811-1812 earthquake sequence; whereas, sand blows that formed during the A.D. 1450 event are composed of only two such units. These observations suggest that the A.D. 900 event, like the 1811-1812 sequence, included three very large earthquakes and that the A.D. 1450 event included only two such shocks (Saucier, 1989; Tuttle, 1999). In addition, comparable thickness and areal distribution of sedimentary units composing the sand blows indicate that the paleoearthquakes had sources and magnitudes similar to the major earthquakes of 1811-1812. The relation between earthquake magnitude and maximum epicentral distance to liquefaction (Ambraseys, 1988) suggests that the 1811-1812 earthquakes were of **M** > 7.5. This relation, however, does not take into account regional differences in liquefaction susceptibility and ground motion characteristics. Given similarities in size distribution of the historic and pre-1811 sand blows, the A.D. 900 and A.D. 1450 events are likely to have included at least one earthquake of **M** > 7.5 (Tuttle, 1999). There is evidence for large earthquakes prior to A.D. 900 but their ages, source areas, and magnitudes are, as yet, poorly constrained.

Liquefaction data suggest an average recurrence interval of 450 years for New Madrid sequences during the past 1200 years (Tuttle, 1999). This estimate is similar to that based on measurements of coseismic deformation along the Reelfoot scarp (Russ, 1982; Kelson et al., 1996). If the A.D. 490 event identified by Saucier (1991) included a very large earthquake, the estimated average recurrence interval would be 440 years for the past 1600 years. The range in possible repeat times of New Madrid sequences is about 200 to 800 years, including actual variations in recurrence and uncertainties in dating. If it continues to behave as it has during the past 1200 years, the NMSZ may generate the next significant earthquake sequence anytime between now and A.D. 2600, and more likely after A.D. 2250.

1. Introduction

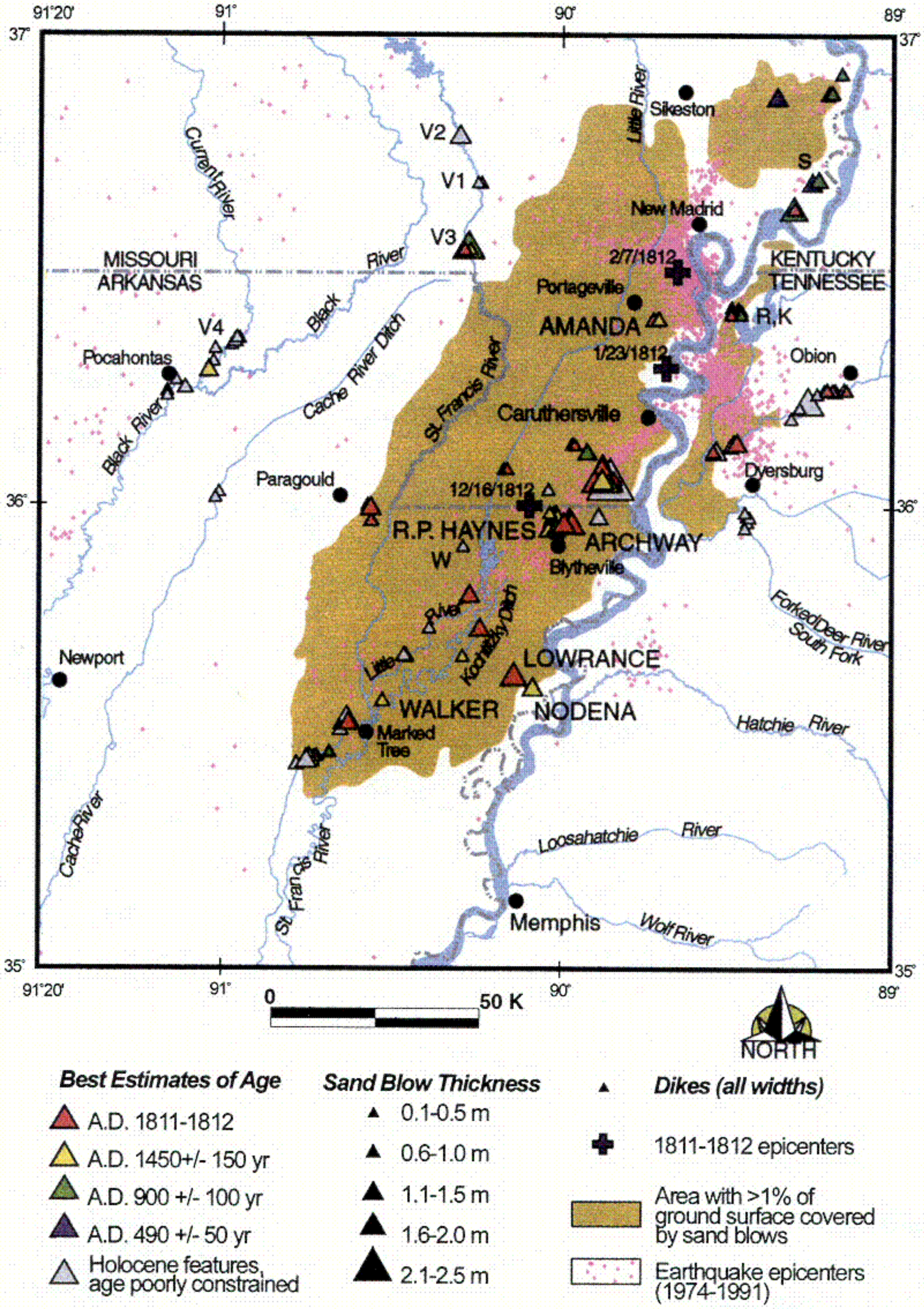

Figure 1.1. Map of the New Madrid seismic zone showing estimated ages and sizes of liquefaction features. This study includes investigations at Amanda, Archway, R.P. Haynes,Lowrance, Nodena, and Walker sites. All other sites previously studied by us except, R, Russ (1982); S, Saucier (1991); V1-4, Vaughn (1994); K, Kelson et al. (1996); W, Wesnousky and Johnson (1996).

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In this report, we present results of detailed investigations of liquefaction features at six sites and their implications for the earthquake potential of the NMSZ. In addition, we report on our effort to construct a soil development index that could be useful for estimating the age of prehistoric sand blows in the New Madrid region.

1.2. Paleoseismological Investigations

The goal of the site investigations is to provide new information on the age and size distribution of liquefaction features in the New Madrid region. During previous studies in the New Madrid region, we found it advantageous to study liquefaction features at Native American archeological sites (e.g., Tuttle et al., 1996 and 1998). Datable materials, such as charcoal, plant remains, and ceramic and lithic artifacts, are often abundant at archeological sites, making it possible to tightly constrain the age of liquefaction features. For this reason, we selected six sites for investigation where sand blows occur in association with Native American occupation horizons (Fig. 1.1). We identified the sites during reconnaissance in northeastern Arkansas and southeastern Missouri for the U.S. Geological Survey, National Earthquake Hazard Reduction Program. The Amanda site in Missouri, and the Lowrance and Upper Nodena sites in Arkansas, are located in areas where no previous liquefaction data had been collected (see Fig. 1.1). The Archway, R.P. Haynes, and Walker sites, all in Arkansas, occur in areas where we had already described liquefaction features, but felt additional data would help to characterize the age and size distribution of liquefaction features. For descriptions of methodologies and archeological terms used in this study and an early related study, please see Tuttle et al. (1998).

During the investigations, the plow zone was first removed and then subsurface material excavated carefully to recover artifacts and charcoal from Native American occupation horizons and features that could help to date liquefaction features. We scraped clean and logged horizontal and vertical sections, recording structural, sedimentological, and stratigraphic characteristics of liquefaction features and host deposits, and properties of soil horizons. In additon, we collected artifacts, charcoal, wood, and soil samples, noting their locations on logs. We excavated archeological test units in Native American occupation horizons below sand blows. At the Amanda, Lowrance, Upper Nodena, and R.P. Haynes sites, we screened soil from the occupation horizons through 1/4 inch mesh and bagged artifacts by provenience. At the Walker site, the occupation horizon was so greasy that we recovered artifacts by shovel skimming the test units. At the Archway site, we recovered artifacts from the wall of the drainage ditch, noting locations of artifacts on sample bags.

Following field work, we reviewed suites of organic samples and selected those that were most likely to constrain the age of the liquefaction features for radiocarbon dating by Beta Analytic, Inc. Mid-Continental Research Associates processed and analyzed artifacts collected at the six sites. Results of the artifact analysis are presented below and in Appendix A. Based on results of site investigations and laboratory analysis, we interpreted the age of liquefaction features and timing of earthquakes.

1.3. Archeological Periods and Artifacts

Readers interested in a summary of the history of archeological investigations in northeast Arkansas, and southeastern Missouri, are referred to Tuttle et al. (1998). The regional archeological chronology and descriptions of artifact types are repeated below for the convenience of the reader. In the New Madrid region, the earliest ceramics are baked clay objects (Table 1.1). These have been dated at 3000 B.C. in adjacent areas and are thought to have been made as late as the Mississippian period. About 1000 B.C. to A.D. 0., two different Woodland ceramic traditions developed. East of Blytheville, Arkansas, was the grog-tempered (usually ground up potsherds 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 about A.D. 900 and becomes dominant after A.D. 1000. 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 were used as early as A.D. 600. Thus, the main sequence of ceramic types has been identified. However, the details of the temporal and geographical ranges of types are poorly defined. The projectile point chronology is similar in this regard. We know that Scallorn points are from the Early Mississippian cultural period, Madison points are Middle Mississippian, and Nodena points are Late Mississippian. We are not certain, however, of the absolute temporal range of these forms.

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.

1.4. Soil Development

The state of a soil system is usually defined as a function of five soil forming factors: climate, biological activity, topography, parent material, and time (Jenny, 1941 and 1961; Birkeland, 1984). Chronosequences (or genetically related suites of soils in which soil forming factors except for time are about equal) provide the opportunity to study soil development over time. Studying chronosequences in different climatic regimes, Harden (1982, 1983) found that soil profiles, as well as certain soil properties, develop systematically with age. Therefore, soil properties and profiles may reflect the age of a soil. Birkeland (1984) found a fairly strong correlation between soil horizons (e.g., A horizons) and orders (classification of soils based on diagnostic horizons; e.g., Alfisols) and the age of underlying deposits.

Most of the sand blows that we have examined in the NMSZ over the past 10 years are less than 2,000 years old and all are less than 6,000 years old. Surficial sand blows that formed during the 1811-1812 earthquake sequence have undergone minimal soil development. Soils that formed in these recent deposits are Entisols and are characterized by thin (~ 10 cm) A horizons overlying C horizons of unaltered sandy parent material. In contrast, soils that have formed in sand blows that are about 1,000 years old (based on radiocarbon dating and archeological analysis) are Inceptisols with ochric epipedons, cambic horizons, and characterized by A, C and A, Bw, and C horizon sequences. See "Keys to Soil Taxonomy," by Soil Survey Staff (1992) for definitions of the various soil orders, horizons, and epipedons.

In the New Madrid region, sand blows of various ages provide an opportunity to study rates of soil development. Topography and biological activity vary little across the Mississippi alluvial valley. Furthermore, most sand blows in the region are composed predominantly of fine to medium sand. Therefore, soil properties of sand blows may reflect the amount of time they have been subjected to soil forming processes as well as variations in environmental factors (e.g., climate, water table). If so, soil properties may provide a way to estimate the age of sand blows. A soil development index could be a valuable dating tool, especially at sites where artifacts and other materials suitable for dating are scarce or absent.

In general, soil pH is likely to be lower in A horizons developed in sand blows than in the underlying C horizons or parent material. This would be due to the acidification of the surface soils by rainwater. In addition, organic matter content should be higher in A horizons than underlying horizons due to the contribution of organics to surface soils by plants and animals. With the accumulation of organic matter over time, A horizons thicken and the depth range over which organic matter content remains high would increase. Iron and other cations are released as the result of weathering of minerals near the ground surface. These cations may be held by organics in A horizons. Because of the chemical activity of organic matter, the cation exchange capacity of a soil will tend to increase along with organic matter content. Over time, cations are washed through the soil profile and accumulate in B horizons where they are held primarily by clay particles. Therefore, it stands to reason that soils developed in liquefaction features will show an increase in pH with depth and a decrease in organic matter content, cation exchange capacity, and iron content. In older liquefaction features, this change with depth may be more pronounced. With features that are old enough to exhibit B horizon development, a reversal in the trends for cation exchange capacity and iron content with depth may be observed.

In an attempt to construct soil development indices, we conducted chemical and physical analyses on suites of soil samples collected at ten liquefaction sites. The soil samples came from the following sites: Braggadocio, Brooke (archeological designation-23PM56), Dodd (23PM46), Eaker 1 (3MS525), Eaker 3 (3MS560), Eightmile Ditch, Hillhouse (23MI699), Haynes (3MS304), Reelfoot and Wilkerson Ditch. Detailed description of liquefaction features and host deposits at these sites are presented in Kelson et al. (1996), Li et al. (1998), Tuttle et al. (1998), and Noonan (1999). Properties that we measured include Munsell color, soil structure, soil consistence, particle size distribution, soil texture, pH, cation exchange capacity (CEC), percent free iron (Fe), and percent organic matter (OM). In addition, we measured the thickness of A horizons developed in sand blows and sand dikes at the sites. Age estimates of the liquefaction features are based on radiocarbon dating and archeological analysis at the sites.

2. RESULTS OF PALEOSEISMOLOGICAL INVESTIGATIONS

2.1. Amanda Site (23PM500)

The Amanda site is located southeast of Portageville, Missouri, and just south of Portage Open Bay (Fig. 1.1 and 1.2). Two trenches were excavated northeast of an historic sand blow, where historic artifacts and potsherds of the Mississippian period (A.D. 800-1670) were found on the ground surface above a weathered and possibly prehistoric sand blow deposit (Fig. 2.1).

In trench 1, a 29-cm wide sand dike crosscuts several soil horizons containing artifacts (Fig. 2.2). The sand dike is composed of several subunits and contains clasts of soil and lignite. Soil horizons are displaced downward by about 15 cm on the south side of the dike relative to horizons on the north side. The plow zone extends into the top of the sand dike and 2A soil horizon that contained a few artifacts. Only a very small portion of a sand blow adjacent to the dike was preserved.

In trench 2, two sand dikes, 74-cm-wide and 12-cm-wide, crosscut the same soil horizons observed in trench 1 (Fig. 2.3). The large sand dikes in the two trenches have similar strikes and dips and occur roughly along strike with one another. The larger sand dike in trench 2 is composed of several subunits that, in general, fine upward from medium to very fine sand. Ball and pillow structures formed in one subunit. A portion of the 2A soil horizon had apparently collapsed into the top of the large dike and partially broken up to form many clasts in the upper part of the dike. A layer of sand that overlies this clast zone and extends about 0.5 m over the 2A soil horizon is interpreted as a sand blow deposit. This deposit is only 20 cm thick. A layer of charcoal occurs in the top of the sand blow deposit. Charcoal collected from the layer yielded a calibrated date of A.D. 1520-1950. Fines have accumulated in the sand blow suggesting some soil development prior to burial by the overlying deposit.

A 12-cm-wide sand dike, south of the larger dike, is composed of medium to fine sand and contains many clasts in its upper 50 centimeters (Fig. 2.3). Soil horizons between the two dikes have been displaced downward by about 6 cm relative to horizons on the south side of the smaller dike and about 10 cm relative to horizons on the north side of the larger dike. The smaller sand dike appears to be related to the layer of coarse to fine sand, containing clasts of silt and lignite, that overlies the charcoal layer and much of the 2A soil horizon. This sand layer, also interpreted as a sand blow deposit, is about 30 cm thick and thickens towards the south. The upper portion of the deposit has been disturbed by plowing. In the upper 10 cm of the undisturbed portion of the deposit, fines have accumulated, suggesting slight soil development.

Artifacts collected from 2A, 2C, and 3A soil horizons are representative of the Early and Middle Mississippian cultural periods (Table 1.1 and 2.1). Most of the artifacts are concentrated in the 2C and 3A soil horizons. A few artifacts occur about 15 cm below the sand blow near the base of the 2A horizon. Charcoal collected from the 2C horizon 19 cm below the sand blow yielded a calibrated date of A.D. 1020-1210 (Table 2.2). This date is consistent with occupation during the Middle Mississippian period. Diagnostic artifacts include Varney and Old Town red filmed pottery, which approached 50% of the recovered sherds. Several sherds are of a type not previously described and are characterized by limestone tempering in the paste. Limestone

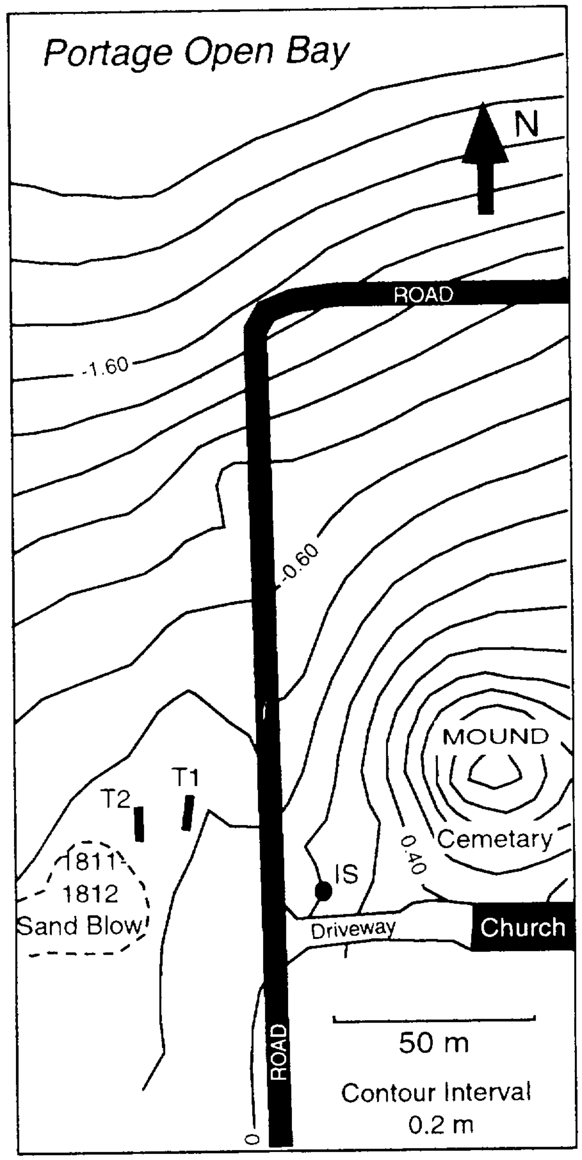

Figure 2.1. Topographic map of Amanda site located in small town of Hayward southeast of Portageville, Missouri. Topographic contours relative to elevation of instrument site (IS). Trench 1 (T1) and trench 2 (T2) are located west of Mississippian mound and near large, historic sand blow exhibiting little soil development. Two generations of sand dikes and sand blows and buried soil horizons containing artifacts of Early to Middle Missippian period are exposed in trenches. Portage Open Bay lies north of site. Topographic map by L. Clark, J.D. Sims, and M. Tuttle.

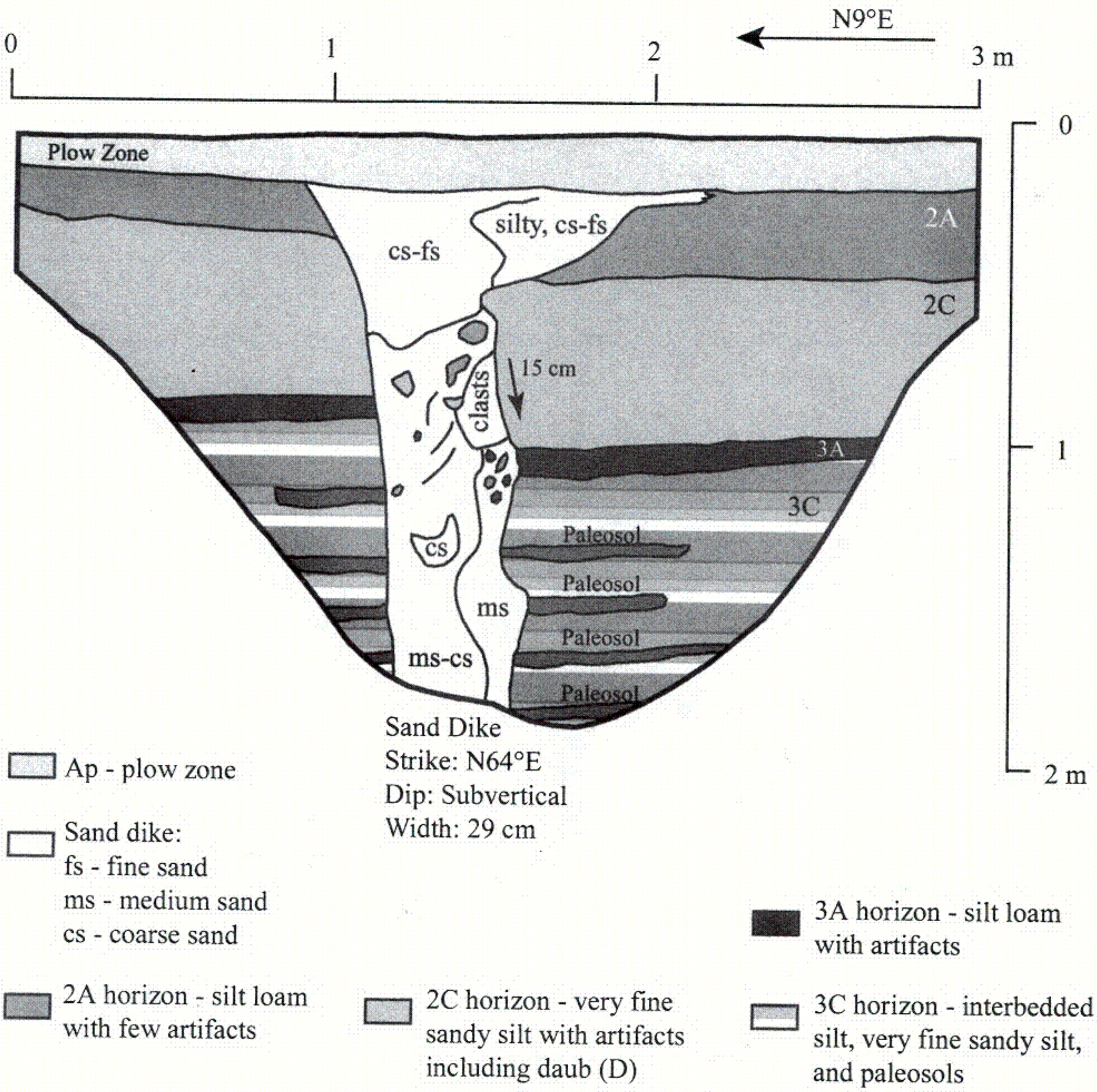

Figure 2.2. Log of east wall of trench 1 at Amanda site in Hayward, Missouri. Plowing has destroyed upper part of dike and any sand blow that may have been related to it. Analysis of artifacts in soil horizons crosscut by dike indicates that liquefaction event(s) occurred during or after Middle Mississippian period. Log by J.D. Sims.

