ALLUVIATION OF THE OHIO RIVER VALLEY NEAR EVANSVILLE, INDIANA, AND ITS EFFECT ON THE DISTRIBUTION OF SAND AND GRAVEL IN THE AREA

Special Report 36

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Alluviation of the Ohio River Valley near Evansville, Indiana, and Its Effect on the Distribution of Sand and Gravel in the Area

By GORDON S. FRASER *and* DAVID A. FISHBAUGH

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Abstract

Alluvium in the Ohio River valley near Evansville was deposited in four distinct episodes. The deposits of each episode can be distinguished by grain size and stratigraphic position and also by relict geomorphic features for some deposits.

The bedrock valley, developed during late Tertiary or early Quaternary time, consists of steep valley walls, two unpaired terrace levels, and a narrow, deep trough. These features were formed during stepwise erosion of the Lexington Plain (Highland Rim Plain).

Four depositional units can be recognized in the valley fill. The basal alluvium consists of consolidated gravel, sand, and mud deposited during a pre-Wisconsinan, possibly Illinoian, ice advance and later retreat. These deposits were eroded before Woodfordian ice advanced and a nearly level valley floor was formed. During the Woodfordian Subage of Frye and Willman (1960), two ice advances into the Miami-Whitewater basin supplied sediment to the Ohio River. Braided streams deposited relatively coarse sediment during each of the two ice advances, but the streams differed in caliber of load and style of deposition. Braided-stream deposits of the two depositional episodes in the Evansville area are separated by an erosion surface formed during temporary retreat of the ice from the basin. After final retreat of the ice another period of erosion produced a locally scoured surface on which sediments of Holocene age were deposited. These are markedly finer grained than the underlying Pleistocene braided-stream deposits, and they accumulated in a meandering stream.

The only potential sand and gravel deposits in the area are those found in the valley-train sediments of Wisconsinan age. Pre-Wisconsinan gravels are well graded but are too deeply buried to have economic potential. Holocene channel sediments are near the surface but are too fine grained to supply coarse grades of aggregate. Valley-train sediments under the upper and lower terraces are relatively coarse grained and are buried by only moderate amounts of overburden; valley-train deposits under the modern flood plain are coarser grained but deeply buried.

Introduction

PREVIOUS STUDIES

Most of the earlier studies of the Ohio River in Indiana were regional reconnaissance studies that stressed the geomorphology and geomorphic evolution of the valley (Veatch, 1898; Leverett, 1902, 1929; Fowke, 1925, 1933). Later investigations, however, studied selected reaches or specific aspects of the river (Theiss, 1922; Patton, 1953; Harvey, 1956; Ray, 1957, 1965, 1966; Walker, 1956; Price, 1964; Gallaher and Price, 1966; Straw, 1968a, 1968b; Webb, 1970; Powell, 1970; Zehner, 1973; Gray, 1979; Gray and others, 1983). Some attempts have been made to synthesize these studies into a regional framework interpreting the geomorphic and sedimentologic history of the valley (Wayne, 1952; Walker, 1957).

Several studies have been made of the Ohio River near Evansville. Theiss (1922) mapped the geology of Henderson County across the river in Kentucky, and Ray (1966) made a detailed analysis of the alluvial history of the

Figure 1. Map of Vanderburgh County, Ind., showing the location of the study area.

valley in the Owensboro area upstream from Evansville. Both workers, however, were hampered by little deep-subsurface information about the nature of the alluvial fill. Straw and others (1977) mapped the surficial geology in the Evansville area and produced an isopachous map of the alluvium and related sediments.

PURPOSE

Despite the large body of literature concerning the Ohio River, only a general knowledge of the internal structure of the alluvium exists. Even in the Vanderburgh County area, for which several studies of the valley-fill sediments have been published, the lack of subsurface samples of the sediments filling the valley has precluded a detailed understanding of the internal structure of the alluvial fill.

This project was intended (1) to provide detailed information about the composition and internal structure of the sediments filling the bedrock valley of the Ohio River near Evansville, (2) to interpret from this information the history of the alluviation of the valley, (3) to establish the quality and distribution of those sediments with economic potential, and (4) to design an exploration model for aiding their exploitation.

