Subdivision, Subsurface Stratigraphy, and Estimated Age of Fluvial-Terrace Deposits in Northwestern Tennessee

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By Donald T. Rodbell

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Subdivision, Subsurface Stratigraphy, and Estimated Age of Fluvial-Terrace Deposits in Northwestern Tennessee

By Donald T. Rodbell[1]

ABSTRACT

Fluvial terraces in western Tennessee may reflect surface deformation in the New Madrid seismic zone. A method for correlating among disjunct terraces that is independent of terrace elevation is needed to distinguish between two equally plausible models of regional terrace correlation that have been proposed. One of these models requires about 10 meters of vertical terrace deformation along the lower 10 kilometers (approximate) of the Obion, Forked Deer, and Hatchie Rivers, which are in the vicinity of the southern margin of the Lake County uplift, whereas the other model requires no surface deformation. Because these models are based solely on the downvalley extrapolation of terrace gradients, they cannot provide an unequivocal assessment of vertical surface deformation.

Quantification of the degree of geomorphic modification of terrace remnants due to the progressive headward incision of low-order streams provides a means for correlating between terrace remnants along the Obion River in northwestern Tennessee. Two indices of incision readily differentiate remnants of the oldest terrace (Humboldt) from remnants of the two younger terraces (Hatchie and Finley), but cannot be used to distinguish between the two younger groups of terraces.

Downvalley terrace gradients are influenced by the presence of eastward-thinning loess deposits that mantle all terraces. Terrace remnants that reach the Mississippi River valley have reverse gradients, and Humboldt terrace remnants there may be mantled by as much as 15 meters of loess. Sediment cores and exposures in borrow pits on the uplands north and south of the Obion River valley reveal four loess units separated by three distinct paleosols. Radiocarbon ages of 24.5, 23.2, and 19.9 ka on wood and charcoal near the base of the uppermost loess unit indicate that this loess unit is correlative with the Peoria Loess. The underlying two loess units correlate with the Loveland Loess and Roxana Silt recognized throughout the Mississippi River valley, and the fourth loess may correlate with a fourth loess on Crowleys Ridge in eastern Arkansas that is at least 200 ka.

Sediment cores indicate that Finley terrace remnants are mantled by Peoria Loess, and a radiocarbon age of 21.6 ka from the underlying alluvium indicates that the alluvium was deposited in the late Wisconsin rather than during the early Wisconsin. Hatchie terrace remnants are mantled by the Roxana Silt and Peoria Loess and are therefore early Wisconsin. A single core of deposits on a Humboldt terrace remnant penetrated more than 8 m of Roxana Silt and Peoria Loess and did not reach the underlying alluvium, but these terraces probably are pre-Wisconsinan based on their height and high degree of fluvial incision.

To assess the degree to which terraces in this region have been tectonically warped, the methods outlined here need to be applied to *all* of the major drainages in western Tennessee. Only by comparison of results from each drainage can a rigorous assessment of regional tectonic deformation be made.

INTRODUCTION

Between December 1811 and February 1812, the four largest historical earthquakes ($m_b \geq 7.0$) in eastern North America occurred in the New Madrid (Missouri) seismic zone. Usher (1837) and Fuller (1912) provided the earliest scientific reports of surface deformation during these seismic events. Subsequent workers have documented the extent of a large (20×50 km) uplifted zone, the Lake County uplift, in northwestern Tennessee, southeastern Missouri, and southwestern Kentucky (reviewed in Russ, 1982) (fig. 1). Surface deformation in the Lake County uplift is 6–10 m and structural relief beneath the uplifted zone is 35–80 m (Russ, 1982). Based on the oldest possible age for deformed sediments in the Mississippi River meander belt and on radiocarbon ages from faulted and folded strata in an exploratory trench across the Reelfoot scarp in northwestern Tennessee, Russ (1982) concluded that much of the nearly 10 m of surface deformation in the region dates from the Holocene.

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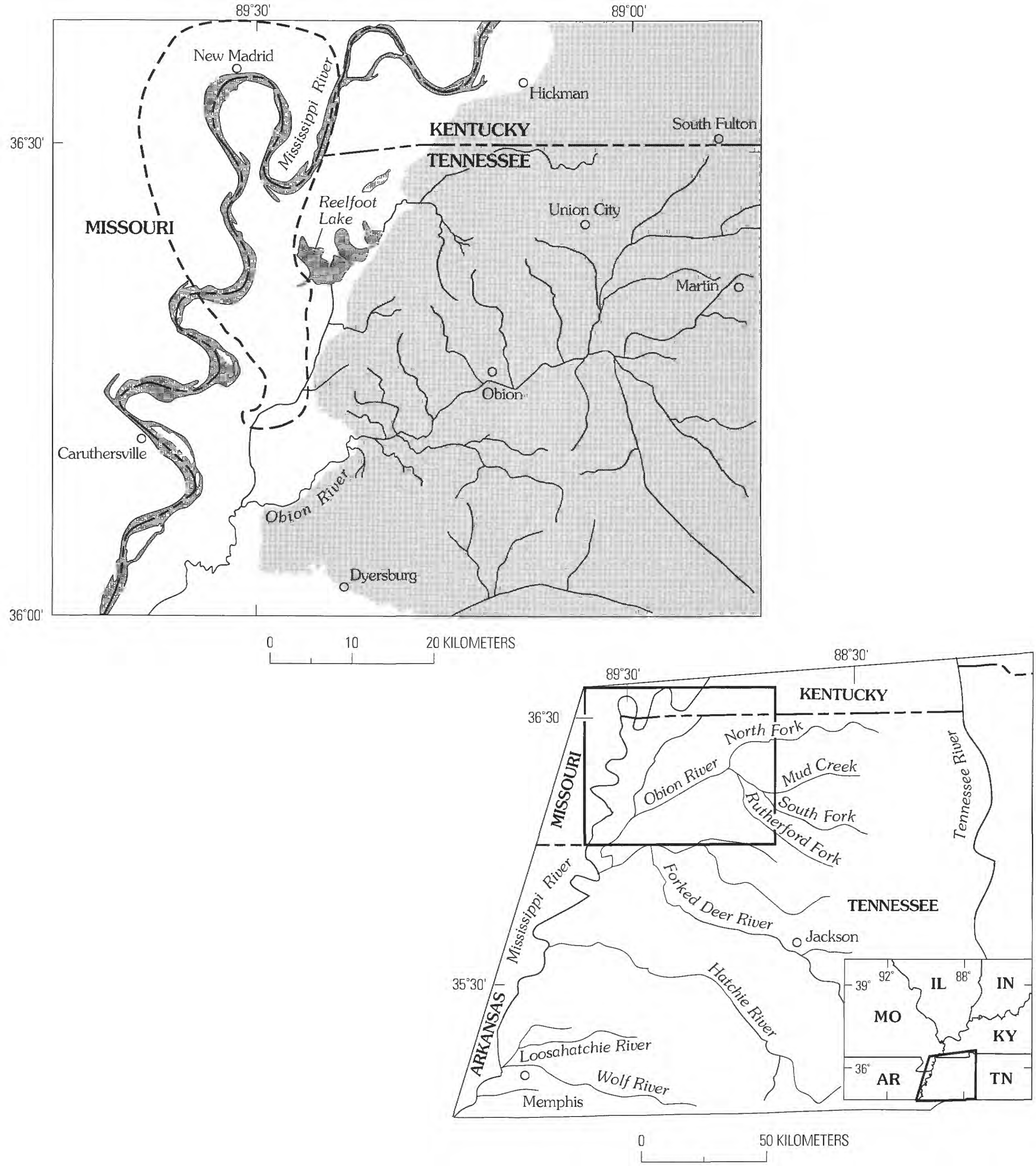

Figure 1. Location of Obion River drainage basin in northwestern Tennessee. Dashed line, extent of the Lake County uplift (Russ, 1982). Shaded area east of Mississippi River is covered by late Quaternary loess and is separated from Mississippi River valley by a prominent bluff line.

Saucier (1987) used the downvalley gradients of a series of late Quaternary fluvial terraces in northwestern Tennessee to provide an additional long-term estimate of possible surface deformation in the vicinity of the Lake County uplift. Saucier used 1:24,000-scale topographic maps and aerial photographs to delineate terraces of four different ages along the Obion, Forked Deer, Hatchie, Loosahatchie, and Wolf Rivers (fig. 1). Terrace profiles were reconstructed by correlating between disjunct terrace remnants and extrapolating their downvalley gradients (Saucier, 1987). Interstream terrace correlations yielded two equally plausible models, one with about 10 m of vertical terrace deformation in the vicinity of the southern margin of the Lake County uplift and a second with no surface deformation (Saucier, 1987). Moreover, assuming that the youngest deformed terraces are about 100,000 years old as suggested by Saucier (1987), the rate of terrace deformation in Saucier's first model is an order of magnitude lower than the rate of surface deformation based on data reviewed in Russ (1982). However, owing to the absence of independent age control for these terraces, the correlation of disjunct terrace remnants and any inferred deformation rate is speculative.

This study was undertaken to (1) establish a means of correlating disjunct terrace segments along the Obion River that is independent of terrace height, (2) document the stratigraphy of selected terrace deposits, and (3) estimate their numerical ages. The lower 60 km of the Obion River valley was chosen because it forms one of the largest drainage basins studied by Saucier (1987), and it contains the most complete stratigraphic sequence of fluvial terraces. In addition, establishing the age of the alluvium underlying these terraces will provide information on the age of the source sands for seismically induced sandblows near the mouth of the Obion River valley (Rodbell and Schweig, 1993). This study represents part of the work that I conducted in geologic risk assessment for the U.S. Geological Survey in 1991 and 1992.

GEOLOGIC SETTING AND PREVIOUS WORK

The Obion River drainage basin heads in the upper Mississippi embayment, about 20 km west of the Tennessee River, encompasses an area about 6,000 km^2, and is the northernmost major drainage basin in western Tennessee (fig. 1). The Obion River valley comprises a relatively flat alluvial valley that contains the flood plain and a series of fluvial terraces that are 7–30 m above the flood plain, and deeply incised uplands (Saucier, 1987). The drainage basin is underlain by poorly consolidated Paleocene and Eocene continental and marine sedimentary rocks that dip gently to the west (Olive, 1980); uplands in the western part of the basin are underlain by the upper Cenozoic Lafayette Gravel (Potter, 1955) and are overlain by a thick sequence of Quaternary loess (fig. 1).

Saucier (1987) recognized terraces of three different ages along the Obion River. From youngest to oldest, he named these the Finley, Hatchie, and Humboldt terraces. Saucier (1987) suggested that Finley terrace remnants are early Wisconsin; at the mouth of the Obion River, these terraces are 7–10 m higher than the flood plain and are separated from it by a distinct scarp. Saucier (1987) noted that the downvalley gradients of Finley terrace remnants are lower than the downvalley gradients of the flood plains in the five drainage basins that he examined, and, thus, the reconstructed Finley terraces of Saucier (1987) merge with and may be buried by the flood plains. The next older terrace, the Hatchie terrace, is 10–15 m above the flood plain at the mouth of the Obion River and is thought to be Sangamon in age (Saucier, 1987). This terrace, as reconstructed by Saucier (1987), also has a low to nil gradient in the lower parts of the drainage basins. Saucier (1987) surmised that the low to nil gradients of the Finley and Hatchie terraces reflect a lacustrine origin due to the damming of the streams in western Tennessee in response to aggradation of the Mississippi River. The presence of possible beach-ridge complexes on the Finley terrace is cited as supporting evidence for this hypothesis (Saucier, 1987). The oldest terraces along the Obion River, the Humboldt terraces, are highly dissected by tributary streams and are 20–30 m above the flood plain near the mouth of the Obion River.

Saucier (1987) interpreted apparently anomalously high elevations of the Humboldt and Hatchie terraces along the Obion and Forked Deer Rivers as possible evidence of regional surface deformation, but this evidence may be a relict of the techniques that he employed for interstream correlation. Saucier's (1987) interstream correlations were made by projecting terraces to an arbitrary, vertical north-to-south plane 30–40 km west of the mouths of each drainage. Any erroneous correlation of terrace remnants within individual drainages will, therefore, result in greatly magnified errors in terrace elevation when projected 30–40 km away. The reconstructed Humboldt terraces of Saucier (1987) are generally parallel to the flood plain except near the mouths of the Obion and Forked Deer drainage basins, where the gradient of the Humboldt terrace is flatter than the gradients of the flood plain. Thus, it is of little surprise that the Humboldt terraces of the Obion and Forked Deer drainage basins are anomalously high when projected westward about 40 km.

Saucier's terrace correlations have an additional uncertainty because he failed to account for the variable thickness of loess on each terrace. The accurate determination of the elevation of the top of the alluvium that underlies each terrace requires subtraction of the thickness of loess that overlies the alluvium from the terrace elevation. Inasmuch as the loess that mantles the landscape in western Tennessee thins with distance east of the Mississippi (Buntley and others, 1977), failure to consider the thickness of the loess that overlies the alluvium will result in erroneously low gradients for the alluvial deposits that underlie these terraces. This error is likely greater for the older terraces, as these are blanketed by thicker loess deposits.

METHODS

I undertook a two-part study of the terraces along the lower 60 km of the Obion River to provide a means of correlating disjunct fluvial terraces along the drainages of western Tennessee.

GEOMORPHOLOGY

With age, the original outline of fluvial terraces becomes increasingly embayed and sinuous as the terraces become incised by low-order streams (fig. 2). This progressive incision provides a basis for the application of two geomorphic indices as relative-dating criteria. The techniques employed in this study were first developed by Colman (1983) in a study of fluvial terraces along the Rappahannock River in northeastern Virginia. The two indices used in the present study, the Area Index and the Incision Index, both increase with increasing incision of terraces. The Area Index is the ratio of the area of the reconstructed original terrace to the area of the present terrace remnant (fig. 2). The calculation of the Incision Index is as follows:

$$\text{Incision Index} = (P_p/A_p)/(P_o/A_o)$$

where P_p and A_p are the perimeter and area, respectively, of the present terrace, and P_o and A_o are the perimeter and area of the original reconstructed terrace.

Outlines of 67 terrace remnants were digitized using the Geographic Information System (GIS). These 66 terrace *remnants* (pl. 1) represent parts of 37 *reconstructed* original terraces (pl. 2). The terrace remnants were identified on 1:64,000-scale aerial photographs and in the field and were plotted on 1:24,000-scale topographic maps. The majority of these maps have 10-foot contour intervals with occasional supplementary 5-foot contour intervals. Several maps that cover the deeply incised uplands south and north of the Obion River's alluvial valley have 20-foot contour intervals.

Uncertainty in the reconstruction of the original terrace outline affects the indices to different degrees. Whereas the outline of the present-day terrace remnant is readily identified on aerial photographs and plotted on topographic maps, reconstruction of the original terrace outline is subjective particularly for the older, highly incised terraces (fig. 2). Because the Area Index incorporates the area of the reconstructed terrace, uncertainty in this parameter will result in uncertainty in the resultant Area Index value. However, the Incision Index employs the perimeter/area ratio of the reconstructed terrace to correct for differences in the perimeter/area ratios of present-day terraces that are due solely to differences in their original shapes (Colman, 1983). Thus, because the Area Index requires a more accurate estimate of the area of the reconstructed terrace, the Incision Index is a more objective index of geomorphic modification than the Area Index. However, both indices should result in a similar subdivision of terraces.

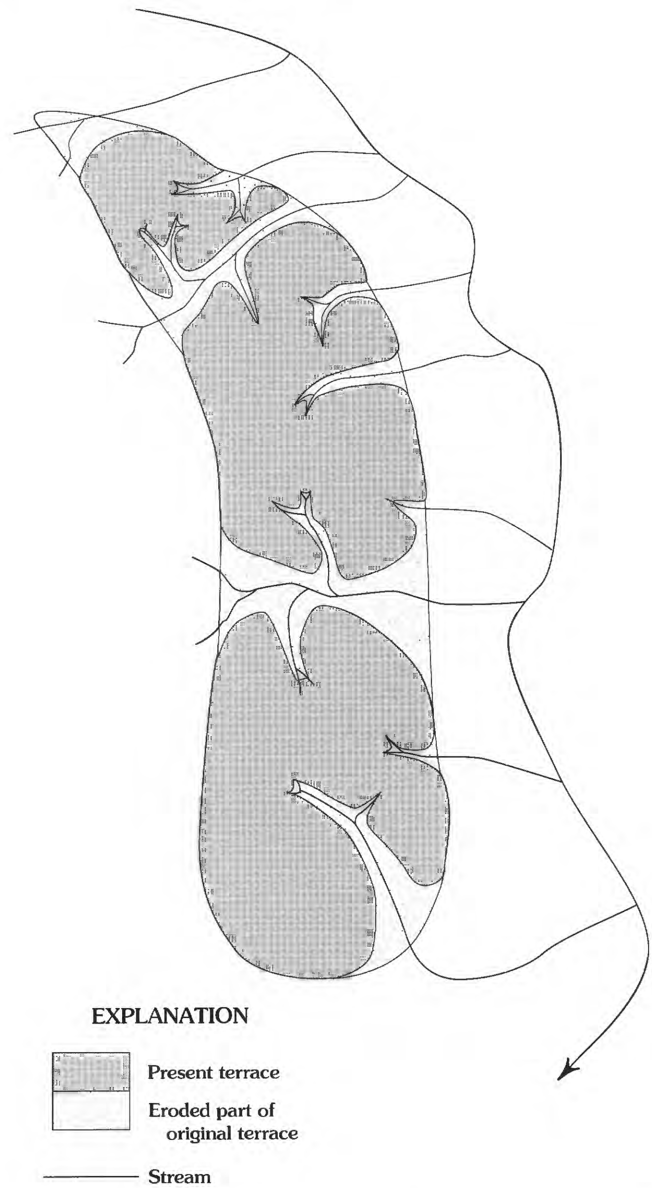

Figure 2. Plan view of a hypothetical incised terrace showing areal extent of present terrace remnants and eroded part of original terrace.

