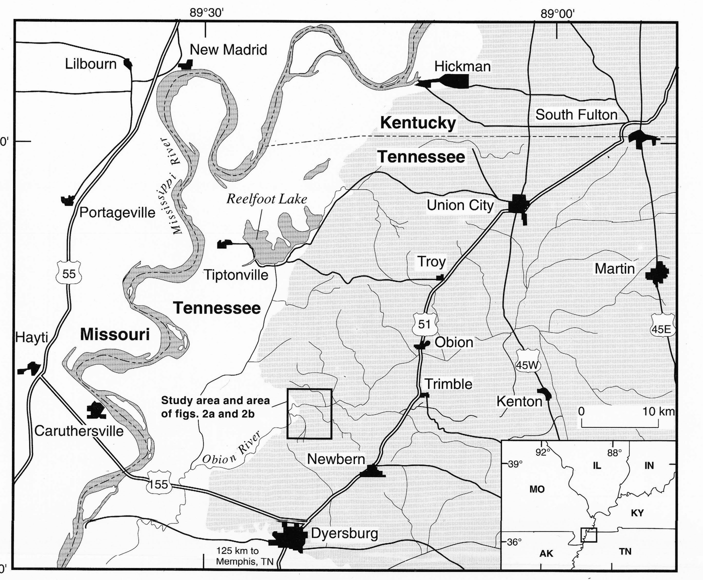


Figure 1. Index map showing location of study area in northwestern Tennessee. Lightly stippled region is area covered by late Quaternary loess.

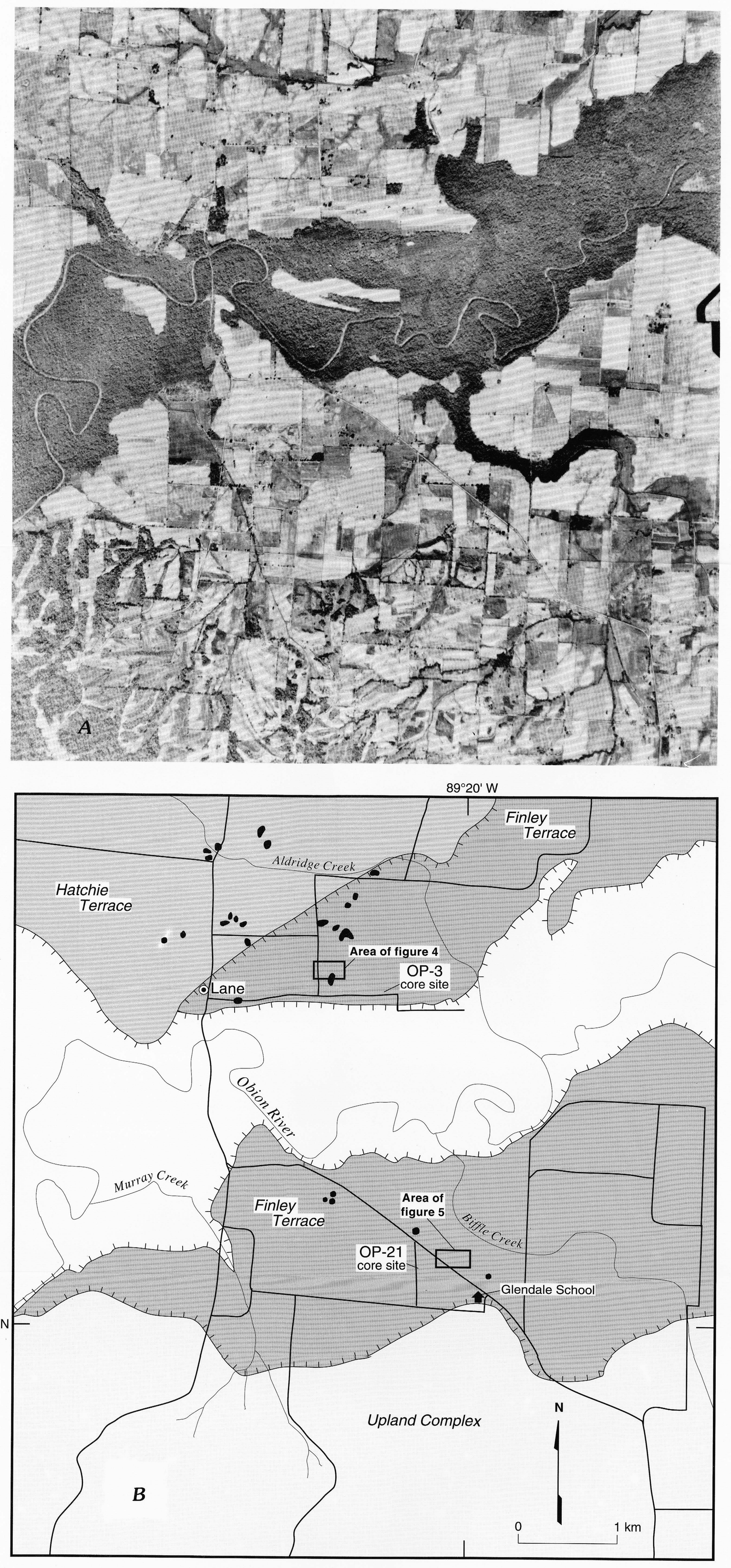
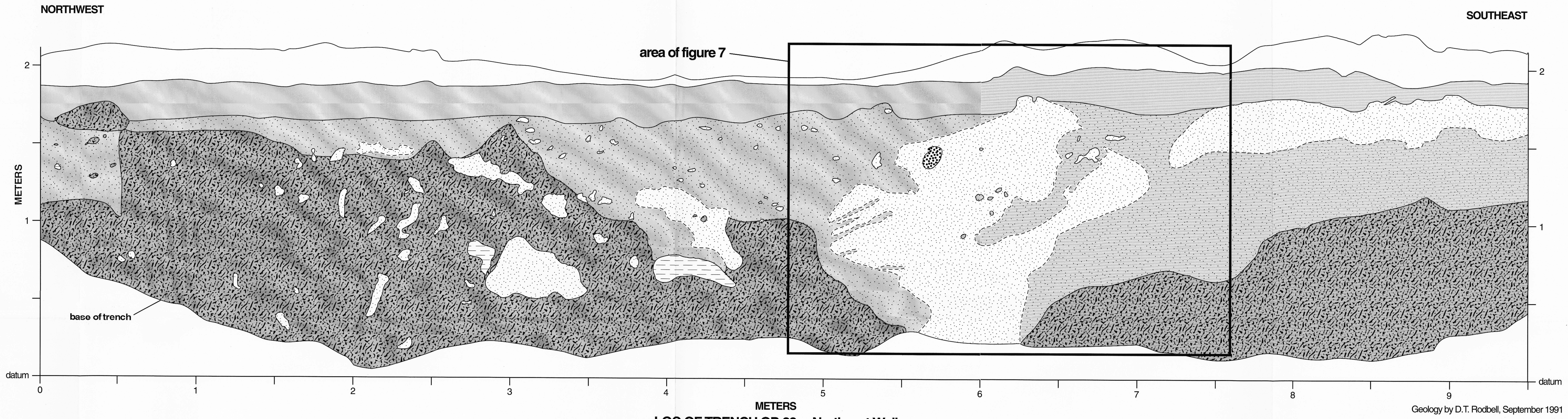