The subject of this investigation is a large meander loop downstream from Evansville (fig. 1). This area was chosen for study for four reasons. First, although the river meanders freely over a broad flood plain, it has been confined within the limits of the bedrock valley, and there were no major shifts in the channel at least through the Pleistocene Epoch. The history of alluviation in this area, therefore, is not complicated by course changes or significant changes in the shape and the extent of the drainage basin. Second, the area appears to be typical of those reaches where the river migrates freely, and principles derived here can also be applied to other meandering reaches. Third, an excellent road grid provided access to most parts of the alluvial plain for the drill truck that was the main tool used in field investigations. Fourth, the Evansville area is a rapidly expanding urban complex with no indigenous sources of aggregate for its construction industry. Therefore, a study of the texture and the composition of the valley-fill sediments in the area might provide information helpful in searching for an adequate source of aggregate.

METHODS OF INVESTIGATION

Drilling records for water and oil wells and data from seismic surveys were used to determine the gross stratigraphy of the alluvial deposits and to construct a bedrock-topography map and an isopachous map of the alluvium and related sediments.

Deep auger holes were drilled along a radial line extending down the middle of the meander loop. The holes were spaced about half a mile apart, and seven of the 15 holes penetrated to bedrock. Care was taken to drill on each major physiographic feature in the area. In all, nearly 400 samples were taken from 4-inch solid-stem augers during the drilling operations.

Samples containing appreciable amounts of mud were wet sieved on a 230-mesh screen. The +230-mesh fraction was dried and sieved at a 0.5 ϕ sieve interval to determine the size distribution of the sand and gravel, and the silt to clay ratio was determined by pipette analysis of the -230-mesh fraction. Samples composed primarily of sand and gravel were dry sieved at a 0.5 ϕ interval. Grain-size data were plotted on log-probability graphs, and mean and standard deviations (sorting) were calculated from these graphs by using the Graphic Inclusive measures of Folk and Ward (1957). Clast composition was determined for samples from one auger hole by making pebble counts of the material coarser than -3.0 ϕ (0.375 inch).

Changes in channel morphology were determined by comparing the two sets of area maps made by the U.S. Army Corps of Engineers. Both sets of maps were drawn at a scale of 1:2,400 and a contour interval of 2.5 feet. One set was made during 1911-14, and the other was made in 1966. Depth soundings, taken along traverses of the river spaced at 1-mile intervals, are shown on both sets of maps, and the bathymetry of the channel bottom was contoured from this information.

Surficial Geology

PHYSIOGRAPHIC SETTING

In the reach between Louisville and Rockport the Ohio River crosses a terrain underlain by relatively resistant rocks through which it has cut a narrow valley bordered by steep valley walls. Downstream from Rockport the river flows across weaker Pennsylvanian rocks. There it has cut a wide valley in which it meanders freely across a broad alluvial plain and only in a few places impinges on the low bedrock hills that form the margins of the valley.

The largest meander is just downstream from Evansville (fig. 1). It is 3 miles (5 km) wide at its widest point and narrows to 1.2 miles (2 km) at its neck. The channel has migrated southward 3.5 miles (6 km) from the valley wall to its present position. The river is from 0.3 mile (0.5 km) to 0.7 mile (1.2 km) wide as it flows around the bend. At irregular intervals along this reach, flow is broken by midchannel islands composed of sand and gravel.

Normal pool elevation at Evansville is 342 feet (104 m) MSL and is controlled by Uniontown dam. Before 1975, when that dam was completed, the normal pool elevation was 338 feet (103 m) MSL and was controlled by a dam at Henderson, Ky., which has since been removed. The lowest recorded water level stood at 330.1 feet when much of the river bottom was exposed, and the highest measured flood crested at 382.4 feet (116.6 m) in January 1937.

GEOMORPHOLOGY

Six geomorphic terrains can be defined in the Evansville area by elevation, surface morphology, and position relative to the river (fig. 2). Farthest from the river and at the highest elevation are the deeply dissected, loess-covered bedrock hills that form the uplands adjacent to the river valley. The crests of the hills form a concordant surface at an elevation of about 470 feet (143 m) MSL, although some hills exceed an elevation of 500 feet (152 m).

There is a high terrace at an elevation of about 380 feet (116 m) at the foot of the valley walls (fig. 2). The surface of this terrace is marked by a ridge and swale system consisting of diamond-shaped ridges separated by long, narrow troughs trending subparallel to the trend of the valley (fig. 3). Coincident in elevation with the high-terrace surface are broad plains with low relief that extend up tributary valleys of the Ohio River. The plains are underlain by lacustrine muds (fig. 2) and are crossed by small sluggish streams.