STRATIGRAPHY

In order to estimate the age and document the stratigraphy of the deposits that underlie these terraces, nine cores about 7 cm in diameter and up to 8.5 m long were extracted by means of a hydraulically powered drill rig. Five exposures in roadcuts and stream cuts also were examined. The cores and the exposures were described following the Soil Survey Staff (1975) format, and material suitable for radiocarbon dating was sampled and submitted for radiocarbon assay (table 1). In order to graphically summarize soil descriptions, two soil properties, soil rubification and moist consistence, were quantified relative to estimated parent material values following the methods outlined in Harden (1982) and Harden and Taylor (1983). Selected cores were analyzed for particle-size distribution following the methods outlined in Singer and Janitsky (1986). Particular attention was paid to the

Table 1. Radiocarbon ages from cores and exposures in the Obion River valley.

Site No. (pl. 1)	Type of site	Sample No.	Depth below surface (cm)	Material	Radiocarbon age ± 1 σ (yr BP)	$\partial^{13}C_{PDB}$ (per mil)	Lab No.
OP-17	Core	OP-C7	254-330	Wood	249 ± 45	-27.0	GX-17028-AMS
OP-7	Exposure	OP-C8	500	Shell	12,760 ± 380	-10.2	GX-17026
OP-16	Core	OP-C6	265	Wood	19,900 ± 230	-25.7	GX-17027-AMS
OP-21	Core	OP-C9	407-440	Shell	21,620 ± 190	-9.6	GX-17029-AMS
OP-25	Exposure	OP-C18	433-447	Charcoal	23,215 ± 485	-29.8	GX-17725-AMS
OP-25	Exposure	OP-C16	277-287	Charcoal	24,450 ± 565	-29.8	GX-17724-AMS

thickness of loess, the number of loess units present in each core and exposure, and the presence of buried soils between loess units. If the terraces are of the ages suggested by Saucier (1987), then they should be mantled by multiple loess units separated by buried soils, and the older terraces should be mantled by more loess units than the younger terraces. To document the complete record of loess deposition in this region, I examined three 6–11-m-high exposures of loess in borrow pits and two cores on the loess-mantled uplands north and south of the Obion River valley.

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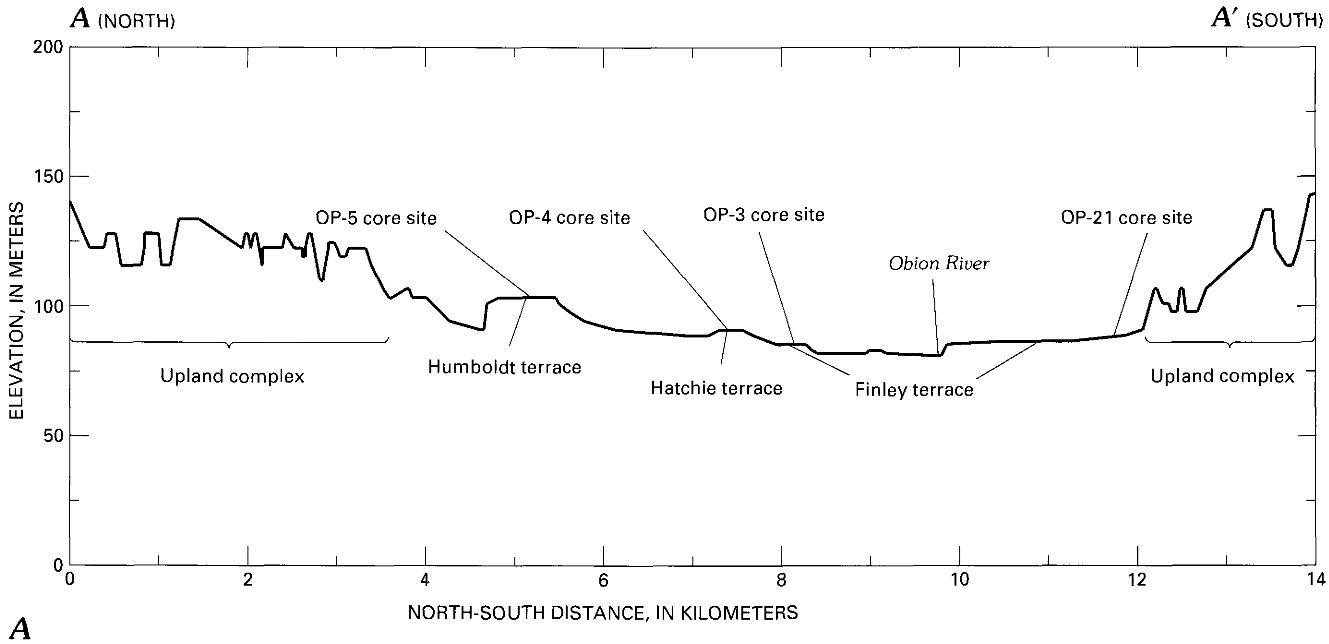
DISTRIBUTION OF TERRACES

Terrace remnants are numerous and conspicuous along the lower 25 km of the Obion River, but decrease in number and degree of preservation upvalley (pl. 1; figs. 3*A*, 3*B*, and 4–7). The distribution of terrace remnants recognized in this study agrees with the findings of Saucier (1987) with a few exceptions. First, I recognize a group of small, high terrace remnants between 20 and 35 m above the Obion River between 5 and 45 km upvalley from the bluff line of the Mississippi River valley (fig. 1), whereas Saucier (1987) did not (fig. 4). Second, I recognize three small, low terrace remnants less than 5 m above the Obion River 35–45 km upvalley from the bluff line (fig. 4) and one small remnant about 10 m above Mud Creek, 48 km upvalley from the bluff line (figs. 1 and 7). Some of these discrepancies may be due to the scales of the maps used; Saucier (1987) compiled terrace maps to scales of 1:250,000 and included only those terraces with areas greater than 1 km^2. In contrast, I compiled terraces at a scale of 1:100,000 (pl. 1) and was, therefore, able to include nearly all terrace remnants.

CORRELATION OF TERRACES

The degree of incision of the terraces along the Obion River generally increases with increasing terrace age. At any particular point along the valley, height above the flood plain can be used as a proxy for relative terrace age, so plotting terrace elevation versus the Incision Index or the Area Index provides a means of comparing relative terrace age with degree of incision (table 2; figs. 8 and 9). In general the higher terraces have been more deeply incised by low-order streams than the lower terraces.

The Incision Index data clearly separate the reconstructed terraces into two groups, and do not support several of the age assignments of Saucier (1987). The first group of terraces are those that yield Incision Index values less than about 2.5, and the second group are those that yield Incision Index values greater than about 3 (fig. 8). All the terraces in the latter group are between about 15 and 30 m above the flood plain, and all are designated as Humboldt terraces by Saucier (1987), except reconstructed terraces 15, 16, and 35, which were not included in the map of Saucer (1987). However, numerous reconstructed terraces (numbers 21, 22, 24, 28, 36, 40, 41), designated as Humboldt terraces by Saucier (1987), yield Incision Index values that plot within the range of Incision Index values from the Hatchie and Finley terraces (fig. 8). Thus, these terraces probably are equivalent to the Hatchie terraces rather than to the Humboldt terraces as suggested by Saucier (1987). Finally, it is not possible to distinguish between the reconstructed Hatchie and Finley terraces based on the Incision Index data (fig. 8).



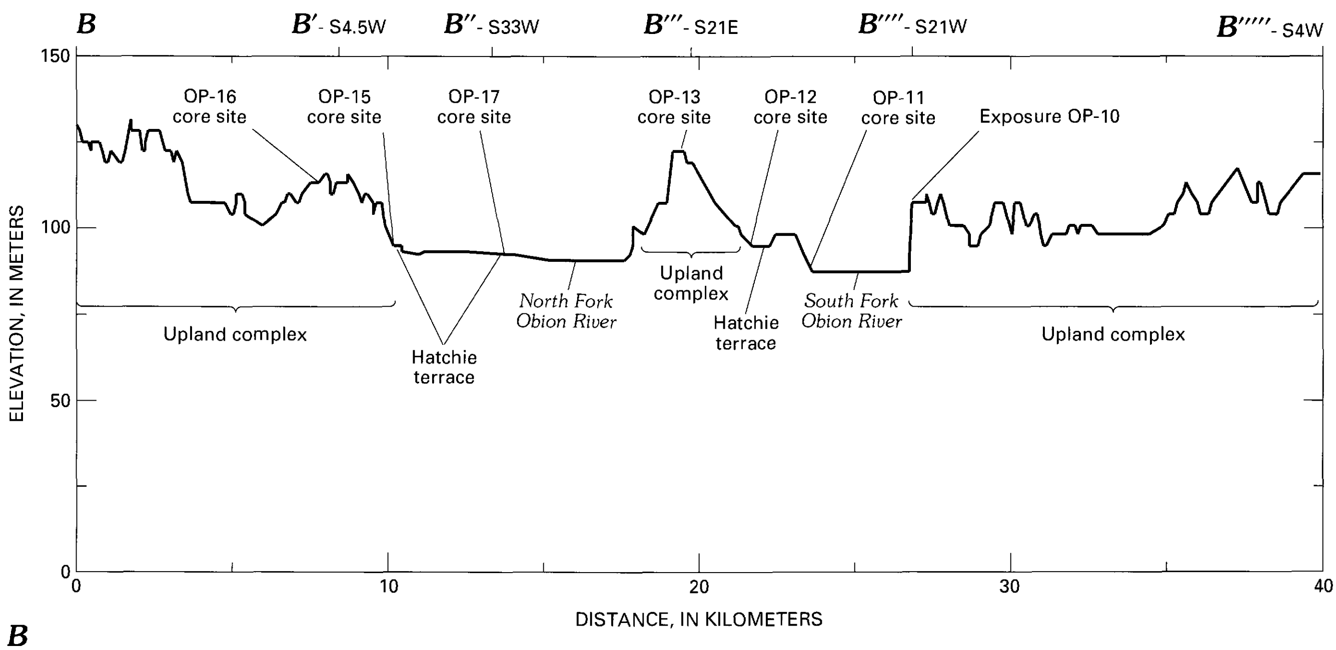


Figure 3. Topographic cross sections. *A*, Section from *A* to *A′* (pl. 1), about 5 km east of bluff line of Mississippi River valley. Core sites are within 1.5 km E. or W. of *A–A′*. Vertical exaggeration ×30. *B*, Section from *B* to *B′′′′′* (pl. 1), about 35 km east of bluff line. Core sites are within 2 km E. or W. of *B–B′′′′′*. Vertical exaggeration ×110. Note different horizontal scale than *A*. Terraces are more conspicuous near bluff line than in upvalley reaches.

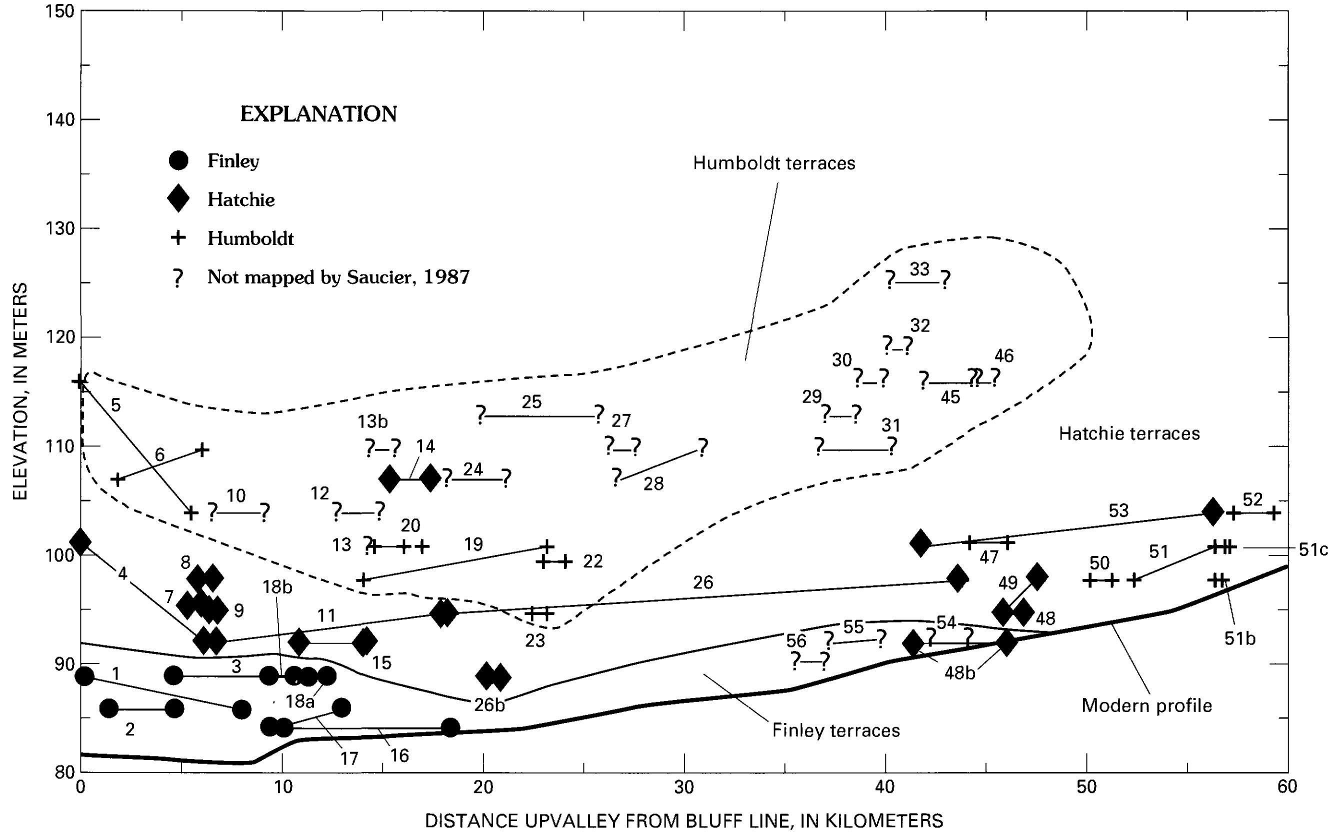


Figure 4. Terrace profiles along main and north forks of Obion River (fig. 1). Symbols indicate Saucier's (1987) age designations, and lines enclosing groups of terraces indicate correlations based on present study. Numbers refer to terrace remnants shown on plate 1.

The Area Index also divides the reconstructed terraces into two groups (fig. 9), a higher and more deeply incised group and a lower, less incised group. However, there is considerable overlap in the Area Index values for the two groups (fig. 9). In particular, reconstructed terraces 12 and 19, which are clearly Humboldt terraces based on the Incision Index data (fig. 8), cannot be correlated with the Humboldt terraces based on the Area Index data (fig. 9). The opposite is true of reconstructed terrace 39 (figs. 8 and 9). In contrast, the same terraces that are mapped as Humboldt terraces by Saucier (1987) and that yield relatively low Incision Index values also yield relatively low Area Index values (fig. 9). This further supports the suggestion in the preceding paragraph that these terraces likely are Hatchie terraces rather than Humboldt terraces.

The Area Index plotted as a function of the Incision Index subdivides the reconstructed terraces into two groups that are independent of terrace elevation (fig. 10). The first group of terraces yield Incision Index values of less than about 2.5 and Area Index values of less than about 1.4, whereas the second group of terraces have Incision Index values of 3.0–4.75 and Area Index values of 1.2–1.6 (fig. 10). The second group is composed of nine reconstructed terraces; of these, six terraces are designated as Humboldt terraces (Saucier, 1987) and three were not included in the map of Saucier (1987). Twenty-seven reconstructed terraces compose the first group, and these terraces were primarily designated as Hatchie and Finley terraces by Saucier (1987). However, this group also contains numerous terraces designated as Humboldt terraces by Saucier (1987) (fig. 10), and these stratigraphic designations probably are erroneous. Finally, reconstructed terrace 39 does not fit into either of the two groups because it yields a high Area Index and a low Incision Index.

To assess whether these two groups of terraces represent statistically distinct populations, I applied the Student's t test to the data. The null hypothesis in this test states that the two groups of terraces belong to the same population. At the 95 percent confidence level, the Student's t test rejects the null hypothesis for both the Incision Index and the Area

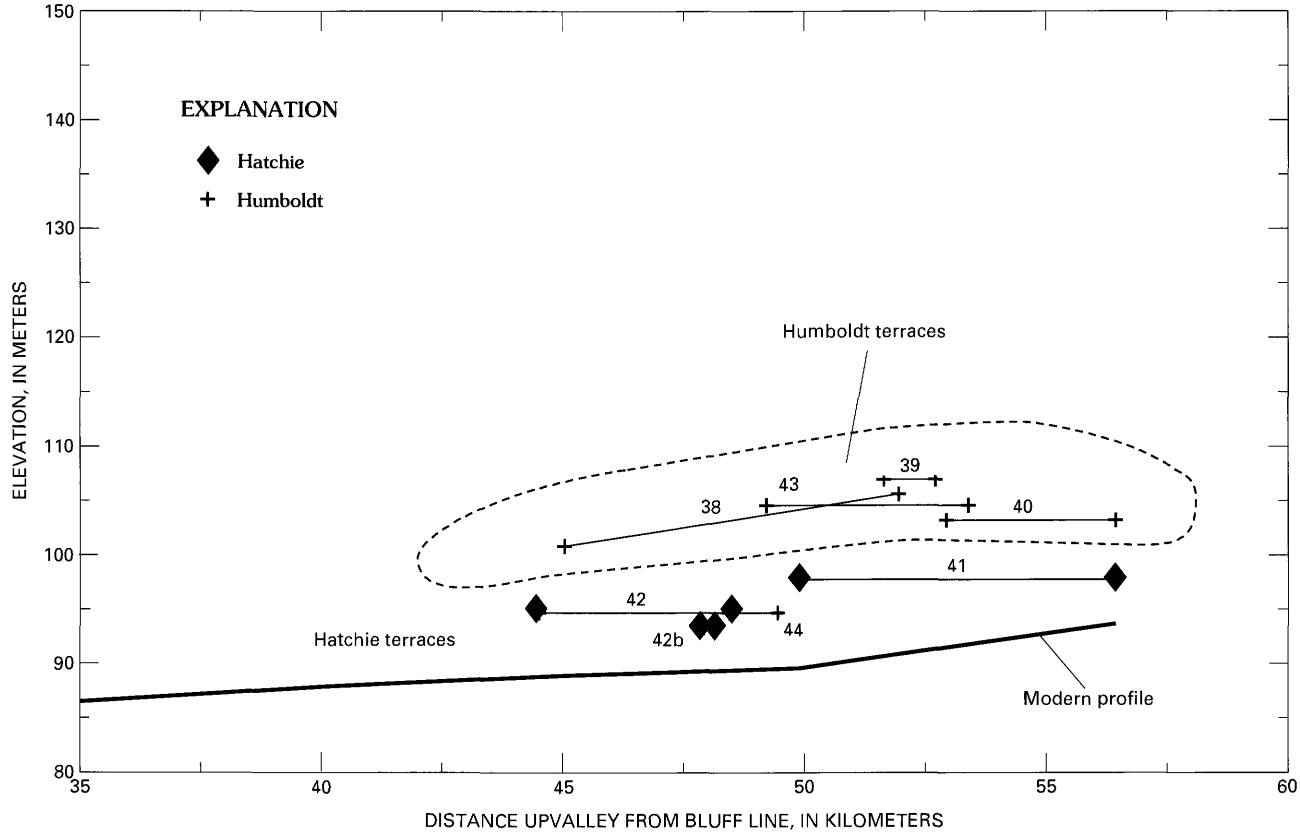


Figure 5. Terrace profiles along South Fork Obion River (fig. 1). Symbols indicate Saucier's (1987) age designations, and line enclosing group of terraces indicates correlations based on present study. Numbers refer to terrace remnants shown on plate 1.