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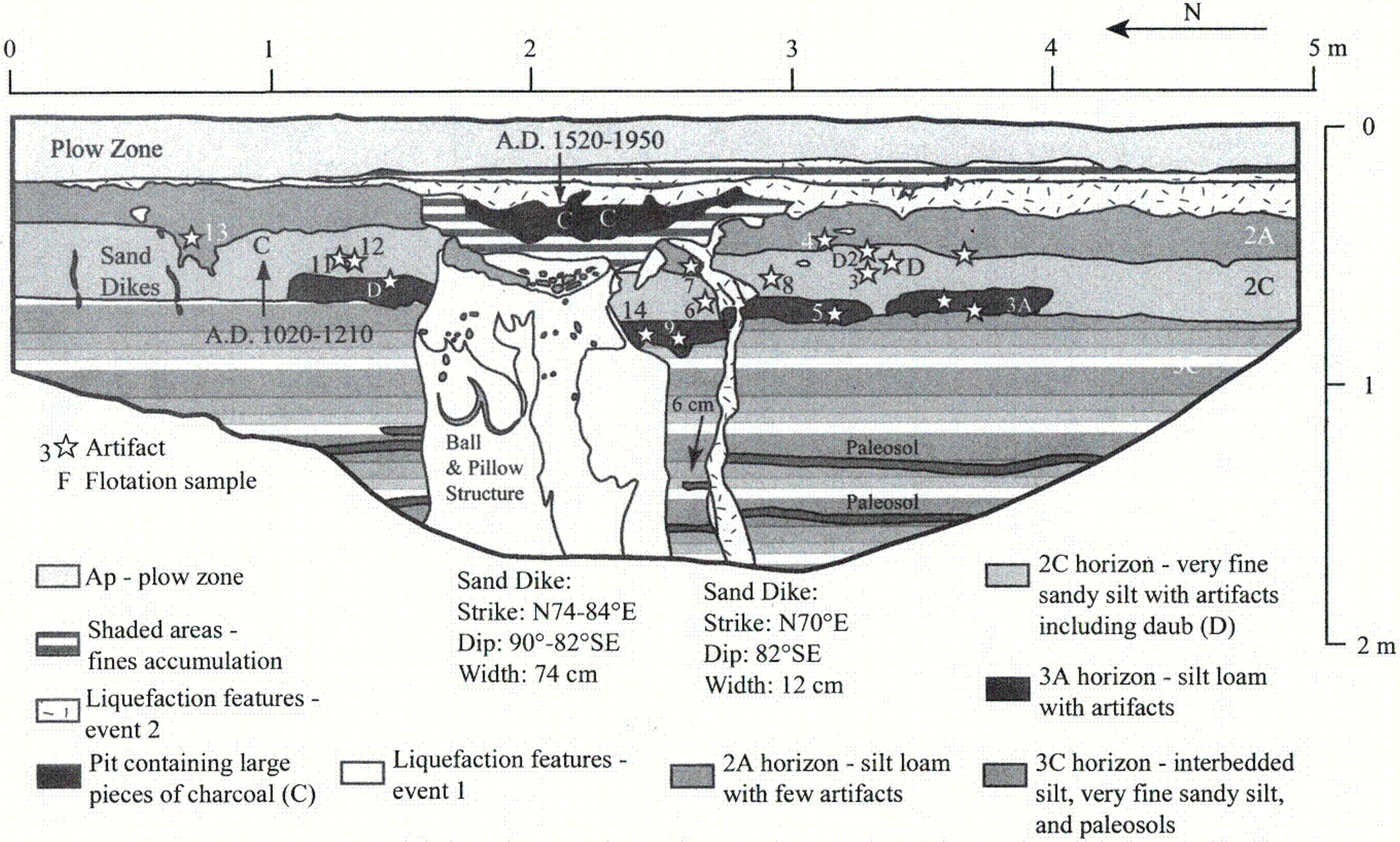

Figure 2.3. Log of east wall of trench 2 at Amanda site in Hayward, Missouri. Structural, stratigraphic and soil charateristics of two generations of sand dikes and sand blows suggest that they formed during two events separated in time. Artifacts in buried soil horizons indicate that event 1 occurred during or soon after Middle Mississippian. This finding is supported by radiocarbon dating of charcoal in buried 2C horizon. Radiocarbon dating of charcoal in top of lower sand blow indicates that event 2 occurred after A.D. 1520. Log by M. Tuttle and L. Clark.

C03

tempering suggests relations with people to the northwest and the Meramec ceramic tradition. There were several sherds with interior brushing, which also is not previously described. Pieces of galena and Burlington chert were recovered about 30 cm below the sand blow. These lithics indicate relations with people to the north, either up the Castor River or via the St. Francis River to the Potosi, Missouri, area and to the Crecent Quarry west of St. Louis. Galena was widely traded and Portage Open Bayou may have been a good transportation route between the St. Francis and Mississippi Rivers.

Relationships at this site indicate that venting of sand and water occurred during two different events separated in time. Radiocarbon dating of the 2C soil horizon crosscut by both dikes indicate that the events occurred after A.D. 1020. Artifacts in the soil horizons crosscut by the large dike suggest that the earlier event occurred during or after the Middle Mississippian period. Given that 15 cm of soil formed between the artifacts and the overlying sand blows, more than two hundred years may have passed from the time the site was occupied until the earlier event. It is possible that the large dike and lower sand blow formed during an earthquake about A.D. 1450 that is thought to have induced liquefaction near Blytheville, Arkansas. Radiocarbon dating of the charcoal-rich layer overlain by the upper sand blow indicates that the later event occurred after A.D. 1520. The upper sand blow thickens towards the south and is probably part of a large historic sand blow mapped on the ground surface.

Table 2.1. Summary of artifacts above and below sand blow at Amanda site.

Above Sand Blow	
White ware	After 1860
Milk glass lid liners	1920-1940
Aqua glass	Before 1916
Clear glass	After 1916
Below Sand Blow	
Varney red filmed	600-1200 AD
Old Town red filmed	800-1000 AD
Unusual incised	
Galena	
Shell tempered brushed interior	post 600 AD

Table 2.2. Radiocarbon analyses of charcoal and wood samples collected at liquefaction sites in the New Madrid region. Analyses performed at Beta Analytic, Inc.

Site Sample No. Lab Sample No.	Measured 14C Age	13C/12C Ratio 0/00	Conventional 14C Age[1]	Cal yr AD/BC (2-sigma)[2]	Comments
Amanda T1-C2 Beta-133004	140 ± 40	-27.2	100 ± 40	AD 1680-1780 AD 1800-1940	charcoal 30 cm below surface
Amanda T2-C13 Beta-133005	940 ± 40	-26.0	920 ± 40	AD 1020-1210	charcoal 19 cm below sand blow
Amanda T2-C14 Beta-133006	300 ± 50	-28.5	240 ± 50	AD 1520-1590 AD 1620-1690 AD 1740-1810 AD 1930-1950	charcoal from charcoal-rich layer in top of lower sand blow
Archway C2 Beta-133007	100 ± 40	-25.7	90 ± 40	AD 1680-1770 AD 1800-1940 AD 1950-1960	charcoal within unit 2a
Archway W6 Beta-133008	130 ± 70	-26.9	100 ± 70	AD 1660-1960	wood 5 cm below sand blow
RP Haynes C2 Beta-133009	180 ± 40	-26.7	160 ± 40	AD 1660-1950	charcoal in occupation horizon 40 cm below surface
RP Haynes C5 Beta-133010	290 ± 80	-26.7	260 ± 80	AD 1450-1710 AD 1720-1890 AD 1910-1950	charcoal in burned root cast within occupation horizon
RP Haynes C100 Beta-142450	990 ± 40	-26.5	970 ± 40	AD 1000-1170	charcoal collected 82 cm below surface and 40 cm below sand blow
Lowrance C1 Beta-133011	350 ± 50	-26.3	330 ± 50	AD 1450-1660	charcoal 43 cm below sand blow
Nodena T1-C1 Beta-133012	290 ± 50	-24.7	290 ± 50	AD 1470-1670 AD 1780-1800	charcoal < 1 cm below sand blow
Nodena T1-C4 Beta-133013	160 ± 50	-17.2	280 ± 50	AD 1480-1680 AD 1780-1800 AD 1940-1950	charcoal 45 cm below sand blow

[1] Conventional ages are derived from measured ages by normalizing them to the modern standard through the use of $^{13}C/^{12}C$ ratios. For this study, $^{13}C/^{12}C$ ratios were measured and used in these calculations in order to minimize errors (± 20 radiocarbon years).

[2] Beta Analytic uses the Pretoria procedure (Talma and Vogel, 1993; Vogel et al., 1993) to calculate calendar years from conventional ages.

Table 2.2 Continued.

Site Sample No. Lab Sample No.	Measured 14C Age	13C/12C Ratio 0/00	Conventional 14C Age[1]	Cal yr AD/BC (2-sigma)[2]	Comments
Nodena T2-C1 Beta-133014	240 ± 50	-25.6	230 ± 50	AD 1520-1580 AD 1630-1690 AD 1730-1810 AD 1930-1950	charcoal in feature in top of sand blow
Nodena T2-C20 Beta-133015	350 ± 40	-24.5	350 ± 40	AD 1450-1650	charcoal 9 cm below sand blow
Nodena T2-C101 Beta-133016	100 ± 30	-10.6	340 ± 30	AD 1460-1650	charcoal 3 cm below sand blow
Walker T2-C1 Beta-133017	43170 ± 720	-22.9	43210 ± 720	NA	charcoal from cultural feature above sand blow
Walker T2-C2 Beta-133018	500 ± 40	-29.0	440 ± 40	AD 1420-1500	charcoal from occupation horizon and just below sand blow
Walker T3-C2 Beta-133019	230 ± 40	-25.1	230 ± 40	AD 1530-1550 AD 1640-1680 AD 1740-1810 AD 1930-1950	charcoal from sand-filled root cast
Walker T3-C3 Beta-133020	1470 ± 40	-24.6	1470 ± 40	AD 540-660	organic material from host cut by dikes

2.2. Archway Site (3MS620)

This site is located northeast of Blytheville, Arkansas (Fig. 1.1), and is characterized by large (2.6 m wide) and small (10 cm wide) sand dikes and a multi-phase sand blow deposit (1.5 m thick). As exposed at the base of a drainage ditch, the large sand dike intrudes, and the sand blow deposit overlies, a paleosol containing Native American artifacts of the Woodland cultural period (Fig. 2.4 and Table 2.3).

The three or four sedimentary units that comprise the sand blow fine upward with the lowermost unit (Unit 4) being the thickest and having the most complex stratigraphic relations with three main subunits (Fig. 2.5). The lowest subunit of the lowermost unit is itself subdivided north of

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[1] Conventional ages are derived from measured ages by normalizing them to the modern standard through the use of $^{13}C/^{12}C$ ratios. For this study, $^{13}C/^{12}C$ ratios were measured and used in these calculations in order to minimize errors (± 20 radiocarbon years).

[2] Beta Analytic uses the Pretoria procedure (Talma and Vogel, 1993; Vogel et al., 1993) to calculate calendar years from conventional ages.

the 6.75-meter mark of the log. The overall gradation of Unit 4 is from medium sand to clay at the top. The upper part of the unit contains abundant lignite clasts and is load-deformed. The next-to-lowest sand blow unit (Unit 3) is composed of two members which comprise a fining upward sequence grading from medium sand to clay. The upper part of this unit is also load-deformed. The lower subunit of Unit 3 is restricted to the area above the main feeder dike. The next higher sand blow deposit (Unit 2) is composed of two members which comprise a fining upward sequence grading from medium sand to silt with millimeter-scale interbeds of fine sand and patches of preserved parallel lamination. The lower subunit of this sand blow deposit has a clearly identifiable feeder dike located on the north edge of the main feeder dike at about the 6.5-meter mark. The uppermost sandy deposit (Unit 1) is thin and has no feeder dike exposed. It is composed of two members that comprise a fining upward sequence grading from medium sand to silt. This fining upward unit may represent a fourth sand blow deposit. An alternative interpretation is that the unit represent post-sand blow deposits of fluvial or eolian origin.

Our interpretation of the sequence of events at this site is that sand and water vented to the ground surface in three to four main phases to form a large, compound sand blow. Load deformation of the upper portions of Units 3 and 4 as well as lack of soil development and formation of dessication cracks in the upper parts of Units 1, 2, 3, and 4 indicate that the process of formation of the sand blow probably took a period of days to weeks and may represent three to four large events in an earthquake sequence.

Radiocarbon dating of charcoal collected from Unit 5 below the compound sand blow and Unit 2a within the top of the sand blow yielded calibrated dates of A.D. 1670-1960 and A.D. 1680-1960, respectively. These dates suggest that the liquefaction features formed after A.D. 1670 and probably during the 1811-1812 earthquake sequence (Table 2.2). One Barnes cordmarked sherd was found above the sand blow and a large sherd that appears to be Withers fabric marked was found below the sand blow (Table 2.3). Withers fabric marked pottery is diagnostic of the terminal Early Woodland period. The positions of Woodland artifacts suggest that the sand blow might be prehistoric age. Additional investigation of the relationship of the sand blow to cultural horizons and features is warranted.

Our current interpretation of the sequence of events that formed the compound sand blow follows: (1) intrusion of large dike and deposition of the first phase of the sand blow represented by Unit 4; (2) intrusion of a dike (not present in section) and deposition of the second smaller phase of the sand blow represented by Unit 3; (3) intrusion of small dike and deposition of the

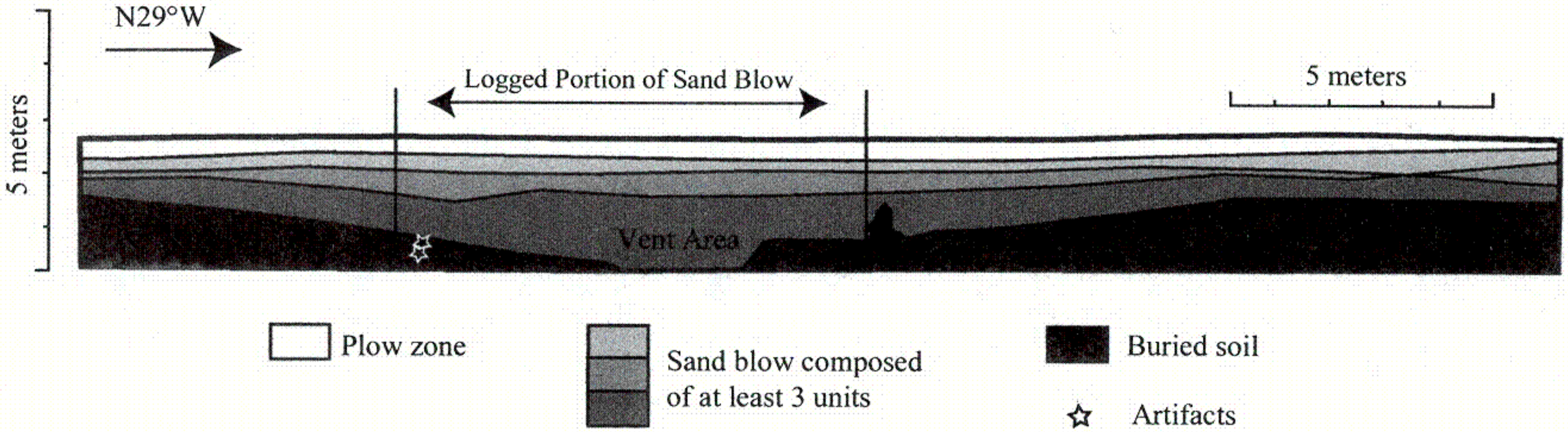

Figure 2.4. Profile of ditch exposure of compound sand blow at Archway site near Blytheville, Arkansas. See Figure 2.5 for detailed log of vent area. Profile by L. Clark, J.D. Sims, and M. Tuttle.

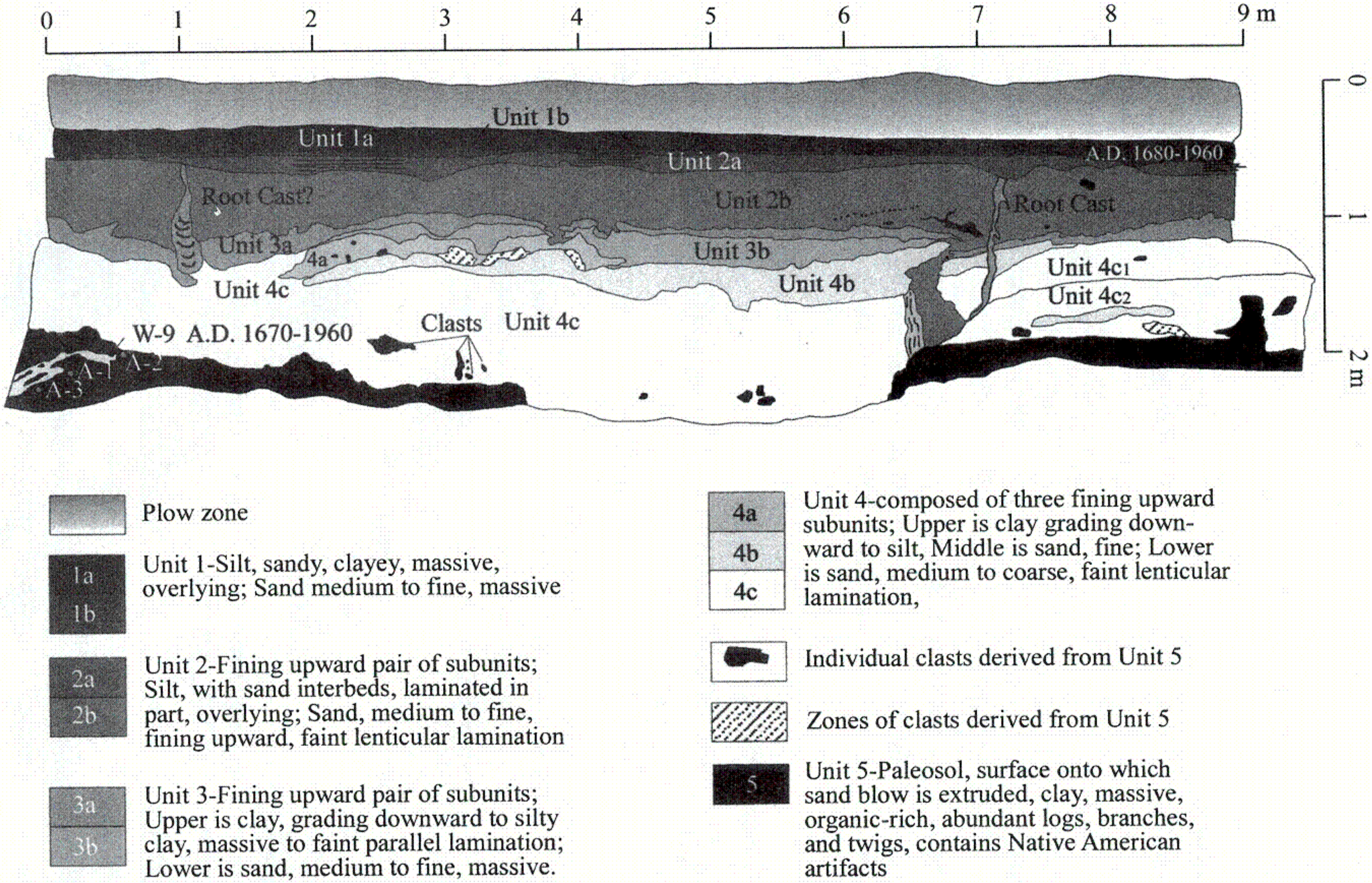

Figure 2.5. Log of ditch exposure at Dillahunty site near Blytheville, Arkansas. Sedimentary characteristics of sand blow suggest three closely timed events. Little soil development of sand blow deposits and radiocarbon dating of wood from Unit 5 and charcoal from Unit 1a suggest compound sand blow formed during 1811-1812 earthquakes. Woodland artifacts from same units suggest sand blow may be prehistoric. Log by J.D. Sims and L. Clark.

Table 2.3. Summary of artifacts above and below sand blow at Archway site.

Above Sand Blow	
Barnes cordmarked	500-1000 AD
Below Sand Blow	
Withers fabric marked	Ca 300 BC-300 AD

third phase of the sand blow represented by Unit 2, which is more extensive than the second phase of the sand blow but less extensive than the first phase; (4) and either intrusion of a dike (not present in section) and deposition of a fourth phase of the sand blow or reworking of portions of Unit 2 by fluvial or eolian processes to form Unit 1. The relative size of the units suggest that the first event was largest in magnitude, the third event the next largest, and the second event the smallest of the three. Interestingly, the largest earthquake in the 1811-1812 sequence occurred December 16th northwest of Blytheville, Arkansas; the second largest event occurred on February 7th southwest of New Madrid, Missouri; and the third largest event occurred on January 23rd north of Caruthersville, Missouri. The relative thickness of the lower 3 units is consistent with the relative magnitudes and distances of the three largest earthquakes in the 1811-1812 sequence.

2.3. Lowrance Site (3MS523)

This site is located north of Wilson, Arkansas (Fig. 1.1), and is characterized by a large sand dike and multi-phase sand blow deposit (Fig. 2.6). The sand dike intrudes and the sand blow deposit overlies a paleosol. Both walls of the trench were logged and each has a different expression of the sand blow deposit. The south trench wall exposes the sand dike and basal sand blow deposit. Here, there are two sand dikes or the dike bifurcates around a large clast at the base of the exposure. The dikes continue toward the surface as east and west components that cut through the paleosol at 30° to 45°. A flap of paleosol overlies the dikes and is depressed over it by about 45-50 centimeters. The dike in the north wall is not as complex as it is in the south wall. Here, the dike is nearly vertical and can be seen deforming the host paleosol rather strikingly. Strong flow line and aligned clasts define the vent area of the dike in the north wall. In addition, a pair of bifurcated small dikes intrudes the paleosol at about the 5- meter mark.

The sand blow deposit in the south trench wall is relatively simple. The depression in the paleosol is filled with three fining upward units of the sand blow. The lower two of these units (Units 2 and 3) appear to be overlapped by Unit 1, which is connected to the sand dike deposit. These relationships indicate that Units 2 and 3 are older and belong to earlier phases of sand blow formation. Many more units were recognized in the north trench wall than the south wall, making it difficult to correlate units across the trench. Many clasts occur within the sand dike as it is exposed in the north wall. In the south wall, paleosol clasts occur only along the base of the paleosol flap and all appear to have been fractured in place and transported little or not at all.

The differences in the stratigraphic succession in the two walls are most likely related to the proximity of different portions of the sand blow to its main vent. Note that the flap of paleosol

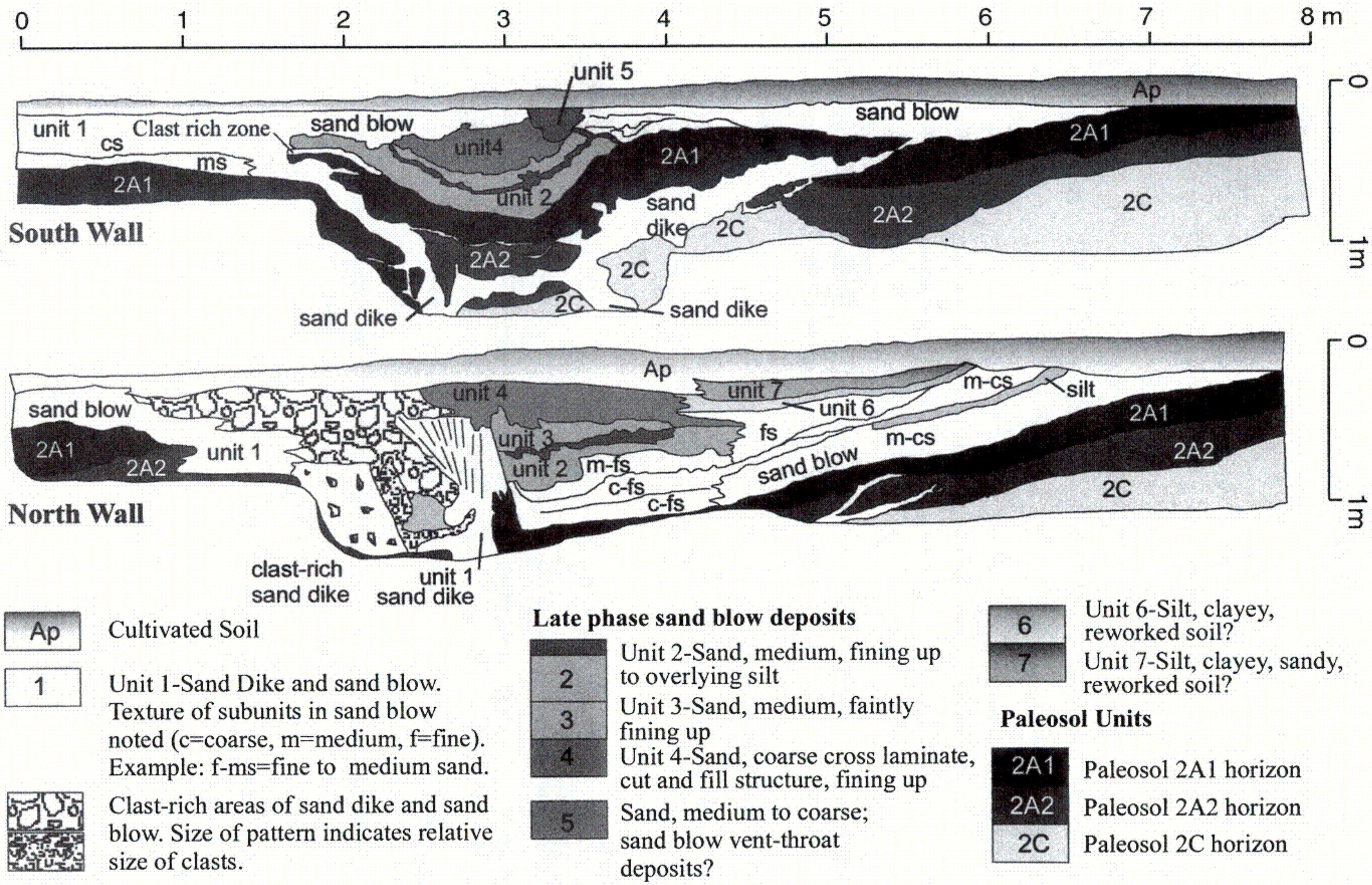

Figure 2.6. Log of trench excavated at Lowrance site near Wilson, Arkansas. Sedimentary characteristics of sand blow suggest a single event with multiple phases of development. Radiocarbon dating of wood and charcoal and analysis of native American artifacts from cultural feature 40 cm below sand blow suggests that liquefaction features formed during 1811-1812 earthquakes. Log by J.D. Sims and L. Clark.