A low terrace at an elevation of about 370 feet (113 m) occupies the neck of the meander loop (fig. 2). This low terrace is not found elsewhere on the Indiana side of the river in the Evansville area, but it is present in Henderson County (Theiss, 1922), and it has been noted upstream at Owensboro (Ray, 1966). The surface of the low terrace, like that of the high terrace, consists of a ridge and swale system. In contrast to the ridge of the high terrace, however, the ridges of the low terrace are narrower but more continuous and are broadly curving features separated by narrow troughs (fig. 3).

The largest area of the meander loop is occupied by the flood plain, which has a surface elevation of about 360 feet (110 m) (fig. 2). The flood plain is marked by a conspicuous pattern of ridges and swales with a local relief of as much as 15 feet (4.5 m) (fig. 4). The ridges and swales curve around

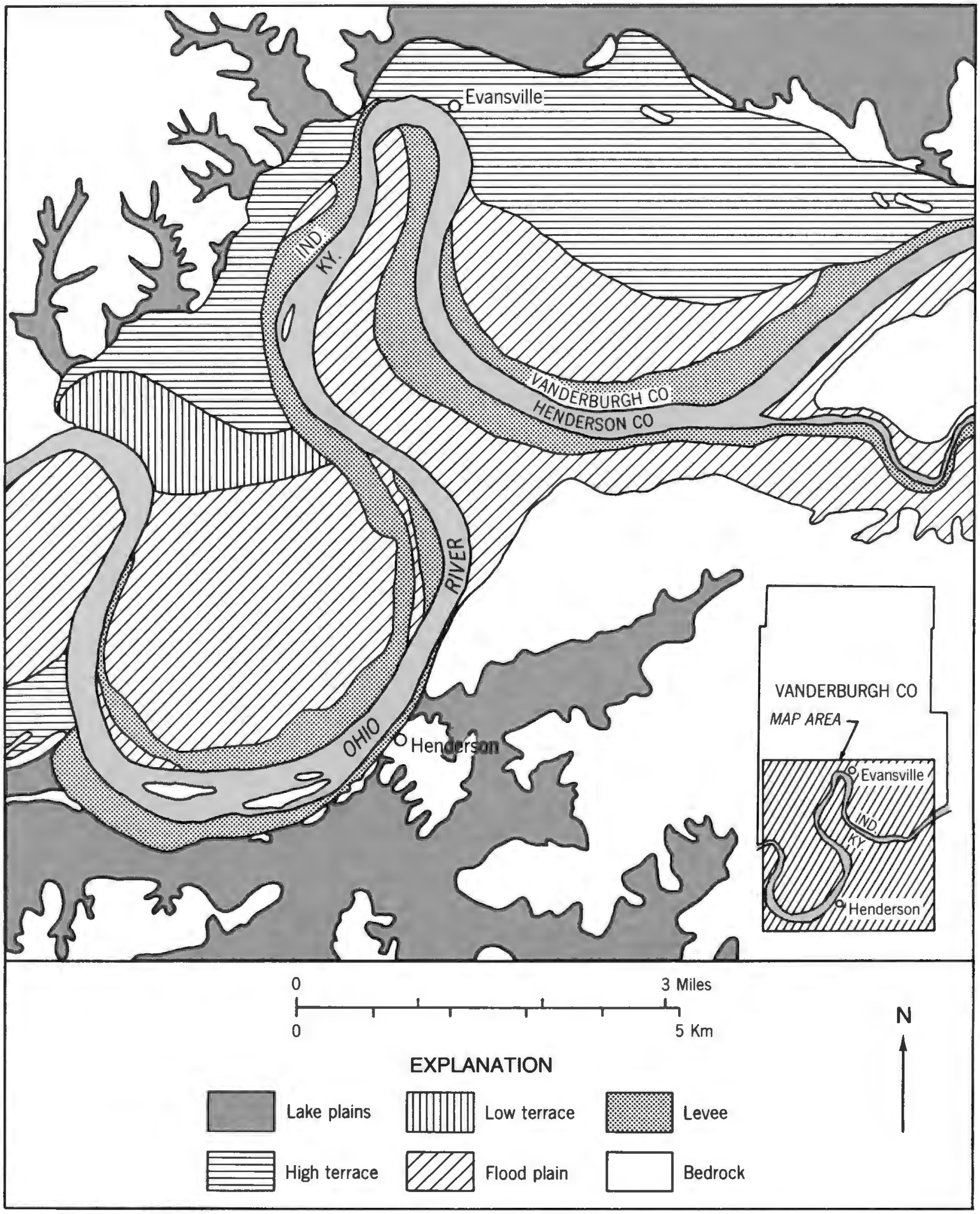


Figure 2. Map showing the geomorphology of the Ohio River valley near Evansville.