Figure 2. Aerial photograph (A) and index map (B) of lower part of Obion River Valley near Lane, Tenn., showing general geomorphology, and trenching and coring sites. Some of the light-colored areas on aerial photograph were interpreted by Obermeier (1989) to be sand blows. A selected group of these sand blows is depicted on the index map as black areas. On index map, hachures represent fluvial terrace scarps; terrace names are from Saucier (1987), and location of terrace scarps from Rodbell (unpub. data, 1991). Aerial photograph is eastern part of AMS 782, taken October 23, 1952.



METERS
LOG OF TRENCH OP-23 - Northeast Wall

EXPLANATION

CONTACT

INDISTINCT CONTACT

SPOIL (disturbed material)

PLOW ZONE
Texture[1] – sandy loam
Color[2] – 10 YR 4/3

SAND-BLOW DEPOSITS

Fine to coarse sand
Texture[1] – sand
Color[2] – 10 YR 7/4-2.5 Y 8/3

Silty sand
Texture[1] – loamy sand-sandy loam

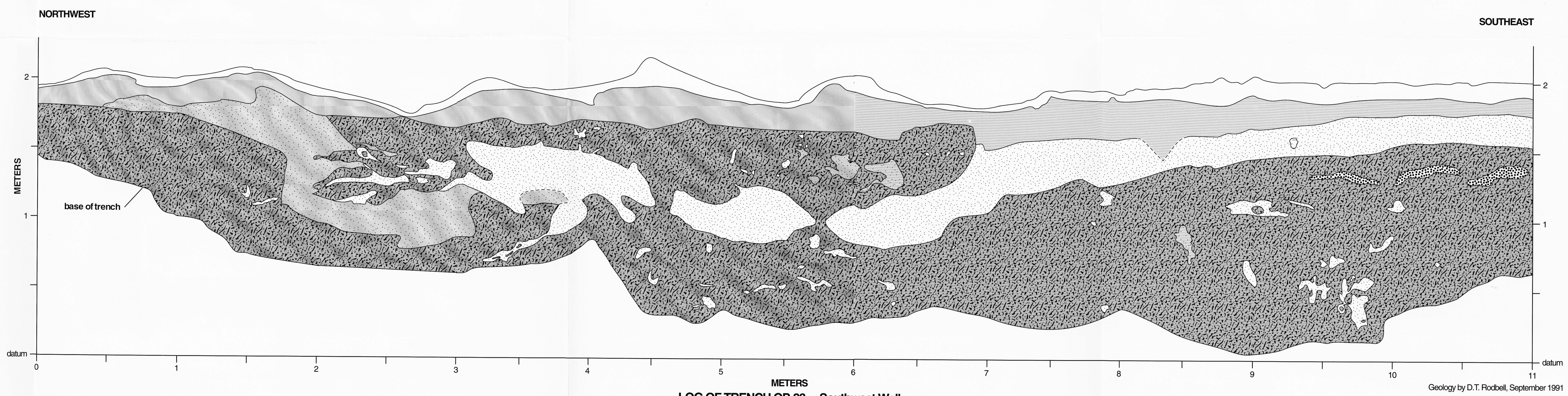
ALLUVIUM AND LOESS

Mottled silt
Texture[1] – silt loam
Color[2] – 10 YR 6/1 to 10 YR 7/4
(FeO nodules 10 YR 5-6/8;
MnO nodules 7.5 YR 2/0)

Clayey silt
Texture[1] – silty clay loam
Color[2] – 10 YR 3/3

MnO NODULES (diameter >2mm)

1 – Soil Survey Staff (1975)
2 – Munsell Color Chart; color is for moist sediment



METERS
LOG OF TRENCH OP-23 - Southwest Wall
(view reversed)

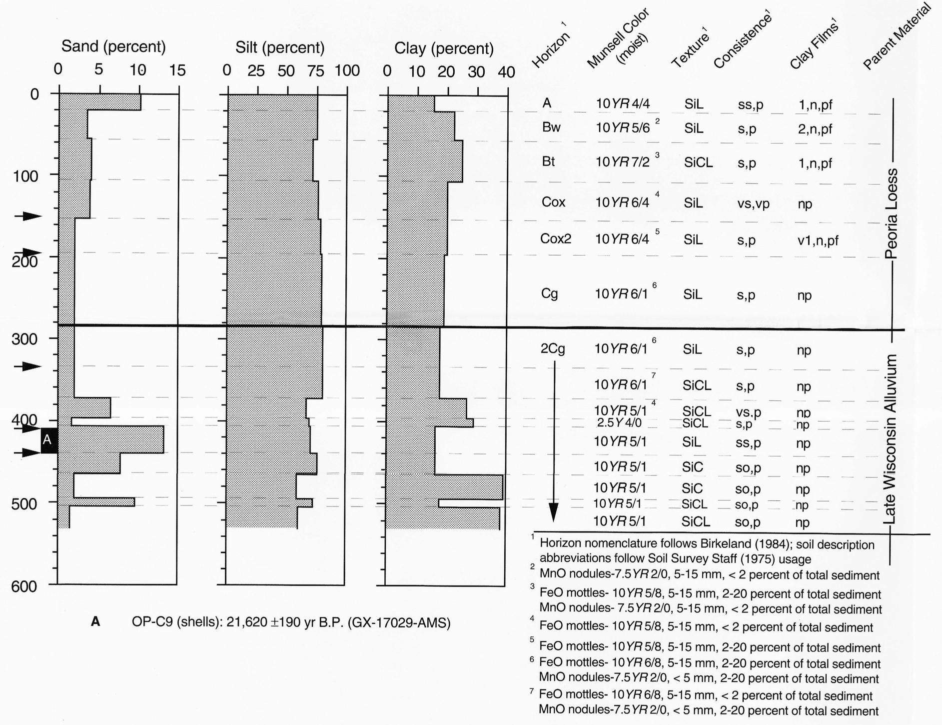


Figure 3. Particle-size distribution, stratigraphic position of radiocarbon-dated shells, and description of soil horizons for core OP-21. Arrows in depth scale represent core-section boundaries, and black rectangle represents the radiocarbon sampling interval.

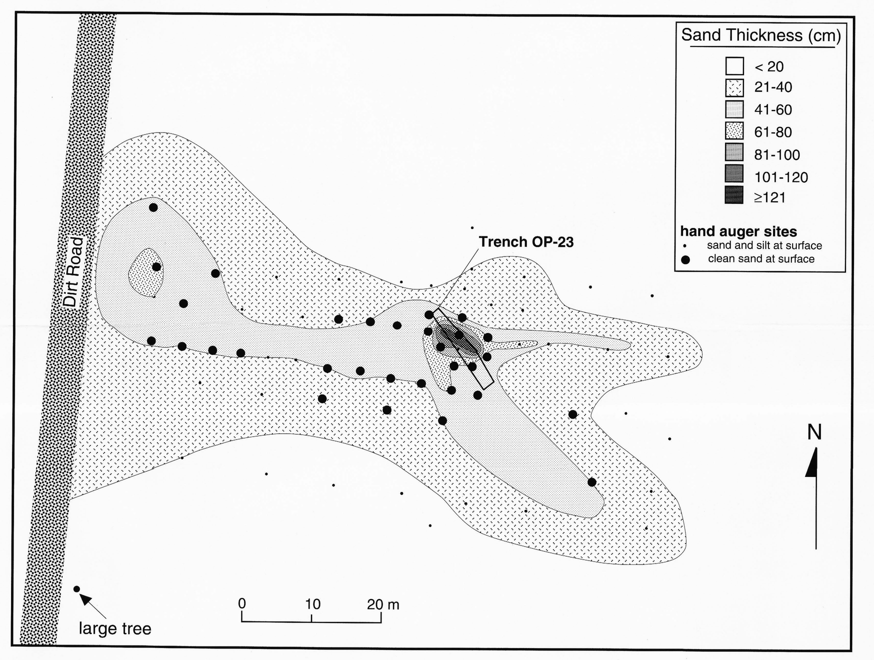


Figure 4. Isopach map of the OP-23 trench site; see figure 2B for location.