C06

does not outcrop in the north wall but that numerous clasts of paleosol are present. This suggests that the force of venting broke up the paleosol completely and redeposited it as clasts, whereas the force was much less in the area of the south wall and only lifted and fractured the flap of paleosol. Interpretation of the sequence of events is complicated by the complex stratigraphy above the main vent. Units exposed in the south wall suggest that the sand blow formed in three to four main phases. The sand blow may have formed during one event or during multiple events in an earthquake sequence.

We recovered artifacts below the sand blow primarily from a 90-cm-wide cultural feature, located about 1 m south of the vent and 40 to 50 cm below the sand blow (Table 2.4). One large rim sherd, characterized by Memphis rim mode and diagonally-notched rounded lip, was recovered from the feature. The sherd was tempered with grog, sand, and very fine shell. The shell in this sherd, as well as other recovered sherds, is extremely fine. The sherds are highly fired, and have reduced cores and oxidized walls. A second sherd is very thin (4 mm) with a Memphis rim mode and very fine diagonal incising. This decorative style fits the type Barton Incised *Variety Barton* (Phillips 1970). Artifacts collected from the cultural feature are diagnostic of the Late Mississippian period. Radiocarbon dating of charcoal collected 43 cm below the sand blow from the cultural feature yielded a calibrated date of A.D. 1450-1660. The thickness of soil above the cultural feature suggests that the overlying sand blow formed several hundred years after occupation. Therefore, this multi-phase sand blow probably formed during the 1811-1812 earthquake sequence.

Table 2.4. Summary of artifacts recovered below sand blow at Lowrance site.

Below Sand Blow	
Shell tempered pottery	Post 1000
Grog, sand & shell tempered notched Memphis rim mode	Post 1400
Incised Memphis rim mode	Post 1400

2.4. R.P. Haynes Site (3MS614)

M. Haynes brought our attention to a large sand blow in association with a Woodland occupation horizon exposed in a drainage ditch north of Blytheville, Arkansas (Fig. 1.1). During reconnaissance of the site, we verified that the sand blow buried an occupation horizon containing Woodland artifacts (Fig. 2.7). Given the relationships, we thought the sand blow might pre-date the A.D. 900 event and selected the site for further investigation. A. Barnes and L. Wolf of Auburn University conducted a geophysical survey at the site (Wolf, 1999) and participated in the paleoseismological study of liquefaction features. The geophysical survey identified several northeast trending sand dikes and related sand blows.

The sand blow and related sand dikes are exposed in a north-south oriented ditch that drains into nearby Pemiscot Bayou. The main feeder dike is 10 to 11-cm wide and filled with fine to

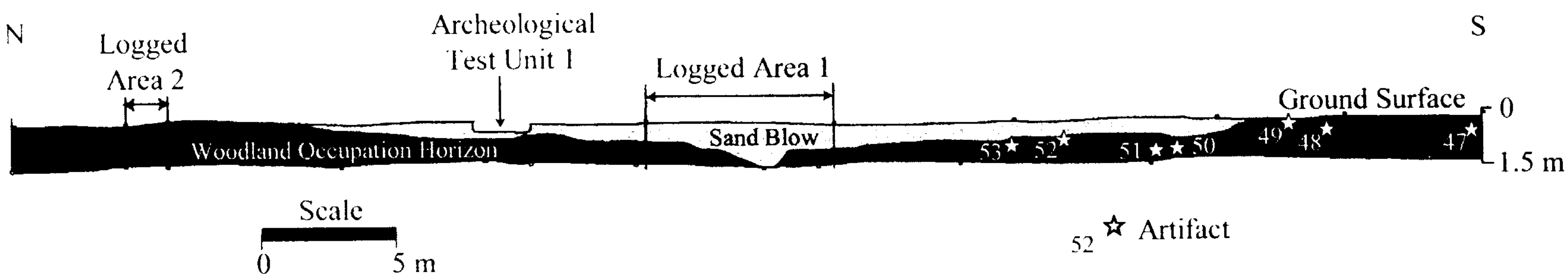

Figure 2.7. Profile of ditch exposure of sand blow at R.P. Haynes site near Blytheville, Arkansas. See Figure 2.8 of logged areas 1 and 2. Large sand blow buries Late Woodland to Early Mississippian occupation horizon. Profile by W. Hoyt and M. Tuttle.

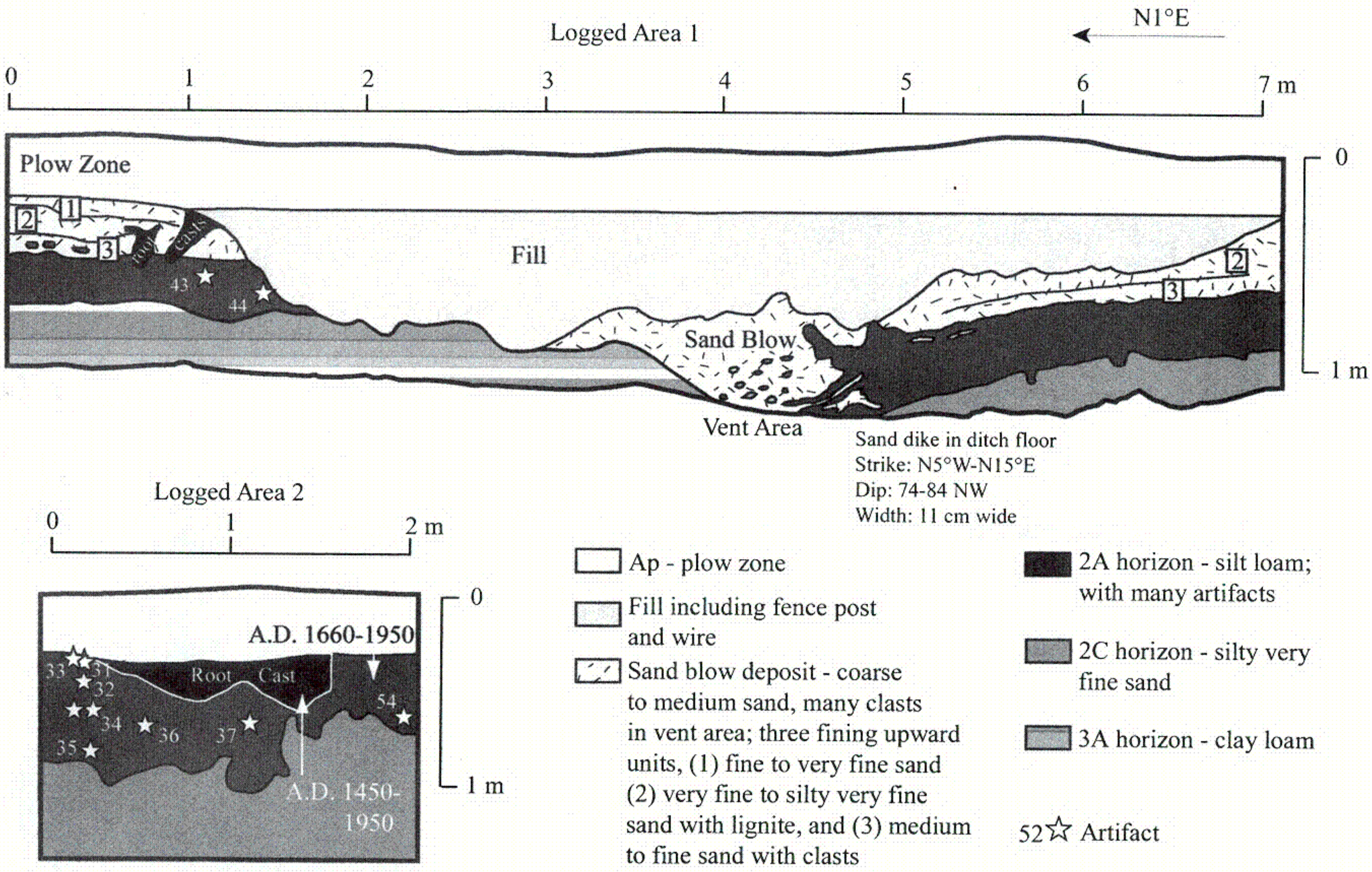

Figure 2.8. Logged areas 1 and 2 at R.P. Haynes site near Blytheville, Arkansas. Sand blow buries Native American occupation horizon including artifacts of Late Woodland and Early Mississppian periods. Charcoal collected from occupation horizon and about 40 cm below sand blow yielded calibrated date of A.D. 1000-1170. Therefore, sand blow probably formed after A.D. 1000 and possibly during 1811-1812 earthquake sequence. See Figure 2.7 for locations of logged areas 1 and 2. Logs by M. Tuttle and A. Barnes.

C07

medium sand and clasts of soil (Fig. 2.8). The dike's orientation varies from N15°E, 84°NW to N05°W, 74°NW. Although disturbed above, the sand blow within the main vent area remains intact and is composed of coarse to medium sand and many soil clasts. This portion of the sand blow is overlain by soil, including milled wood and barbed wire, which was probably used to fill a gully that formed in the top of the sand blow. To either side of the fill, the sand blow is about 1 m thick and made up of three fining upward sedimentary units. The basal unit is a fine to medium sand that fines upward to a fine sand and contains clasts of clay and soil. The middle unit is a very fine sand that fines upward to a silty very fine sand and contains small pieces of lignite. This unit pinches out laterally a short distance from the vent. The upper unit is a fine sand that fines upward to a very fine sand. The sand blow is overlain by an exceptionally deep (27-34 cm) plow zone. Only small slivers of an undisturbed A horizon occur below the plow zone. We found no *in situ* artifacts or organic material that could be used to constrain the minimum age of the sand blow.

The sand blow overlies a Native American occupation horizon. Most of the diagnostic artifacts recovered from the horizon are grog-and-sand mixed temper Barnes/Baytown plain and cordmarked pottery (Table 2.5). Some grog-tempered Mulberry Creek cordmarked occurs toward the bottom of the horizon. Toward the south end of the profile (Fig. 2.7), we collected one sherd each of shell-tempered cordmarked (AKA Cahokia cordmarked) and Varney red filmed pottery from the top of the horizon. These types date to the Late Woodland and Early Mississippian periods.

Table 2.5. Summary of artifacts below sand blow at R.P. Haynes site.

Below Sand Blow	
Grog and sand tempered plain	Ca. 500-900 AD
Mulberry Creek cordmarked	Ca. 1 AD
Grog tempered cordmarked	1-900 AD
Plain	1-900 AD
Shell tempered cordmarked	~800-1000 AD
Varney red filmed	800-1000 AD

One piece of charcoal was recovered from the occupation horizon about 40 cm below the sand blow. Radiocarbon dating of the sample yielded a calibrated date of A.D. 1000-1170. The sample provides a maximum age for the sand blow and indicates that it formed after A.D. 1000. Given the depth of the sample, the sand blow may have formed during the 1811-1812 earthquakes. In logged area 2 located 5.5 m north of the sand blow (see Figs. 2.7 and 2.8), charcoal from a burned root cast in the occupation horizon yielded a calibrated date of A.D. 1450-1710, 1720-1890, and 1910-1950. Another piece of charcoal collected within 20 cm of the burned root cast yielded a similar calibrated date of A.D. 1660-1950. In this location, the occupation horizon is overlain by the plow zone, and in fact, probably has been disturbed by plowing. Given that their relationship to the sand blow is unclear, the charcoal samples do not help determine the age of the sand blow. Additional dating is required at this site to confirm the age of the sand blow.

2.5 Upper Nodena Site (3MS4)

The Upper Nodena archeological site is located northeast of Wilson, Arkansas (Fig. 1.1) and is the type locality of the Nodena point (Table 1.1). On aerial photographs provided by the Hampson Archeological Museum (Fig. 2.9), light colored, elliptical patches likely to be sand blows are clearly visible adjacent to the Upper Nodena mounds. During reconnaissance, we found several sand blows northeast of the mounds that exhibit fairly thick soil development. We selected three sand blows with a high concentration of large ceramic artifacts on their surfaces for investigation (Fig. 2.10).

In trenches 1 and 3, sand deposits bury a 2A1 soil horizon containing a few Native American artifacts (Fig. 2.11). Even though feeder dikes were not observed, the sand deposits are interpreted as distal portions of sand blows based on their similarity in sedimentary character and stratigraphic position to a sand blow deposit in trench 2. Alternatively, these deposits may represent small remnants of fluvial deposits. Radiocarbon dating of charcoal collected from the buried 2A1 horizon and about 1 cm below the sand deposit yielded a calibrated date of A.D. 1470-1800. Charcoal collected from the underlying 2A2 horizon yielded a similar date, but with a broader range, of A.D. 1480-1950.

In trench 2, small discontinuous sand dikes crosscut soil horizons containing abundant artifacts (Fig. 2.12). The dikes range up to 8 cm in width and are filled predominantly with fine sand. Two of the dikes connect with an overlying sand deposit, interpreted as a sand blow, that buries a 2A1 soil horizon. The main feeder dike contains small pieces of lignite aligned parallel to the dike margins. A subhorizontal dike, which branches off the main dike, exhibits planar bedding and contains small clasts of soil. Down the paleoslope from the vent area of the main dike, the sand blow is composed of two fining upward units. The lower unit fines upward from fine sand to very fine sand and includes discontinuous beds of lignite. The upper unit fines upward from a coarse sand including many soil clasts to a very fine sand. The units thin and fine towards the north, pinching out about 9 m from the vent. We found no intact A horizon below the 25-30 cm thick plow zone. We encountered several root casts within the sand blow and underlying 2A1 horizon. A piece of charcoal collected from the occupation horizon 3 cm below the sand blow yielded a calibrated date of A.D. 1460-1650. Similarly, another piece of charcoal collected 9 cm below the sand blow yielded a date of A.D. 1450-1650.

The soil horizons buried by the sand blow deposits contain many artifacts in great diversity (Table 2.6). Pieces of daub and fired clay, representative of Native American home sites, occur in the horizon immediately below the sand blow. The position of the artifacts within the horizon suggests that the site was occupied at or near the time of burial. Many of the potsherds exhibit Memphis Rim mode, which is a Late Mississippian trait. Other sherds are very finely made Barton and Mathews incised. These types are generally assigned to the Late Mississippian period but have been dated as early as A.D. 1200. We recovered sherds with Campbell appliqué rims, also diagnostic of the Late Mississippian period. The recovered pottery is very highly fired. Under magnification, one can see that the clay vitrified during firing. We also collected two large chunky discs that had been cut from sherds. Note the proximity of the "chunky field" identified by previous archeological investigations on Figure 2.9. Natives first made chunky discs, more like small cylinders, in the Early Mississippian. Over time, the cylinders gave way

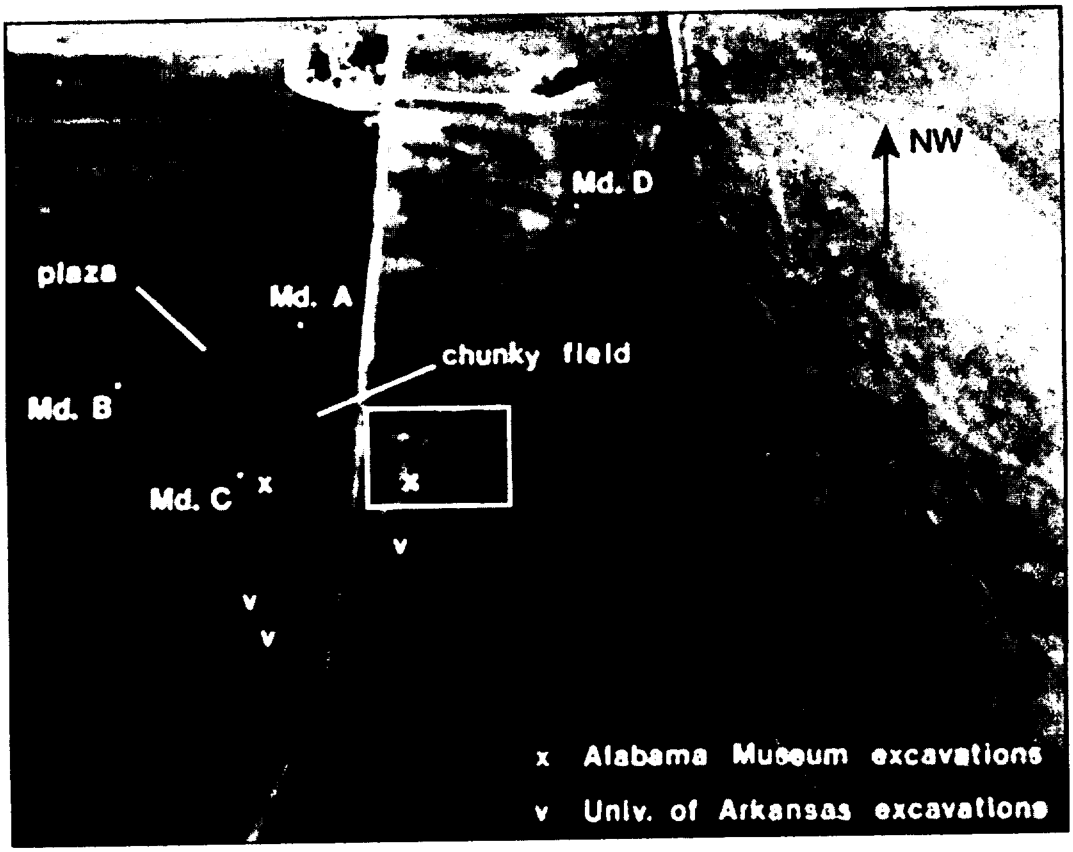

Figure 2.9. Aerial photograph of Upper Nodena archeological site provided by Hampson Museum. Locations of Mississippian mounds and previous archeological excavations are indicated. Note light-colored linear patches on northeast side of farm road. Excavations for study are located in area outlined by white rectangle. See Figure 2.10 for topographic map of site and trench locations.

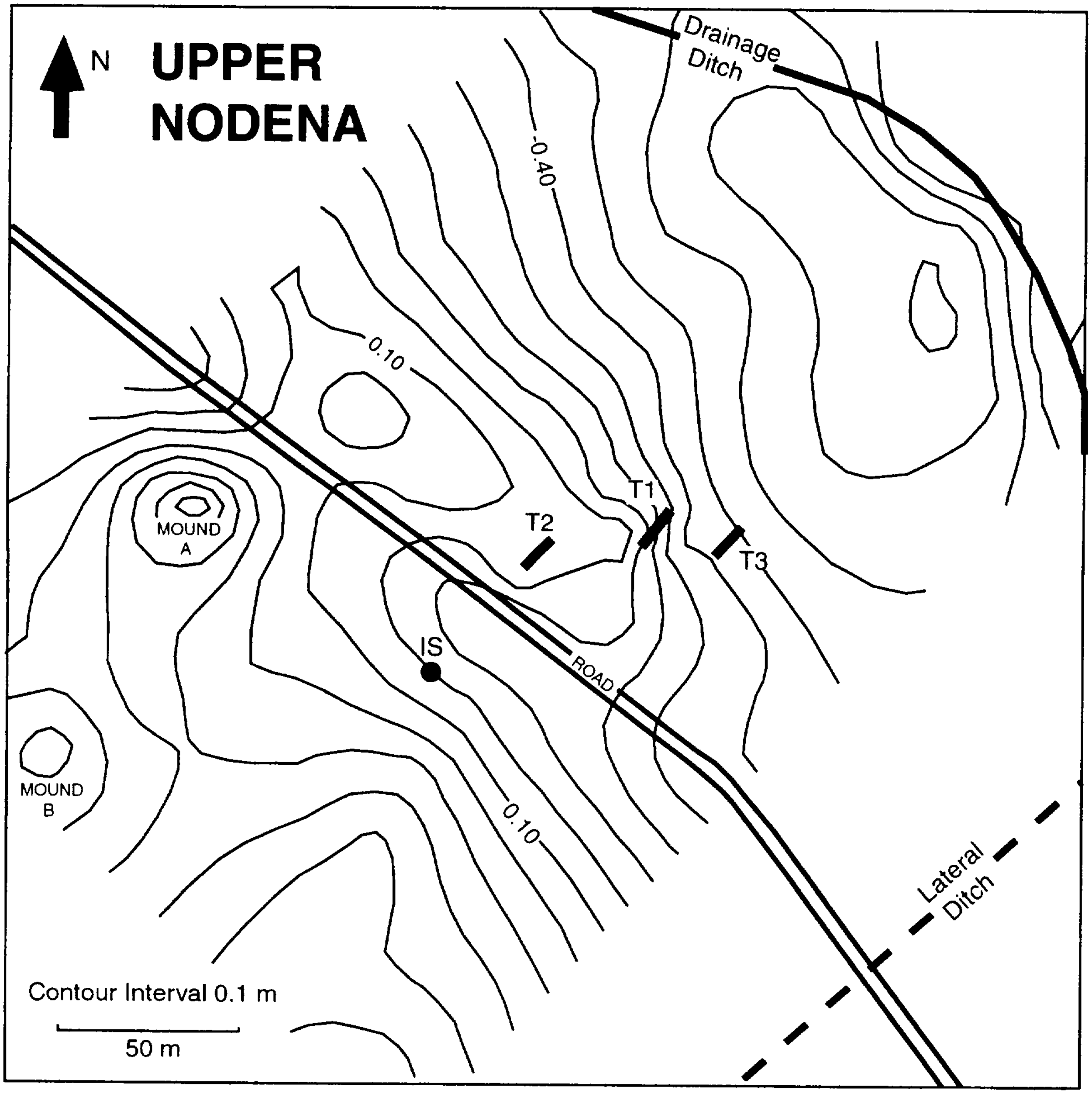

Figure 2.10. Topographic map of Upper Nodena site located northeast of Wilson, Arkansas, and near Mississippi River. Trenches 1 (T1), 2 (T2), and 3 (T3) are located east of Mississippian mound A. Sand dikes and sand blow are exposed in T2. Distal portions of similar age sand blows are exposed in T1 and T2. Sand blows bury Late Mississippian occupation horizon. Topographic contours relative to elevation of instrument site (IS). Map by L. Clark, E. Schweig, and M. Tuttle.