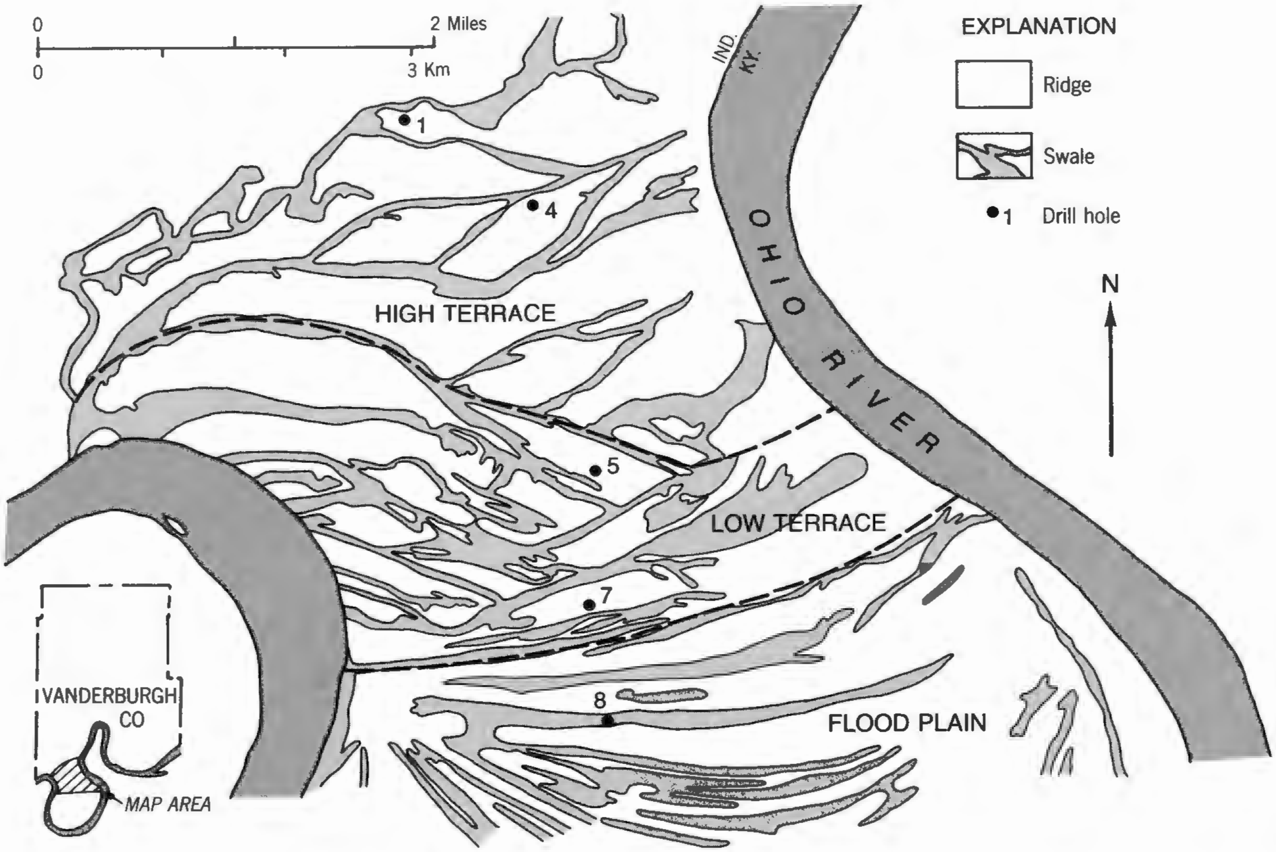


Figure 3. Map showing the relict bar forms (ridges) on the upper and lower terraces.

the meander, and at first glance they appear to be continuous around the bend. Careful tracing of individual sets, however, shows that the ridges and swales join and bifurcate in a complex pattern (fig. 4).

In places the river is flanked by a broad natural levee (fig. 2). The levee is slightly higher than the adjacent ridges and swales, and where it cuts across their trend the levee has obscured the pattern of the ridges and swales by depositional smoothing of the topography.