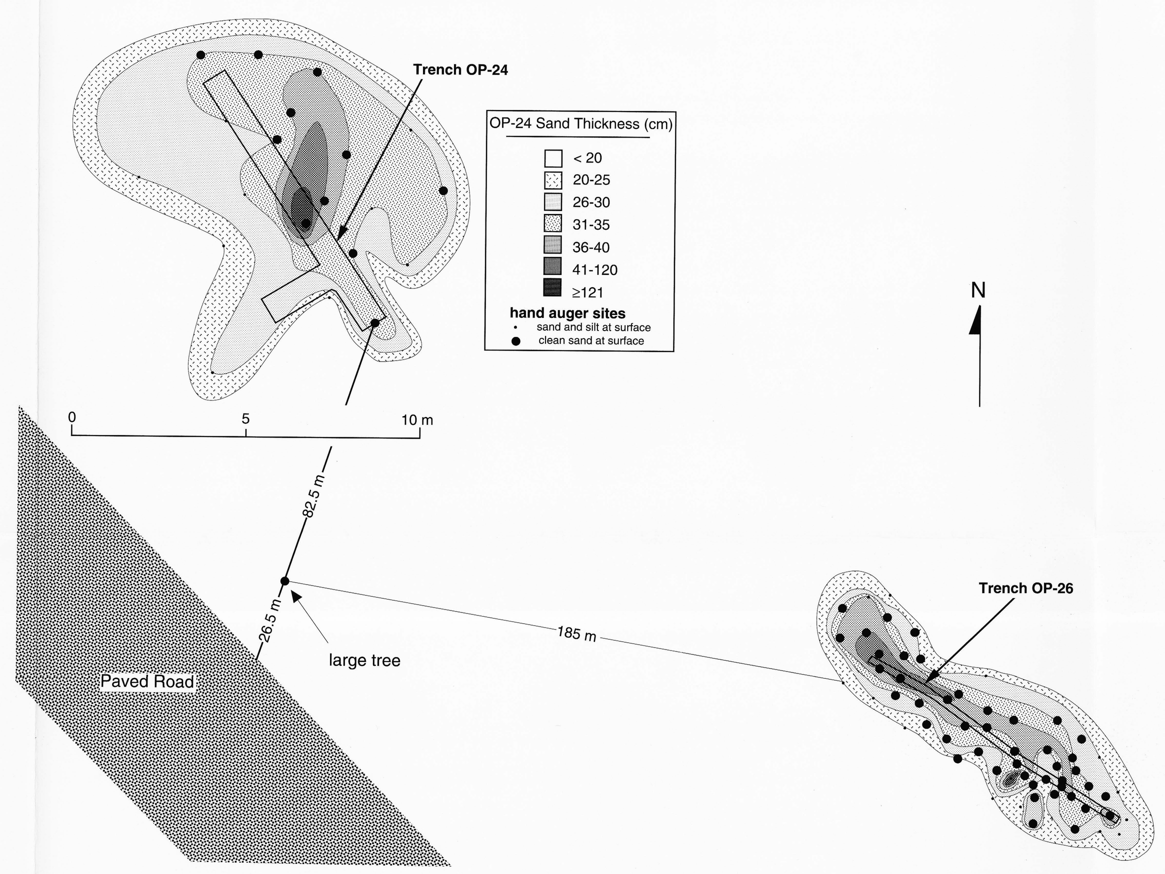


Figure 5. Isopach map of the OP-24 and OP-26 trench sites, see figure 2B for location. Graphic scales are for sand-blow deposits only.