Index data sets. Furthermore, the Incision Index data set rejects the null hypothesis at the 99.95 percent confidence level, and thus the two groups of terraces represent two distinct populations. The Area and Incision Indices should assist in discriminating between Saucier's (1987) two models of interstream terrace correlation because they subdivide the terraces into two relative-age groups; moreover, they are independent of terrace height.

All terrace remnants that belong to the group of reconstructed terraces with higher Incision and Area Index values (fig. 10) are designated as Humboldt terraces, and all other terrace remnants, except terrace remnant 39, are designated as either Hatchie or Finley terrace remnants (figs. 4–7; pl. 1). Discrimination between Hatchie and Finley terraces is based on height above the flood plain; where two terraces are present below the Humboldt terraces, the higher terrace is designated as a Hatchie terrace and the lower terrace is designated as a Finley terrace. In cases where only one terrace is preserved below the level of the Humboldt terrace, or where there are more than two terraces below the Humboldt terrace, age designations are based on extrapolation of terrace gradients to the nearest terrace remnant of known age. Finally, terrace remnant 39 is designated as a Humboldt terrace remnant because it is located adjacent to and slightly higher than terrace remnant 38, which is located along the South Fork Obion River about 53 km upvalley from the bluff line of the Mississippi River (fig. 5). Terrace remnant 38 is a Humboldt terrace based on its Area and Incision Index values (fig. 10).

TERRACE GRADIENTS

Terrace remnants along the mouth of the Obion River that can be traced to the bluff line of the Mississippi River valley have gradients that may reflect the presence of westward-thickening loess deposits or surface deformation in the New Madrid seismic zone, or both (fig. 4). For example, terrace remnant 1, which is mapped as a Finley terrace by Saucier (1987), slopes upvalley at 0.38 m/km; terrace 4, a Hatchie

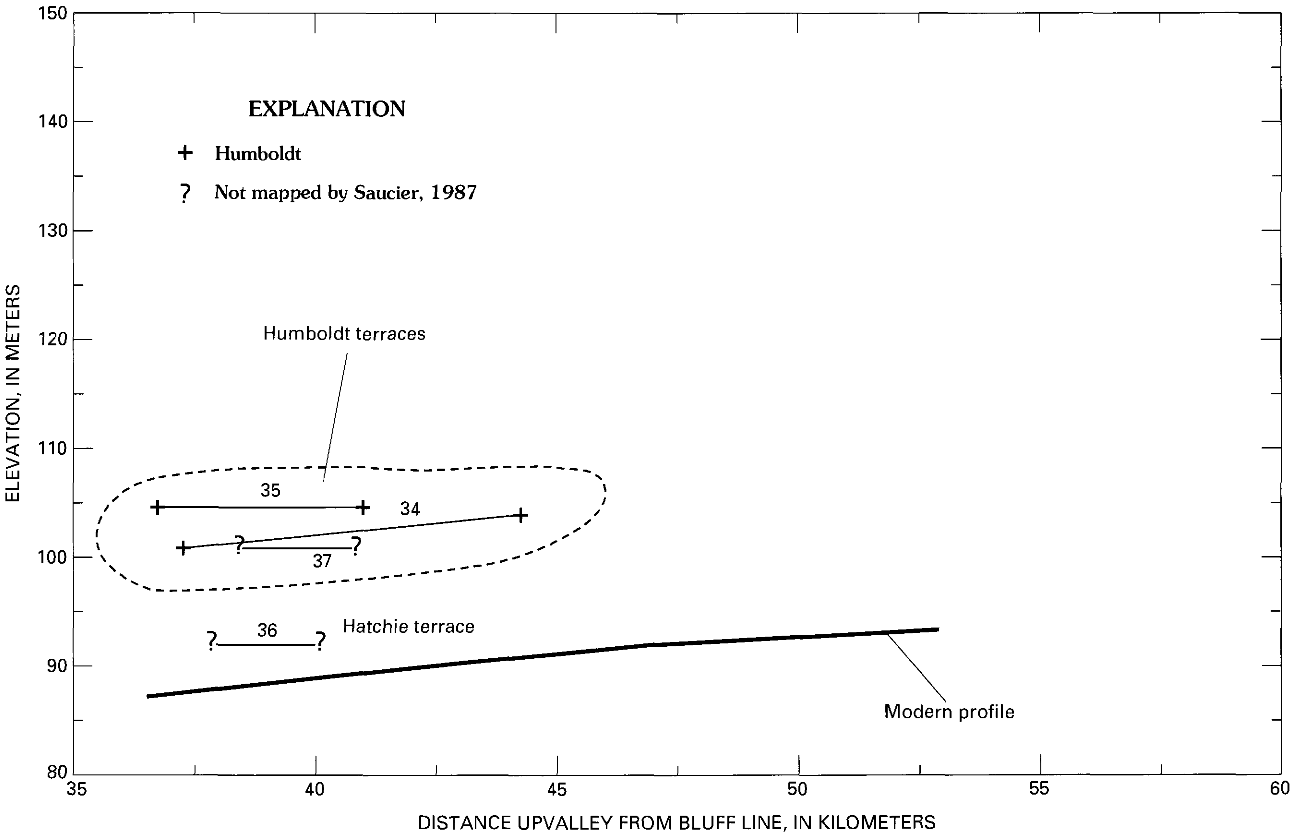


Figure 6. Terrace profiles along Rutherford Fork Obion River (fig. 1). Symbols indicate Saucier's (1987) age designations, and line enclosing group of terraces indicates correlations based on present study. Numbers refer to terrace remnants shown on plate 1.

terrace, slopes upvalley at 1.46 m/km; and terrace 5, a Humboldt terrace, has an upvalley gradient of 2.22 m/km. Terrace remnants 1, 4, and 5 can be traced upvalley to nearby (less than 5 km) correlative terraces that have downvalley gradients. Terrace remnant 1 can be correlated with confidence across the Obion River to terrace remnants 2 and 3 and upvalley to nearby terrace remnants 16, 17, and 18a and 18b (fig. 4; pl. 1). These upstream terrace remnants have low downvalley gradients, and, thus, if it is assumed that terrace remnant 1 originally had a similar gradient, then it is apparent that the elevation of the Finley terrace at the bluff line of the Mississippi River valley has increased about 3 m. Terrace remnant 4 can be correlated with confidence to nearby terrace remnants 11 and 26, and these have an average downvalley gradient of 0.19 m/km over a distance of 37.5 km (fig. 4). Extrapolation of the downvalley gradient of terraces 11 and 26 to the bluff line suggests that at the mouth of the Obion River terrace 4 should have an elevation of about 90 m above sea level (masl) whereas it has an elevation of about 100 masl. Similarly, correlation of terrace remnant 5 to terrace remnants 10 and 12 indicates that at the bluff line the elevation of terrace 5 should be about 104 masl whereas it is 116 masl (fig. 4). Sediment cores from terrace remnants and estimated rates of loess thinning with distance east of the bluff line, discussed in the following section, suggest that these anomalous terrace gradients reflect the presence of eastward-thinning loess rather than surface deformation.

LOESS AND TERRACE STRATIGRAPHY AND ESTIMATED AGES

LOESS STRATIGRAPHY

An exposure in a borrow pit 1.25 km north-northeast of Hornbeak, Tenn. (site OP–25, pl. 1), provides the thickest and most complete record of loess deposition in the Obion River drainage basin. At this site, which is located approximately 8.75 km east of the bluff line of the Mississippi River valley,

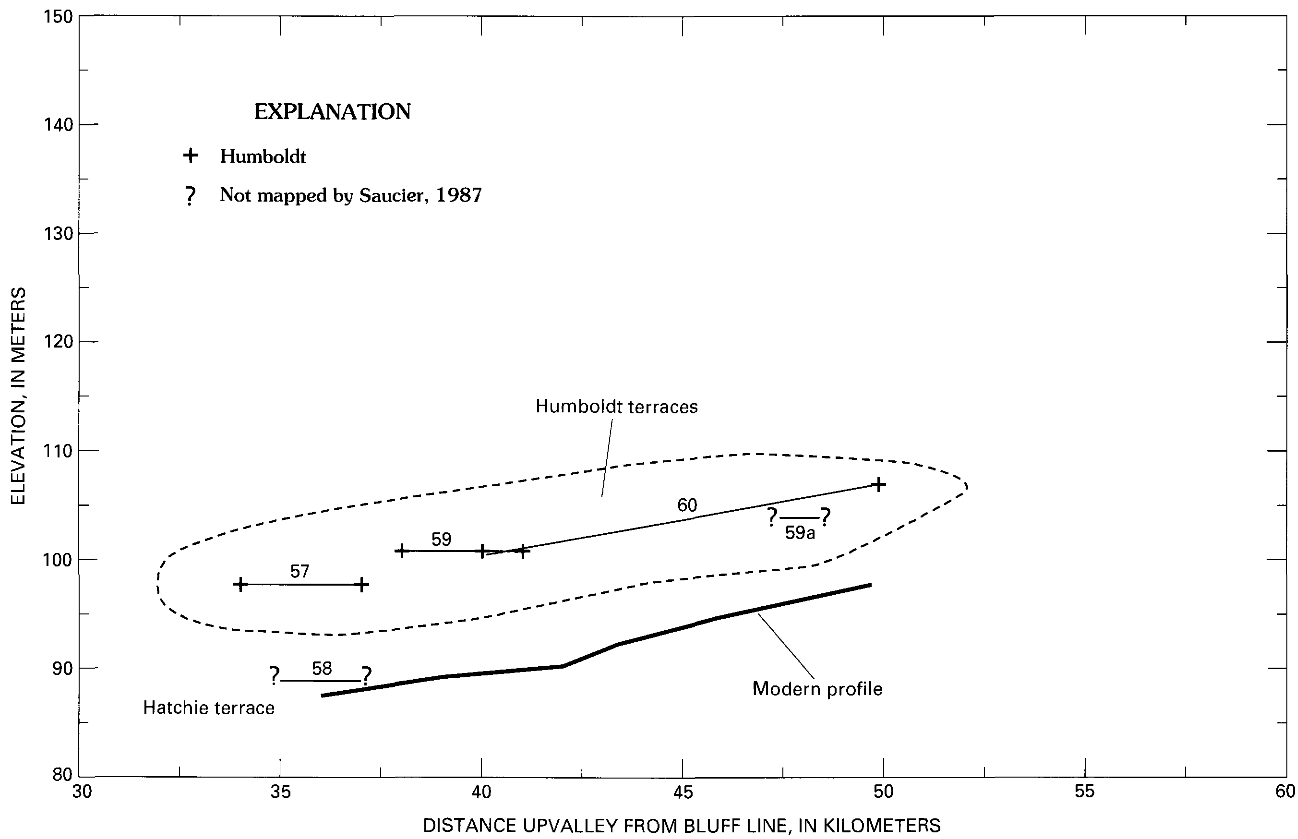


Figure 7. Terrace profiles along Mud Creek, tributary to Obion River (fig. 1). Symbols indicate Saucier's (1987) age designations, and line enclosing group of terraces indicates correlations based on present study. Numbers refer to terrace remnants shown on plate 1.

four loess units totaling about 11 m and separated by three major paleosols overlie the Lafayette Gravel (fig. 11*A*; table 3). The surface soil extends to a depth of about 3 m. Moist Munsell colors (Goddard, 1975) in the surface soil range from 10*YR* 4/3 to 10*YR* 5/4 (brown to yellowish brown). In contrast, colors between 3 and 3.5 m are 2.5*Y* 5/3 (light olive brown); these colors, the presence of primary carbonate, and the lack of clay films indicate that the uppermost loess unit is relatively unaltered between 3 and 3.5 m (fig. 11*A*; table 3). This is the only unaltered loess noted in the study area, and I assume that its color, texture, and consistence are representative of the original properties of all other loesses deposited in the region. However, the original mean grain size of loess probably decreased with increasing distance east of the bluff line (Follmer, 1983; Ruhe, 1983) and may have varied considerably from site to site (Ruhe, 1984).

Paleosols are recognized primarily on the basis of abrupt down-profile changes in color, texture, structure, and consistence that cannot be attributed to pedogenic variations within an individual solum. Accordingly, a buried paleosol is recognized in the interval between 4.5 and 7.8 m at the OP–25 locality (table 3). Moist Munsell colors range from 10*YR* 5/5 to 7.5*YR* 5/5 (yellowish brown), and moist consistence values indicate slightly more clay in the middle part of this interval (fig. 11*A*; table 3). A second paleosol is present between 7.8 and 10.2 m. Moist Munsell colors range from 5*YR* 5/7 (yellowish red) in the upper part of this paleosol to 7.5*YR* 5/6 (strong brown) in the lower part, and both texture and consistence values indicate that slightly more clay is present in this interval. Finally, a fourth paleosol, present below 10.2 m, has moist Munsell colors of between 7.5*YR* 5/6 (strong brown) and 5*YR* 5/7 (yellowish red), and textures and moist consistence values indicative of relatively high clay content (fig. 11*A*; table 3).

I have used two radiocarbon dates and the physical properties of the loess and intervening paleosols to correlate the loess units present in the OP–25 exposure to the established midwestern loess stratigraphy (for example, Willman and Frye, 1970; Follmer, 1983; Pye and Johnson, 1988; Forman and others, 1992). Radiocarbon-datable material was found only in the lower part of the uppermost loess unit. Small charcoal fragments less than 1 mm in size sampled

Table 2. Area and Perimeter Index data for terrace remnants and reconstructed terraces in the Obion River valley.

Reconstructed terrace number (pl. 2)	Terrace remnant number (pl. 1)	Terrace remnant area (m^2)	Terrace remnant perimeter (m)	Reconstructed terrace area (m^2)	Reconstructed terrace perimeter (m)	Incision index	Area index
1	1	13051486	33043.289	13785513	17341.22	1.74	1.06
2	2+3	12390911.5	9097.253	15319021	21250.12	1.72	1.24
3	4+7+8+9+11	25051199.8	29228.455	27846416	39830.78	2.01	1.11
4	5+6+10	11274344.5	35319.676	14955235	22089.521	3.35	1.33
17	12+13+13B+14	8563577.807	21779.559	13557907	16249.55	4.68	1.58
6	16+17	15625015.3	19588.158	17513106	19478.02	2.50	1.12
9	18A+18B	575746.156	2565.68	751838.3	5835.25	2.01	1.31
8	19+20+22+23	13595984.9	2348.594	20993268	26596.71	3.53	1.54
5	15	894533.625	14355.601	1162374	6811.187	1.46	1.30
12	34+35	23630155	29809.557	29531180	30928.13	3.02	1.25
27	36	456430.5	13619.715	527548.9	5709.928	1.40	1.16
26	37	1134761	11908.017	1085280	6324.679	1.27	0.96
23	42+42B	1751220.19	1691.163	2397951	7875.192	1.68	1.37
22	44	322451.5	19828.426	433549.3	3522.301	1.59	1.34
21	43	2962615	7651.22	3127703	11181.55	1.55	1.06
20	41	9329204	34003.145	7339324	15662.87	1.84	0.79
19	38+39+40	12699781.9	9502.364	15107471	25538.63	3.15	1.19
24	60	16095561	6292.997	16682942	27091.67	1.90	1.04
28	59+57	7781433	2708.942	9691480	18425.18	1.91	1.25
29	58	501039.7	43223.34	582443.1	5977.278	1.23	1.16
30	55	303352.1	10488.41	283945.4	2978.685	1.25	0.94
18	56	484302	4550.375	427048	3507.778	1.38	0.88
25	59A	711848.8	3522.824	839793.9	3639.273	1.70	1.18
32	53	16580602	3633.107	19425154	27944.96	2.31	1.17
41	50	406946.8	20460.27	488923.7	2958.055	1.35	1.20
40	51	2205669	42323.53	2739472	11288.5	1.91	1.24
39	52+51B+51C	707357.78	75726.71	1231674	5751.894	2.38	1.74
31	49	371658.2	1896.356	521478.4	3423.27	1.55	1.40
33	54	964446.2	11987.86	942859.8	7021.13	1.32	0.98
37	48	563228.1	25357.57	578473.1	3612.332	1.72	1.03
36	47	2481322	4689.17	2589300	6452.255	1.97	1.04
34	48B	10835042	4350.604	9680080	15396.66	1.51	0.89
38	46	9118604	9208.958	13466350	17154.04	3.11	1.48
35	29-33+45	8927836.5	2443.345	13428593	24226.73	2.89	1.50
16	27+28	9822014	6950.343	14202457	16043.35	3.37	1.45
15	24+25	16667111	44361.14	20567760	18538.81	4.18	1.23
14	26+26B	32564839.6	30355.86	38654460	44541.59	2.03	1.19

from a depth of 2.77–2.87 m yielded an AMS (accelerator mass spectrometer) radiocarbon age of 24,450±565 yr BP (GX-17724-AMS), and similar material sampled from a depth of 4.33–4.47 m yielded an AMS radiocarbon age of 23,215±485 yr BP (GX-17725-AMS). Although these ages are stratigraphically inverted, the two ages are indistinguishable at ±2σ (table 1). The two samples of charcoal are separated by about 1.6 m of unweathered loess that probably reflects rapid deposition, so the near equivalency of the radiocarbon ages is not surprising. These ages indicate that deposition of the upper loess unit began about 25 ka, and that this loess unit is correlatable with the Peoria Loess, deposited throughout the Mississippi Valley between about 25 ka and 10 ka (Ruhe, 1983, 1984; Pye and Johnson, 1988; Forman and others, 1992).