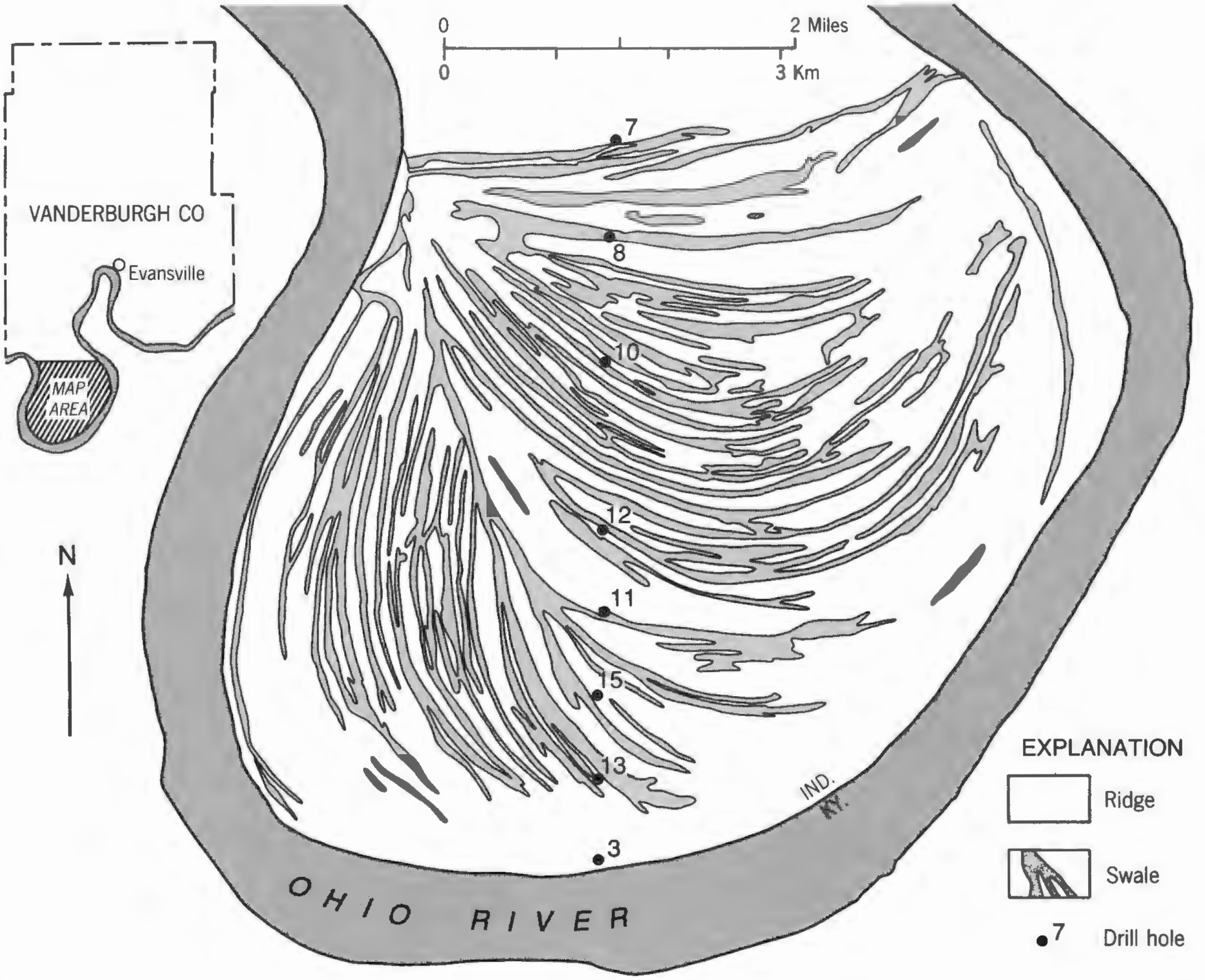
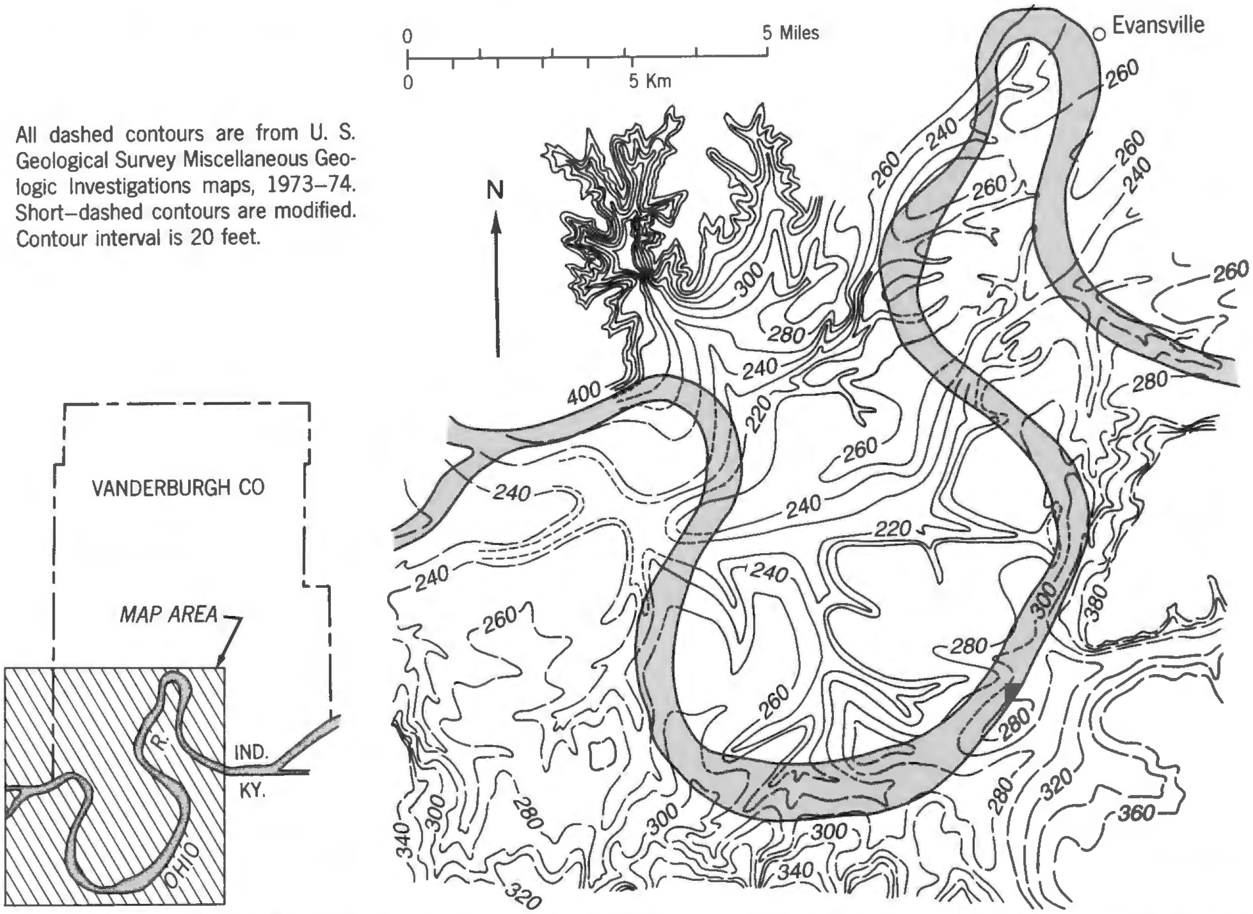