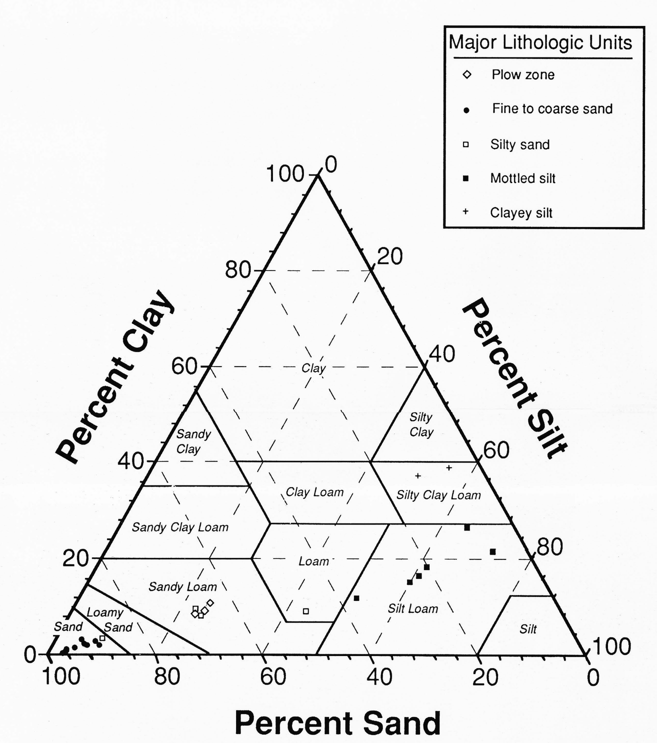


Figure 6. Ternary diagram of percentage sand, silt, and clay for 26 samples of five major lithologic units mapped in trenches OP-23, OP-24, and OP-26.

INTRODUCTION

From December 1811 to February 1812, four large earthquakes ($m_b \geq 7.0$) occurred in the New Madrid (Missouri) Seismic Zone (NMSZ). These have been the largest historical earthquakes in eastern North America. Although this area has been the focus of considerable seismological research, estimates of the repeat time of large-magnitude seismic events remain poorly constrained. Past estimates were primarily based on earthquake-frequency statistics and on paleoseismology studies. Johnston and Nava (1985) compiled historical seismicity data covering about 180 years and instrumental data covering 10 years, and they concluded that the repeat time for large-magnitude events ($m_b \geq 7.0$) is between 550 and 1,100 yrs. However, this estimate is based on assumptions that the data set is representative of the seismicity of the region over the past 1,000 yrs, and that the relation between earthquake frequency and magnitude is constant (Johnston and Nava, 1985). Because these assumptions cannot be verified, this estimated recurrence interval of 550-1,100 yrs must be considered tentative (S. G. Wesnousky and L. M. Leffler, written commun., 1991).

Investigation of exploratory trenches across the Reelfoot scarp in northwestern Tennessee documented the only unequivocal Holocene surface faulting in the upper Mississippi embayment (Russ and others, 1978; Russ, 1979). Fluvial sediment younger than about 2,250 yrs old is faulted, and the net vertical displacement is more than 3 m. Stratigraphic relations indicate at least two episodes of faulting occurred between about 2,250 yr B.P. and the 1811-12 seismic events. Russ (1979) used these data, the dating error limits, and the 1811-12 events to estimate an average recurrence interval of less than 600 yrs for large-magnitude earthquakes in the NMSZ. However, inasmuch as Russ (1979) found no evidence for any historical offset on the Reelfoot scarp, the relation between the Reelfoot scarp and large paleoearthquakes in the NMSZ has not been clearly established.

The development of widespread liquefaction features during the 1811-12 earthquake series (Obermeier, 1989; Obermeier and others, 1990) and the probable development of similar features during previous large-magnitude seismic events ($m_b \geq 6.2$, Nuttli, 1982) have been the basis for several attempts to document the history of paleoliquefaction. Haller and Crone (1986) found evidence of only one episode of sand-blow development in exploratory trenches in late Pleistocene alluvium in eastern Arkansas and concluded that this liquefaction event was probably associated with the 1811-12 earthquake series. Saucier (1989) reported evidence of three liquefaction events in the past approximately 1,000 yrs in an exploratory trench in eastern Arkansas. On the basis of the apparent absence of post-depositional erosion separating the three sand-blow deposits, Saucier (1989) concluded that they formed in a relatively short period of time, probably during the 1811-12 earthquake series. Similarly, Schweig and Marple (1991) found evidence of only recent (probably 1811-12) liquefaction in exploratory trenches on late Wisconsin braided-stream deposits in southeastern Missouri. Leffler and Wesnousky (1991) and Wesnousky and Leffler (written commun., 1991) examined tens of kilometers of recently re-excavated drainage ditches in late Wisconsin braided-stream deposits in eastern Arkansas and found no evidence for prehistorical liquefaction events during the last 10,000 yrs. In contrast, Saucier (1991) estimated an average recurrence interval of about 470 yrs on the basis of historical ages of liquefaction-producing seismic events and two radiocarbon-age-constrained prehistorical sand blows in southeastern Missouri. Thus, Saucier's (1991) study is prominent in that it documents the only evidence for prehistorical liquefaction in the NMSZ. The lack of similar evidence from other sites implies a prehistorical liquefaction-producing seismic event in southeastern Missouri that was considerably smaller than the 1811-12 earthquake series.

The apparent absence of paleoliquefaction features in late Wisconsin fluvial deposits in the zone of most intense 1811-12 liquefaction indicates that the repeat time of large ($m_b \geq 7.0$) seismic events in the NMSZ is at least 10,000 yrs (Saucier, 1991; Wesnousky and Leffler, written commun., 1991). The present study was undertaken to verify this conclusion by documenting the record of liquefaction in late Wisconsin fluvial deposits along the Obion River, in northwestern Tennessee. This region was identified by Obermeier (1989) as an area deserving further study because of its proximity to the NMSZ and to areas of historical liquefaction.