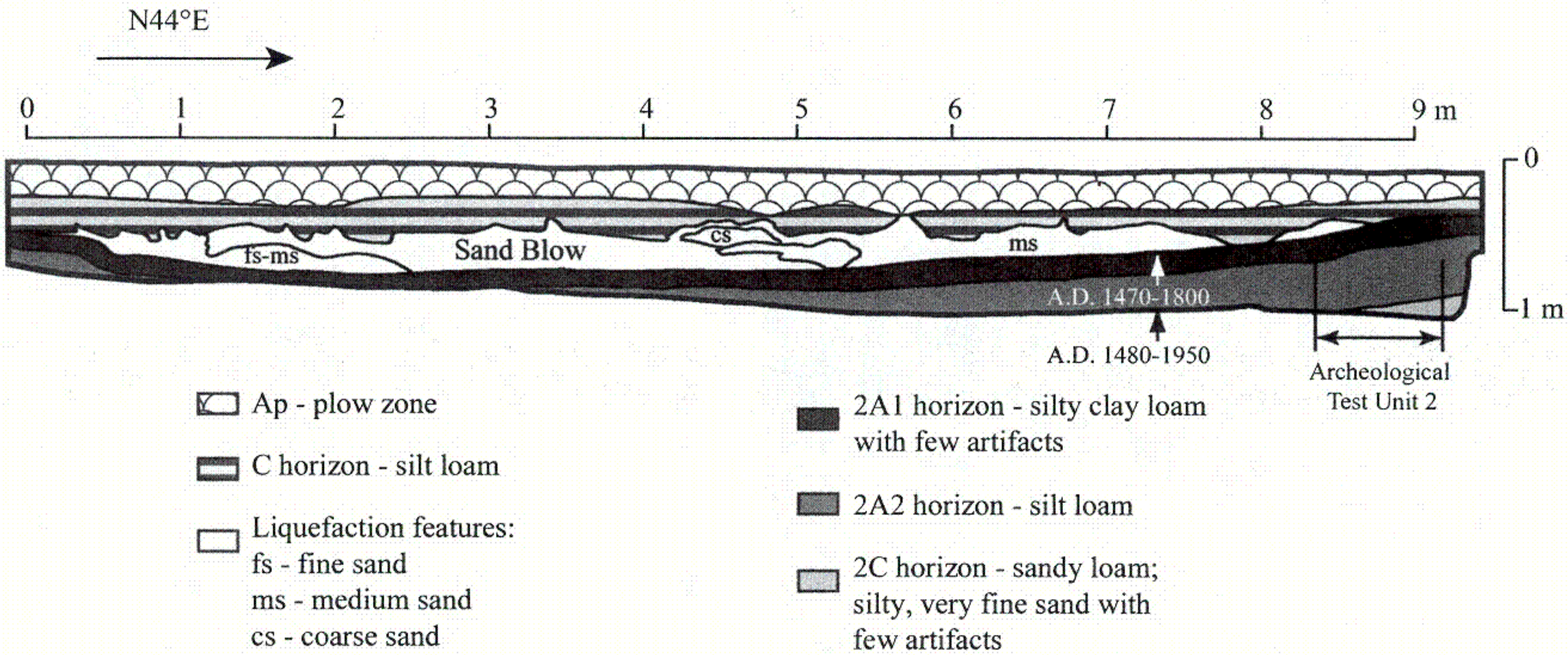

Figure 2.11. Log of northwest wall of trench 1 at Upper Nodena site near Wilson, Arkansas. Radiocarbon dating of charcoal from soil horizons below sand blow provides maximum age for event of A.D. 1470. Log by J.D. Sims.

C08

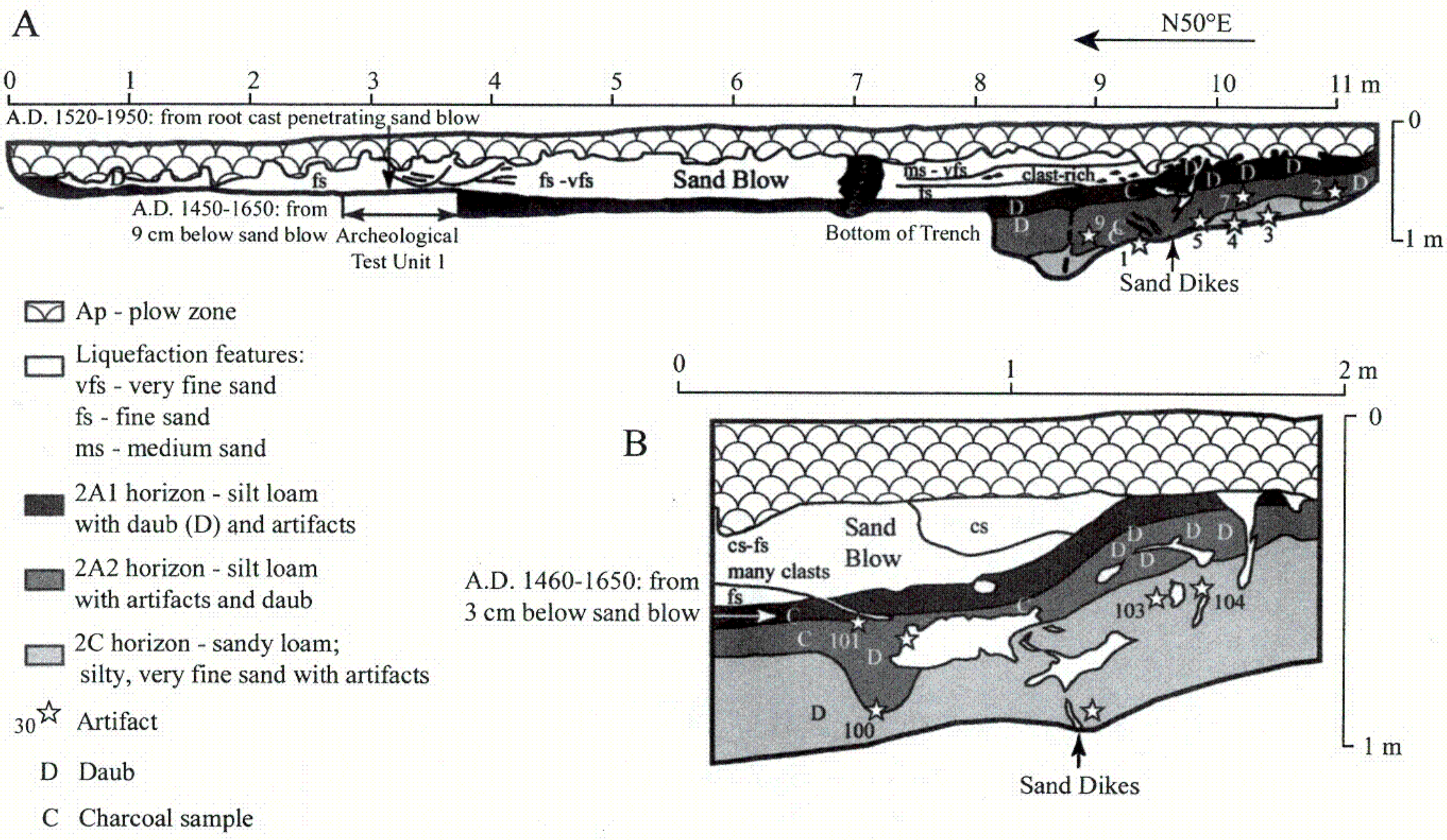

Figure 2.12. (A) Log of southeast wall of trench 2 at Upper Nodena site near Wilson, Arkansas. (B) Log of northwest wall at southwest end of same trench. Sand blow immediately overlies Late Mississippian occupation horizon, suggesting event between A.D. 1400 and 1670. Radiocarbon dating of charcoal from occupation horizon provides close maximum ages for event of A.D. 1450 and A.D. 1460. Logs by L. Clark, S. Diehl, E. Schweig, and M. Tuttle.

to the larger discs like the ones we collected. The artifact assemblage points to a Late Mississippian (A.D. 1400-1670) occupation of the site, which is consistent with the age estimate of the horizon based on radiocarbon dating.

Table 2.6. Summary of artifacts above and below sand blow at Upper Nodena site.

Above Sand Blows	
Shell tempered pottery	1000-1700 AD
Below Sand Blows	
Memphis rim modes	1400-1700 AD
Mathews and Barton incised	Post 1200 AD
Large sherd chunky disks	Post 1400 AD
Campbell appliqué rims	Post 1400 AD

Relationships at this site indicate that venting of sand and water occurred during two closely timed phases, or two events in the same earthquake sequence. Radiocarbon dating of soil horizons crosscut by the sand dikes and buried by the compound sand blow in trench 2 indicates that the events occurred after A.D. 1450. Given the assemblage and position of artifacts in the soil horizons overlain by the sand blow, the earthquakes that induced liquefaction at this site probably occurred during the Late Mississippian period and more specifically between A.D. 1450 and 1670.

2.6 Walker Site (3PO32)

The Walker site located near Marked Tree, Arkansas, is notable for its well-preserved Mississippian mound (Fig. 2.13). We examined aerial photographs of the area and found that light-colored elliptical patches, likely to be sand blows, occur in the fields surrounding the mound. During reconnaissance, which included geophysical surveying conducted by A. Barnes and L. Wolf of Auburn University (Wolf, 1999), we dug test pits in the light-colored elliptical patches and verified that they are indeed sand blows. The geophysical survey defined the orientations of the sand dikes and related sand blows and played a crucial role in the selection of trench locations. Two sand blows on the west side of the mound and one on the south side are characterized by fairly thick (~20 to 30 cm) A horizons, suggesting that they are prehistoric in age. In addition, we found ceramic and lithic artifacts of the Middle and Late Mississippian periods on the ground surface above the sand blows (Table 2.7). In collaboration with Barnes and Wolf, we trenched the three sand blows in order to examine stratigraphic relations and to collect artifacts and other material for the purpose of dating the sand blows.

The first sand blow we trenched on the west side of the mound was very thin and almost completely within the depth range of plowing (Fig. 2.13). Due to the degree of disturbance of the sand blow, we abandoned trench 1 and excavated a second trench a few meters farther west in a thicker portion of the sand blow. In trench 2, we found a sand dike and part of its associated sand blow preserved below the plow zone (Fig. 2.14). The sand blow is intact only on the south side of the sand dike. Soil horizons occur about 18 cm lower on the south side of the dike than they do on the north side. Thus, we interpret that the ground surface on the south side of the dike subsided relative to the north side during the liquefaction event. The vertical displacement of the ground surface allowed for a thicker deposit of vented sand to accumulate on the south side of the dike than may have accumulated on the north side. The sand dike is 19 cm wide, has a strike and dip of N26°W, 83°SW, and is composed of fine to medium sand. The overlying sand blow is 35 cm thick (including plow zone) and is composed of fine sand above the dike. The sand blow deposit includes an interbed of silty, very fine sand and fines towards the south to very fine sand. Silt has accumulated along the basal contact of the sand blow.

Table 2.7. Summary of artifacts above and below sand blow at Walker site.

Above Sand Blow	
Shell tempered pottery	1000-1700 AD
Slipped, Old Town red	post ~1100 AD
Incised, Mathews or Barton	post 1400 AD
Madison/Nodena point tip	1200-1700 AD
Below Sand Blow	
Shell tempered pottery	1000-1700 AD
Strap handle	1200- ~1450 AD
Slipped	post 1100 AD
Burnished Bell plain	post 1200 AD
Mill Creek chert	after ~1200 AD

The sand blow immediately overlies a Native American occupation horizon containing a large amount of fired clay and pottery sherds. This relationship suggests that the site was occupied at the time of the event. All of the pottery collected from the horizon is shell tempered, including a large heavy strap handle (Table 2.7). Strap handles are a hallmark of the Middle Mississippian period in the lower Mississippi Valley and are extremely rare in Late Mississippian mortuary pottery (Ford 1961; Morse and Morse, 1983). A sherd of black, burnished Bell Plain pottery from the horizon is diagnostic of the Middle and Late Mississippian periods. The assemblage of artifacts suggests that the horizon was occupied during the Middle Mississppian or Middle and Late Mississppian periods. Radiocarbon dating of charcoal collected from the occupation horizon within a centimeter of the base of the sand blow yielded a calibrated age of A.D. 1420-1500. The date suggests that the sand blow formed after A.D. 1420. The stratigraphic relations, artifact analysis, and radiocarbon dating indicate that the liquefaction features formed during the Late Mississippian period and between A.D. 1420 and 1670.

We also trenched a sand blow on the south side of the mound (Fig. 2.13). In trench 3, we found two sand dikes, an undisturbed basal portion of the sand blow between the dikes, and a sand-filled root cast (Fig. 2.15). The two sand dikes are separated by about 80 cm. The more northerly of the two dikes is 26 cm wide and has a strike and dip of N17°W, 83°SW. The other dike is 45 cm wide and is oriented N43°W, 78°SW. The dikes are filled with fine to medium sand and fine upward to a fine sand containing pieces of lignite. Silt has accumulated in the upper 10 cm of the dikes and along their margins. Also, soil lamellae have formed in the upper 40 cm of

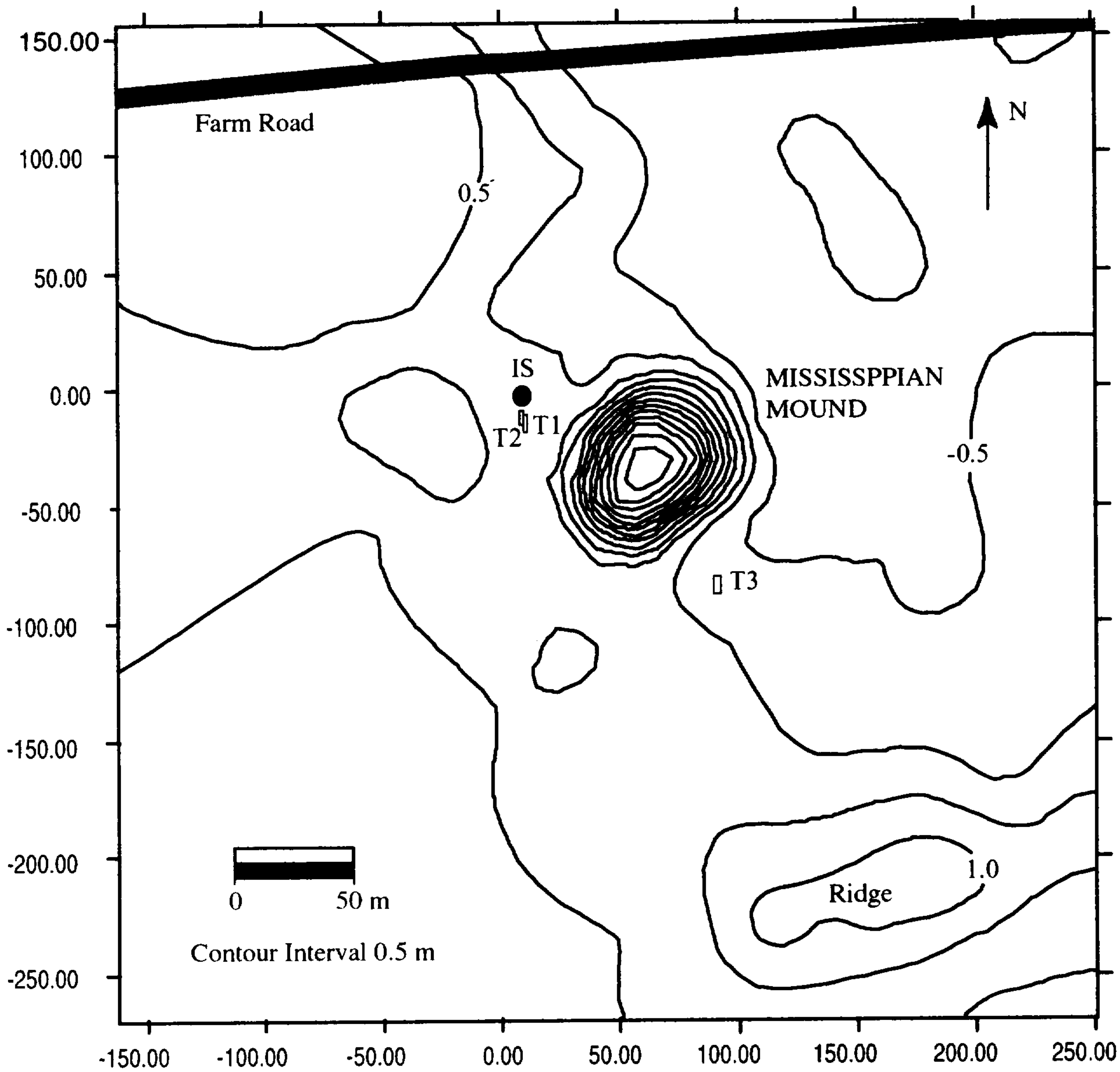

Figure 2.13. Topographic map of Walker site located near Marked Tree, Arkansas, where trenches 1 (T1) and 2 (T2) were excavated west of Mississippian mound and trench 3 (T3) was excavated southeast of mound. Sand blows that bury a Middle to Late Mississippian occupation horizon are exposed in trenches 2 and 3. Topographic contours relative to elevation of instrument site (IS). Map by L. Clark, W. Hoyt, E. Schweig, and M. Tuttle.

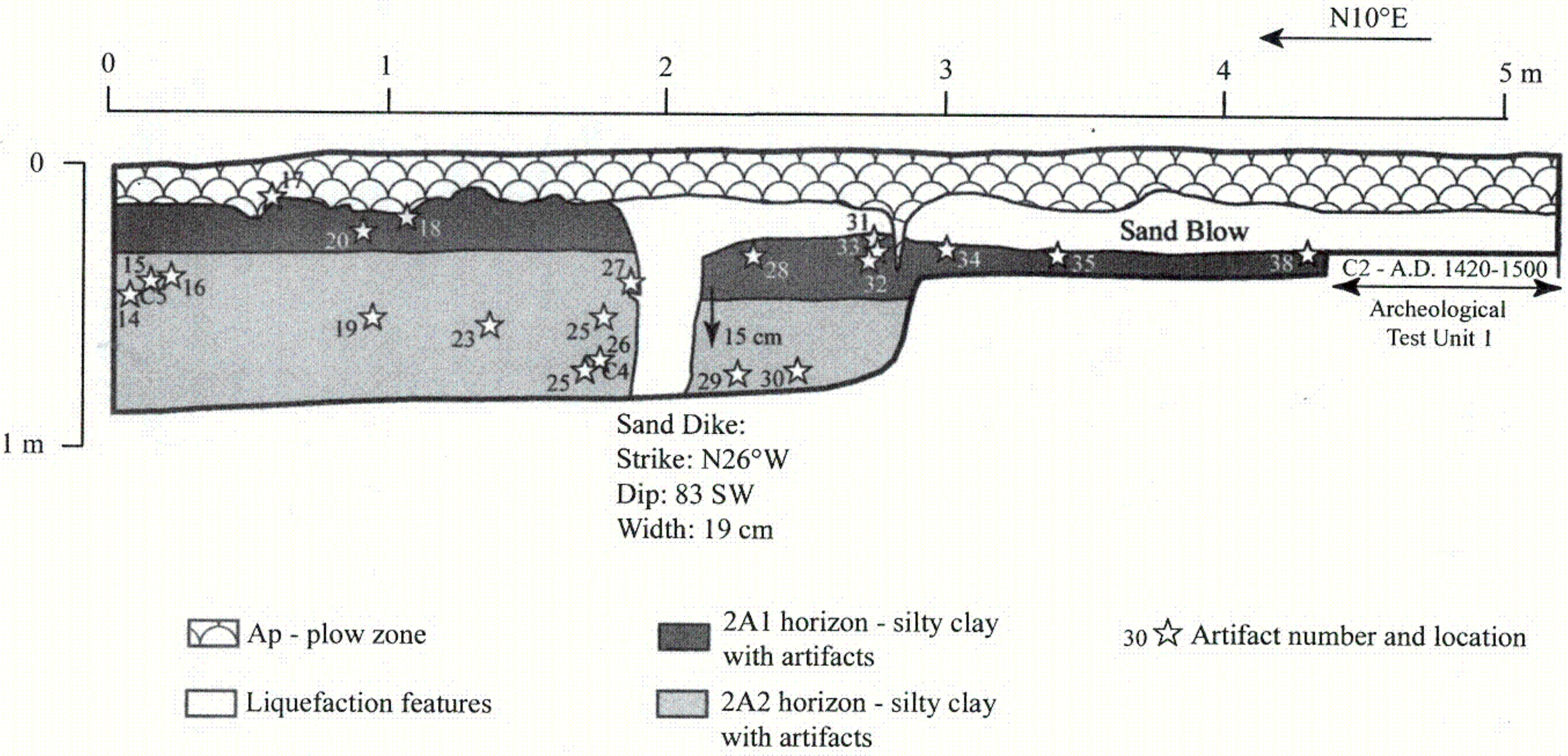

Figure 2.14. Log of east wall of trench 2 at Walker site near Marked Tree, Arkansas. Radiocarbon dating of sample C2 collected from occupation horizon immediately below sand blow suggests that it formed soon after A.D. 1420. Similarly, artifacts in horizon buried by sand blow suggest that liquefaction features formed during the Middle to Late Mississippian.

C18

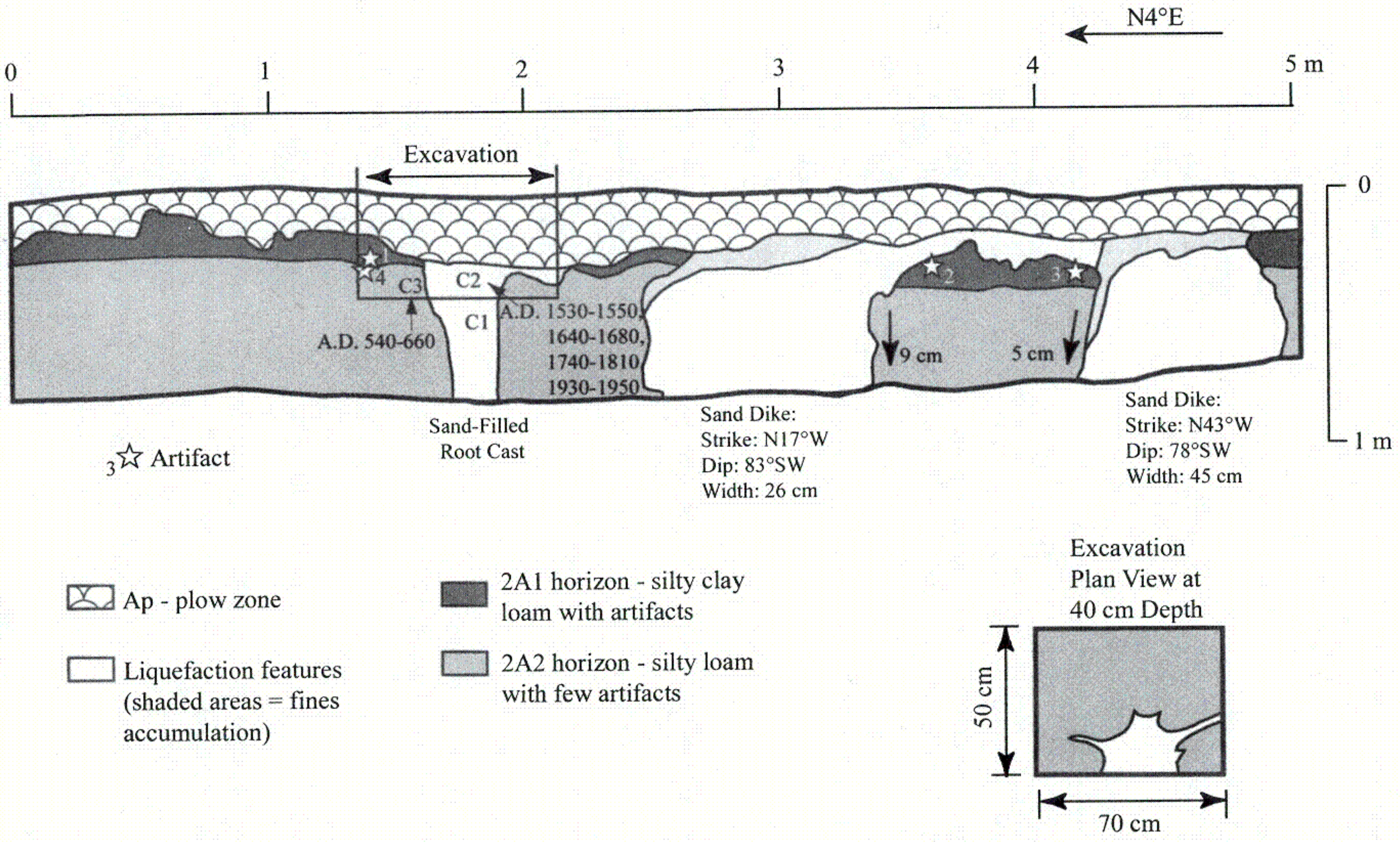

Figure 2.15. Log of east wall of trench 3 at Walker site near Marked Tree, Arkansas. Sand dikes cross-cut and related sand blow overlies similar occupation horizon to that exposed in trench 2 suggesting that liquefaction features formed during same event. Sand-filled root cast exposed in vertical and horizontal sections may have formed during same or later event.

C11

the dikes. Only the basal portion of the sand blow has not been disturbed by plowing. Soil horizons below the sand blow are displaced downward by about 10 cm relative to horizons on either side of the two dikes. This can be explained by subsidence of the ground between the two dikes during the liquefaction event. We cut a horizontal section into the east wall of the trench to examine the morphology of the sand-filled root cast (see Fig. 2.15). The feature is of limited lateral extent and has an irregular boundary typical of root casts. The root cast is filled with a sandy loam containing many small pieces of charcoal. The occurrence of charcoal throughout the fill suggests that the root burned prior to intrusion by the sand. Soil lamellae were not observed in the sand-filled root cast; however, the top of the root cast has been truncated by the plowing.