Figure 4. Map showing the ridge and swale topography on the flood-plain surface of the meander loop just downstream from Evansville.



All dashed contours are from U. S. Geological Survey Miscellaneous Geologic Investigations maps, 1973–74. Short–dashed contours are modified. Contour interval is 20 feet.

Figure 5. Map showing the bedrock topography of the Ohio River valley near Evansville. Long dashed lines are from the U.S. Geological Survey. Short dashed lines show the modifications that reflect new data.

Bedrock Topography

The alluvial and lacustrine sediments associated with the Ohio River in the Evansville area have an average thickness of about 100 feet (30 m). They fill a valley cut in shale and sandstone of Pennsylvanian age in which three morphologic elements can be recognized, the valley walls, the valley floor, and the deep trench (fig. 5). The valley walls descend from present uplands at an elevation of about 470 feet (143 m) to the slope break with the valley floor at 280 feet (85 m). The valley floor appears to consist of two unpaired terraces: one at 260 feet (79 m) lying mainly on the south side of the channel axis, and the other at 240 feet (73 m) lying mainly on the north side. At 240 feet (73 m) a slope break occurs where the bedrock surface descends rapidly to a narrow trench floor at an elevation of about 200 feet (61 m). The trench is joined along its length by a well-developed set of tributaries with secondary and tertiary stream channels that cut into the terraces. Not all of the tributaries can be joined to valleys in the present uplands.