STUDY AREA

The study area is in the Obion River drainage basin near the town of Lane, Tenn. (figs. 1, 2A, and 2B), at the eastern edge of the zone of abundant sand blows associated with the 1811-1812 New Madrid earthquake series (Obermeier, 1989). The study area has two late Quaternary fluvial terraces and a higher, deeply incised upland complex of loess overlying Tertiary gravels. The distribution of fluvial terraces along the Obion River was discussed by Saucier (1987); he named the lowest terrace the Finley terrace, which is about 5 m above the valley flat. The next higher terrace, the Hatchie terrace (Saucier, 1987), is about 10 m above the modern floodplain. On the basis of height above the valley flat, Saucier (1987) correlated deposits that form the Finley terraces with early Wisconsin braided-stream deposits along the Mississippi River. However, inasmuch as there has been little numerical age control for the fluvial terraces in western Tennessee, this age assignment is considered tenuous.

Trenches were excavated on the Finley terraces, which occupy both sides of the Obion River. As mapped, liquefied sand covers between 1 and 15 percent of the terraces (Obermeier, 1989). On aerial photographs and in the field, liquefied sand at the surface contrasts markedly with the darker, fine-grained (silt and clay) sediment that mantles the remainder of the terrace (fig. 2A).

METHODS

In order to determine the age of the Finley terrace, two approximately 5-m-long cores (OP-3 and OP-21, fig. 2B) were retrieved by means of a hydraulically powered drill rig. The cores were described following standard Soil Survey Staff (1975) nomenclature (see also Birkeland, 1984). The cores were sampled according to the visible stratigraphy (texture, color, and sedimentary structures). Core OP-21 was further analyzed for particle-size distribution; the percentage of sand was determined by seiving, and the percentages of silt and clay were determined by pipette analysis using methods described by Singer and Janitsky (1986). Organic material from the cores was sampled, dried, and submitted for accelerator mass-spectrometer (AMS) radiocarbon dating.

To locate possible trenching sites, an auger was used to determine the variability of sand thickness and the center of suspected sand blows. Sand isopach maps were made at scales of 1:100-1:550 with a compass, tape measure, and the sand thickness data. Finally, backhoe trenches were excavated through the center of suspected sand blows. A network of vertical and horizontal grid lines was attached to the trench walls every 0.5 or 1.0 m with nails and string, and logs of trench walls were constructed at scales of 1:14-1:20.

RESULTS

CORING RESULTS

Core OP-21 is 5.3 m long and is composed of two texturally distinct sedimentary units (fig. 3). The basal 2.5 m of the core (2.8 - 5.3 m) is primarily a silty clay loam having very thin ($\leq$ 1 mm) laminations of fines (silt and clay) and sand. This sediment typically has Munsell colors of 10YR 5-6/1 when moist, contains nodules of iron and manganese oxides, and lacks clay films (fig. 3). In contrast, sediment above the 2.8-m depth is massive, and has Munsell colors that are typically 10YR 4-7/4. These redder colors and the presence of clay films reflect soil development in the upper part of the core. The ground-water table was about 4 m below the surface.

Core OP-3 has a similar stratigraphy, except that fine- to coarse-grained, quartzose sand is present below about 6 m. Sediment above the 2.8-m depth is massive, whereas sediment below this level contains thin laminations of fines (silt and clay) and sand. The ground-water table was intersected at a depth of about 5 m; above this level, nodules of iron and manganese oxides are common.

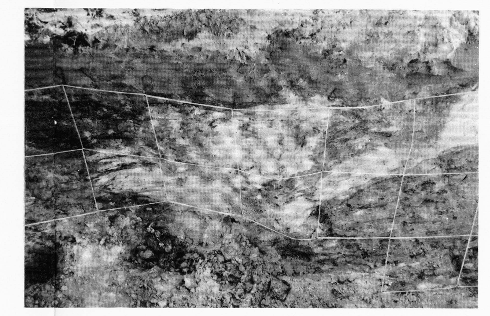


Figure 7. Large sand blow in interval between 5 and 8 m on northeast wall of trench OP-23.

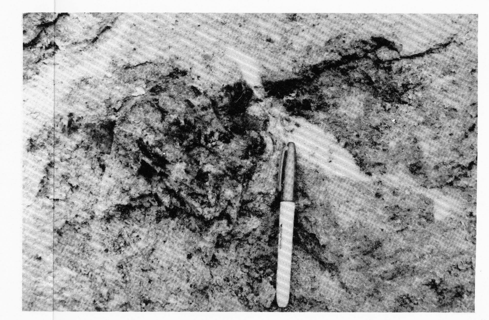


Figure 8. Decomposed stump breached by a small sand dike at 5.75 m of northeast wall of trench OP-24. Pen is 14 cm long.