In trench 3, we found only a few artifacts in the 2A1 horizon crosscut by the dikes and root cast and overlain by the sand blow. The sherds are shell tempered and indicative of the Mississippian period. Organic material collected 35 cm below the surface from the 2A2 horizon yielded a calibrated date of A.D. 540-660. A sample of charcoal collected 30 cm below the surface from the sand-filled root cast yielded a date with several ranges of A.D. 1530-1550, 1640-1680, 1740-1810, and 1930-1950. The sand dikes clearly formed after A.D. 540. Given that the sand blow overlies a soil horizon containing Mississippian artifacts and that the sand dikes exhibit similar soil development, the liquefaction features in trench 3 probably formed during the same event as those in trench 2. Radiocarbon dating of charcoal in the root cast suggests that it was intruded by sand after A.D. 1530. This could mean that the penultimate event occurred during the Late Mississippian but after A.D. 1530. Alternatively, the root cast may have been intruded during a later event, possibly the 1811-1812 earthquakes.

3. RESULTS OF SOIL ANALYSES

The results of physical and chemical analyses of soils developed in sand blows and sand dikes at various sites are presented in Appendix B. Changes in soil properties with depth are presented in Appendix C and summarized below in Table 3.1.

1) Braggadocio: We analyzed samples from the two sand blows at this site. The upper sand blow, thought to have formed in 1811-1812, shows a consistent trend in soil properties. There is an increase in pH with depth while values for all other properties decrease with depth. The lower sand blow, thought to have formed about A.D. 1450, shows a decrease in cation exchange capacity (CEC) and percent organic matter (OM) with depth; however, percent soil iron (Fe) shows an overall increase with depth and pH decreases with depth.

2) Brooke (23PM56): The sand blow at this site probably formed in 1811-1812. Soil pH increases with depth while the organic matter content shows an overall decrease with depth. No trend could be discerned in measurements of CEC and Fe.

3) Dodd (23PM46): The sand blow at this site probably formed about A.D. 1450 and was buried at some time in the past 200 years by overbank deposits. The pH of the samples collected from the sand blow increases with depth, while CEC, Fe and OM all decrease.

4) Eaker 1 (3MS525): The sand blow at this site probably formed about A.D. 1450 and was buried at some time in the past 200 years by overbank deposits. Overall, pH increases with depth and CEC and OM decrease with depth. Fe shows a mixed trend.

5) Eaker 3 (3MS560): There are two sand blows at this site that are thought to have formed during an earthquake sequence about A.D. 900. CEC, Fe and OM decrease with depth in both sand blows. Soil pH increases in the upper sand blow but decreases in the lower sand blow, supporting the idea that the lower sand blow was not exposed to soil forming processes for very long prior to burial by the overlying sand blow.

6) Eightmile Ditch: This sand blow probably formed in 1811-1812 and was covered with ditch spoil about 30 years ago. Soil pH increases with depth. CEC, Fe and OM all decrease with depth.

7) Hillhouse (23MI699): Soil samples were collected from both a sand blow and sand dike that formed about A.D. 900. The liquefaction features appear to have been reoccupied by Native American shortly after they formed. In the sand blow, soil pH as well as CEC, Fe and OM decrease with depth. In the sand dike, pH, CEC, and OM decrease with depth, but FE shows the reverse trend.

8) Haynes (3MS304): Soil samples were collected from stratified A horizons developed in overbank deposits rather than from the liquefaction features. In the fluvial deposits, pH decreases with depth; whereas there are no clear trends in the CEC, FE, and OM data. This may be due to the stratified nature of the profile.

9) Reelfoot: Samples were collected from a sand dike thought to have formed in 1811-1812. In the sand dike, pH increases with depth, while CEC and Fe decrease with depth. OM is fairly low throughout the profile.

10) Wilkerson Ditch: There are two sand blows at this site. The upper sand blow probably formed in 1811-1812 and the lower sand blow formed about A.D. 900. For the upper sand blow, pH increases with depth, while CEC, Fe and OM decrease with depth. Two samples collected in the upper part of the lower sand blow were used for radiocarbon dating and no material was left for soil analyses. Below the upper part of the lower sand blow, pH as well as CEC, FE, and OM decrease with depth.

The soils data show the expected increase in pH and decrease in CEC, FE, and OM with depth at the Dodd, Eightmile Ditch, and Reelfoot sites and in the upper sand blows at Braggadocio, Eaker 3, and Wilkerson Ditch sites. The results are mixed, however, at the Brooke and Eaker 1 sites and for the sand dike at the Hillhouse site and the lower sand blow at Braggadocio. At all the sites, OM decreased with depth. With the exception of the Brooke site, CEC decreased with depth. With the exception of the Hillhouse site and the lower sand blow at the Braggadocio site, pH increased with depth. Of the four chemical properties, FE was the least likely to follow the expected trend. For the Hillhouse site, properties of the samples collected from the narrow sand dike may have been influenced by the host deposit.

Table 3.1. Summary of changes in soil properties with depth and estimated ages and time of soil development of liquefaction features.

Site Name	pH	Cation Exchange Capacity (ppm)	Fe (%)	Organic Matter Content (%)	A horizon Thickness (cm)	Estimated Age of Liquefaction ± 100 yr	Estimated Time of Soil Development ± 100 yr
Braggadocio							
Upper Sand Blow	increase	decrease	decrease	decrease	15	190	190
Lower Sand Blow	decrease	decrease	increase	decrease	25	500	500
Brooke (23PM56)	increase	mixed	mixed	decrease	< 20	190	190
Dodd (23M46)	increase	decrease	decrease	decrease	20	500	300
Eaker 1 (3MS525)	increase	decrease	mixed	decrease	25	500	300
Eaker 3 (3MS560)							
Upper Sand Blow	increase	decrease	decrease	decrease	35	1100	1100
Eightmile Ditch	increase	decrease	decrease	decrease	10	190	160
Hillhouse (23MI699)							
Sand Blow	decrease	decrease	decrease	decrease	45	1100	1100
Sand Dike	decrease	decrease	increase	decrease	62	1100	1100
Reelfoot	increase	decrease	decrease	decrease	NA[1]	190	NA
Wilkerson Ditch							
Upper Sand Blow	increase	decrease	decrease	decrease	10	190	190
Lower Sand Blow	NA	NA	NA	NA	37	1100	910

Key

[1]NA = Not Available

The actual pH, CEC, FE, and OM values or change in these values with depth do not appear to reflect the ages of the liquefaction feature. For example, the sand blow at Eightmile Ditch, exposed to soil forming processes for only 160 years, exhibits similar pH values to the sand blow at Eaker 3, exposed to soil forming processes for about 1100 years. Over a depth interval of 20 cm, the Eightmile Ditch and Eaker 3 sand blows increase in pH by 0.27 and 0.76 units, respectively. In this case, the change is greater for the older sand blow. However, the Eaker 1 sand blow, exposed for about 300 years, exhibits a decrease of 1.1 pH units over a depth range of 22 cm.

We followed established procedures in our soils analysis, so laboratory error is probably not a major factor contributing to the mixed results. We found that the sand blow deposits commonly contain a few percent of clay. The small amount of clay may have affected other soil properties of the liquefaction features. For example, sample 6 collected from the sand blow at Eaker 3 and containing about 1.4 percent clay has measured pH, CEC, Fe and OM values of 6.45, 4.20, 0.49 and 0.24, respectively. In contrast, sample 8 containing about 30.4 percent clay has pH, CEC, Fe and OM values of 6.93, 32.6, 0.69 and 2.86, respectively. Acidity of the parent material undoubtedly varied from site to site and affected the pH of soils developed in the liquefaction features. In addition, agricultural practices may have affected soil properties at the study sites. Most of the land in the New Madrid region has been cleared and is currently cultivated. The addition of fertilizers may have affected soil pH and CEC. In addition, cultivation may have led to the loss of topsoil due to accelerated erosion. In future studies, sites should be selected in the few relatively undisturbed areas to minimize the agricultural affect on soil properties.

Despite these problems, A horizon thickness increases with time as expected. In other words, older sand blows have thicker A horizons. For example, A horizons of the sand blows at Eightmile Ditch, Eaker 1, and Eaker 3 are 10 cm, 25 cm, and 35 cm thick, respectively (Table 3.1). We estimated the amount of time the various sand blows have been exposed to soil forming processes based on the stratigraphic relations and estimated ages of the sand blows. At the Dodd, Eaker 1, Eightmile Ditch, and Wilkerson Ditch sites, where sand blows were buried by overbank deposits, the time of soil formation is less than the age of the liquefaction features. Using the soils data, we performed regression analysis to develop relations between A horizon thickness and years of soil development (Fig. 3.1). We fit the data with both polynomial and linear trendlines (least squares fit). The equation used for calculating the polynomial trendline was of the form:

$$y = b + c_1x + c_2x^2 + c_3x^3 + \ldots c_6x^6$$

where b and $c_1 \ldots c_6$ are constants. The resultant relation is

$$y = -4E\text{-}05x^2 + 0.0745x,$$

where y is A horizon thickness and x is years of soil development. The R-squared value, representing an approximation of the variance in y attributable to the variance in x, for this equation is 0.9356 and reflects the decrease in the rate of A horizon formation with time as a state of equilibrium is approached. According to this relation, a surface sand blow with a 15 cm

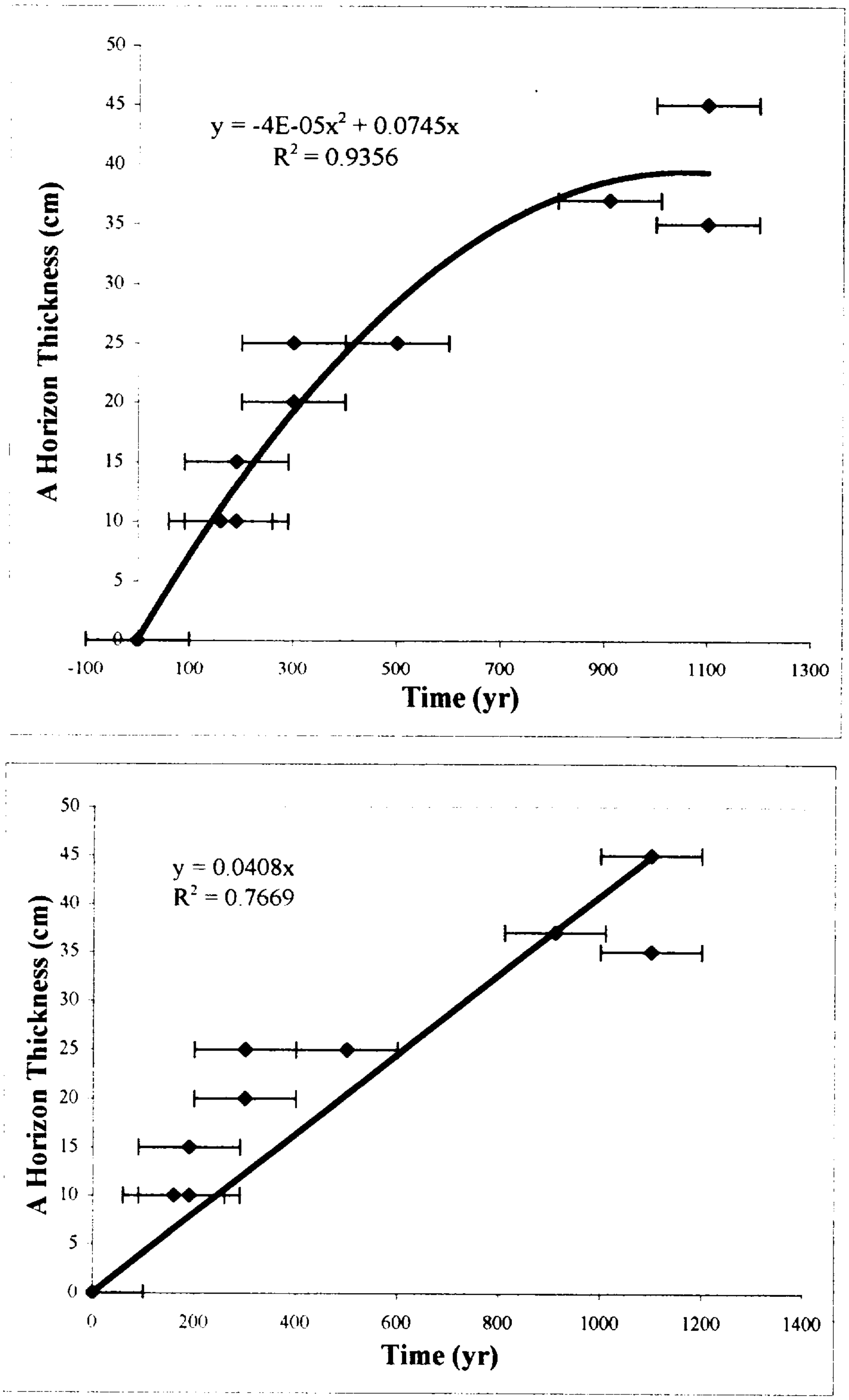

Figure 3.1. Relations between A horizon thickness and years of soil development of earthquake-induced liquefaction features. Bars reflect uncertainties in age estimates of liquefaction features; diamonds mark midpoints of possible age ranges.

thick A horizon would be about 230 $\pm$ 100 years old; whereas, a surface sand blow characterized by a 27 cm thick A horizon would be about 500 $\pm$ 100 years old.

The equation used for calculating the linear trendline was of the form:

$y = mx + b,$

where m is the slope and b is the y intercept. Since a sand blow has no A horizon at the time of formation, b is equal to 0 and the resultant relation is

$y = 0.048x,$

where y is A horizon thickness and x is years of soil development. The R-squared value for this equation is 0.7669. According to this relation, a surface sand blow with a 10 cm thick A horizon would be about 245 $\pm$ 100 years old; whereas, a surface sand blow characterized by a 30 cm thick A horizon would be about 735 $\pm$ 100 years old. The linear relation does not fit the data as well as the polynomial relation.

A horizon thickness is easy to measure in the field and can provide a quick and inexpensive estimate of the amount of time that a liquefaction feature has been exposed at the surface. Stratigraphic relations must also be considered when figuring the age of the liquefaction features. The soil development relation is not intended to replace radiocarbon dating or artifact analysis in estimating the age of liquefaction features. Instead, the relation may best be employed in selecting liquefaction features for detailed investigations. In those cases where materials are not available for more traditional dating techniques, the soil development relation can be used to help estimate the age of features whose A horizons are no more than 37 cm thick.

4. CONCLUSIONS

Sand blows at the Amanda, Archway, Lowrance, and R.P. Haynes sites appear to have formed during the 1811-1812 earthquake sequence and provide new data for comparison of the size distribution of prehistoric and historic liquefaction features. The sand blows at these sites are similar in thickness and sedimentary characteristics to other historic sand blows in the region.

Sand blows at Amanda, Upper Nodena, and Walker sites may have formed during an earthquake or earthquake sequence about A.D. 1450 and provide new data in areas where there was previously a gap in information. More specifically, the Amanda site adds confidence in the correlation of features of this age across the central part of the New Madrid seismic zone, and the Upper Nodena and Walker sites extend the liquefaction field for this event towards Memphis. The prehistoric sand blows at the Amanda, Upper Nodena, and Walker sites are smaller and composed of fewer fining upward layers than historic sand blows in the same areas, supporting an earlier hypothesis that an event in A.D. 1450 $\pm$ 150 yr included fewer very large earthquakes than the 1811-1812 sequence. In addition, the A.D. 1450 event appears to have affected the southern part of the region less severely than the historic earthquake sequence.

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Of the eight soil characteristics measured at ten sites, only A horizon thickness shows a consistent trend with age of liquefaction features. The lack of consistent trends for the other properties may be due to clay content of the samples, acidity of parent material, and modification of natural soils by agricultural practices. From soil data, we develop relations between A horizon thickness and estimated time of soil development. The polynomial equation, $y = -4E\text{-}05x^2 + 0.0745x$, provides the best fit and reflects a decrease in the rate of A horizon formation with time. Although based on only a few measurements of samples collected from less than pristine field conditions, the soil development relation appears to be useful for making preliminary age estimates of sand blows. As additional data on A horizon thickness becomes available for pre-A.D.900 sand blows, relations can be developed for a longer time span. Until then, these relations should not be used to estimate the ages of sand blows with A horizons greater than 37 cm thick.

The results of this study add confidence in our previous estimates of the timing, source area, and magnitudes of prehistoric earthquakes and recurrence intervals of New Madrid earthquake sequences. Nevertheless, more work is needed to further define and compare the liquefaction fields induced by prehistoric and historic earthquakes. The comparison of areas affected by prehistoric and historic earthquakes will help to quantify the magnitude of paleoearthquakes and the seismic hazard in the New Madrid region. In addition, it is important to extend the paleoearthquake chronology farther back in time to improve estimates of recurrence intervals of New Madrid earthquakes and our understanding of the long-term behavior of the New Madrid seismic zone.

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APPENDIX A. RESULTS OF ARCHEOLOGICAL ANALYSIS

Table A.1. Artifacts above and below sand blow at Amanda site.

Amanda Site	Above SB		Below SB	
Historic	ct.	wt.	ct.	wt.
Porcelain	1	45.3		
Whiteware	8	27		
Whiteware Handle	1	17.3		
Stoneware	4	62		
Molded Milk Glass	1	3.8		
Milk Glass Liner	1	2.2		
Clear Windowpane	1	1		
Aqua Windowpane	1	1.9		
Clear Glass	6	22.7		
Aqua Glass	5	13		
Aqua Soda Glass	1	33.8		
Amethyst Glass	3	15.6		
Molded Amethyst Glass	1	1.6		
Modern Color Glass	2	10.7		
Melted Clear Glass	2	4.3		
Brick	5	20		
Misc Metal	1	1		
Nail	1	45.3		
Coal	2	0.4		
Pottery				
Fclay		1.5		10.7
Sherds		0.7		16.9
Shell Rim w/slip			1	14
Shell Body sherd			8	38.7
Shell Body sherd w/ slip			7	41.4
Incised Shell Body sherd			1	12.2

Appendix A

Table A.1. continued.

Amanda Site	Above SB		Below SB	
Pottery	ct.	wt.	ct.	wt.
Lithic				
Shatter				
Burlington Flake			1	1.2
Mounds Preform			1	45.2
FCR	1	266.2		
Unmodified				
Pebble	1	0.2		
Shale	1	0.7		
Galena			2	37.1
Lime			1	4.8
Miscellaneous				
Bone	1	0.2		

Table A.2. Artifacts above and below sand blow at Archway site.

Archway	Above SB		Below SB	
Pottery	ct.	wt.	ct.	wt.
Sand Body sherd			2	44.4
Fabric Sand Body sherd	1	3.9		
Crdmrk Sand Body sherd			1	60.4
Misc.				
Bone			3	0.1

Table A.3. Artifacts from test unit 1 at R.P. Haynes site.

R.P. Haynes	Level I (56-57 cmbs)		Level II (57-60 cmbs)		Level III (60-63 cmbs)		Level IV (63-66 cmbs)		Level V (66-69 cmbs)			
Pottery	ct.	wt.	ct.	wt.	ct.	wt.	ct.	wt.	ct.	wt.	Total ct.	Total wt.
Fired clay						0.5		1.9		1.2		3.6
sherd		5		24.2		25		14.4		22.8		91.4
Grog Body sherd					1	1.7			1		2	1.7
Grosand Body sherd			1	2.4	2	12			4	11.8	7	26.2
Grosand Dec Body sherd	2	8.9	3	9	3	10.8			3	12.9	11	41.6
Grogsand cordmk Body sherd							1	7.8			1	7.8
Grog cordmk Body sherd											0	0
Unmodified												
Lignite	6	0.3									6	0.3
Pebble									1	1.9	1	1.9

Test unit 1 continued.

	Level VI (69-72 cmbs)		Level VII (72-75 cmbs)		Level VIII (75-78 cmbs)		Level IX (78-81 cmbs)		Level X (81-84 cmbs)			
Pottery	ct.	wt.	ct.	wt.	ct.	wt.	ct.	wt.	ct.	wt.	Total ct.	Total wt.
Fclay		4.8		3		2.1		3.2		2.9		16
sherd		43.3		31.8		20.7		18.2		3.3		117.3
Grog Body sherd							1	1.9			1	1.9
Grosand Body sherd	6	20	5	14.4	4	18.2	2	7.4			17	60
Grosand Dec Body sherd	3	13.4	7	35	4	15	3	20.8			17	84.2
Grogsand cordmk Body sherd	1	5.6			2	12					3	17.6
Grog cordmk Body sherd					2	11.8					2	11.8
Unmodified												
Lignite											0	0
Pebble					1	2.6					1	2.6

Table A.4. Artifacts above and below sand blow at R.P. Haynes site.

R.P. Haynes	Above SB		Below SB	
Pottery	ct.	wt.	ct.	wt.
Fclay		10		
Sherds		51.4		4.2
Grog Rim	1	2.8		
Grosand Rim	1	9.3		
Crdmk Grosand Rim	1	7.4		
Grog Body sherd	16	65.6		
Sand Body sherd			1	1.8
Grosand Body sherd	9	43.4		
Dec Grog Body sherd	14	87.5		
Dec Grosand Body sherd	35	216.5		
Crdmk Grog Body sherd	3	20.8		
Crdmk Grosand Body sherd	2	15.9	2	10.3
Crdmk Sand Body sherd			2	3.3
Crdmk Shell Body sherd			1	2.5
Fabric Sand Body sherd			1	3.4
Baytown Body sherd			1	10.8
Lithic				
Shatter		15.3		
Mounds Flake	1	0.5		
Burlington Flake	2	2.3		
Mounds Decort flk	2	4.5		
Heated Mounds Decort flk	2	4.8		
Unmodified				
Pebble	4	6		
Lignite	8	35.7		
Slate	1	3		
Miscellaneous				
Bone	4	4.5		
Shell		1.5		
Brick	1	3.9		
Nail	1	4.5		
Metal	1	0.4		

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Table A.5. Artifacts from test unit 1 at Upper Nodena site.

Upper Nodena	Level I (43-46 cmbs)		Level II (46-49 cmbs)		Level III (49-52 cmbs)		Level IV (52-55 cmbs)		Level V (55-58 cmbs)		Level VI (58-61 cmbs)	
Pottery	ct.	wt.	ct.	wt.	ct.	wt.	ct.	wt.	ct.	wt.	ct.	wt.
Fclay		1.4		10.2		69.3		69		77.7		185.7
Daub				1.4		47.6		17.2		46		100
Sherd				4.9		40.5		29.3		35.7		57.1
Modeled object									1	5.8		
Shell Incised Effigy							1	1.6				
Shell Disc							1	27.5				
Shell Body sherd			1	1.5	33	83.4	26	99.2	22	70.6	34	136.3
Shell Punctate Body sherd											2	4.3
Applique Shell Body sherd					1	3.6						
Incised Shell Body sherd					1	1	2	9.7	2	8.7	2	5.5
Shell Shoulder											1	19.9
Shell Dec Shoulder							1	7.9				
Shell Rim											1	10.5
Shell Folded Rim											1	1.8
Applique Shell Rim											1	1.3
Applique Incised Shell Rim							1	12.3				
Notched Shell Rim							3	14.4	1	13.3	1	14.3
Applique Notched Shell Rim							1	6.6				
Lithic												
Shatter				6.2		8.1	6	7.1		1.4		8.5
Mounds Flake					6	2.8	5	3.4	2	0.1		
Heated Mounds flk			1	0.1	1	0.1	2	1.4				
Cobden Flake											1	0.1

Table A.5. continued.

Upper Nodena	Level I (43-46 cmbs)		Level II (46-49 cmbs)		Level III (49-52 cmbs)		Level IV (52-55 cmbs)		Level V (55-58 cmbs)		Level VI (58-61 cmbs)	
Flake			1	0.1								
Kaolin Flake					1	0.1	1	0.4				
Heated Kaolin flk					2	0.5						
Mounds Decort flk			1	1	1	1.6	6	5.8	6	9	1	10.5
Heated Mounds Decort flk							7	6.6	1	4.9	1	1.5
Mounds Decort Rum flk											12	60.1
Kaolin Decort flk					1	1						
Mounds CHAA											1	41.2
Kaolin CHAA									1	7.5		
FCR					2	0.8	2	1.2	3	1	3	1.3
Unmodified												
Pebble	1	0.3			3	2.2	3	1.8	49	36.2	1	0.2
Lignite	4	0.1	5	0.6	7	2						
Sandstone			1	0.4								
Pumice					1	0.3						
Hematite											1	0.8
Shale					1	0.1						
Slate											1	0.6
Miscellaneous												
Bone			12	2.6	44	12.5	48	12.2			43	8.6
Carbon			3	0.4			5	1	7	0.6		0.5

Appendix A

Table A.6. Artifacts from test unit 2 at Upper Nodena site.