Internal Structure of the Valley Fill

COMPOSITION OF THE SEDIMENTS

The gross stratigraphy of the sediments in the valley has long been known to consist of an upper mud unit, a middle sand unit, and a lower sand and gravel unit. This three-part stratigraphy is common to the valley-fill sediments up and down the Ohio River, but even a cursory examination of samples in the field reveals marked variations in texture

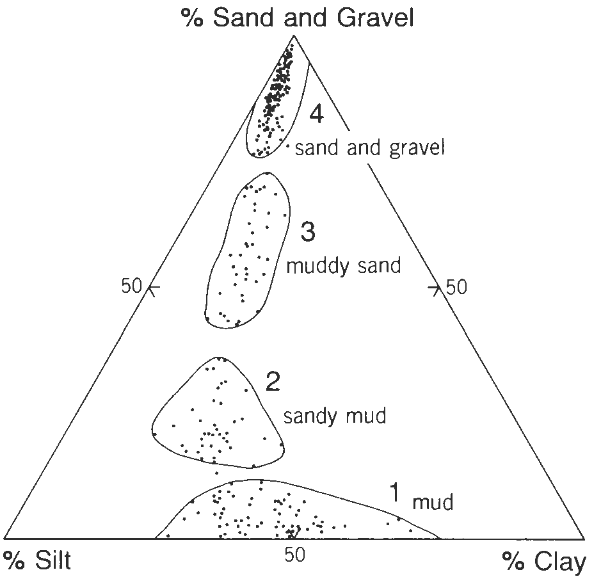
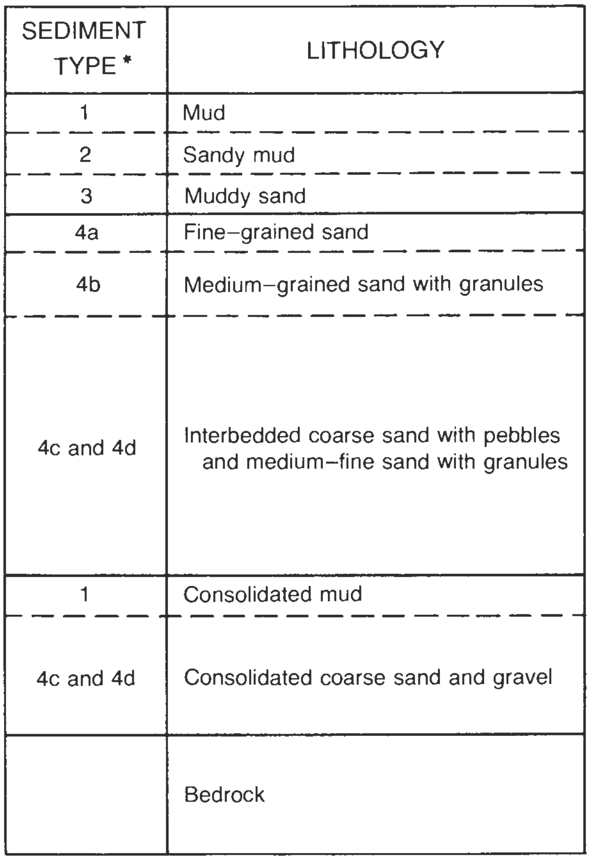


Figure 6. Ternary diagram showing the distribution of four sediment textures of samples of Ohio River alluvium. Numbers refer to sediment types shown in figure 7.



SEDIMENT TYPE *	LITHOLOGY
1	Mud
2	Sandy mud
3	Muddy sand
4a	Fine–grained sand
4b	Medium–grained sand with granules
4c and 4d	Interbedded coarse sand with pebbles and medium–fine sand with granules
1	Consolidated mud
4c and 4d	Consolidated coarse sand and gravel
	Bedrock

* Sediment type identified in tables 1 and 2.

Figure 7. Generalized vertical distribution of the sediment types in the alluvium.

within these units that allow a more detailed analysis of the structure of the alluvium. Textural analyses in the laboratory confirm this initial finding and suggest that seven distinct sediment types are present in the valley fill near Evansville. Four sediment types can be defined on a ternary diagram with end members of clay, silt, and sand plus gravel (fig. 6) (table 1). The three sediment types containing appreciable amounts of mud preferentially occur in the upper part of the section, and the sediment type composed primarily of sand and gravel occurs in the lower part (fig. 7).

A scatter diagram plotting mean size against the coarsest 1.0 percentile of type 4 sediments indicates that the sands and gravels can be subdivided into four groups (fig. 8) (table 2) that also occupy unique stratigraphic positions (fig. 7).