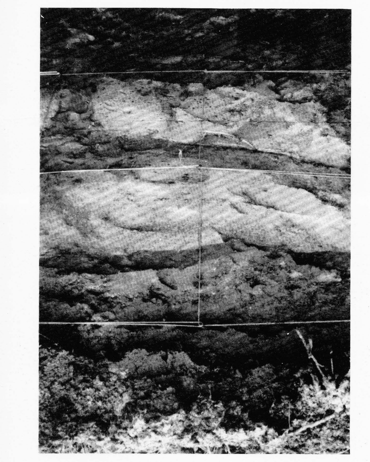


Figure 9. Liquefied sand in interval between 3.5 and 4 m on southwest wall of trench OP-26. Sand is light colored and massive, whereas mottled silt is darker. Hand excavation perpendicular to trench wall revealed that the two layers of sand coalesce to form a single sand layer.

Sediment below a depth of 2.8 m in both cores is interpreted as alluvium on the basis of the presence of laminations of fines (silt and clay) and sand. Sediment above about 2.8 m is interpreted as loess because it lacks laminations and is texturally very similar to the ubiquitous loess that mantles the uplands in western Tennessee (Buntley and others, 1977; Rodbell, unpub. data, 1991). On the basis of its stratigraphic position and the degree of development of the surface soil (fig. 3), this loess can probably be correlated with the Peoria Loess deposited elsewhere in the Mississippi Valley 25-10 ka (Pye and Johnson, 1988; Forman and others, 1992). This interpretation is supported by an AMS radiocarbon age of $21,620 \pm 190$ yr B.P. (GX-17029-AMS) on gastropod shells that we obtained from a depth of 4.07-4.40 m in the underlying alluvium (fig. 3). The absence of a buried soil between the alluvium and the overlying loess (fig. 3) suggests that loess deposition began during or soon after fluvial deposition.

The radiocarbon date of 21.6 ± 0.2 ka for the alluvium indicates that the Finley terrace is late Wisconsin in age rather than early Wisconsin as suggested by Saucier (1987). Moreover, this date indicates that sandy alluvium has been within several meters of the terrace surface for the last 20,000 yrs. Finally, the apparent presence of Peoria Loess on the terrace is convincing evidence that the terrace surface has not been the site of significant fluvial deposition for at least the past 10,000 yrs. Thus, exploratory trenches in these sediments should provide a record of seismically induced liquefaction at that site for at least the past 10,000 yrs and perhaps longer.

TRENCH LOCATIONS AND STRATIGRAPHY

Exploratory trenches were excavated through three sand blows exposed on the surface of the Finley terrace. Trench OP-23 was on the north side of the Obion River in the eastern part of a broad region of sand 1.25 km east-northeast of Lane, Tenn. (figs. 2B and 4). The trench was oriented northwest-southeast in the central, thickest part of the sand blow where there is more than 1.2 m of sand, although most of the region is covered with 20-80 cm of sand (fig. 4). Trenches OP-24 and OP-26 were on the south side of the Obion River, 3.5 km southeast of Lane and 0.5 km northwest of Glendale School, respectively (figs. 2B and 5). Both trenches were oriented northwest-southeast in the central parts of two smaller regions of sand. Sand was observed to be as much as 1.2 m thick at the OP-24 trench site and 50 cm thick at the OP-26 site (fig. 5). The trenches were 15-60 m long and were excavated to a depth of approximately 2.5 m.

Both the northeast and southwest walls of the three trenches were logged. The vertical scale for all trench logs is in meters above an arbitrary datum, and the horizontal scale for all trench logs is in meters from the northwest ends of the trenches. The only exception to this is the southwest wall of the OP-24 trench, which is intersected by a 2-m-long perpendicular trench. As a result, the log of the southwest wall of this trench is divided into two parts, a northwest-southeast-southwest leg and a southwest-northeast-southeast leg (see location map on OP-24 trench log).

The walls of the trenches are composed of five major lithologic units, and in general these units are texturally distinct (see trench logs; fig. 6). Sand-blow deposits are mostly fine to coarse sand, whereas other units are primarily silt, clayey silt, or buried organic material. All units are massive except for the sand-blow deposits, which commonly contain clasts of silt and clay (fig. 7). Nodules of iron and manganese oxides, similar to those noted in the OP-3 and OP-21 cores (fig. 3), are particularly common in the mottled-silt deposits.