Comparison of color, texture, and structure of the underlying paleosols indicates that the second loess unit at the OP–25 locality is correlatable with the Roxana Silt on Crowleys Ridge in eastern Arkansas (West and others, 1980) and at numerous other Mississippi Valley localities (Forman and others, 1992; Pye and Johnson, 1988). Similarly, the third loess at this site probably is equivalent to the Loveland Loess of the northern Mississippi River valley (Follmer, 1983) and with the Sicily Island Loess of the southern Mississippi River valley (Autin and others, 1991). Finally, the fourth loess at this site probably correlates with the fourth loess on Crowleys Ridge of eastern Arkansas (Autin and others, 1991). Thermoluminescence (TL) ages for the Roxana Silt indicate that it could be as old as 85 ka (Pye and Johnson, 1988) or as young as 45–30 ka (Forman and others, 1992), and TL ages on the Loveland Loess suggest ages greater than 130 ka (Pye and Johnson, 1988) or as young as 85–70 ka (Forman and others, 1992). The fourth loess is probably older than 125 ka based on TL ages from the upper

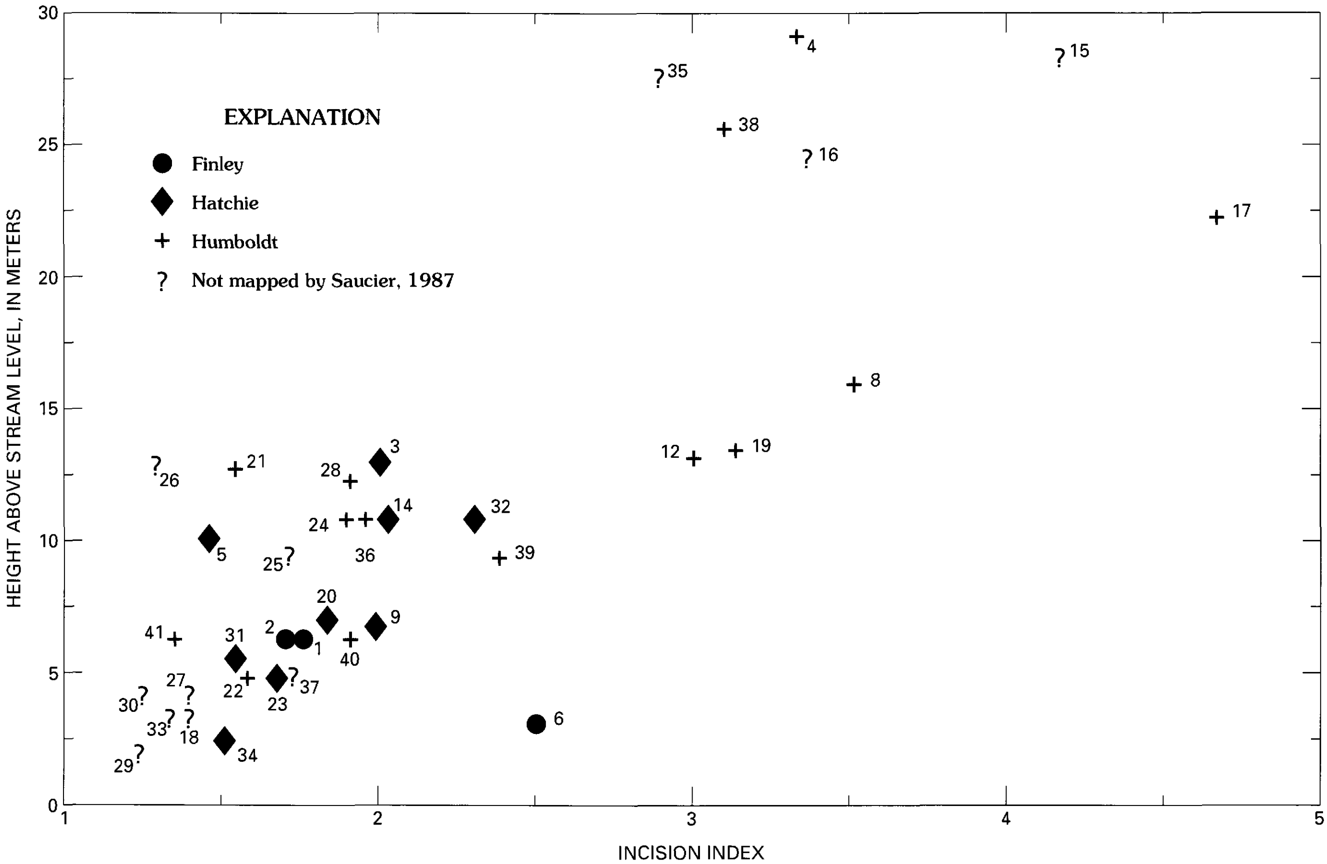


Figure 8. Height above stream level of 37 reconstructed terraces versus Incision Index (see "Methods" section). The higher and, therefore, older terraces generally have been incised to a greater degree than the lower and, therefore, younger terraces. Symbols indicate age designations of Saucier (1987) and numbers refer to reconstructed terraces (pl. 2).

Mississippi River valley (Forman and others, 1992). Therefore, late Wisconsin terraces should be mantled by the Peoria Loess, early Wisconsin terraces should be mantled by the Roxana Silt and Peoria Loess, and terraces older than about 130 ka should be mantled by the Loveland Loess, Roxana Silt, and Peoria Loess.

Four other exposures in the uplands flanking the Obion River valley reveal a similar loess stratigraphy to that documented at the OP–25 locality, although none reveal a stratigraphy that is as complete. A borrow pit at site OP–1, 14.25 km east of the bluff line of the Mississippi River valley and 4.4 km west of Troy, Tenn. (pl. 1), exposes approximately 7 m of the Roxana Silt and Peoria Loess overlying the Lafayette Gravel (fig. 11*B*; table 3). The contact between the Roxana Silt and Peoria Loess is apparent as an abrupt increase in clay with depth (fig. 11*B*; table 3). The Peoria Loess at this site is weathered throughout and rubification values are about twice those for the Peoria Loess at the OP–25 locality. In contrast, rubification values for the Roxana Silt at the OP–1 site are similar to values at the OP–25 site. The thickness of the Peoria Loess at this site is about 1 m less than at the OP–25 site, whereas the thickness of the Roxana Silt is about the same (fig. 11*A* and *B*).

At site OP–16, 28.25 km east of the bluff line of the Mississippi River valley and 1.6 km northeast of Union City, Tenn. (pl. 1), a core recovered approximately 4 m of loess overlying red (10*R* 4/8), poorly consolidated sand (fig. 11*C*). The loess at this site is subdivided into the Roxana Silt and Peoria Loess based on down-profile trends in percentage clay, rubification, and moist consistence (fig. 11*C*; table 3). Wood near the base of the Peoria Loess yielded an AMS radiocarbon age of 19,900±230 yr BP (GX-17027-AMS; table 1).

A core from site OP–13, 33.25 km east of the bluff line of the Mississippi River valley and 4 km southeast of Rives, Tenn., penetrated approximately 6 m of loess overlying red

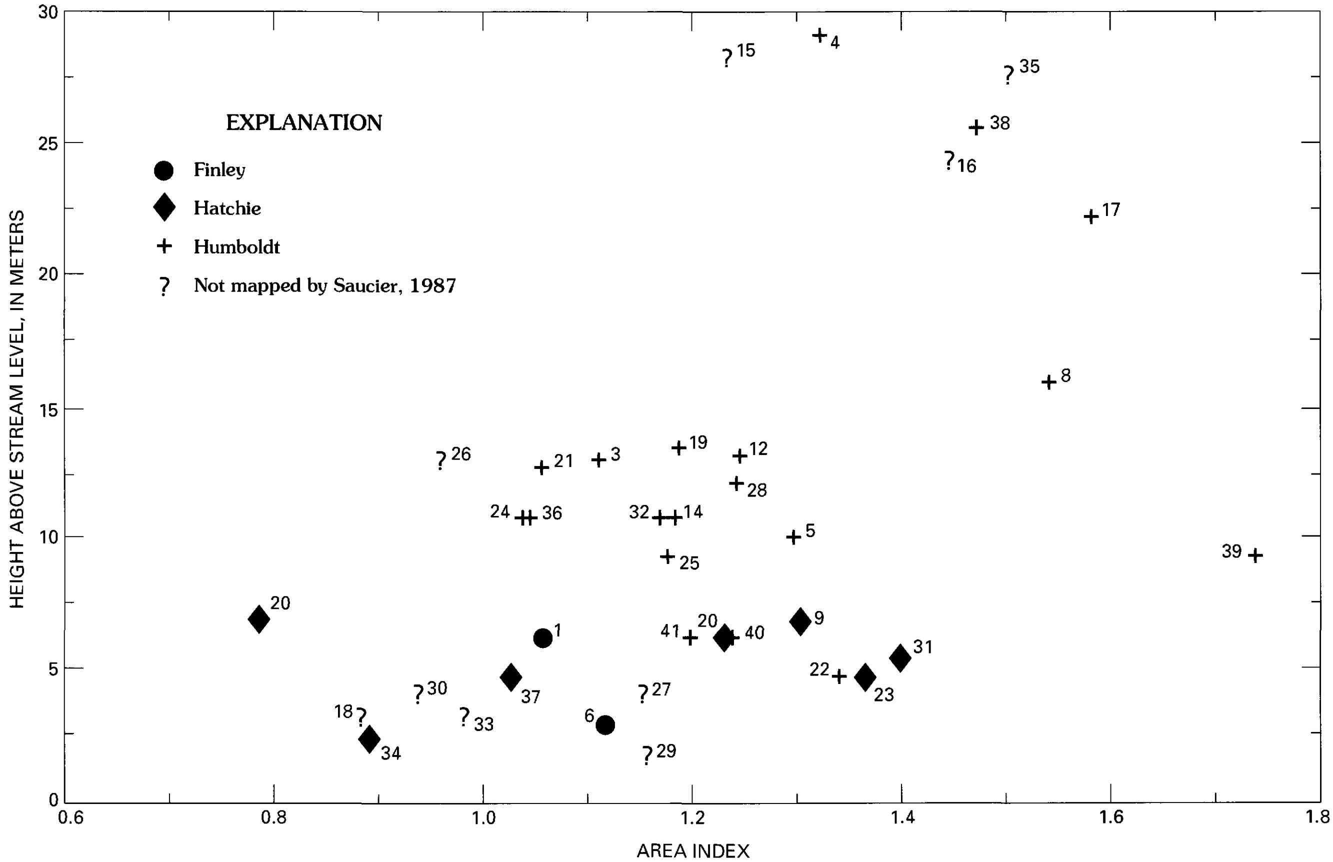


Figure 9. Height above stream level of 37 reconstructed terraces versus Area Index (see "Methods" section). The higher and, therefore, older terraces generally have been geomorphically modified to a greater degree than the lower and, therefore, younger terraces. Symbols indicate age designations of Saucier (1987) and numbers refer to reconstructed terraces (pl. 2).

(10*R* 4/8) poorly consolidated sand (fig. 11*D*). I have used rubification values to subdivide the loess at this site into three units that are correlated with the Peoria Loess, Roxana Silt, and Loveland Loess (fig. 11*D*; table 3).

A borrow pit at site OP–10, located 35 km east of the bluff line of the Mississippi River valley and 7.7 km north of Kenton, Tenn. (pl. 1), exposes approximately 3 m of loess overlying red (2.5*YR* 4/6) fluvial sand similar to that noted in the OP–13 and OP–16 cores (fig. 11*E*; table 3). The sand unit contains numerous westward-dipping foreset beds and occasional rip-up clasts of clay. I have used down-profile changes in rubification and clay content to subdivide the overlying loess into two units that are correlative with the Peoria Loess and Roxana Silt.

Several trends are apparent in the distribution and thickness of the loesses that I examined in the Obion River drainage basin. The thickness of the Peoria Loess progressively decreases from about 4.5 m, 8.75 km east of the bluff line, to 1.5 m, 35 km east of the bluff line (fig. 12). Similarly, the Roxana Silt progressively thins from about 3 m to about 1.25 m over the same distance (fig. 12). The Loveland Loess is present at sites OP–25 and OP–13 and is absent at all other sites, and a fourth loess is only present at site OP–25 (fig. 11*A–E*). Inasmuch as the individual loess units have distinctive paleosols that define their upper contacts (West and others, 1980; Rutledge and others, 1985), it is unlikely that the apparent absence of the Loveland Loess and a fourth loess from several sites is due to their misidentification. Apparently, an episode of erosion occurred at some sites prior to deposition of the Roxana Silt. A linear regression line of loess thickness with distance east of the bluff line of the Mississippi River valley (fig. 12) suggests that at the bluff line the Peoria Loess is 5.2 m thick, the Roxana Silt is 4.5 m thick and the Loveland Loess is 3.3 m thick. However, Buntley and others (1977) reported that the Peoria Loess at the bluff line in western Tennessee is about 15 m thick and that the Roxana

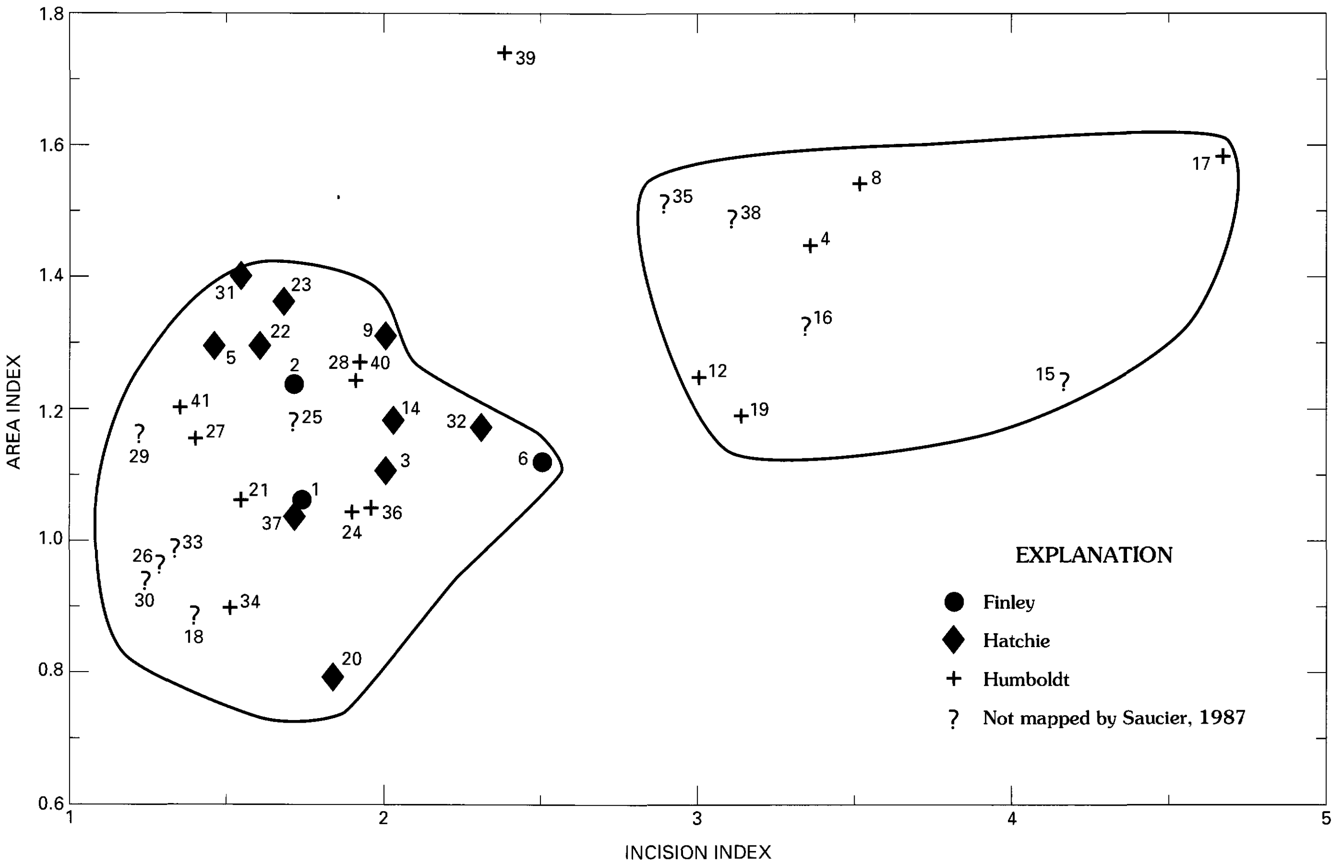


Figure 10. Area Index versus Incision Index of 37 reconstructed terraces. Symbols indicate Saucier's (1987) age designations, numbers refer to reconstructed terraces (pl. 2), and lines enclosing two groups of terraces indicate correlations based on this study.

Silt is about 8 m thick, and thus they concluded that these loesses thin exponentially with distance east of the bluff line. These trends in loess thickness and possible exponential thinning with distance east of the bluff line probably explain the aforementioned upvalley gradients of terrace remnants 1, 4, and 5 near the mouth of the Obion River (fig. 4).

ALLUVIAL STRATIGRAPHY

Three cores and one roadcut on Finley terrace remnants reveal Peoria Loess overlying laminated silty alluvium and sand. The loess is up to 6.5 m thick and thins to the east. A core from terrace remnant 2, located 9.4 km east of the bluff line of the Mississippi River valley (site OP–3, pl. 1), recovered 4 m of Peoria Loess, which in turn overlies 2 m of horizontally laminated silt and about 50 cm of medium to coarse quartzose sand (fig. 13*A*). The Peoria Loess is massive and yields rubification values that are similar to those noted for the Peoria Loess at site OP–25 (table 3). In addition, the thickness of the Peoria Loess at this site is nearly identical to that noted at site OP–25, thus supporting the predicted thinning of loess with distance east of the bluff line (fig. 12). With the exception of occasional lenses of very fine sand, the laminations in the silty alluvium are not prominent; rather they are thin (1–2 mm thick), slight variations in grain size expressed as subtle variations in color. The slightly coarser silt is oxidized to 10*YR* 5/4 (yellowish brown) whereas the fine-grained laminae have reduced colors of 10*YR* 6/2 (light brownish gray). I interpret the laminated silty alluvium to be fluvial overbank sediment, although a partially lacustrine origin as postulated by Saucier (1987) is possible. Identification of the contact between the loess and underlying silty

Figure 11 (facing page). Texture, moist consistence, rubification (Harden, 1982, and Harden and Taylor, 1983), and grain size in upland exposures and cores of loess and soils in Obion River drainage basin (see pl. 1 for locations). *A*, Exposure OP–25; *B*, Exposure OP–1; *C*, Core OP–16; *D*, Core OP–13; *E*, Exposure OP–10. Radiocarbon ages are listed in table 1, and radiocarbon sampling intervals are denoted by black boxes in depth scale. S, Si, and C, sand, silt, and clay.