Upper Nodena	Level I (70-76 cmbs)		Level II (76-79 cmbs)			
Pottery	ct.	wt.	ct.	wt.	Total ct.	Total wt.
Fclay		0.1		5.8	0	5.9
Sherd		3.3		2.4	0	5.7
Shell Body sherd	6	40.4	2	9.3	8	49.7
Shell Impressed Body sherd	1	35.3			1	35.3
Handle of Shell Body sherd	1	55			1	55
Lithic						
Abraded Sandstone			1	76.8	1	76.8
Unmodified						
Unknown			6	1.1	6	1.1
Miscellaneous						
Bone	93	109			93	109
Carbon		0.7			0	0.7

Table A.7. Artifacts above and below sand blow at Upper Nodena site.

Upper Nodena	Above SB		Below SB	
Pottery	ct.	wt.	ct.	wt.
Fclay		0.8		25.1
Sherds		3.4		77.4
Daub		39.2		26
Modeled Object	1	6.7		
Shell Base	1	9.6	1	47.1
Shell Rim	1	15.1	8	248.3
Notched Shell Rim			1	9.6
Incised Shell Rim			1	4.8
Notched Pinched Shell Rim	1	3.8		
Notched Applique Shell Rim	1	8.4	1	8.7
Grog Body sherd	1	10.1		
Shell Body sherd	4	25.1	50	453.2
Shell Discoidal			1	34.8
Lithic				
Shatter		23.8		26.5
Mounds Core			1	32.6
Mounds Pebtool	1	51.9		
Chert Flake			1	0.1
Kaolin Flake	1	0.1		
Heated Kaolin Flake			2	0.5
Mounds Flake			1	1.4
Mounds Decort Flake	3	22.5	1	5.6

Table A.7. continued.

Upper Nodena	Above SB		Below SB	
Pottery	ct.	wt.	ct.	wt.
Heated Mounds Decort flk			2	2.3
Polished Burlington flk	1	0.3		
Mounds RUM flk	1	1.3		
Mounds Spokeshave	1	9.8		
Mounds Preform	1	15.3		
Biface			1	4.4
Mounds PPK (Madison?)	1	1.5		
Mounds PPK	2	20		
Perg			1	12.3
Scraper			1	9.3
Chopper			1	259.9
CHAA			4	130.4
Mounds Grip	1	231.3	1	900.9
Pumice Grip			1	30
Orthoquartzite Grip			1	425.4
Unmodified				
Pebble	1	23.3	3	84.6
Sandstone			2	72.8
Lignite			29	8.2
Iron concretion			1	0.6
Miscellaneous				
Bone	1	2.1	16	20.1

Table A.8. Artifacts from test unit 1 at Walker site.

Walker	Level I (26-33 cmbs)		Level II (33-36 cmbs)		Level III (36-39 cmbs)		Level IV (39-42 cmbs)		Level V (42-45 cmbs)		Level VI (45-48 cmbs)			
Pottery	ct.	wt.	ct.	wt.	ct.	wt.	ct.	wt.	ct.	wt.	ct.	wt.	Total ct.	Total wt.
Fired clay		42.6		21.2		85.2		41.8		76.2		7		274
Daub		51.2		16.4						32.9				100.5
Model object	1	1.5					1	9.1					2	10.6
Coil							2	0.8					2	0.8
sherd		12.4		13.5		22.2		8.7		13.8		1.7	0	72.3
Shell Body sherd	12	32.4	13	32.5	1	1.4	27	171.5	43	172.4	3	8.9	98	417.7
Grosh Body sherd			3	13.7	1	6.2							4	19.9
Burnished Grosh Body sherd							1	2.1					1	2.1
Shell Rim							1	9					1	9
Lithic														
Shatter				1.7		2.4		0.6				0.6		5.3
Miller decort flk			1	1									1	1
Mounds decort flk			1	0.3	1	4.3							2	4.6
Heated Mounds decort flk					1	0.2							1	0.2
Mounds Flake			1	0.1					1	0.2			2	0.3
Polished Miller flk							1	1.7					1	1.7
RUM Mounds Flake									1	3.2			1	3.2
PPK preform					1	3.7							1	3.7
Unmodified														
Pebble	1	3.5		7.1			2	2.5	2	10			5	23.1
Sandstone					3	21.7							3	21.7

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Table A.9. Artifacts above and below sand blow at Walker site.

Walker	Above SB		Below SB	
Pottery	ct.	wt.	ct.	wt.
Fclay		1.7		
Daub		29.9	4	4.1
Sherds		7.6		8.6
Modeled object			1	20
Modeled Earplug	1	8.7		
Shell Rim	5	81.6	2	83.6
Grosh Rim			1	0.8
Shell Rim w/slip	1	3.1		
Sandshell Body sherd	1		1	1.1
Grosh Body sherd			7	40.2
Shell Body sherd	13	126.8	30	139.5
Shell Body sherd w/slip	2	14.4	2	33.1
Dec Shell Body sherd	1	1.2		
Incised Shell Body sherd	1	4.9		
Shell Handle Rim			1	83.5
Noded Shell Handle	1	64.1		
Lithic				
Shatter		6.9		
Kaolin Flake	1	6.9		
Mounds Flake	1	0.2		
Mounds Decort flk	2	4.1		
Abraded Sandstone				
Preform	1	11.2		
PPK	2	7.9		
Millcr Hammerstone	1	47.1		
Polished Millcr CHAA	1	8.2		
FCR	1	1.2		
Unmodified				
Hematite	1	4.5		
Quartzite	1	3.7		
Pebble	2	11.4		
Miscellaneous				
Bone			37	82.6

APPENDIX B. RESULTS OF PHYSICAL AND CHEMICAL ANALYSIS OF SOILS AT LIQUEFACTION SITES

Table B. 1. Results of soil analysis for Braggadocio site.

Sample #	Depth (cm)	Color	Structure [1]	Consis-tency[2]	PSA[3]			T[4]	pH	CEC[5] (ppm)	Fe[6] (%)	OM[7] (%)	Age ± 100 Yrs	Context
					%sand	% silt	%clay							
4	4	2.5Y 4/2	mod, m, sbk	sh	68.1	20.4	11.5	sl	7.55	5.90	0.75	3.7	190	A horizon
3	10	2.5Y 4/2	mod, f, sbk	so	71.4	18.6	10.0	sl	7.63	5.10	0.45	1.9		A horizon
5	4	2.5Y 4/2	mod, m, sbk	so	74.3	15.6	10.1	sl	7.45	5.70	0.45	2.8	500	A horizon
2	10	2.5Y 5/2	wk, vf, sbk	so	73.0	16.5	10.5	sl	7.02	6.10	0.44	2.1		A horizon
1	20	2.5Y 5/2	mod, f, sbk	so	80.7	11.5	7.8	ls	7.08	4.60	0.50	1.7		A horizon

Table B. 2. Results of soil analysis for Brooke site.

Sample #	Depth (cm)	Color	Structure[1]	Consistency[2]	PSA[3]			T[4]	pH	CEC[5] (ppm)	Fe[6] (%)	OM[7] (%)	Age ± 100 Yrs	Context
					%sand	% silt	%clay							
1	10	2.5Y 6/2	mod, f, sbk	so	71.6	22.6	5.8	sl	4.94	3.3	0.22	1.2	190	A_p[8]
2	20	2.5Y 6/2	mod, m, sbk	h	72.9	21.5	5.6	sl	5.12	2.9	0.53	1.2		A_p
3	30	2.5Y 5/4	wk, f, sbk	lo	94.2	2.6	3.2	s	5.86	1.4	0.34	0.2		C horizon - sand blow
4	40	2.5Y 5/4	wk, f, sbk	lo	92.4	4.7	2.9	s	5.78	1.6	0.43	0.3		C horizon - sand blow
5	50	2.5Y 6/4	wk, f, sbk	lo	93.6	4.4	2.0	s	6.08	1.2	0.34	0.1		C horizon - sand blow
6	60	2.5Y 6/4	sg	lo	96.0	2.5	1.5	s	6.29	1.1	0.27	0.1		C horizon - sand blow
7	70	2.5Y 6/4	wk, m, sbk	so	92.8	5.1	2.2	s	6.20	1.4	0.33	0.1		C horizon - sand blow
8	80	2.5Y 5/4	mod, m, sbk	so	90.9	4.8	4.3	s	6.25	2.5	0.44	0.3		C horizon - sand blow
9	90	2.5Y 6/2	str, c, sbk	vh	58.5	28.6	12.9	sl	6.39	6.7	0.51	1.7		IIA horizon - midden

Table B. 3. Results of soil analysis for Dodd site.

Sample #	Depth (cm)	Color	Structure[1]	Consis-tency[2]	PSA[3]			T[4]	pH	CEC[5] (ppm)	Fe[6] (%)	OM[7] (%)	Age ± 100 Yrs	Context
					% sand	% silt	% clay							
1	40	2.5Y 5/2	str, vc, sbk	eh	30.4	47.3	22.3	l	5.86	7.80	0.90	1.9		A horizon
2	50	2.5Y 5/2	str, vc, sbk	eh	36.7	38.4	24.9	l	5.87	7.30	0.86	2.2	500	IIA horizon - midden
3	60	2.5Y 5/2	str, vc, sbk	eh	72.4	12.3	15.3	sl	5.91	5.00	0.61	1.7		IIA horizon - midden
4	70	2.5Y 4/2	str, vc, sbk	eh	92.9	1.3	5.8	s	5.98	1.60	0.47	0.5		IIC horizon - sand blow
5	80	2.5Y 6/4	wk, m, sbk	so	97.5	0.5	2.0	s	6.21	3.60	0.29	0.1		IIC horizon - sand blow
6	90	2.5Y 6/3	wk, m, sbk	lo	97.9	0.5	1.6	s	6.39	1.60	0.27	0		IIC horizon - sand blow
11	150	2.5Y 5/2	str, vc, sbk	eh	15.7	63.0	21.3	stl	6.42	NA	0.85	2.2		IIIA horizon - midden

Table B. 4. Results of soil analysis for Eaker 1 site.

Sample #	Depth (cm)	Color	Structure[1]	Consistency[2]	PSA[3] %sand	PSA[3] % silt	PSA[3] %clay	T[4]	pH	CEC[5] (ppm)	Fe[6] (%)	OM[7] (%)	Age ± 100 Yrs	Context
1	10	10YR 4/2	mod, f, sbk	fr	70	10	21	scl	5.73	3.8	1.26	1		A_p[8]
2	20	10YR 4/3	mod, med, sbk	fr	63	31	6	sl	5.29	4.8	1.24	1.16		A horizon
3	30	10YR 4/2	mod, f, sbk	fr	66	28	6	sl	5.73	4.5	1.21	1.03		B horizon
4	35	10YR 4/3	mod, f, sbk	fr	52	37	10	sl	6.1	6.8	1.1	2.24	500	IIA horizon - midden
5	45	10YR 4/3	mod, f, sbk	fr	71	21	8	sl	7.15	5.3	0.96	2.26		IIA horizon - midden
7	50	10YR 5/3	mod, med, sbk	fr	67	29	4	sl	7.95	3.8	1.08	0.54		IIC horizon - sand blow
8	60	10YR 5/3	wk, m, sbk	vfr	91	8	1	s	8.12	2.4	1.4	0.41		IIC horizon - sand blow
9	67	10YR 5/3	wk, vf, sbk	vfr	89	11	1	s	8.24	2.2	1.42	0.12		IIC horizon - sand blow
10	72	10YR 6/2	wk, vf, sbk	h	72	23	5	sl	8.07	7.3	0.22	3.01		IIC horizon - sand blow
11	80	10YR 4/2	sg	lo	94	5	1	s	8.27	2.5	1.35	0.22		IIC horizon - sand blow
12	90	10YR 5/2	wk, vf, sbk	vfr	95	5	1	s	8.43	2.3	1.44	0.07		IIC horizon - sand blow
13	100	10YR 5/2	wk, vf, sbk	vfr	92	7	1	s	8.38	2.8	1.03	0.95		IIC horizon - sand blow
14	115	10YR 4/2	mod, f, sbk	fr	27	58	16	stl	8.05	3.8	1.47	1.42		IIIA horizon - midden
15	130	10YR 5/2	mod, f, sbk	h	8	71	21	stcl	7.63	3.6		1.2		IIIA horizon - midden
20	42	10YR 5/3	mod, med, sbk	h	86	1	13	ls	6.85	3.1	1.29	0.78		IIC horizon - vent
21	50	10YR 5/3	mod, med, sbk	sh	37	55	7	stl	8.22	3.7	1.09	3.49		IIC horizon - vent
22	55	10YR 4/2	mod, f, sbk	sh	62	30	8	sl	8.31	3.8	1.06	0.61		IIC horizon - vent
23	73	10YR 5/5	wk, vf, sbk	vfr	92	1	7	s	8.58	2.5	1.5	0.07		IIC horizon - vent
24	87	10YR 5/2	mod, med, sbk	fr	68	30	2	sl	8.25	2.3	0.91	0.48		IIC horizon - vent

Table B. 5. Results of soil analysis for Eaker 3 site.

Sample #	Depth (cm)	Color	Structure[1]	Consistency[2]	PSA[3] % sand	PSA[3] % silt	PSA[3] % clay	T[4]	pH	CEC[5] (ppm)	Fe[6] (%)	OM[7] (%)	Age ± 100 Yrs	Context
1	20	10YR 3/2	wk, f, sbk,	fr	59.68	29.8	10.57	sl	5.07	14.1	0.49	1.94		Ap[8]
2	30	10YR 3/2	wk, f, sbk,	fr	64.33	24.7	10.96	sl	5.35	15.1	0.47	1.74	1100	A horizon
3	35	10YR 3/2	wk, f, sbk,	fr	64.37	24.9	10.75	sl	5.38	14.4	0.40	1.62		A horizon
4	40	2.5Y 3/2	sg, gr	lo	95.06	3.35	1.59	s	5.9	4.3	0.16	0.36		C horizon - sand blow
5	50	2.5Y 5/3	sg, gr	lo	95.28	3.33	1.39	s	6.11	4.5	0.59	0.31		C horizon - sand blow
6	60	2.5Y 5/3	sg, gr	lo	95.58	3.07	1.35	s	6.45	4.2	0.49	0.24		C horizon - sand blow
7	70	2.5Y 4/3	sg, gr	lo	94.06	3.67	2.27	s	6.77	6.3	NA	0.44		C horizon - sand blow
8	77	2.5Y 4/3	str, med, sbk	fi	6.24	63.4	30.41	stcl	6.93	32.6	0.69	2.86		C horizon
9	80	2.5Y 4/3	str, med, sbk	fi	21.55	64.7	13.76	stl	7.58	25.5	0.63	3.32		C horizon
10	90	2.5Y 4/3	wk, f, sbk,	fr	70.83	23.7	5.46	sl	8.16	19.4	0.61	0.90		C horizon - sand blow
11	100	2.5Y 4/3	sg, gr	lo	81.39	16.2	2.38	ls	8.13	14.9	0.33	0.44		C horizon - sand blow
12	110	2.5Y 4/3	sg, gr	lo	54.96	26.7	18.32	sl	8.33	3.0	0.45	0.32		C horizon - sand blow
13	120	2.5Y 4/3	sg, gr	lo	90.85	4.17	1.99	s	8.25	2.6	0.37	0.48		C horizon - sand blow
14	130	2.5Y 4/3	sg, gr	lo	92.85	5.56	1.59	s	8.22	2.2	0.19	0.36		C horizon - sand blow
15	135	10YR 3/1	str, med, sbk	fi	26.8	52.1	21.09	stl	7.47	9.7	0.21	2.19		A horizon
16	140	10YR 3/1	str, med, sbk	fi	21.68	60.5	17.86	stl	7.38	12.9	0.59	2.25		A horizon

Table B. 6. Results of soil analysis for Eightmile Ditch.

Sample #	Depth (cm)	Color	Structure[1]	Consis-tency[2]	PSA[3]			T[4]	pH	CEC[5] (ppm)	Fe[6] (%)	OM[7] (%)	Age ± 100 Yrs	Context
					%sand	% silt	%clay							
101	4	2.5Y 6/4	mod, m, sbk	vh	26.5	51.5	21.9	l	5.33	5.2	0.69	2.3		overlying silt A horizon
102	10	10YR 6/4	mod, m, sbk	sh	78.1	11.7	10.2	sl	5.15	4.2	0.99	2.3	190	AC horizon
103	20	10YR 6/6	wk, m, sbk	so	88.1	9.3	2.6	s	5.13	2.8	0.70	0.7		C horizon - sand blow
104	30	10YR 5/6	wk , m, sbk	so	92.5	3.1	4.4	s	5.32	2.0	0.63	0.5		C horizon - sand blow
100	46	2.5Y 6/3	mod, m, sbk	vh	61.6	17.1	21.3	scl	6.06	6.8	1.04	2.1		IIA horizon

Table B. 7. Results of soil analysis for Hillhouse site.

Sample #	Depth (cm)	Color	Structure[1]	Consis-tency[2]	PSA[3] % sand	PSA[3] % silt	PSA[3] % clay	T[4]	pH	CEC[5] (ppm)	Fe[6] (%)	OM[7] (%)	Age ± 100 Yrs	Context
1	10	2.5Y 4/1	str ,f, sbk	eh	31.3	35.2	33.5	cl	6.79		NA	3.8		A horizon - midden
2	20	2.5Y 4/1	str, f, sbk	eh	48.8	26.4	24.9	scl	6.61	9.80	0.69	2.8		A horizon
3	30	2.5Y 4/1	str, f-c, sbk	eh	62.6	19.0	18.5	sl	6.61	7.50	0.58	1.7	1100	IIA horizon - sand blow
4	40	2.5Y 4/2	mod, f, sbk	eh	67.1	16.4	16.6	sl	6.45	6.50	0.51	1.5		IIA horizon - sand blow
5	50	2.5Y 4/2	mod, m, sbk	eh	63.5	20.7	15.8	sl	6.51	6.30	0.48	1.3		IIA horizon - sand blow
6	60	2.5Y 6/4	mod, m, sbk	eh	12.5	57.5	30.0	stcl	6.70	NA	NA	2.2		IIB horizon
7	33	2.5Y 4/1	str, c, sbk	eh	16.2	46.5	37.3	stcl	6.71	NA	NA	3.4		A horizon - midden
8	43	2.5Y 4/2	str, m, sbk	eh	57.0	8.8	34.3	scl	6.62	NA	NA	2.2	1100	IIA horizon - sand dike
9	53	2.5Y 4/2	mod, f-c, sbk	eh	83.0	5.4	11.6	ls	6.43	4.40	0.46	1		IIA horizon - sand dike
10	65	2.5Y 4/2	mod, m, sbk	eh	85.6	4.9	9.5	ls	6.59	3.60	0.74	0.8		IIA horizon - sand dike
11	75	2.5Y 4/2	mod, f, sbk	h	81.9	7.9	10.2	ls	6.61	3.60	0.66	1		IIA horizon - sand dike
12	90	2.5Y 4/2	str, m, sbk	eh	56.8	24.3	18.8	sl	6.48	7.60	0.68	2.1		IIA horizon - sand dike

Table B. 8. Results of soil analysis for Haynes site.

Sample #	Depth (cm)	Color	Structure[1]	Consis-tency[2]	PSA[3]			T[4]	pH	CEC[5] (ppm)	Fe[6] (%)	OM[7] (%)	Age ± 100Yrs	Context
					% sand	% silt	% clay							
1	10	10YR 4/2	mod, f, sbk	fr	55.7	37.8	6.4	sl	5.12	8.50	0.22	1.26		A_p[8]
2	30	10YR 4/3	mod, med, sbk	fr	23.0	61.5	15.5	stl	5.83	7.70	0.43	1.86	1100	A_1 horizon - midden
3	52	10YR 4/2	mod, f, sbk	fr	26.2	56.5	17.3	stl	6.25	9.10	0.38	1.53		A_2 horizon
4	64	10YR 4/3	mod, f, sbk	fr	20.5	64.2	15.3	stl	6.30	8.40	0.40	1.73		IIA_1 horizon - midden
5	78	10YR 4/3	mod, f, sbk	fr	20.5	64.5	15.0	stl	6.43	9.40	0.38	1.57		IIA_2 horizon
6	94	10YR 4/3	mod, f, sbk	sh	20.1	65.5	14.5	stl	6.50	7.60	0.41	1.80		$IIIA_1$ horizon - midden
7	120	10YR 5/3	mod, med, sbk	fr	6.4	73.0	20.6	stcl	6.48	8.90	0.48	1.66		C horizon

Table B. 9. Results of soil analysis for Reelfoot site.

Sample #	Depth (cm)	Color	Structure[1]	Consistency[2]	PSA[3]			T[4]	pH	CEC[5] (ppm)	Fe[6] (%)	OM[7] (%)	Age ± 100 Yrs	Context
					% sand	% silt	% clay							
1	30	2.5Y 6/4	mod, m-c, sbk	vh	80.5	12.1	7.4	ls	5.97	4.5	0.54	0.1	190	C horizon - sand dike
2	60	2.5Y 6/3	mod, f-m, sbk	h	81.0	11.7	7.4	ls	6.45	4.5	0.49	0.5		C horizon - sand dike
3	90	2.5Y 6/4	wk, f, sbk	sh	89.0	6.5	4.5	s	6.70	3.1	0.46	0.3		C horizon - sand dike
4	105	2.5Y 6/4	wk, f, sbk	so	88.1	7.2	4.7	s	6.67	2.9	0.42	0.3		C horizon - sand dike
5	120	2.5Y 6/4	wk, v-f, sbk	so	89.0	6.3	4.6	s	6.69	2.9	0.40	0.3		C horizon - sand dike
6	135	2.5Y 5/4	wk,f, sbk	so	92.2	5.2	2.6	s	7.11	2.4	0.42	0.4		C horizon - sand dike

Table B. 10. Results of soil analysis for Wilkerson Ditch site.