Trench OP-23 exposed the largest single liquefaction feature seen in the study. A sand blow was formed in the interval between 5 and 7 m on the northeast wall (fig. 7). The central part of this vent is composed of fine- to coarse-grained quartzose sand and is surrounded by silty sand. The boundary between these two lithologic units is commonly gradational, typically over a distance of 5-10 cm. The gradational boundary and lack of any evidence of pedogenesis along this boundary suggest that these two units were deposited during a single liquefaction event. The silty sand at the outer margin of the sand blow is probably a mixture of liquefied sand from depth and the loess and fine-grained alluvium through which the sand blow penetrated. Thus, we interpret the silty sand deposits as having formed along the contact between the main dike of intruding sand and the surrounding host of loess or fine-grained alluvium. Alternatively, the silty sand may have been deposited during the initial phase of liquefaction, whereas the fine to coarse sand may represent a later stage. The numerous contacts between the fine to coarse sand and the silty sand at the northwest edge of the central part of the sand blow (5.5 m, northeast wall, OP-23; fig. 7) indicate either that more than one episode of liquefaction occurred at this site or that quartzose sand was injected into the silty sand at multiple levels. The absence of any soil other than localized oxidation to 10YR 7/4 colors in both the fine to coarse sand and the silty sand indicates that if there were multiple episodes of liquefaction at this site, they were recent. Numerous small lenses of fine to coarse sand that we interpret as small feeder dikes were also exposed in the trench.

The fine to coarse sand in the trenches was probably derived from the alluvial sands noted in the OP-3 and OP-21 cores. The similarity in color, texture, and composition of the sands in the trenches and the fluvial sands below about 6 m in the OP-3 core and below about 3.75 m in the OP-21 core (fig. 3) indicates that the sands in the blows originated at least several meters below the terrace surface. A 50-cm-long block of clayey silt at 4 m in the OP-23 trench is also interpreted to have been part of the fluvial sediment. This block of sediment probably originated from at least several meters below the surface because such sediment was noted only below about 4 m in the OP-21 core (fig. 3).

The southwest wall of the OP-23 trench reveals a similar stratigraphy, but this wall did not intersect the central part of the vent and exposed much less silty sand. Numerous pods of mottled silt are present in the sand lenses (for example, the sand lens at 9 m on the southwest wall), and we interpret these to be clasts that were incorporated into the liquefied sand as the sand blow penetrated the mottled silt.

The OP-24 trench exposed additional relatively recent liquefaction features. Liquefied sand exposed within 3 m of the southeast end of the southwest wall indicates that a small sand blow is present in this area. The trench also exposed numerous sand dikes in the interval between 6 and 8 m on the southwest wall and a decomposed stump breached by a small sand dike at 5.75 m on the northeast wall (fig. 8). Sand at the surface of this site shows little evidence of soil development except for localized oxidation and mixture with silt and clay in the plow zone.

Only the southeast 22 m of the OP-26 trench was logged. The remaining 40 m of the trench exposed a thin (< 40 cm) cover of clean, fine- to coarse-grained quartzose sand overlying mottled silt containing numerous small, sand-filled feeder dikes. The northeast wall of the OP-26 trench intersected sand bodies at the 7- to 9-m interval and at the 17- to 19-m interval. These sand bodies are probably sand blows, but this exposure does not show evidence that the sand bodies reached the surface. Hand excavation perpendicular to the trench wall revealed that these probable sand blows vented to the surface near the middle of the trench and that the contact between the base of the sand blows and the preliquefaction ground surface was destroyed during excavation.

Sand dikes and a probable third sand blow are exposed in the interval between 3 and 5 m of the southwest wall (fig. 9). This sand blow was not exposed in its entirety, but a 50-cm-long block of mottled silt in the fine to coarse sands at this site indicates forceful injection of liquefied sands. Hand excavation perpendicular to the trench wall revealed that the two layers of sand (fig. 9) coalesce to form a single layer. Thus, sand was injected into the mottled silt at two levels at this site. This trench also exposed numerous clasts of fine-grained sediment within the sand-blow deposits and several small dikes and sills of fine to coarse sand. These sand-blow deposits show little evidence of soil development, except for slight oxidation.

The lack of soil in any sand-blow deposit observed in this study indicates that liquefaction occurred recently, probably during the 1811-12 New Madrid earthquake series. Evidence for multiple episodes of liquefaction, which is particularly strong in the OP-23 trench, probably reflects the several episodes of strong ground shaking between December 1811 and February 1812.

CONCLUSIONS

No evidence of prehistorical liquefaction was observed in three exploratory trenches through sand blows exposed at the surface of late Wisconsin (about 20 ka) fluvial terraces at the mouth of the Obion River in northwestern Tennessee. Overlying these terraces is a blanket of loess about 3 m thick, which is probably correlative with the Peoria loess (25-10 ka). The absence of evidence for significant soil development on these sand blow deposits indicates that they were most likely deposited during the multiple episodes of strong ground shaking during the 1811-12 New Madrid earthquake series. No older sand blows were noted in the trenches. These observations add to a growing body of evidence from the upper Mississippi embayment that the repeat time of large-magnitude seismic events in the NMSZ is at least 10,000 yrs and may be substantially longer.

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LOGS OF EXPLORATORY TRENCHES THROUGH LIQUEFACTION FEATURES ON LATE QUATERNARY TERRACES IN THE OBION RIVER VALLEY, NORTHWESTERN TENNESSEE

By
Donald T. Rodbell and Lee-Ann Bradley

1993

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