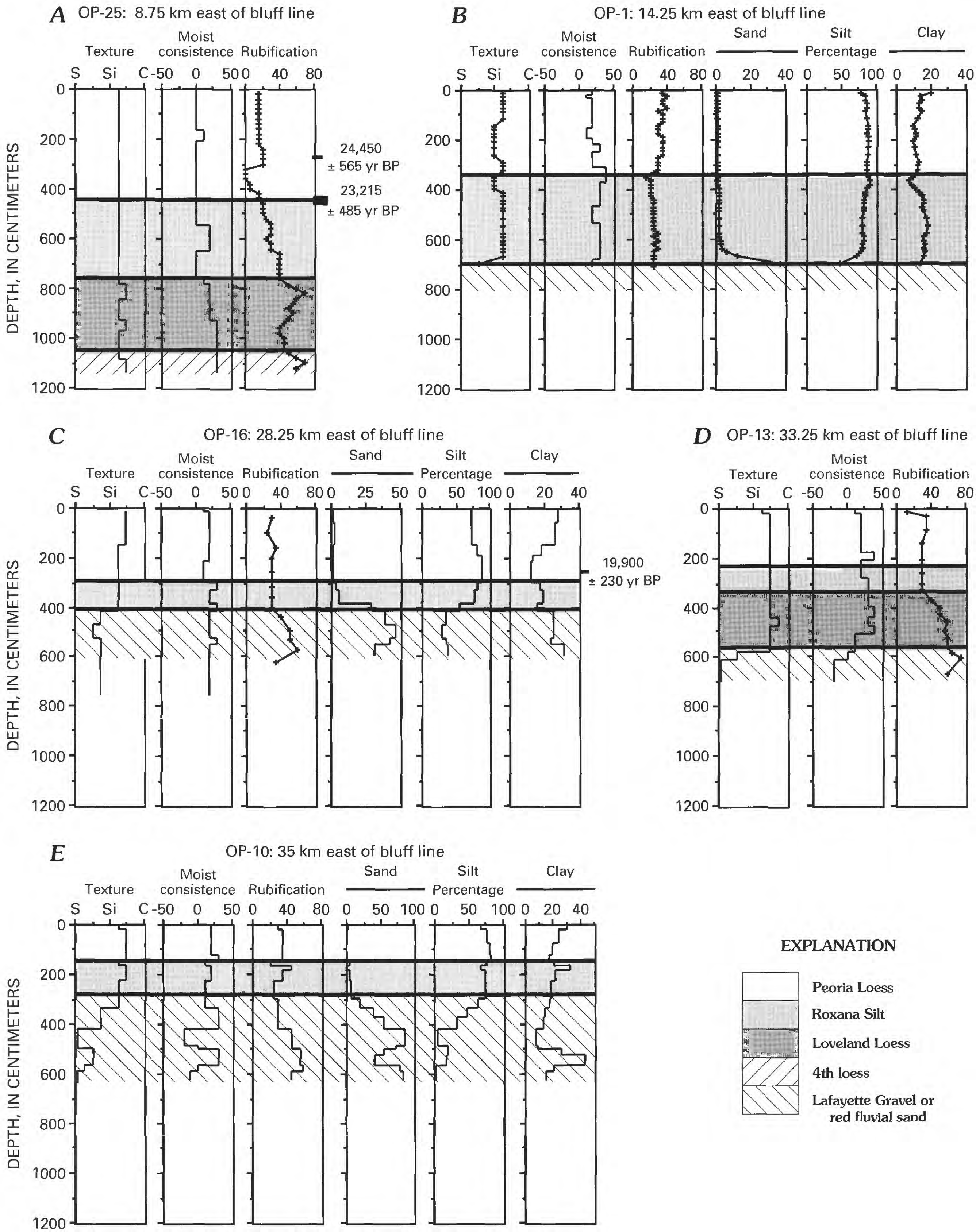

A OP-25: 8.75 km east of bluff line
Texture
Moist consistence
Rubification
S Si C -50 0 50 0 40 80
24,450 ± 565 yr BP
23,215 ± 485 yr BP
DEPTH, IN CENTIMETERS
B OP-1: 14.25 km east of bluff line
Texture
Moist consistence
Rubification
Sand
Silt
Clay
Percentage
C OP-16: 28.25 km east of bluff line
19,900 ± 230 yr BP
D OP-13: 33.25 km east of bluff line
E OP-10: 35 km east of bluff line
EXPLANATION
Peoria Loess
Roxana Silt
Loveland Loess
4th loess
Lafayette Gravel or red fluvial sand

Table 3. Field and laboratory data for samples from cores and exposures in the Obion River valley.

Site No. (pl. 1)	Core or exposure	Depth interval (cm)	Horizon[1]	Texture[1]	Moist consistence[1]	Moist consistence points [2]	Clay films[1]	Structure[1]	Depth of sample for laboratory analyses (cm)	Sand (%)[4]	Silt (%)[4]	Clay (%)[4]	Texture[5]	Color moist [3,6]	Color dry [3,6]	Rubification points [7]
OP-1	Exposure	0-17	A		s,p	20	np	2,c,gr	10.0	0.80	79.16	20.03	SiL	10YR 4/5	10YR 6/6	35.0
		17-31	Bw		ss,p	10	v1,n,po	2,c,sbk	25.0	0.75	85.41	13.81	SiL	10YR 4/6	10YR 6.5/6	40.0
		31-48	Bw2		s,p	20	1,n,po	2,c,abk	40.0	0.88	84.54	14.55	SiL	10YR 4/5	10YR 6.5/6	35.0
		48-150	Cox		s,p	20	1,n,po	2,c,abk	55.0	0.48	86.59	12.91	SiL	10YR 4/5	10YR 6.5/6	35.0
		150-195	Cox2		ss,p	10	np	2,c,abk	70.0	0.56	86.52	12.91	SiL	10YR 4/6	10YR 6.5/6	40.0
		195-220	Btb		s,p	20	v1,n,po	2,c,abk	85.0	0.85	84.44	14.69	SiL	10YR 4/4	10YR 6.5/6	30.0
		220-248	Bt2b		vs,p	30	1,n,po	2,c,abk	100.0					10YR 4/5	10YR 6.5/6	35.0
		248-308	Coxb		s,p	20	2,n,pf	2,c,abk	115.0	0.65	87.05	12.28	SiL	10YR 4/5	10YR 6.5/6	35.0
		308-367	Btb2		vs,vp	40	1,n,po	2,c,abk	130.0					10YR 4/5	10YR 6.5/6	35.0
		367-390	Bt2b2		s,vp	30	1,n,po	3,c,abk	145.0	0.90	89.81	9.26	Si	10YR 4/4	10YR 6.5/6	30.0
		390-465	Bt3b2		vs,p	30	1,n,pf	3,c,abk	160.0	0.53	89.12	10.35	Si	10YR 4/4	10YR 6.5/6	30.0
		465-532	Bt4b2		s,p	20	1,n,pf	3,c,abk	175.0	0.76	87.99	11.25	Si	10YR 4/4	10YR 6.5/6	30.0
		532-577	Btb3		vs,p	30	2,mk,pf	3,c,abk	190.0	0.77	88.31	10.92	Si	10YR 4/5	10YR 6.5/6	35.0
		577-610	Bt2b3		vs,p	30	3,mk,pf	3,c,abk	205.0	0.73	89.92	9.32	Si	10YR 4/5	10YR 6.5/6	35.0
		610-676	Bt3b3		vs,p	30	3,mk,pf	3,c,abk	215.0					10YR 4/5	10YR 6.5/6	35.0
		676-712	2Coxb3		s,p	20	3,mk,pf	2,m,abk	230.0	0.91	88.64	10.42	Si	10YR 4/5	10YR 6.5/6	35.0
									245.0					10YR 4/5	10YR 6.5/6	35.0
									260.0	0.90	88.18	10.89	Si	10YR 4/5	10YR 6.5/6	35.0
									275.0					10YR 4/4	10YR 6.5/6	30.0
									290.0	0.98	85.87	13.13	SiL	10YR 4/4	10YR 6.5/6	30.0
									305.0	0.96	86.87	12.16	SiL	10YR 4/4	10YR 6.5/6	30.0
									320.0	1.00	87.22	11.76	SiL	10YR 4/4	10YR 6.5/6	30.0
									335.0					10YR 4/4	10YR 6.5/5	25.0
									350.0	0.99	89.57	9.41	Si	10YR 4/3	10YR 6.5/4	15.0
									365.0	1.12	91.59	7.30	Si	10YR 4/4	10YR 6.5/4	20.0
									380.0	1.08	90.44	8.45	Si	10YR 4/4	10YR 6.5/4	20.0
									395.0	1.36	87.91	10.73	Si	10YR 4/4	10YR 6/4	20.0
									410.0	1.64	84.99	13.35	SiL	10YR 3/4	10YR 6/4	20.0
									425.0	1.52	83.88	14.61	SiL	10YR 3/4	10YR 6/4	20.0
									440.0	1.73	82.75	15.50	SiL	7.5YR 4/4	10YR 6/4	25.0
									455.0	1.50	83.26	15.24	SiL	7.5YR 4/4	10YR 6/4	25.0
									470.0	1.40	83.61	14.99	SiL	7.5YR 4/4	10YR 6/4	25.0
									485.0	1.55	83.00	15.43	SiL	7.5YR 4/4	10YR 6/4	25.0
									500.0					7.5YR 4/4	10YR 6/4	25.0
									515.0	1.33	80.89	17.76	SiL	7.5YR 4/4	10YR 6/4	25.0
									530.0					7.5YR 4/4	10YR 6/4	25.0
									545.0	1.40	80.55	18.03	SiL	7.5YR 4/4	10YR 6/4	25.0
									560.0					7.5YR 4/4	10YR 6/4	25.0
									575.0	1.72	81.12	17.14	SiL	7.5YR 4/4	10YR 6/5	30.0
									590.0	2.05	82.21	15.72	SiL	7.5YR 4/4	10YR 6/4	25.0
									605.0	2.36	81.75	15.89	SiL	7.5YR 4/4	10YR 6/5	30.0
									620.0	2.64	80.66	16.68	SiL	7.5YR 4/4	10YR 6/4	25.0
									635.0	3.74	80.64	15.62	SiL	7.5YR 4/4	10YR 6/5	30.0
									650.0	5.77	77.87	16.34	SiL	7.5YR 4/4	10YR 6/4	25.0
									665.0	12.00	72.45	15.55	SiL	7.5YR 4/4	10YR 6/4	25.0
									680.0					7.5YR 4/4	10YR 6/4	25.0
									695.0	37.60	48.44	13.94	L	10YR 4/5	10YR 6.5/4	25.0
									710.0					10YR 4/5	10YR 7/4	25.0
0P-2	Exposure	0-34	A	SiL	ss.ps	0	v1,n,po	1,c,abk	0-34					10YR 3/4	10YR 6/4	20.0
		34-58	Bw	SiCL	s,p	20	1,n,pf	2,c,abk	34-58					7.5YR 4/4	10YR 6/5	30.0
		58-70	Bw2	SiCL	s,p	20	1,n,pf	2,c,abk	58-70					7.5YR 4/4	10YR 7/5	30.0
		70-90	Bw3	SiCL	s,p	20	2,mk,pf	2,c,abk	70-90					7.5YR 4/4	10YR 7/5	30.0
OP-3	Core	0-110		SiL					25.0					10YR 5/3	10YR 7/3	10.0
		110-260		SiL					65.0					10YR 5/3	10YR 7/3	10.0
		260-390		SiL					105.0					10YR 5/3	10YR 7.5/3	10.0
		390-430		SiL					140.0					10YR 5.5/3	10YR 7.5/3	10.0
		430-515		L					185.0					10YR 5/4	10YR 6.5/3	15.0
		515-550		SiL					245.0					10YR 5/4	10YR 7/5	25.0
		550-610		L					292.5					10YR 5/4	10YR 7/5	25.0
		610-635		LS					332.5					10YR 5/4	10YR 7/5	25.0
		635-660		LS					387.5					10YR 5/3	10YR 7/5	20.0
									417.5					10YR 5/3	10YR 7/5	20.0
									467.5					10YR 5/3	2.5Y 7/4	10.0
									512.5					10YR 5/4	10YR 7/5	25.0
									557.5					10YR 5/4	2.5 Y 7/5	20.0
									625.0					10YR 5/2.5	10YR 7/2.5	10.0
									647.5					10YR 4/1.5	10YR 6.5/2	10.0
OP-4	Core	0-33		SiL	ss,ps	0	np		12.5					10YR 3/3	10YR 6/4	15.0
		33-110		SiCL	s,vp	30	2,mk,pf		55.0					10YR 5/3	10YR 7/3.5	12.5
		110-135		SiCL	s,p	20	2,n,pf		122.5					10YR 5/4	10YR 7/5	25.0
		135-180		SiCL	s,p	20	2,n,pf		152.5					10YR 5/4	10YR 6/5	25.0
		180-260		SiCL	s,p	20	1,n,pf		202.5					10YR 4.5/6	10YR 6.5/6	40.0
		265-395		SiL	ss,ps	0	v1,n,po		247.5					10YR 5/5	10YR 6.5/6	35.0
		395-432		SiCL	s,p	20	v1,n,po		277.5					10YR 5/4	10YR 6.5/6	30.0
		432-437		S	so,po	-20	np		307.5					10YR 4.5/4	10YR 6.5/5	25.0
		437-450		SiL	ss,p	10	np		342.5					10YR 4/3	10YR 6/5	20.0
		450-455		S	so,po	-20	np		372.5					10YR 4/3	10YR 6.5/5	20.0
		455-510		S	so,po	-20	np		412.5					10YR 5/4	10YR 6.5/5	25.0
		510-568		S	so,po	-20	np		426.0					10YR 4/3	10YR 6/5	20.0
		568-680		S	so,po	-20	np		434.5					10YR 5/4	10YR 7/5	25.0
		680-720		SiL	ss,ps	0	np		444.5					10YR 5/3	2.5Y 7/5	15.0
		720-740		SL	so,ps	-10	np		452.5					2.5Y 4.5/4	2.5Y 7/5	15.0
		740-752		SiL	ss,ps	0	np		467.5					10YR 4.5/3	10YR 6.5/5	20.0
		752-780		SiL	ss,p	10	np		497.5					10YR 6/4	10YR 7.5/4	20.0
									527.5					10YR 6/3.5	10YR 7/3	12.5
									557.5					10YR 6/3.5	10YR 7/3	12.5
									582.5					10YR 5.5/4	10YR 7/4	20.0
									622.5					10YR 5/3.5	10YR 6.5/5	22.5
									647.5					10YR 4.5/4	10YR 6.5/5	25.0
									672.5					10YR 4.5/4	10YR 6.5/5	25.0
									697.5					10YR 5.5/3	10YR 7/3	10.0
									727.5					2.5Y 5/2	2.5Y 7/2	0.0
									746.0					10YR 5/2.5	2.5Y 7.5/4	10.0
									762.5					2.5Y 5/2.5	2.5Y 7/2.5	10.0

Table 3—Continued.