Sample #	Depth (cm)	Color	Structure[1]	Consis-tency[2]	PSA[3] % sand	PSA[3] % silt	PSA[3] % clay	T[4]	pH	CEC[5] (ppm)	Fe[6] (%)	OM[7] (%)	Age ± 100Yrs	Context
1	75	7.5YR 3/2	mod, f - m, sbk	vfr	64.4	11.2	24.4	sl	5.7	9.9	0.8	2.6	190	IIA horizon - sand blow
2	85	10 YR 5/6	weak, vf, sbk	so	97.4	0.5	2.1	s	5.6	4.5	0.3	0.3		IIC horizon - sand blow
3	92	10 YR 5/4	weak, sg, loose	lo	85.7	11.8	2.5	s	6	5.7	0.7	0.5		IIC horizon - sand blow
4	100	10 YR 3/1	str, vf, sbk	fr	NA	NA	NA	NA	NA	NA	NA	NA	1100	IIIA horizon - sand blow
5	110	10 YR 3/1	str, vf, sbk	fr	NA	NA	NA	NA	NA	NA	NA	NA		IIIA horizon - sand blow
6	120	10 YR 5/2	mod, med, sbk	sh	84.6	6.1	9.2	s	6.3	9.0	0.3	0.9		IIIC horizon - sand blow
7	130	10 YR 5/4	weak, f, sbk	vfr	93.1	3.4	3.6	s	6.3	2.3	0.3	0.5		IIIC horizon - sand blow
8	140	10 YR 5/4	weak, med sbk	so	96.9	1.3	1.8	s	6.3	1.4	0.2	0.3		IIIC horizon - sand blow
9	150	10 YR 5/4	weak, med, sbk	so	95.8	3.1	1.1	s	6.2	1.6	0.3	0.3		IIIC horizon - sand blow
10	160	10 YR 5/3	sg, gr	lo	96.7	2.2	1.1	s	6.2	2.2	0.7	0.3		IIIC horizon - sand blow
11	170	10 YR 5/3	sg, gr	lo	95.9	4.1	0	s	6.2	5.5	0.3	0.2		IIIC horizon - sand blow
12	180	10 YR 5/4	sg, gr	lo	95.9	2.8	1.3	s	6.1	3.4	0.3	0.2		IIIC horizon - sand blow
13	190	10 YR 5/4	sg, gr	lo	97.2	1.7	1.1	s	6	4.0	0.3	0.3		IIIC horizon - sand blow
14	200	10 YR 4/3	sg, gr	lo	95.6	2.2	2.2	s	6	9.7	0.4	0.6		IIIC horizon - sand blow
15	210	10 YR 5/3	sg, gr	lo	97.6	1.4	1	s	6.1	2.7	0.0	0.3		IIIC horizon - sand blow
16	220	10 YR 5/3	sg, gr	lo	97.1	1.8	1.1	s	6.2	3.0	0.0	0.3		IIIC horizon - sand blow
17	230	10 YR 5/3	sg, gr	lo	97.1	1.8	1.1	s	6.2	4.4	0.3	0.2		IIIC horizon - sand blow
18	240	10 YR 5/4	sg, gr	lo	96.2	2.8	1	s	6.2		0.1	0.3		IIIC horizon - sand blow
19	250	10 YR 5/2	mod, f, sbk	h	79.7	15	5.3	ls	6.1	NA	0.5	0.7	NA	IVA horizon
20	260	5 YR 3/1	str, f-m, sbk	fi	80.0	14	6	ls	6	NA	1.0	2.9	NA	IVA horizon

Footnotes

[1]Structure (grade; size; type)

grade m = massive; sg = single grains; wk = weak; mod= moderate; str = strong

size vf = fine; f = fine; m = medium; c = coarse

type gr = granular; sand blowk = subangular blocky

[2]Consistence (dry; moist;)

dry lo = loose; so = soft; sh = slightly hard; h = hard; vh = very hard;

moist lo = loose; vfr = friable; fr = friable; fi = firm;

[3]PSA = particle size analysis

[4]T = texture: cl-clay loam, sltcl-silty clay loam
stl-silt loam, l-loam, ls-loamy sand, s-sand,
scl-sandy clay loam, sl-sandy loam,

[5]CEC = cation exchange capacity

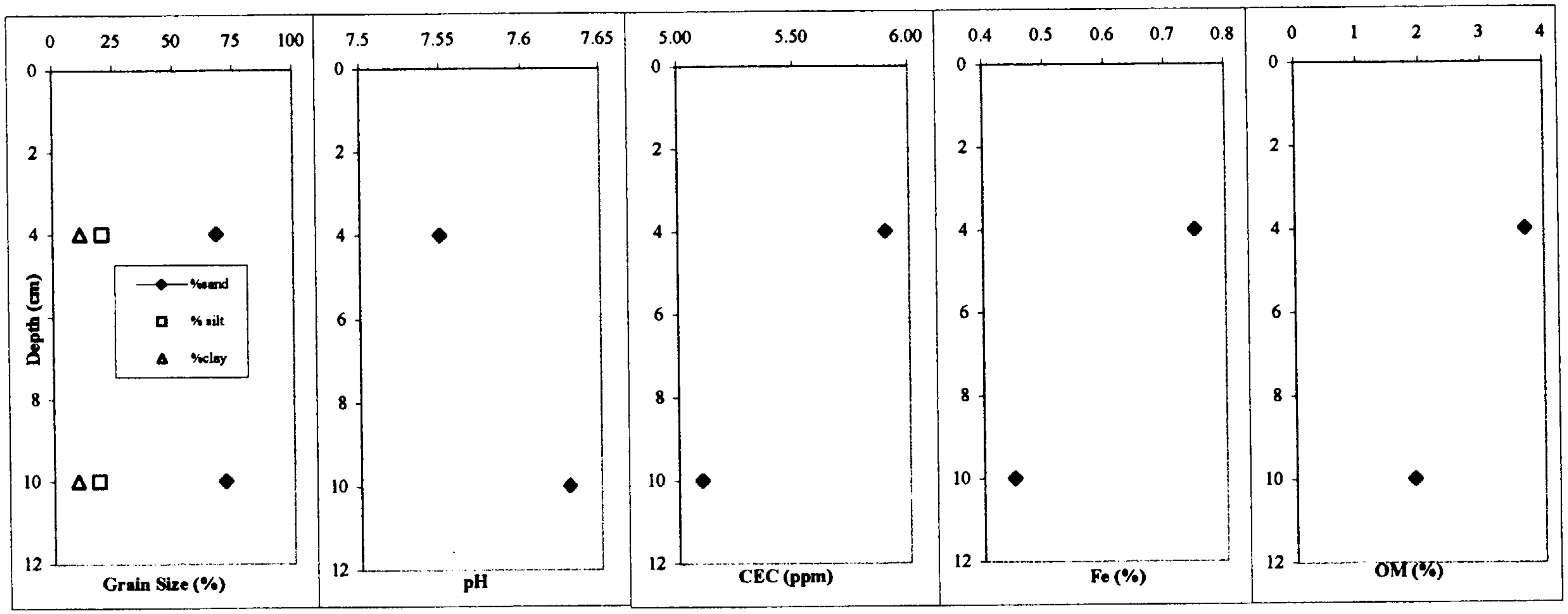
[6]OM = organic matter content

[7]A_p = A horizon disturbed by plowing

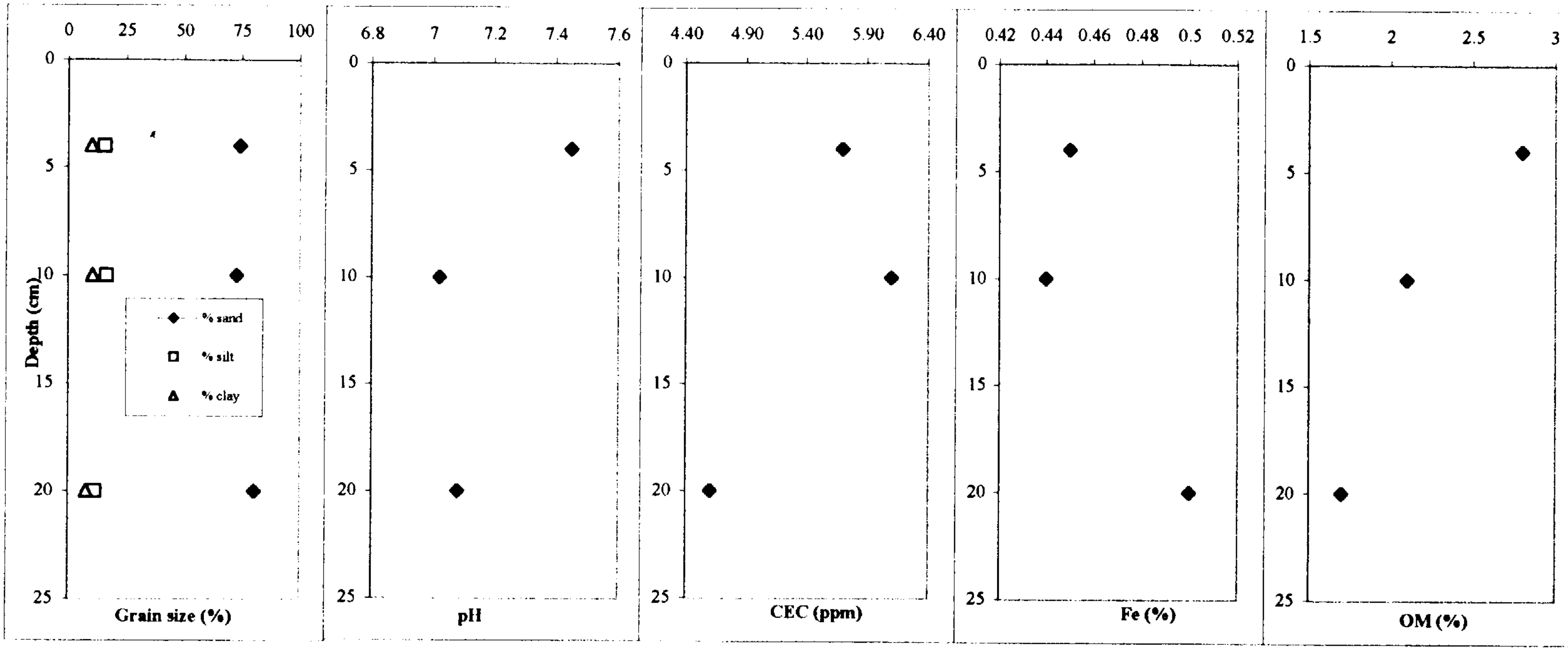
[8]Fe = % free iron

APPENDIX C. SOIL CHARACTERISTICS OF LIQUEFACTION FEATURES WITH DEPTH

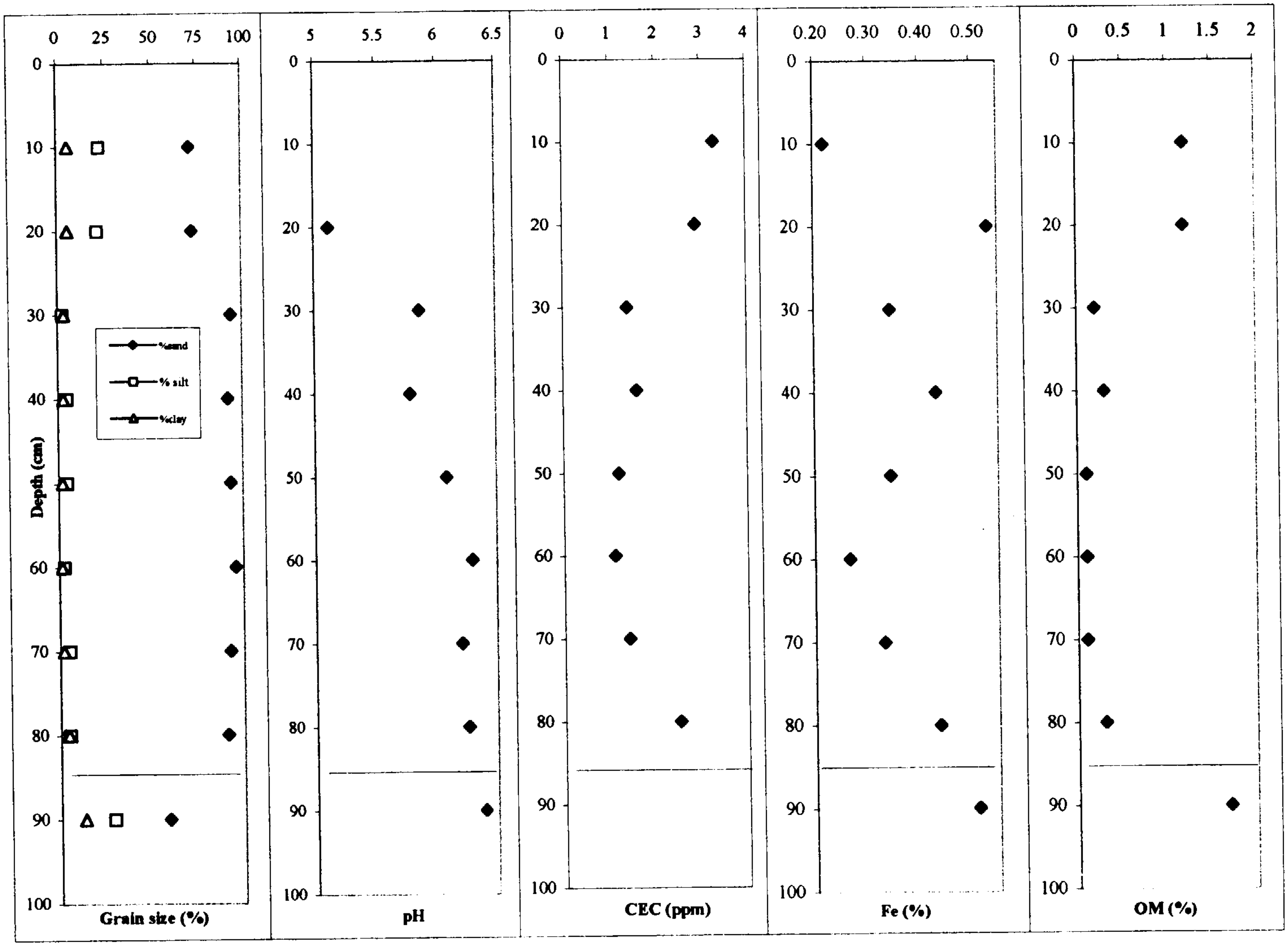
Graph C. 1. Soil characteristics of upper sand blow at Braggadocio site.



Graph C. 2. Soil characteristics of lower sand blow at Braggadocio site.

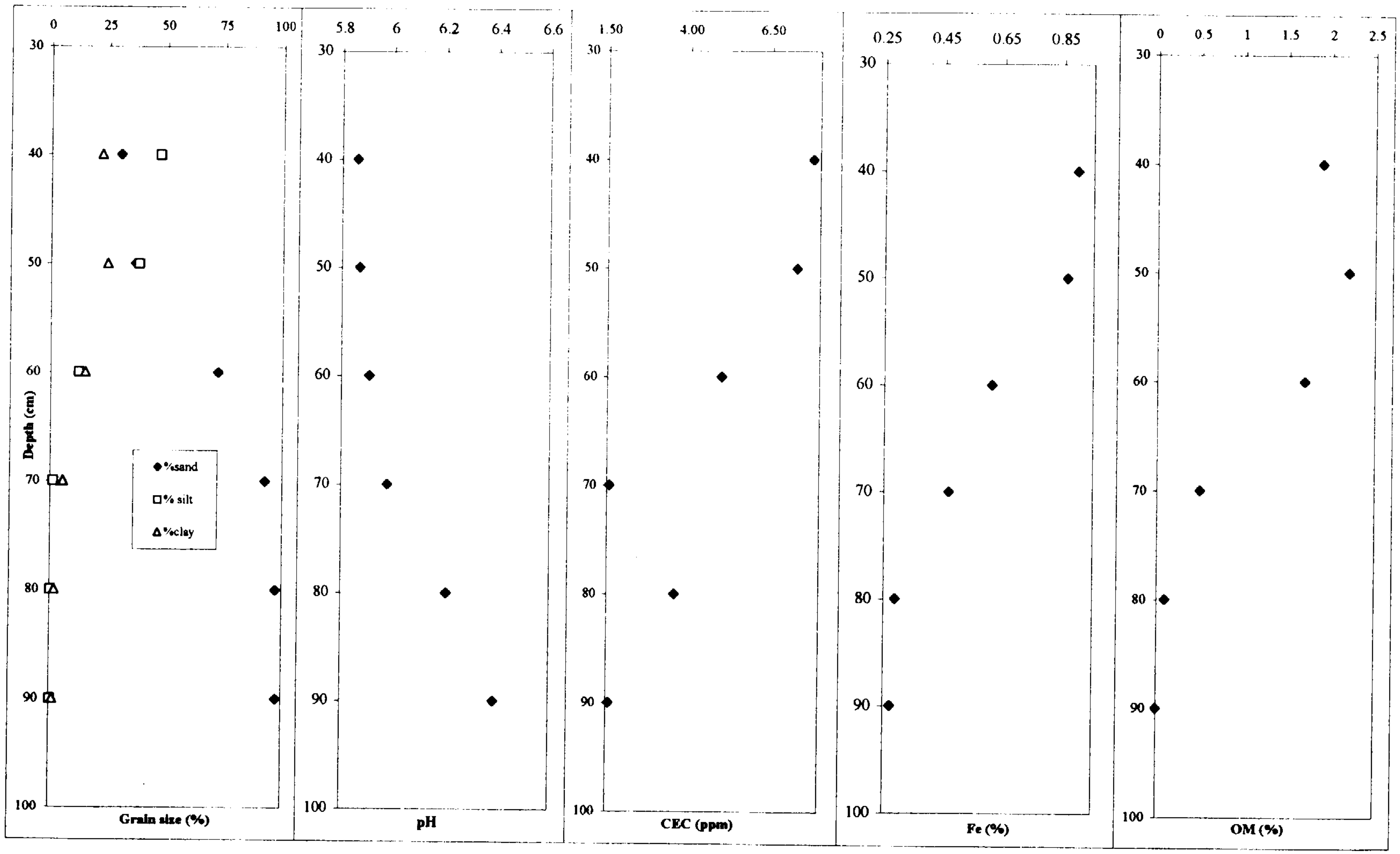


Graph C. 3. Soil characteristics of liquefaction features at Brooke site.

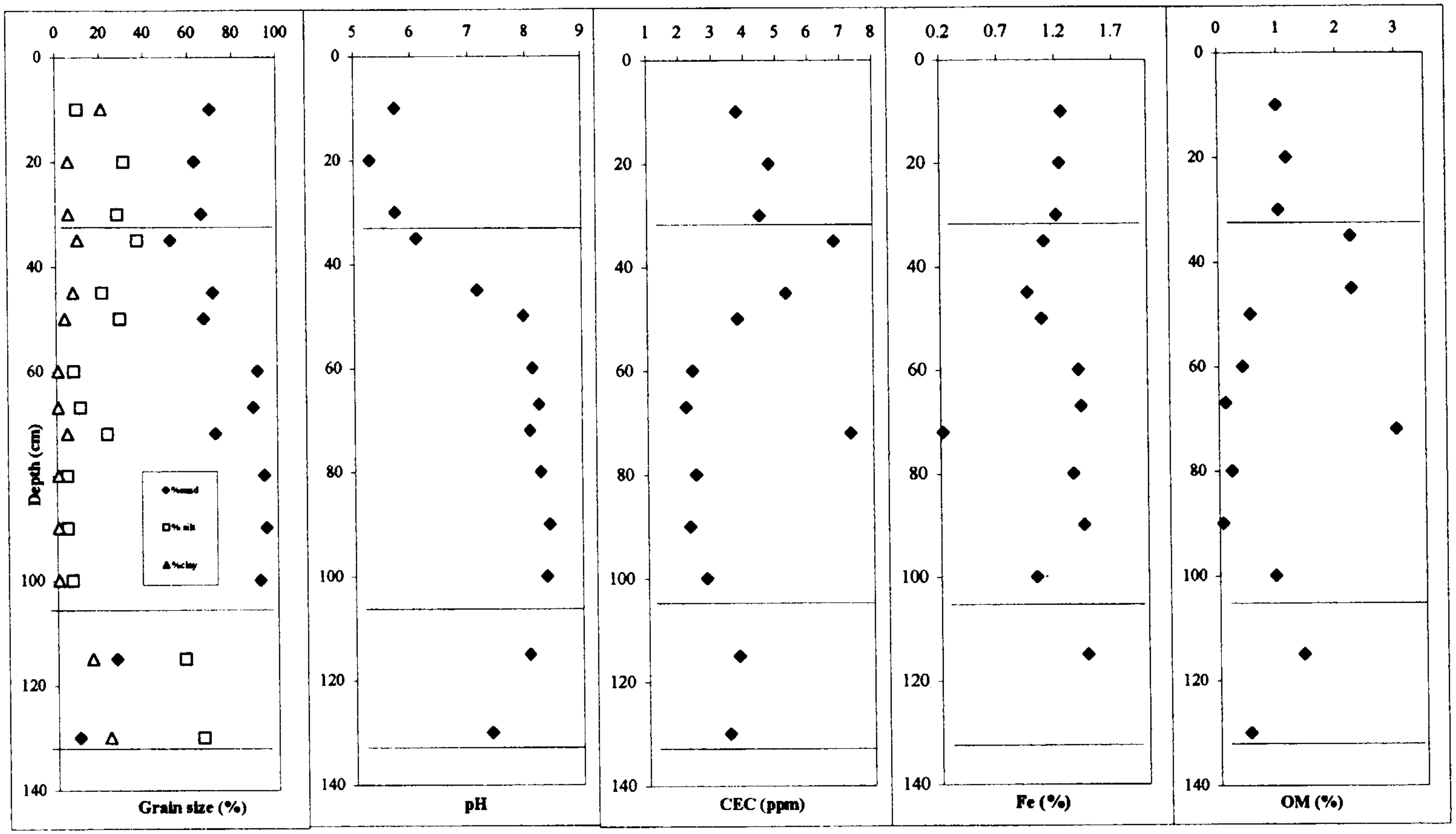


Horizontal lines drawn on graph correspond to stratigraphic breaks in deposits also shown on tables in Appendix B.

Graph C. 4. Soil characteristics of liquefaction features at Dodd site.

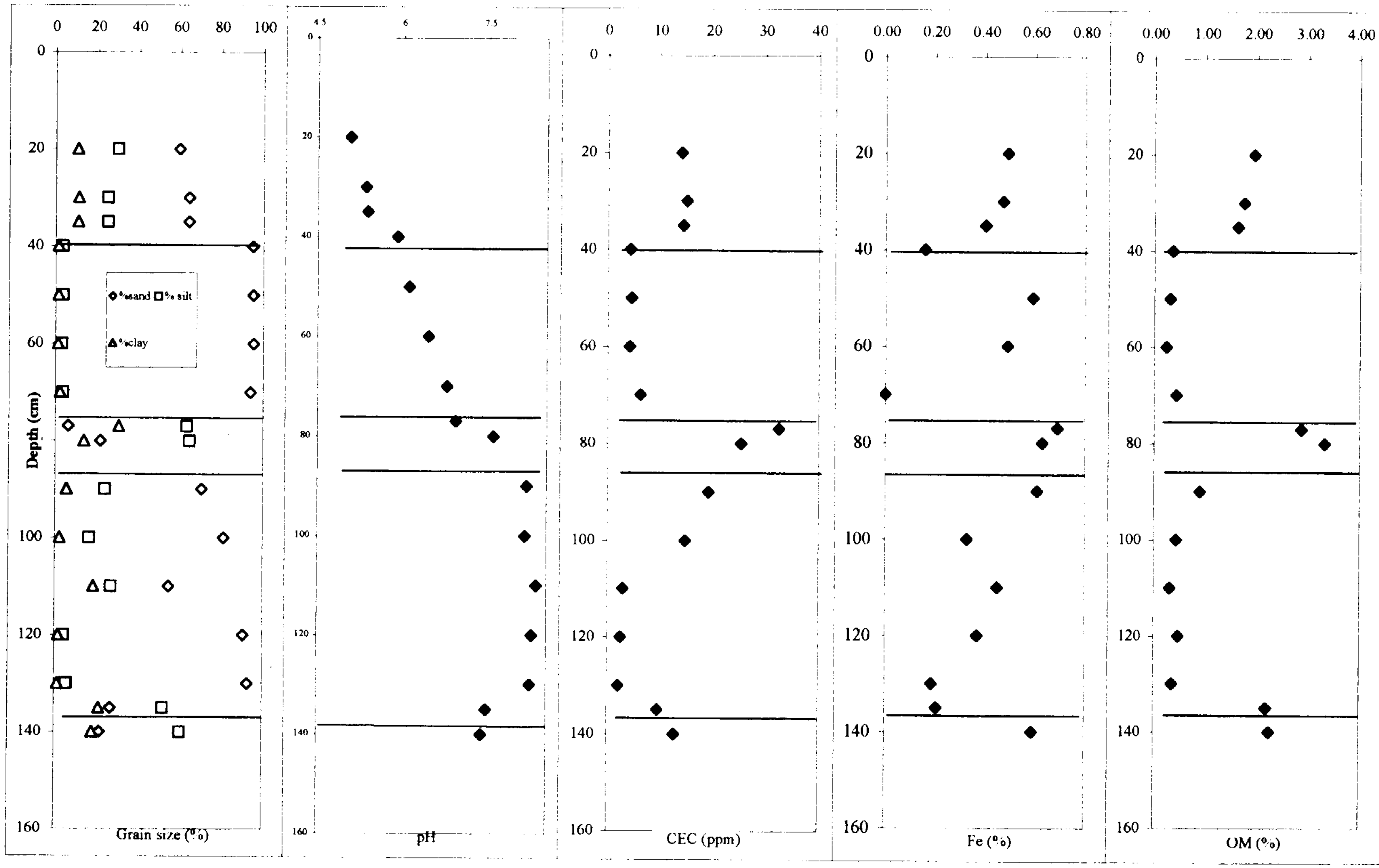


.Graph C. 5. Soil characteristics of liquefaction features at Eaker 1 site.