Site No. (pl. 1)	Core or exposure	Depth interval (cm)	Horizon[1]	Texture[1]	Moist consistence[1]	Moist consistence points [2]	Clay films[1]	Structure[1]	Depth of sample for laboratory analyses (cm)	Sand (%)[4]	Silt (%)[4]	Clay (%)[4]	Texture[5]	Color moist [3,6]	Color dry [3,6]	Rubification points [7]
OP-5	Core	0-32		SiL	ss,ps	0	1,n,po		12.5					10YR 5/3	10YR 7/3	10.0
		32-51		SiCL	s,vp	30	1,n,po		42.5					10YR 4.5/2	10YR 7/2.5	10.0
		51-75		SiCL	s,p	20	2,n,pf		67.5					10YR 6/3	10YR 7.5/2.5	10.0
		75-87		SiL			2,mk,pf		81.0					10YR 5/2.5	10YR 6/2.5	10.0
		87-230		SiL	ss,ps	0	2,mk,pf		107.5					10YR 5/4	10YR 6 5/4	20.0
		230-260		SiL	s,p	20			147.5					10YR 5/3.5	10YR 6.5/5	22.5
		260-300		SiL	so,p	0	np		187.5					10YR 5/4	10YR 6.5/5	25.0
		300-350		SiL	so,p	0	np		212.5					10YR 4.5/3	10YR 6/5	20.0
		350-406		SiL	ss,p	10			242.5					10YR 4.5/3.5	10YR 6.5/5	22.5
		406-437		SiL	ss,p	10			267.5					10YR 4.5/4	10YR 6.5/5	25.0
		437-462		SiL	ss,p	10			297.5					10YR 5/4	10YR 7/5	25.0
		462-485		SiL	ss,p	10			317.5					10YR 4.5/4	10YR 6.5/5	25.0
		485-555		SiL	ss,p	10			337.5					10YR 5/4	2.5Y 7/5	20.0
		555-580		SiL	ss,po	-10			362.5					10YR 4.5/5	10YR 6.5/5	30.0
		580-622		SiL	ss,p	10			397.5					10YR 4.5/5	10YR 6.5/5	30.0
		622-702		SiL	ss,p	10			427.5					10YR 4/3	10YR 6/5	20.0
		702-737		SiL	ss,p	10			456.0					10YR 4/4	10YR 6.5/5	25.0
		737-752		SiL	so,p	10			477.5					10YR 5/4	2.5Y 7/5	20.0
		752-850		SiL	ss,ps	0			497.5					10YR 4/5	10YR 6.5/6	35.0
									532.5					10YR 4/3	10YR 6.5/5	20.0
									567.5					10YR 5/4	2.5Y 7/5	20.0
									587.5					2.5Y 5.5/3	2.5Y 7.5/2	0.0
									600.0					2.5Y 5.5/2	2.5Y 7.5/2	0.0
									637.5					10YR 5/4	10YR 6.5/5	25.0
									677.5					10YR 3.5/4	10YR 6/5	25.0
									717.5					10YR 4/4	10YR 6.5/5	25.0
									747.5					2.5Y 5/2.5	2.5Y 7.5/2.5	0.0
									782.5					10YR 4/4	10YR 6.5/5	25.0
									812.5					10YR 4/3	10YR 6.5/5	20.0
									845.0					10YR 5/3	2.5Y 7/4	10.0
									860.0					2.5Y 5/1	2.5 Y 7/2	0.0
									883.5					2.5Y 5/2	2.5Y 7/2	0.0
OP-6	Exposure	0-25	Bw	SiL	ss,p	10	np	2,c,abk	0-25					10YR 4/3	10YR 6.5/5	20.0
		25-37	Bw2	SiL	so,p	0	np	2,c,abk	25-37					10YR 4/3	10YR 6.5/4	15.0
		37-52	Bt	SiCL	s,vp	30	1,n,po	3,vc,abk	37-52					10YR 4/3	10YR 7/4	15.0
		52-92	Ab	SiL	s,vp	30	1,n,po	3,vc,abk	52-92					10YR 3/2	10YR 6/3.5	12.5
		92-150	Bwb	SiL	ss,p	10	1,n,po	2,vc,abk	92-150					10YR 5/4	10YR 7/4	20.0
		150-210	Btb	SiL	ss,p	10	2,n,pf	3,vc,abk	160.0					10YR 4/4	10YR 6.5/5	25.0
		210-330	Bt2b	SiCL	s,p	20	2,mk,pf	3,vc,abk	180.0					10YR 5/4	2.5Y 7/5	25.0
									210-330					10YR 5/3	10YR 6.5/4	15.0
OP-7	Exposure	0-30	Ap		ss,p	10	np	2,m,sbk	0-30	3.41	85.89	10.68	SiL	2.5Y 4.5/3	2.5Y 6.5/5	10.0
		30-50	Bt		s,p	20	v1,n,po	2,c,abk	30-50	1.55	86.55	11.88	SiL	10YR 4/3	10YR 6.5/4	15.0
		50-70	Bt2		s,vp	30	1,n,pf	2,c,abk	50-70	1.47	83.28	15.23	SiL	10YR 4/3	10YR 6.5/5	20.0
		70-94	Bt3		ss,p	10	2,mk,pf	2,c,abk	70-94	1.53	86.42	12.02	SiL	10YR 4/4	10YR 6.5/4	20.0
		94-123	Bt4		ss,vp	20	2,mk,pf	2,c,abk	94-123	1.86	84.26	13.86	SiL	10YR 4/4	10YR 6.5/5	25.0
		123-150	Bt5		ss,p	10	1,n,pf	3,c,abk	123-150	2.03	84.67	13.28	SiL	10YR 4.5/4	10YR 6.5/4	20.0
		150-245	Btb		s,p	20	3,mk,pf	3,vc,abk	150-245	4.04	83.39	12.55	SiL	10YR 5/4	10YR 7/4	20.0
		245-275	Bt2b		s,vp	30	3,mk,pf	3,vc,abk	245-275	3.13	86.57	10.28	SiL	2.5Y 5/3	2.5Y 7/3	0.0
OP-8	Exposure	0-26	Ap	SiL	s,p	20	1,n,pf	2,c,abk	0-26					10YR 4.5/3	10YR 6.5/3	10.0
		26-65	Bw	SiL	ss,p	10	2,mk,pf	3,vc,abk	26-65					10YR 5/3	10YR 7/3	10.0
		65-95	Bt	SiCL	s,vp	30	2,mk,pf	3,vc,abk	65-95					10YR 5/3	10YR 7/2.5	10.0
		95-130	Bt2	SiCL	s,p	20	3,mk,pf	3,vc,abk	95-130					10YR 5.5/3	2.5Y 7/3	5.0
OP-9	Exposure	0-22	A	SiL	ss p	10	1,n,pf	1,m,sbk	0-22					10YR 4.5/4	10YR 6.5/4	20.0
		22-74	Bt	SiCL	vs,p	30	4,k,pf	2,m,abk	22-74					7.5YR 4/4	10YR 6.5/6	35.0
		74-100	Bt2	SiCL	vs,p	30	4,k,pf	3,c,abk	74-100					7.5YR 4/4	10YR 6.5/6	35.0
OP-10	Exposure	0-18	A		s,p	20	np	1,c,sbk	0-18	1.09	68.05	30.84	SiCL	10YR 4/5	10YR 6/5	30.0
		18-70	Bt		s,p	20	3,k,pf	3,vc,abk	18-70	0.80	75.35	23.83	SiL	10YR 4/5	10YR 6.5/6	35.0
		70-120	Bt2		s,p	20	3,k,pf	3,vc,abk	70-120	0.61	80.00	19.37	SiL	10YR 4/5	10YR 6.5/6	35.0
		120-145	Bt3		s,vp	30	3,mk,pf	3,c,abk	120-145	0.64	81.86	17.49	SiL	10YR 4/5	10YR 6.5/6	35.0
		145-165	Ab		ss,p	10	1,n,po	1,c,sbk	145-165	3.53	75.48	20.97	SiL	10YR 3.5/4	10YR 6/4	20.0
		165-181	Btb		s,p	20	3,k,pf	3,m,abk	165-181	1.00	66.51	32.48	SiCL	7.5YR 4/6	10YR 6.5/6	45.0
		181-226	Bt2b		s,p	20	3,k,pf	2,vc,abk	181-226	3.69	74.39	21.91	SiL	7.5YR 4/5	10YR 7/5	35.0
		226-333	Bt3b		ss,p	10	3,k,pf	3,vc,abk	226-297	7.53	74.34	18.11	SiL	7.5YR 4/4	10YR 7/4	25.0
		333-367	2Btb		s,vp	30	4,k,pf	3,c,abk	297-333	20.49	62.53	16.97	SiL	7.5YR 4/5	10YR 6.5/4	30.0
		367-417	2Bt2b		s,vp	30	4,k,pf	2-3,c,abk	333-367	39.59	46.74	13.66	L	7 5YR 4/5	10YR 6.5/4	30.0
		417-485	3Coxb		so,po	-20	3,mk,po	2,c,abk	367-417	54.49	32.11	13.39	SL	7.5YR 4/5	10YR 6.5/4	30.0
		485-497	3Cox2b		ss,ps	0	3,mk,po	2,c,abk	417-485	87.24	5.18	7.61	LS	7.5YR 4/5	7.5YR 6/6	45.0
		497-520	4Btb2		s,vp	30	4,mk,pf	3,c,abk	485-497	72.30	18.71	8.98	SL	7.5YR 5/6	7.5YR 7/5	45.0
		520-563	4Bt2b2		s,vp	30	4,k,pf	3,vc,abk	497-520	53.87	20.43	25.70	SCL	2.5YR 4/6	5YR 5.5/8	55.0
		418-445	4Bwb2		ss,ps	0	4,mk,br	3,vc,abk	520-563	40.26	16.81	43.34	C	2.5YR 4/6	5YR 5/8	55.0
		445-480	4Bw2b2		so,po	-10	4,mk,br	3,vc,abk	418-445	78.17	1.31	21.13	SCL	2.5YR 4/6	2.5YR 4.5/8	60.0
									445-480	84.39	1.18	14.71	SL	2.5YR 4/6	5YR 6/6	45.0
OP-11	Core	0-22		SiL	ss,p	10	np		10.0					10YR 5/3	10YR 7/3	10.0
		22-38		SiL	s,p	20	1,n,po		30.0					10YR 3.5/3	10YR 7/3	10.0
		38-112		SiCL	s,p	20	1,n,po		75.0					10YR 5.5/3	10YR 7.5/3	10.0
		112-135		SiCL	s,p	20	1,n,po		120.0					10YR 6/3	10YR 7.5/3	10.0
		135-151		SiL	ss,p	10	1,n,po		170.0					10YR 5.5/2	10YR 7/2.5	10.0
		151-190		SiCL	s,p	20	np		210.0					2.5Y 5.5/2	2.5Y 7/3	0.0
		190-232		SiCL	s,p	20	np		265.0					2.5Y 5.5/2	2.5Y 7/3	0.0
		232-303		SiCL	s,p	20	np		325.0					2.5Y 5/3	2.5Y 7/5	0.0
		303-355		SiL	ss,p	10	np		360.0					2.5 Y 6/3	2.5Y 7.5/3	0.0
		355-367		SiL	s,p	20	np		385.0					2.5Y 5/3	2.5Y 7/4	5.0
		367-406		SiL	ss,p	10	np		400.0					2.5Y 5/2	2.5Y 7/3	0.0
		406-413		SiL	so,p	10	np		425.0					2.5Y 5/2	2.5Y 7.5/3	0.0
		413-437		SiL	ss,p	10	np							10YR 5/4	2.5Y 7/4	15.0

Table 3—Continued.

Site No. (pl. 1)	Core or exposure	Depth interval (cm)	Horizon[1]	Texture[1]	Moist consistence[1]	Moist consistence points [2]	Clay films[1]	Structure[1]	Depth of sample for laboratory analyses (cm)	Sand (%)[4]	Silt (%)[4]	Clay (%)[4]	Texture[5]	Color moist [3,6]	Color dry [3,6]	Rubification points [7]
OP-12	Core	0-35		SiL	ss,p	10	np		20.0					10YR 5/3.5	2.5Y 7/4	12.5
		35-62		SiL	ss,vp	20	vl,n,po		50.0					10YR 5.5/3	2.5Y 7.5/2	5.0
		62-150		SiCL	s,p	20	1,n,pf		100.0					10YR 5/2.5	10YR 7/2.5	10.0
		150-175		SiCL	s,p	20	3,mk,pf		160.0					10YR 5/2.5	10YR 7/2.5	10.0
		175-240		SiCL	s,p	20	3,mk,pf		200.0					2.5Y 5/4	2.5Y 7/5	15.0
		240-272		SiCL	s,p	20	2,mk,pf		255.0					2.5Y 5/4	2.5Y 7/5	15.0
		272-310		SiL	ss,p	10	1,n,pf		290.0					2.5Y 5/4	2.5Y 7/5	15.0
		310-342		SiL	ss,p	10	np		325.0					2.5Y 5/4	2.5Y 7/4	10.0
		342-357		L	so,ps	-10	np		350.0					2.5Y 5.5/2	10YR 7.5/2	5.0
		357-380		L	so,ps	-10	np		380.0					10YR 3.5/3	10YR 6.5/3.5	12.5
		380-385		L	so,ps	-10	np							10YR 4.5/6	10YR 7/5	35.0
OP-13	Core	0-18		SiL	ss,p	10	np		10.0					10YR 4.5/6	10YR 7/5	35.0
		18-55		SiCL	s,p	20	2,n,pf		30.0					10YR 5/5	10YR 7/5	30.0
		55-105		SiCL	s,p	20	2,n,pf		85.0					10YR 4.5/5	10YR 6.5/5	30.0
		105-175		SiCL	s,p	20	3,n,pf		140.0					10YR 4/5	10YR 6.5/5	30.0
		175-205		SiCL	vs,vp	40	1,n,pf		205.0					7.5YR 4/4	10YR 6.5/5	30.0
		205-250		SiCL	s,p	20	1,n,pf		225.0					7.5YR 4/4	10YR 7/5	30.0
		250-277		SiCL	s,p	20	1,n,pf		260.0					7.5YR 4/4	10YR 6.5/5	30.0
		277-320		SiCL	s,vp	30	2,n,pf		300.0					7.5YR 4.5/4	7.5YR 6.5/6	40.0
		320-350		SiCL	s,vp	30	1,n,pf		330.0					5YR 4/5	7.5YR 6/6	50.0
		350-395		SiCL	s,vp	30	2,mk,pf		370.0					5YR 4/5	7.5YR 6/6	50.0
		395-408		SiCL	vs,vp	40	2,mk,pf		400.0					5YR 4/6	7.5YR 6/7	60.0
		408-444		SiCL	vs,vp	40	3,mk,pf		430.0					5YR 4/6	7.5YR 6.5/6	55.0
		444-480		SiC	vs,p	30	4,k,pf		460.0					5YR 4/6	7.5YR 6.5/7	60.0
		480-510		CL	vs,vp	40	4,k,pf		495.0					5YR 4/6	7.5YR 6.5/7	60.0
		510-550		CL	ss,p	10	3,mk,pf		530.0					5YR 4/6	5YR 5.5/7	65.0
		550-580		CL	ss,p	10	3,mk,pf		565.0					5YR 4/7	5YR 5/8	75.0
		580-588		SL	ss,ps	0	2,mk,pf		585.0					5YR 4/6	7.5YR 5/7	60.0
		588-615		SL	ss,ps	0	np		608.0					10YR 4/3	10YR 7/3	10.0
		615-700		S	so,po	-20	np		675.0					10YR 5/3	10YR 7/3	10.0
OP-15	Core	0-17		SiL	ss,p	10	np		25.0					10YR 5/3	10YR 7.5/3	10.0
		17-32		SiCL	s,vp	30	np		50.0					10YR 5/3	10YR 7/3	10.0
		32-68		SiL	s,vp	30	np		85.0					10YR 5/3.5	2.5Y 7/4	12.5
		68-100		SiL	s,vp	30	1,n,po		115.0					2.5Y 5/3	2.5Y 7/3	0.0
		100-130		SiCL	s,vp	30	np		150.0					2.5Y 5/4	2.5Y 7/5	15.0
		130-185		SiCL	s,p	20	np		200.0					10YR 5/4	2.5Y 7/5	20.0
		185-240		SiCL	vs,vp	40	np		260.0					10YR 5/4	10YR 7/5	25.0
		240-305		SiL	ss,p	10	np		290.0					10YR 5/4	10YR 7/4	20.0
		305-382		SiL?	ss,p?	10	np		320.0					2.5Y 5/4	2.5Y 7/4	10.0
		382-410		SiL	s,p	20	np		360.0					10YR 5/4	10YR 7/4	20.0
		410-448		SiL	s,p	20	np		395.0					10YR 5/4	10YR 7/4	20.0
		448-495		SiL	s,vp	30	np		430.0					2.5Y 5.5/4	2.5Y 7/5	15.0
		495-515		SiL	ss,p	10	np		470.0					2.5Y 5.5/4	2.5Y 7/5	15.0
		515-530		L	ss,p	10	np		505.0					2.5Y 5.5/4	2.5Y 7/5	15.0
		530-560		L	ss,p	10	np		522.0					10YR 4.5/5	10YR 6.5/5	30.0
									545.0					10YR 5/5	10YR 7/4	25.0
OP-16	Core	0-13			ss,p	10	np		35.0	1.22	71.32	27.44	SiCL	10YR 4.5/6	10YR 6.5/5	35.0
		13-55			s,p	20	2,n,pf		100.0	2.51	71.32	26.16	SiCL	7.5YR 4/4	10YR 7/5	30.0
		55-148			s,p	20	np		160.0	0.96	81.07	17.95	SiL	7.5YR 4/4	10YR 6.5/5	30.0
		148-185			s,p	20	2,n,pf		200.0	0.72	86.09	13.17	SiL	7.5YR 4/4	10YR 6.5/5	30.0
		185-210			s,p	20	1,n,pf		255.0	1.00	86.54	12.44	SiL	7.5YR 4/4	10YR 6.5/5	30.0
		210-295			ss,p	10	np		315.0	3.43	79.40	17.15	SiL	10YR 4.5/5	10YR 6.5/5	30.0
		295-330			s,vp	30	1,n,pf		360.0	5.39	75.70	18.89	SiL	10YR 5/6	10YR 7/6	40.0
		330-380			s,p	20	np		400.0	29.88	54.03	16.08	SiL	10YR 5/7	10YR 7/7	50.0
		380-419			s,vp	30	np		440.0	39.00	35.67	25.31	L	10YR 5/7	10YR 7/7	50.0
		419-470			s,p	20	2,mk,pf		500.0	47.01	27.61	25.37	SCL	7.5YR 5/8	7.5YR 6.5/6	60.0
		470-525			s,p	20	2,n,pf		535.0	42.68	34.08	23.24	L	7.5YR 5.5/4	7.5YR 7/5	35.0
		525-550			s,vp	30	1,n,po		575.0	31.94	36.38	31.67	CL	10YR 3.5/2	10YR 6.5/2	10.0
		550-600			s,p	20	np		625.0					10YR 5/3	2.5Y 7/4	10.0
		600-660			s,p	20								2.5Y 5/3	2.5Y 7/3	0.0
		660-760			s,p	20								2.5Y 5/3	2.5Y 7/3	0.0
OP-17	Core	0-22			ss,p	10	np		10.0	2.99	84.52	12.50	SiL	2.5Y 5/3	2.5Y 7/3	0.0
		22-70			s,vp	30	2,n,pf		50.0	3.63	70.31	26.06	SiL	2.5Y 5/3	2.5Y 7/3	0.0
		70-105			vs, vp	40	2,n,pf		85.0	2.71	73.92	23.37	SiL	2.5Y 5.5/5	2.5Y 7/5	20.0
		105-127			s,p	20	2,n,pf		115.0	2.93	75.91	21.16	SiL	2.5Y 5/4	2.5Y 7/4	10.0
		127-170			s,p	20	1,n,po		150.0	2.75	79.20	18.05	SiL	2.5Y 6/3	2.5Y 8/2	0.0
		170-240			s,p	20	1,n,pf		205.0	2.22	79.07	18.70	SiL	10YR 5/4	2.5Y 7/4	15.0
		240-308			s,p	20	np		275.0	1.457	86.70	11.85	Si	10YR 5/5	2.5Y 7/5	25.0
		308-357			s,p	20	np		330.0	2.727	83.94	13.33	SiL	10YR 5/5	2.5Y 7/5	25.0
		357-375			s,p	20	np		395.0	5.77	75.50	18.73	SiL	10YR 5/4	2.5Y 7/4	15.0
		375-418			s,p	20	np							2.5Y 5/3	2.5Y 7/4	5.0
OP-18	Exposure	0-40	Ap	SiL	ss,p	10	1,n,po	1,m,abk	0-40					10YR 4/3	2.5Y 6.5/4	10.0
		40-62	Bt	SiCL	s,p	20	2,n,pf	2,c,abk	40-62					10YR 4/3	10YR 7/3.5	12.5
		62-78	Bt2	SiCL	s,p	20	2,n,pf	2,c,abk	62-78					10YR 5/4	2.5Y 7/5	20.0
		78-105	Bt3	SiCL	s,p	20	2,n,pf	3,vc,abk	78-105					10YR 3.5/3	10YR 7/3	10.0
		105-135	2Cox	SiCL	vs,vp	40	2,n,pf	3,vc,abk	105-135					10YR 5/5	2.5Y 7/5	25.0
OP-19	Exposure	0-34	Ap	SiL	ss,p	10	1,n,po	1,m,abk	0-34					10YR 5/3.5	10YR 7.5/3.5	15.0
		34-50	Bt	SiCL	s,p	20	2,n,pf	2,c,abk	34-50					2.5Y 5.5/4	2.5Y 7.5/3	5.0
		50-125	2Cox	SiCL	s,p	20	3,n,pf	2,vc,abk	50-125					2.5Y 5/4	2.5Y 7/4	10.0
OP-21	Core	0-20			ss,p	10	1,n,pf		10.0	10.25	74.19	15.54	SiL	2.5Y 5/4	2.5Y 7/5	15.0
		20-55			s,p	20	2,n,pf		35.0	3.50	74.23	22.25	SiL	2.5Y 5/3	2.5Y 7/3	0.0
		55-106			s,p	20	1,n,pf		80.0	4.00	71.26	24.72	SiCL	2.5Y 5.5/3	2.5Y 7.5/3	0.0
		106-152			vs,vp	40	np		130.0	3.92	76.01	20.05	SiL	2.5Y 5/2	2.5Y 6.5/2	0.0
		152-195			s,p	20	v1,n,pf		180.0	2.07	78.03	19.89	SiL	10YR 4.5/1	10YR 6.5/1	10.0
		195-335			s,p	20	np		240.0	2.02	78.80	19.16	SiL	10YR 4.5/1.5	10YR 6/1.5	10.0
		335-372			s,p	20	np		300.0	2.07	80.07	17.84	SiL	10YR 5/1.5	10YR 7/1.5	10.0
		372-397			vs,p	30	np		355.0	6.64	66.6	26.74	SiCL	10YR 4.5/1.5	10YR 7/1.5	10.0
		397-407			s,p	20	np		385.0	1.69	69.42	28.87	SiCL	10YR 4 5/2	10YR 6.5/2	10.0
		407-440			ss,p	10	np		402.0	13.24	70.29	16.45	SiCL	10YR 4.5/1.5	10YR 6.5/1.5	10.0
		440-495			so,p	0	np		407-440	7.75	76.18	16.05	SiL	10YR 4/4	10YR 6.5/4	20.0
		495-530			so,p	0	np		452.5	2.08	59.13	38.78	SiC	10YR 5/4	10YR 7/3.5	17.5
									480.0	9.68	72.57	17.73	SiCL	10YR 5/3	10YR 7.5/3	10.0
									500.0	1.55	60.48	37.96	SiCL	2.5Y 6/3	2.5Y 7.5/3	0.0

Table 3—Continued.

Site No. (pl. 1)	Core or exposure	Depth interval (cm)	Horizon[1]	Texture[1]	Moist consistence[1]	Moist consistence points [2]	Clay films[1]	Structure[1]	Depth of sample for laboratory analyses (cm)	Sand (%)[4]	Silt (%)[4]	Clay (%)[4]	Texture[5]	Color moist 3,6	Color dry 3,6	Rubification points [7]
OP-22	Core	0-15		SiCL	s,p	20	np		10.0							
		15-35		SiL	s,p	20	np		25.0							
		35-100		SiL	so,p	0	np		60.0							
		100-180		SiL	ss,p	10	np		150.0							
OP-25	Exposure	0-30	A	SiL	ss,ps	0	np	2,m,gr/sbk	20.0					10YR 4/3	10YR 5.5/4	15.0
		30-77	Bw	SiL	ss,ps	0	np	2,m,abk	40.0					10YR 4/4	2.5Y 6.5/4	15.0
		77-165	Bw$_{2}$	SiL	ss,ps	0	np	2,m,abk	60.0					10YR 5/4	2.5Y 6.5/4	15.0
		165-205	Bw$_{3}$	SiL^{+}	ss,p	10	np	2,m,abk	81.0					10YR 4.5/4	2.5Y 6.5/4	15.0
		205-230	Bw$_{4}$	SiL^{+}	ss,ps	0	np	2,m,abk	100.0					10YR 4.5/4	2.5Y 6.5/4	15.0
		230-245	Bw$_{5}$	SiL^{+}	ss,ps	0	np	2,m,abk	120.0					10YR 4/4	2.5Y 6.5/4	15.0
		245-282	Bw$_{6}$	SiL	ss,ps	0	np	2,m,abk	140.0					10YR 4.5/4	2.5Y 6.5/4	15.0
		282-310	Cox	SiL	ss,ps	0	np	1,m,abk	160.0					10YR 4.5/4	2.5Y 6.5/4	15.0
		310-400	2Cu	SiL^{-}	ss,ps	0	np	1,m,abk	180.0					10YR 4.5/4	2.5Y 7/4	15.0
		400-442	3Cu	SiL	ss,ps	0	np	1,m,abk	200.0					10YR 5/4	2.5Y 6.5/4	15.0
		442-455	4Cu	SiL	ss,ps	0	np	2,m,abk	220.0					10YR 5/4	2.5Y 6.5/4	15.0
		455-480	Btb	SiL^{+}	ss,ps	0	np	3,c,abk	240.0					10YR 5/4	2.5Y 7/5	20.0
		480-545	Btb	SiL^{+}	ss,ps	0	np	3,c,abk	260.0					10YR 4.5/4	2.5Y 6.5/5	20.0
		545-650	Bt$_{2b}$	SiL^{+}	s,p	20	2,n,po-br	3,c,abk	280.0					10YR 5/4	2.5Y 6.5/5	20.0
		650-755	Bwb	SiL	ss,ps	0	1,n,po-br	3,c,abk	300.0					10YR 5/4	2.5Y 6.5/5	20.0
		755-780	Btb	SiL^{+}	s,ps	10	1,n,po-br	3,c,abk	320.0					2.5Y 5/3	2.5Y 7/3	0.0
		780-845	Bt$_{b2}$	SiCL	s,p	20	3,mk,pf	3,vc,abk	340.0					2.5Y 5/3	2.5Y 7/3	0.0
		845-930	Bt$_{2b2}$	SiCL	s,p	20	2,mk,pf	3,vc,abk	360.0					10YR 5.5/2	2.5Y 7/3	0.0
		930-970	Bt$_{3b2}$	SiCL	s,vp	30	2,n,pf	3,vc,abk	380.0					10YR 5/3	2.5Y 7/3	5.0
		970-1020	Bt$_{4b2}$	SiL	s,vp	30	2,n,pf	3,vc,abk	400.0					10YR 5/3	2.5Y 7/3	5.0
		1020-1084	Bt5$_{b2}$	SiL^{+}	s,vp	30	3,n,po-br	3,vc,abk	417.5					10YR 5/4	2.5Y 7/4	15.0
		1084-1105	Btb3	SiCL^{+}	vs,p	30	4,k,pf	3,vc,abk	437.5					10YR 5/4	2.5Y 7/4	15.0
		1105-1140	Bt2b3	SiCL^{+}	vs,p	30	4,k,pf	3,vc,abk	460.0					10YR 5/4	10YR 7/4	20.0
									480.0					7.5YR 5/3	10YR 6.5/4	20.0
									500.0					7.5YR 4/3	10YR 6.5/4	20.0
									520.0					7.5YR 4.5/4	10YR 6.5/4	25.0
									540.0					10YR 5/5	10YR 6.5/5	30.0
									560.0					10YR 5/5	10YR 7/5	30.0
									580.0					10YR 5/5	10YR 6.5/5	30.0
									600.0					7.5YR 4.5/4	10YR 6.5/4	25.0
									620.0					10YR 5/5	10YR 7/5	30.0
									640.0					7.5YR 4.5/4	10YR 7/5	30.0
									660.0					7.5YR 5/5	7.5 YR 6.5/5	40.0
									680.0					7.5YR 5/5	7.5 YR 6/5	40.0
									700.0					7.5YR 4.5/5	7.5 YR 6.5/5	40.0
									720.0					7.5YR 4.5/5	7.5 YR 6.5/5	40.0
									740.0					7.5YR 4.5/5	10YR 6.5/6	40.0
									760.0					7.5YR 5/5	10YR 6.5/6	40.0
									785.0					7.5YR 5/6	10YR 7/7	50.0
									800.0					5YR 4.5/6	7.5YR 6/7	60.0
									820.0					5YR 5/7	7.5YR 6/8	70.0
									840.0					5YR 5/6	10YR 6.5/8	60.0
									860.0					7.5YR 5/6	10YR 7/8	55.0
									880.0					7.5YR 5.5/6	10YR 7/7	50.0
									900.0					7.5YR 5/7	10YR 7/7	55.0
									920.0					7.5YR 5/6	10YR 7/7	50.0
									940.0					10YR 5/7	10YR 7/6	45.0
									960.0					10YR 5/6	10YR 7/6	40.0
									980.0					10YR 5/6	10YR 7/6	40.0
									1000.0					7.5YR 4.5/6	10YR 7/6	45.0
									1017.5					7.5YR 4.5/6	10YR 7/6	45.0
									1040.0					7.5YR 5/6	10YR 7/6	45.0
									1060.0					7.5YR 5/6	10YR 7/7	50.0
									1080.0					7.5YR 5/7	7.5YR 6.5/7	60.0
									1095.0					7.5YR 4.5/8	7.5YR 6/8	70.0
									1120.0					7.5YR 5/7	7.5YR 6/7	60.0

1 Field description abbreviations and horizon designations follow Soil Survey Staff (1975); horizon designations follow Birkeland (1984); horizons not designated for sediment cores.
2 Based on assumption that parent material was ss,ps; calculation follows Harden (1982) and Harden and Taylor (1983).
3 Munsell color notation.
4 Particle size analysis on less than 2 mm fraction; sand is material between 2 mm and 50 μm, silt is material between 50 μm and 2 μm, and clay is material less than 2 μm.
5 Based on particle size data.
6 Color is for laboratory sample.
7 Average of moist and dry colors based on assumption that parent material was 2.5*Y* 7/3 (dry) and 2.5*Y* 5/3 (moist); calculation follows Harden (1982) and Harden and Taylor (1983).

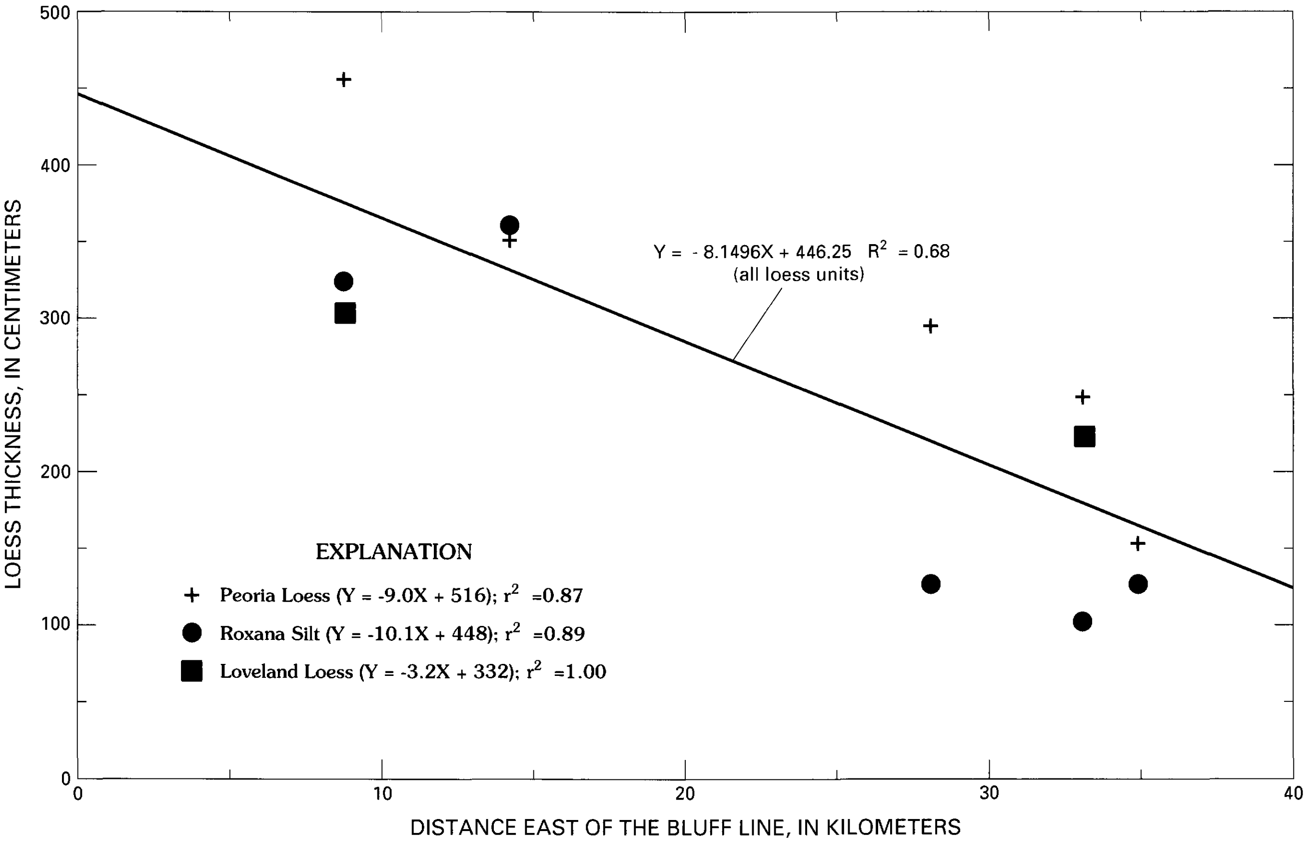


Figure 12. Loess thicknesses at upland sites in the Obion River drainage basin with distance east of bluff line of Mississippi River valley. Only upland sites were used to establish dependence of loess thickness on distance east of bluff line because of difficulty encountered in distinguishing between loess and alluvium in sediment cores from terraces. Pre-Wisconsin terraces near bluff line of Mississippi River valley may be mantled by 15 m of loess or more, and the upvalley gradients of terrace remnants 1, 4, and 5 (fig. 4) probably reflect the presence of eastward-thinning loess deposits.

alluvium in all cores is difficult, because the textures and gross appearance of the two units are similar (compare West and Rutledge, 1987), and delineation of the laminated silty alluvium depends on recognition of the aforementioned subtle grain-size variations. The quartzose sand is very well sorted, subrounded and massive, and likely represents in-channel deposition. A nearby roadcut on terrace remnant 2 approximately 11 km east of the bluff line (site OP–8, pl. 1) exposes 1.25 m of Peoria Loess (fig. 13*B*). This loess has nearly identical rubification and moist consistence values as the loess in core OP–3.

A 5.25-m-long core from a Finley terrace remnant (site OP–21, pl. 1) about 12 km east of the bluff line of the Mississippi River valley contained 3 m of Peoria Loess that overlies 1 m of laminated silty alluvium and 1.25 m of sandy alluvium (fig. 13*C*; Rodbell and Schweig, 1993). The Peoria Loess at this site has rubification and moist consistence values that are similar to those noted at upland site OP–1, approximately 14 km east of the bluff line. However, the thickness of the Peoria Loess at this site is slightly less than anticipated (fig. 12). In addition, grain-size data from this site indicate that the upper part of the Peoria Loess is sandier than the Peoria Loess noted elsewhere (compare figs. 13*C* and 11*B*). This may reflect the presence of seismically induced sandblows at site OP–21 (Rodbell and Bradley, 1993). The underlying laminated silty alluvium is similar to that noted in the OP–3 core, but the sandy alluvium contains more silt and clay (fig. 13*C*). Gastropod shells from the sandy alluvium yielded a radiocarbon age of 21,620±190 yr BP (GX-17029-AMS, Rodbell and Schweig, 1993; table 1). This age and the presence of Peoria Loess overlying the alluvium indicate that the Finley terrace is late Wisconsin rather than early Wisconsin as postulated by Saucier (1987).