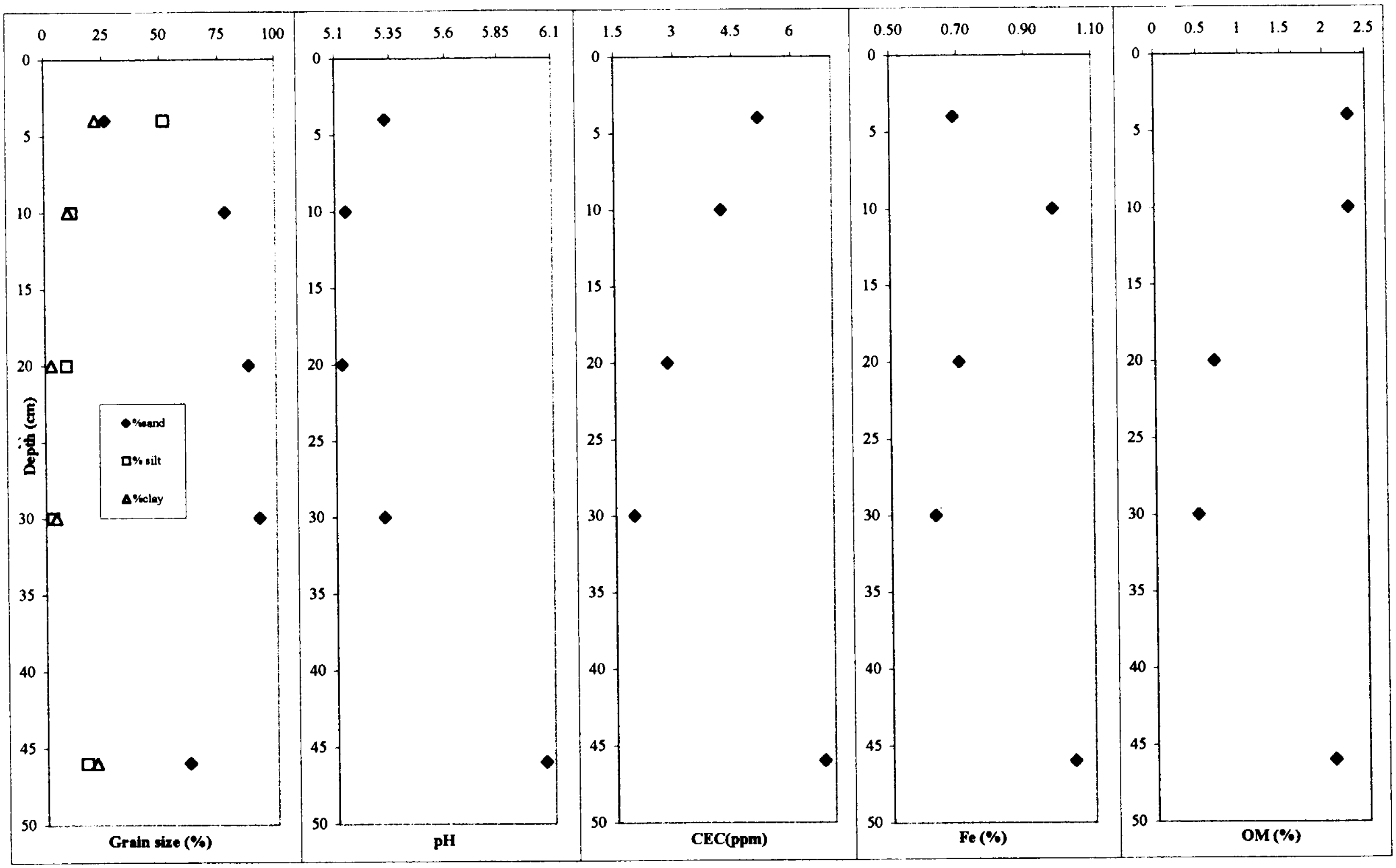
Horizontal lines drawn on graph correspond to stratigraphic breaks in deposits also shown on tables in Appendix B.

Graph C. 6. Soil characteristics of liquefaction features at Eaker 3 site.

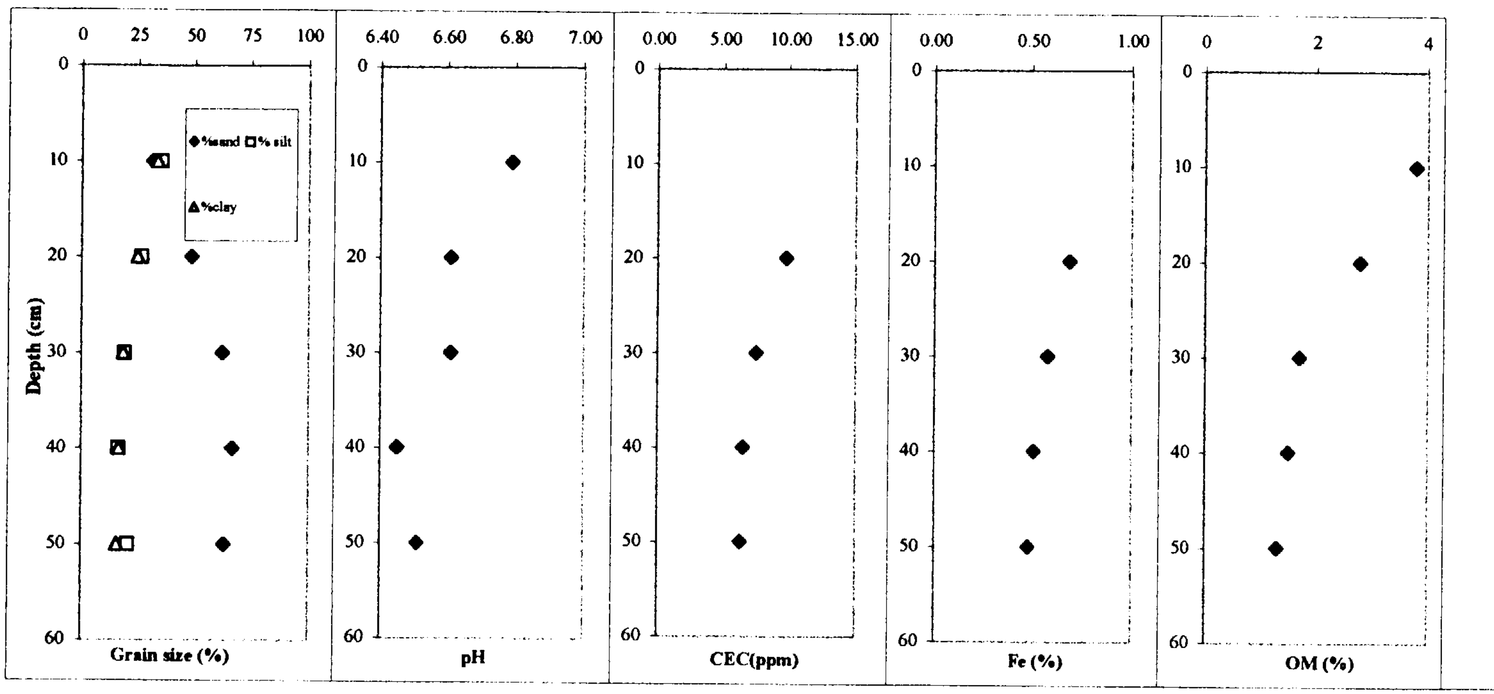


Horizontal lines drawn on graph correspond to stratigraphic breaks in deposits also shown on tables in Appendix B.

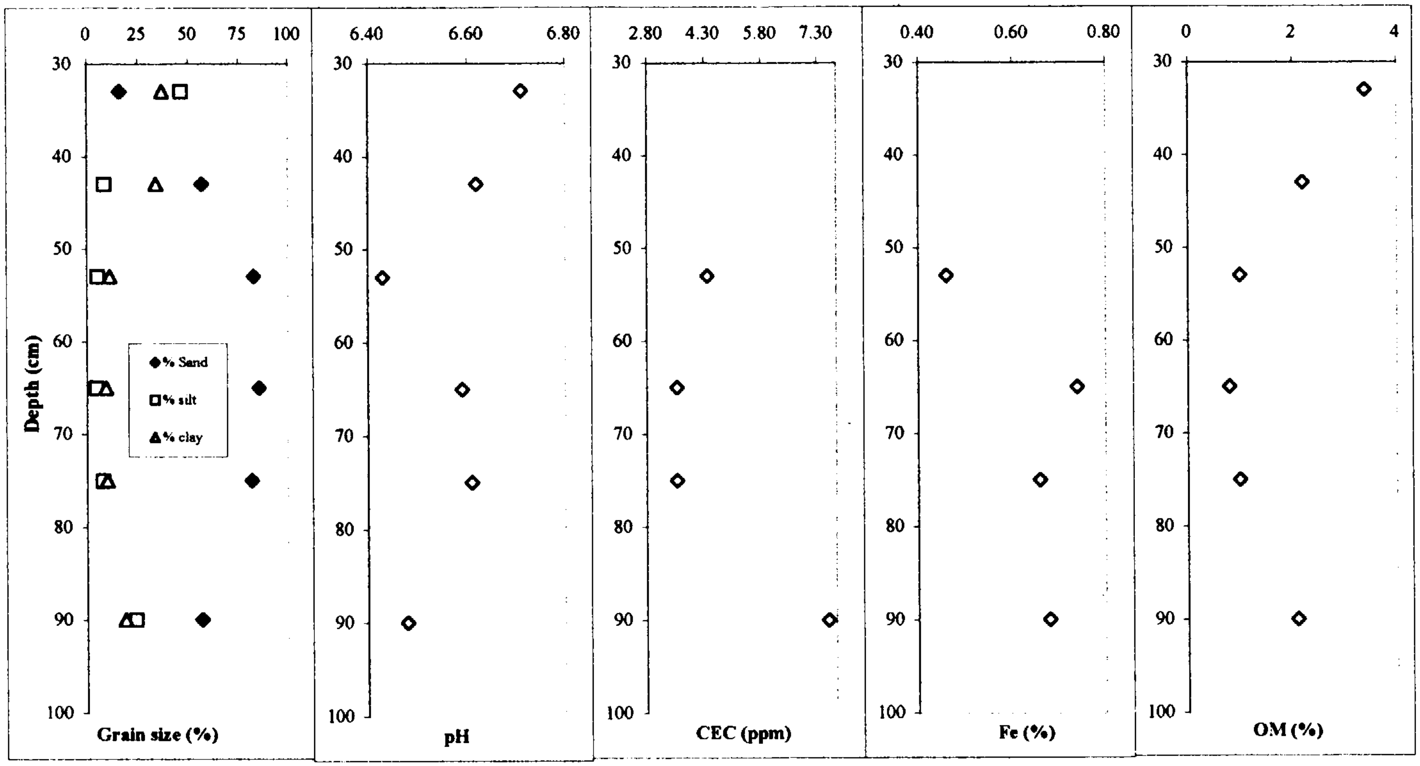
Table C. 7. Soil characteristics of liquefaction features at Eightmile Ditch.



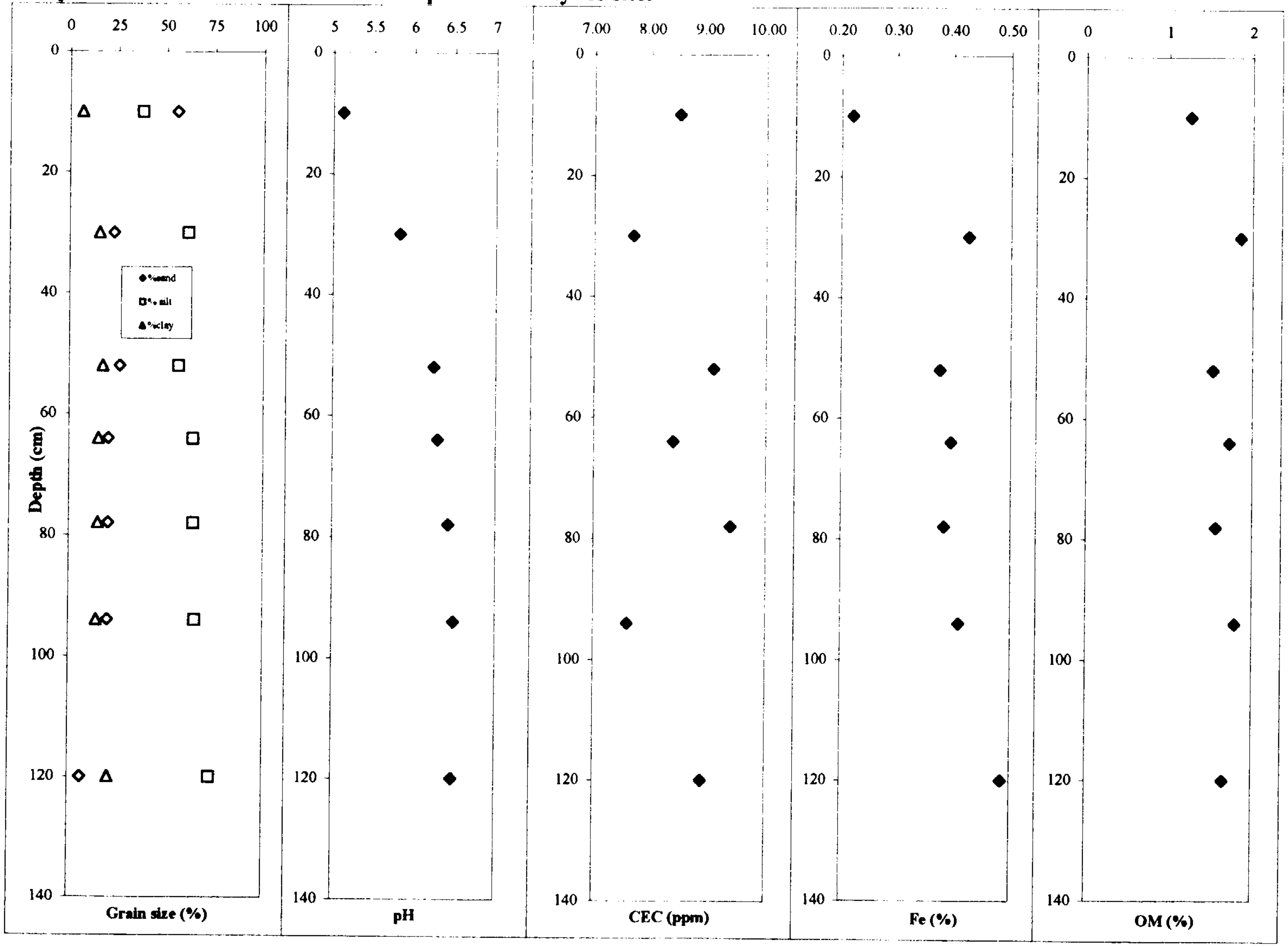
Graph C. 8. Soil characteristics of liquefaction features of sand blow at Hillhouse site.



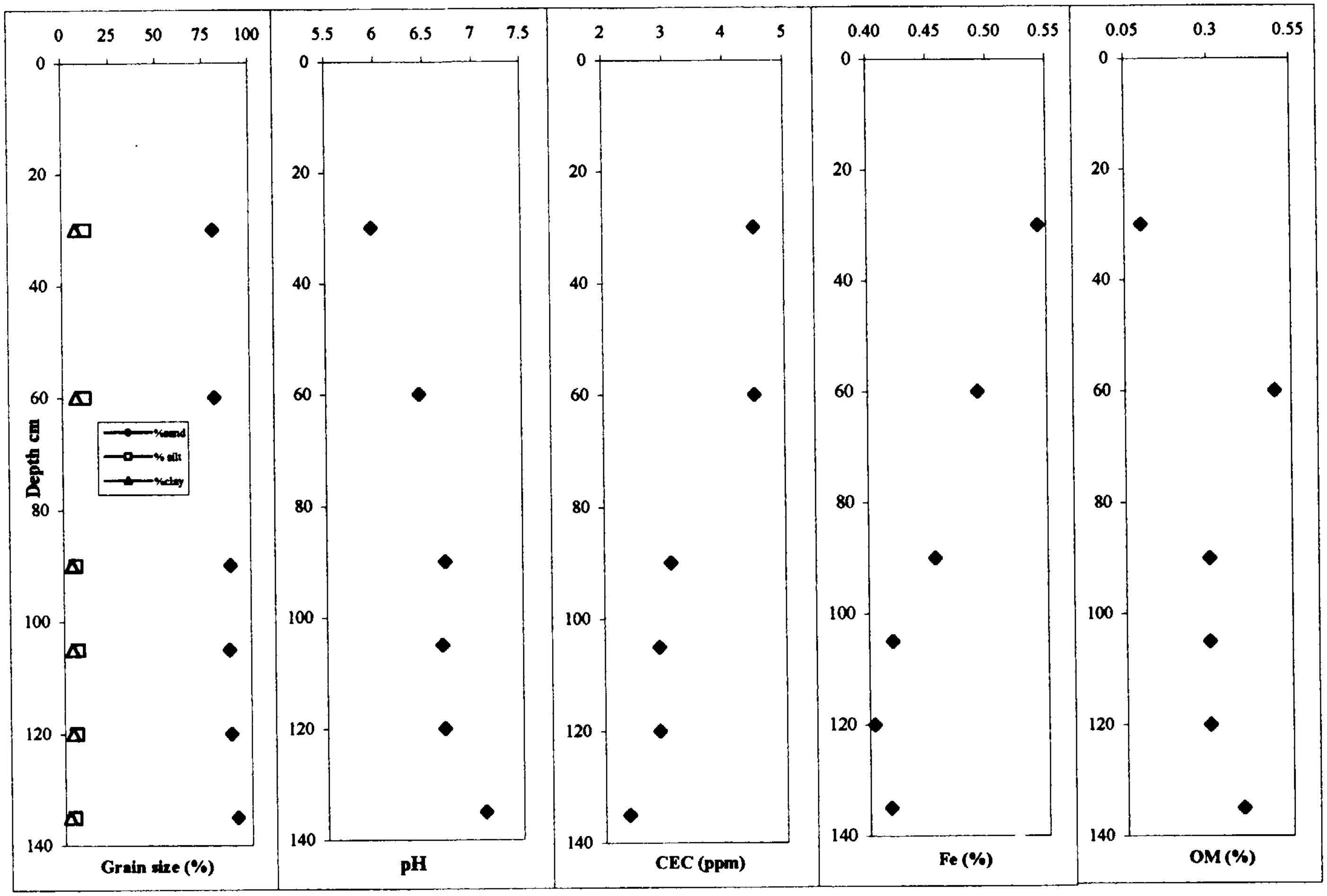
Graph C. 9. Soil characteristics of sand dike at Hillhouse site.



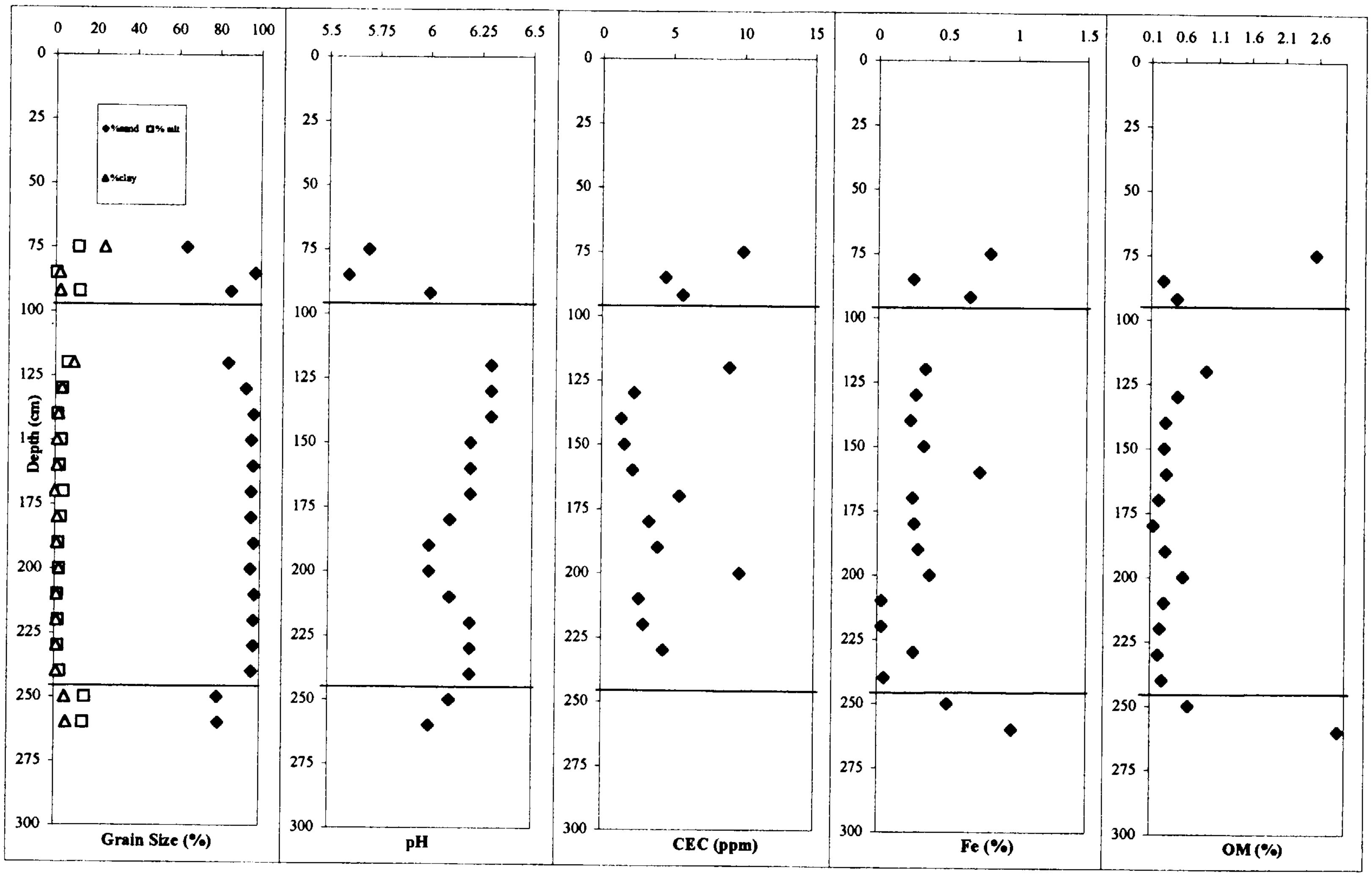
Graph C. 10. Soil characteristics of soil profile at Haynes site.



Graph C. 11. Soil characteristics of liquefaction features at Reelfoot site.



Graph C. 12. Soil characteristics of liquefaction features at Wilkerson Ditch site.



Horizontal lines drawn on graph correspond to stratigraphic breaks in deposits also shown on tables in Appendix B.

NRC FORM 335 (2-89) NRCM 1102, 3201, 3202 U.S. NUCLEAR REGULATORY COMMISSION **BIBLIOGRAPHIC DATA SHEET** *(See instructions on the reverse)*	1. REPORT NUMBER **(Assigned by NRC, Add Vol., Supp., Rev., and Addendum Numbers, if any.)** NUREG/GR-0018
2. TITLE AND SUBTITLE Dating of Liquefaction Features in the New Madrid Seismic Zone	3. DATE REPORT PUBLISHED MONTH: August YEAR: 2000 4. FIN OR GRANT NUMBER G6903
5. AUTHOR(S) M.P. Tuttle, J.D. Sims, K. Dyer-Williams, R.H. Lafferty, III, E.S. Schweig, III	6. TYPE OF REPORT Technical 7. PERIOD COVERED *(Inclusive Dates)* September 1997 - July 2000

8. PERFORMING ORGANIZATION - NAME AND ADDRESS *(If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)*

University of Maryland
Department of Geology
College Park, MD 20742

9. SPONSORING ORGANIZATION - NAME AND ADDRESS *(If NRC, type "Same as above"; if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)*

Division of Engineering Technology
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

10. SUPPLEMENTARY NOTES

E. Zurflueh, NRC Project Manager

11. ABSTRACT *(200 words or less)*

Investigations at six liquefaction sites in Arkansas and Missouri provide new data regarding sedimentary characteristics of historic sand blows and the distribution of liquefaction features generated by earthquake sequences circa A.D. 900 and A.D. 1450. These results support earlier findings that the New Madrid seismic zone has produced earthquake sequences that include at least one very large (M>7.5) earthquake on average every 450 years over the past 1200 years. In addition, a relation between A horizon thickness and years of soil development may be a useful tool for estimating ages of sand blows in the New Madrid region.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*	
Paleoseismology Archaeology Earthquake recurrence	13. AVAILABILITY STATEMENT unlimited 14. SECURITY CLASSIFICATION *(This Page)* unclassified *(This Report)* unclassified 15. NUMBER OF PAGES 16. PRICE

Printed
on recycled
paper

Federal Recycling Program

ISBN 0-16-050471-6

90000

9 780160 504716

NUREG/GR-0018

DATING OF LIQUEFACTION FEATURES IN THE NEW MADRID SEISMIC ZONE

AUGUST 2000

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

1975 25 2000
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