A core from a Finley terrace remnant (remnant 48b; site OP–17, pl. 1), 29 km east of the bluff line, exposed 2.5 m of massive silty alluvium overlying about 1.5 m of laminated silty alluvium (fig. 13*D*). Wood fragments from between 2.5 and 3.3 m yielded a radiocarbon age of 249±45 yr BP (GX-17028-AMS; table 1). This age is supported by the lack of a loess mantle at this site; the massive silty alluvium is distinguished from loess by its relatively high sand content (fig. 13*D*). Terrace remnant 48b is only about 1.5 m above the

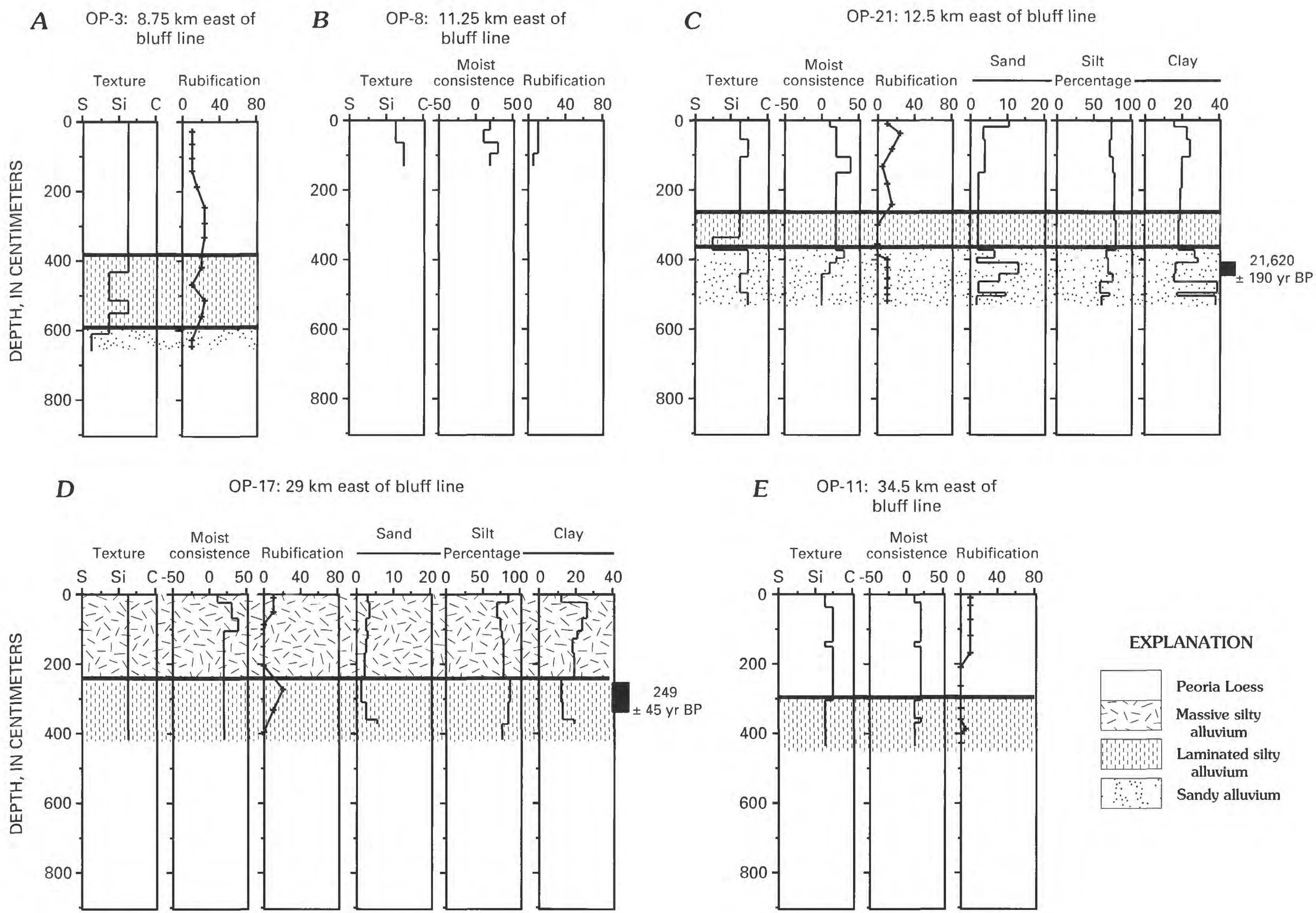


Figure 13. Texture, moist consistence, rubification (Harden, 1982, and Harden and Taylor, 1983), and grain size in cores and in an exposure from Finley terrace deposits (see pl. 1 for locations). *A*, Core OP–3; *B*, Exposure OP–8; *C*, Core OP–21; *D*, Core OP–17; *E*, Core OP–11. Radiocarbon ages are listed in table 1, and radiocarbon sampling intervals are denoted by black boxes in depth scale. S, Si, and C, sand, silt, and clay.

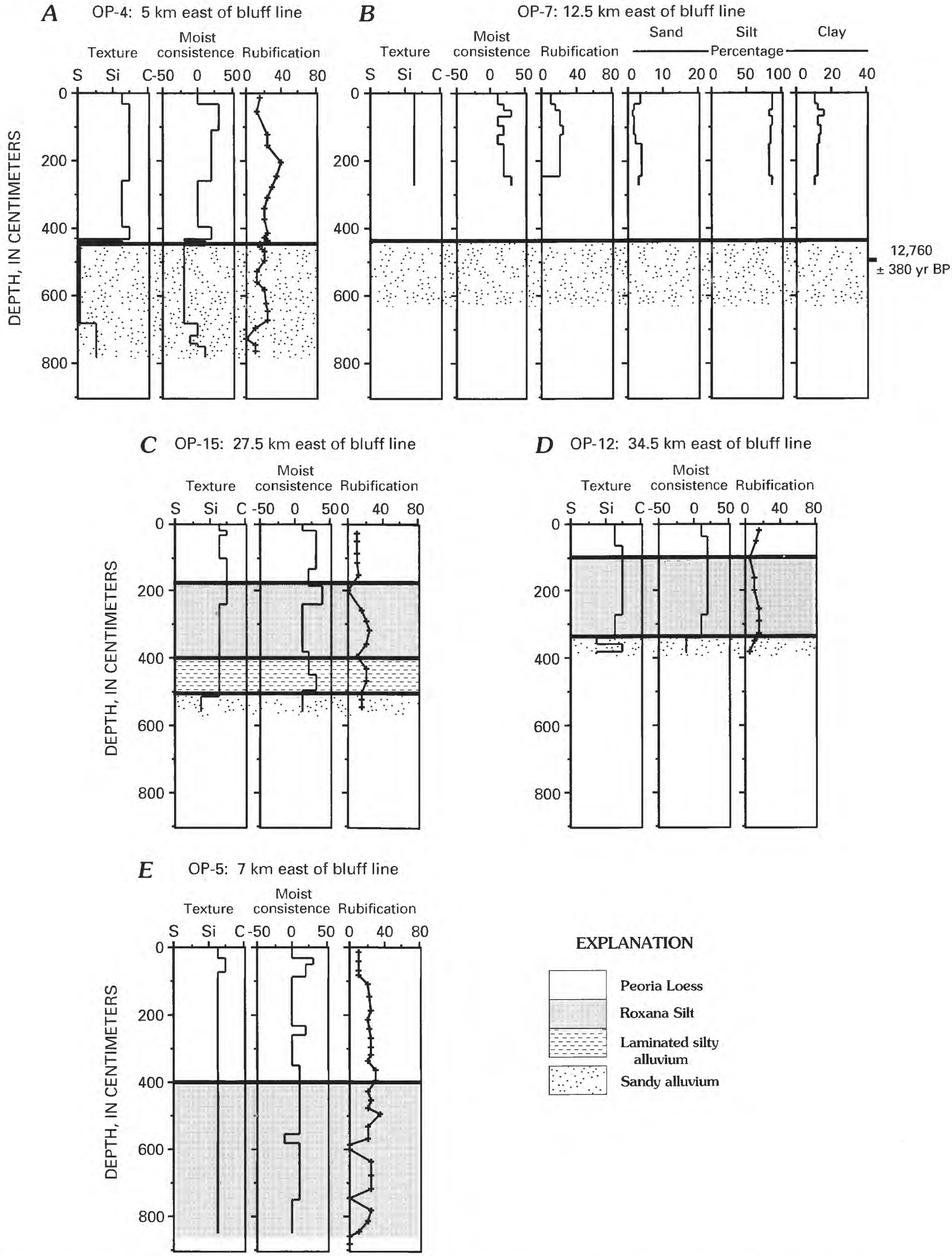


Figure 14. Texture, moist consistence, rubification (Harden, 1982, and Harden and Taylor, 1983), and grain size with depth in cores and in an exposure from Hatchie terrace deposits (*A–D*) and one Humboldt terrace deposit (*E*) (see pl. 1 for locations). *A*, Core OP–4; *B*, Exposure OP–7; *C*, Core OP-15; *D*, Core OP–12; *E*, Core OP–5. Radiocarbon ages are listed in table 1, and radiocarbon sampling intervals are denoted by black boxes in depth scale. S, Si, and C, sand, silt, and clay.

flood plain of both the Obion River and a tributary stream, Hoosier Creek. Thus, this site has been repeatedly inundated by flooding events over the last several hundred years. Finally, a core from terrace remnant 58 (site OP–11, pl. 1), 34.5 km east of the bluff line, revealed approximately 3 m of Peoria Loess overlying laminated silty alluvium (fig. 13*E*).

Three cores and one stream cut from Hatchie terrace remnants expose as much as 4 m of loess overlying laminated silty and sandy alluvium (fig. 14*A–D*). An 8-m-long core (OP–4, fig. 14*A*) from terrace remnant 4, drilled 5 km east of the bluff line of the Mississippi River valley, revealed approximately 4.5 m of Peoria Loess overlying massive, sandy, quartzose alluvium, similar to that noted in the lowermost 0.5 m of the OP–3 core (fig. 13*A*). An exposure in the west bank of Clover Creek on terrace remnant 11 (site OP–7, fig. 14*B*), located 12.5 km east of the bluff line, revealed at least 2.5 m of sandy loess overlying more than 2 m of massive, sandy alluvium. Gastropod shells in the underlying alluvium yielded a radiocarbon age of 12,760±380 yr BP (GX-17026; table 1). This age is problematic because this terrace is higher and therefore older than terrace remnant 1, a Finley terrace radiocarbon dated at about 22 ka (site OP–21, fig. 13*C*). Moreover, it seems unlikely that more than 2.5 m of Peoria Loess was deposited 12 km east of the bluff line after 12.8 ka. Two mutually exclusive explanations seem equally plausible. The first is that the gastropod shells were contaminated by young carbon due to the solution and recrystallization of calcium carbonate. This is a common problem encountered when dating shells and, despite routine leaching pretreatments to remove secondary calcite, many workers consider all radiocarbon ages from shells to be minimum-age estimates (Bradley, 1985). The second explanation for this anomaly is that the radiocarbon age accurately dates the underlying alluvium but that the alluvium was deposited as a cut-and-fill sequence by nearby Clover Creek. Clover Creek may have locally incised through the alluvium of the Obion River and subsequently filled its channel to the level of the surrounding terrace during a late Wisconsin alluvial episode. Such episodes have been recognized in several drainages in northern Mississippi (Grissinger and others, 1982). Thus, the dated alluvium may rest unconformably on alluvium of the Obion River that elsewhere underlies the Hatchie terrace. This implies that the apparent sandy loess that mantles the alluvium at this site is not entirely Peoria Loess but is massive alluvium derived from the loess-mantled uplands that surround the upper reaches of Clover Creek.

A 5.5-m-long core from terrace remnant 48, located 28 km east of the bluff line (site OP–15, pl. 1), recovered 2 m of Peoria Loess, 2 m of Roxana Silt, and 1.5 m of silty and sandy alluvium (fig. 14*C*). Nearby, a 4-m-long core from terrace remnant 57, located 34.5 km east of the bluff line (site OP–12, pl. 1), recovered approximately 1 m of Peoria Loess, 2.5 m of Roxana Silt, and 0.5 m of sandy alluvium (fig. 14*D*). The presence of Roxana Silt on these terrace remnants indicates that they are at least early Wisconsin. The absence of Roxana Silt overlying the alluvium at the OP–4 site (fig. 14*A*) is problematic and suggests either that terrace remnant 4 is considerably younger than terrace remnants 48 and 57, or that the Roxana Silt at site OP–4 was buried by sandy alluvium prior to deposition of the Peoria Loess.

The only stratigraphic data from a Humboldt terrace remnant are from an 8.5-m-long core from terrace remnant 5, drilled 7 km east of the bluff line (site OP–5, pl. 1). This core penetrated about 4 m of Peoria Loess and 4.5 m of Roxana Silt, but no alluvium was encountered (fig. 14*E*). The presence of these two loess units indicates that the Humboldt terrace is at least early Wisconsin.

CONCLUSIONS

The gradients of fluvial terrace remnants of three different ages in the Obion River valley are affected by the presence of eastward-thinning loess deposits that mantle nearly all geomorphic surfaces older than about 10,000 yr. About 15 m of loess may mantle the oldest terraces at the bluff line of the Mississippi River valley, and terrace remnants that reach the bluff line have reverse gradients. These reverse gradients are due to an eastward-thinning loess mantle rather than surface deformation as postulated by Saucier (1987).

Sediment cores and exposures in borrow pits in uplands north and south of the Obion River valley reveal four loess units that are bounded by paleosols. Radiocarbon ages of 19.9 ka, 23.2 ka, and 24.5 ka from the base of the uppermost loess unit indicate that this loess can be correlated with the Peoria Loess. Pedogenic properties of the paleosols that separate the underlying loess units suggest that these loesses are correlative with the Roxana Silt and Loveland Loess. Remnants of a fourth loess may correlate with the fourth loess on Crowleys Ridge in eastern Arkansas.

Quantification of the degree of fluvial incision of terrace remnants by means of the Incision and Area Indices (Colman, 1983) provides a method of correlating disjunct terraces that is independent of elevation. This method readily delineates the Humboldt terraces from the Hatchie and Finley terraces but is not useful in distinguishing the Hatchie terraces from the Finley terraces.

Eight sediment cores and two exposures provided valuable information on the subsurface stratigraphy of selected terraces. Gastropod shells from alluvium about 4 m below the surface of a Finley terrace yielded a radiocarbon age of 21.6 ka. Thus, the Finley terraces are late Wisconsin rather than early Wisconsin as previously postulated. Finley terraces are mantled by the Peoria Loess whereas Hatchie terraces are mantled by the Roxana Silt and Peoria Loess and are, therefore, early Wisconsin. A single core from a Humboldt terrace deposit recovered 8.5 m of Peoria Loess and Roxana Silt but did not reach the underlying alluvium. These terraces are likely pre-Wisconsin based on their height and high degree of fluvial incision.

REFERENCES CITED

Autin, W.J., Burns, S.F., Miller, B.J.. Saucier, R.T., and Snead, J.I., 1991, Quaternary geology of the lower Mississippi Valley, *in* Morrison, R.B., ed., Quaternary nonglacial geology; Conterminous U.S.: Boulder, Colo., Geological Society of America, The Geology of North America, v. K–2, p. 547–582.

Birkeland, P.W., 1984, Soils and geomorphology: New York, Oxford University Press, 372 p.

Bradley, R.S., 1985, Quaternary paleoclimatology: Winchester, Mass., Allen and Unwin, 472 p.

Buntley, G.J., Daniels, R.B., Gamble, E.E., and Brown, W.T., 1977, Fragipan horizons in soils of the Memphis-Loring-Grenada sequence in west Tennessee: Soil Science Society of America Journal, v. 41, p. 400–407.

Colman, S.M., 1983, Progressive changes in the morphology of fluvial terraces and scarps along the Rappahannock River, Virginia: Earth Surface Processes and Landforms, v. 8, p. 201–212.

Follmer, L.R., 1983, Sangamon and Wisconsinan pedogenesis in the midwestern United States, *in* Porter, S.C., ed., Late-Quaternary environments of the United States, Volume 1, The late Pleistocene: Minneapolis, Minn., University of Minnesota Press, p. 138–144.

Forman, S.L., Bettis, E.A. III, Kemmis, T.J., and Miller, B.B., 1992, Chronologic evidence for multiple periods of loess deposition during the late Pleistocene in the Missouri and Mississippi River Valley, United States—Implications for the activity of the Laurentide ice sheet: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 93, p. 71–83.

Fuller, M.L., 1912, The New Madrid earthquake: U.S. Geological Survey Bulletin 494, 118 p.

Goddard, E.N., chairman, 1975, Rock color chart: Distributed by Geological Society of America, Boulder, Colo.

Grissinger, E.H., Murphey, J.B., and Little, W.C., 1982, Late-Quaternary valley-fill deposits in north-central Mississippi: Southeastern Geology, v. 23, p. 147–162.

Harden, J.W., 1982, A quantitative index of soil development from field descriptions—Examples from a chronosequence in central California: Geoderma, v. 28, p. 1–28.

Harden, J.W., and Taylor, E.M., 1983, A quantitative comparison of soil development in four climatic regions: Quaternary Research, v. 20, p. 342–359.

Olive, W.W., 1980, Geologic maps of the Jackson Purchase region, Kentucky: U.S. Geological Survey Miscellaneous Investigation Series Map I–1217, scale 1:250,000.

Potter, P.E., 1955, The petrology and origin of the Lafayette gravel, Part 2—Geomorphic history: Journal of Geology, v. 63, p. 115–132.

Pye, K., and Johnson, R., 1988, Stratigraphy, geochemistry and thermoluminescence ages of lower Mississippi Valley loess: Earth Surface Processes and Landforms, v. 13, p. 103–124.

Rodbell, D.T., and Bradley, L.A., 1993, Logs of exploratory trenches through liquefaction features on late Quaternary terraces in the Obion River Valley, northwestern Tennessee: U.S. Geological Survey Miscellaneous Field Studies Map MF–2218, 2 sheets.

Rodbell, D.T., and Schweig, E.S., III, 1993, The record of seismically-induced liquefaction on late Quaternary terraces in northwestern Tennessee: Bulletin of the Seismological Society of America, v. 83, p. 269–278.

Ruhe, R.V., 1983, Depositional environment of late Wisconsin loess in the midcontinental United States, *in* Porter, S.C., ed., Late-Quaternary environments of the United States, Volume 1, The late Pleistocene: Minneapolis, Minn., University of Minnesota Press, p. 130–137.

———1984, Loess-derived soils, Mississippi Valley region, I—Soil-sedimentation system: Soil Science Society of America Journal, v. 48, p. 859–863.

Russ, D.P., 1982, Style and significance of surface deformation in the vicinity of New Madrid, Missouri: U.S. Geological Survey Professional Paper 1236–H, p. 95–114.

Rutledge, E.M., West, L.T., and Omakupt, M., 1985, Loess deposits on Pleistocene age terraces in eastern Arkansas: Soil Science Society of America Journal, v. 49, p. 1231–1238.

Saucier, R.T., 1987, Geomorphological interpretations of late Quaternary terraces in western Tennessee and their regional tectonic implications: U.S. Geological Survey Professional Paper 1336–A, 19 p.

Singer, M.J., and Janitsky, Peter, eds., 1986, Field and laboratory procedures used in a soil chronosequence study: U.S. Geological Survey Bulletin 1648, 49 p.

Soil Survey Staff, 1975, Soil taxonomy—A basic system of soil classification for making and interpreting soil surveys: Washington, D.C., U.S. Department of Agriculture Soil Conservation Service Agricultural Handbook 436, 754 p.

Usher, F.C., 1837, On the elevation of the banks of the Mississippi in 1811: Silliman's Journal (American Journal of Science, First Series), v. 31, p. 291–294.

West, L.T., and Rutledge, E.M., 1987, Silty deposits of a low, Pleistocene-age terrace in eastern Arkansas: Soil Science Society of America Journal, v. 51, p. 709–715.

West, L.T., Rutledge, E.M., and Barber, D.M., 1980, Source and properties of loess deposits on Crowleys Ridge in Arkansas: Soil Science Society of America Journal, v. 44, p. 353–358.

Willman, H.B., and Frye, J.C., 1970, Pleistocene stratigraphy of Illinois: Illinois State Geological Survey Bulletin 94, 204 p.

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