VERTICAL DISTRIBUTION OF SEDIMENT TYPES

The basic sequence of the alluvial fill consists of mud at the top passing downward through sandy mud and muddy sand into clean fine-grained sand (fig. 7). These sands locally overlie medium-grained granular sand that in turn overlies interbedded pebbly coarse sand and granular medium-fine sand. The basal part of the sequence consists of highly consolidated mud and pebbly sand that fill in an irregular topography on bedrock. Variations in the relative thickness of some sediment types and the presence or absence of others are functions of position on the meander loop.

The sequence beneath the long, arcuate ridges of the flood plain consists of mud at the top grading to sandy mud by the addition of thin, discontinuous laminae of very fine grained sand (fig. 9). Underlying the sandy mud in some holes is a layer of fine-grained sand of variable thickness, but in others the muddy sediments rest with sharp contact on pebbly coarse sand. The greatest part of the section consists of interbedded medium-fine

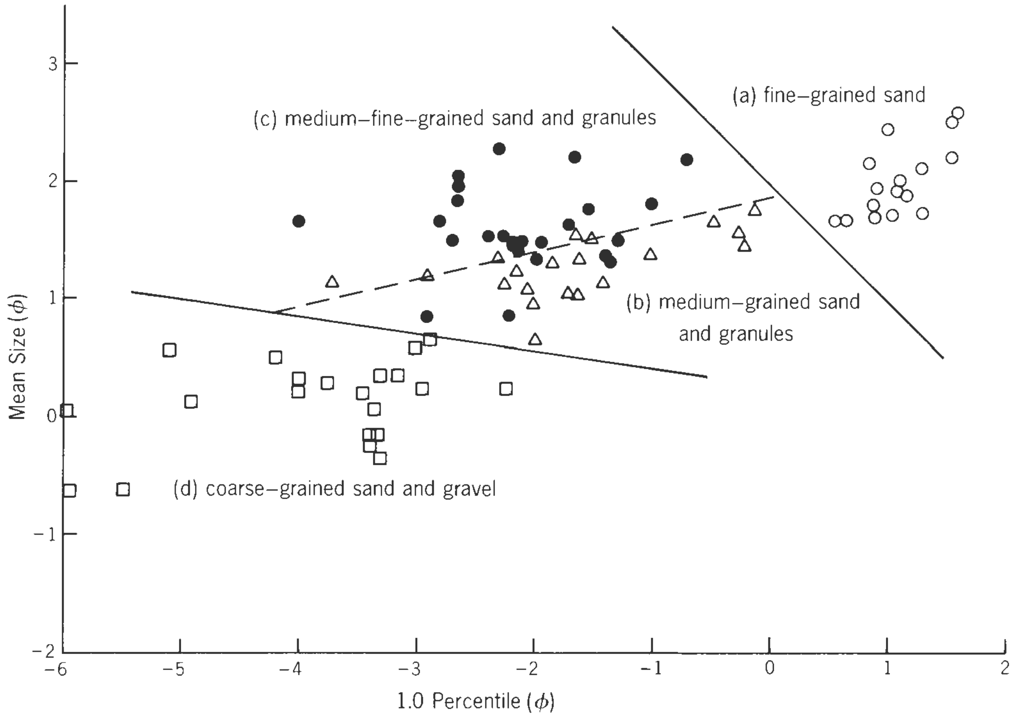


Figure 8. Scatter diagram plotting the mean size of sand versus the coarsest 1.0 percentile of samples composed of greater than 75 percent sand and gravel.

Table 1. Clay:Silt:Sand plus gravel ratios of the four basic sediment types in the alluvial fill near Evansville

Sediment type	Sand plus gravel (pct)	Silt (pct)	Clay (pct)
1. Mud	0 to 10	25 to 75	25 to 75
2. Sandy mud	15 to 35	40 to 65	15 to 40
3. Muddy sand	40 to 70	15 to 40	5 to 20
4. Sand and gravel	80 to 100	0 to 20	0 to 10

Table 2. Grain-size characteristics of sand and gravel (type 4) in the alluvial fill near Evansville

Sediment type	Mean size (φ)	Coarsest 1.0 percentile (φ)
4a. Fine-grained sand	1.5 to 2.5	0.0 to 2.0
4b. Medium-grained sand and granules	0.5 to 1.5	-4.0 to 0.0
4c. Medium-fine-grained sand and granules	1.5 to 2.5	-4.0 to 0.0
4d. Coarse-grained sand and pebbles	-1.0 to 1.0	-6.0 to -2.0

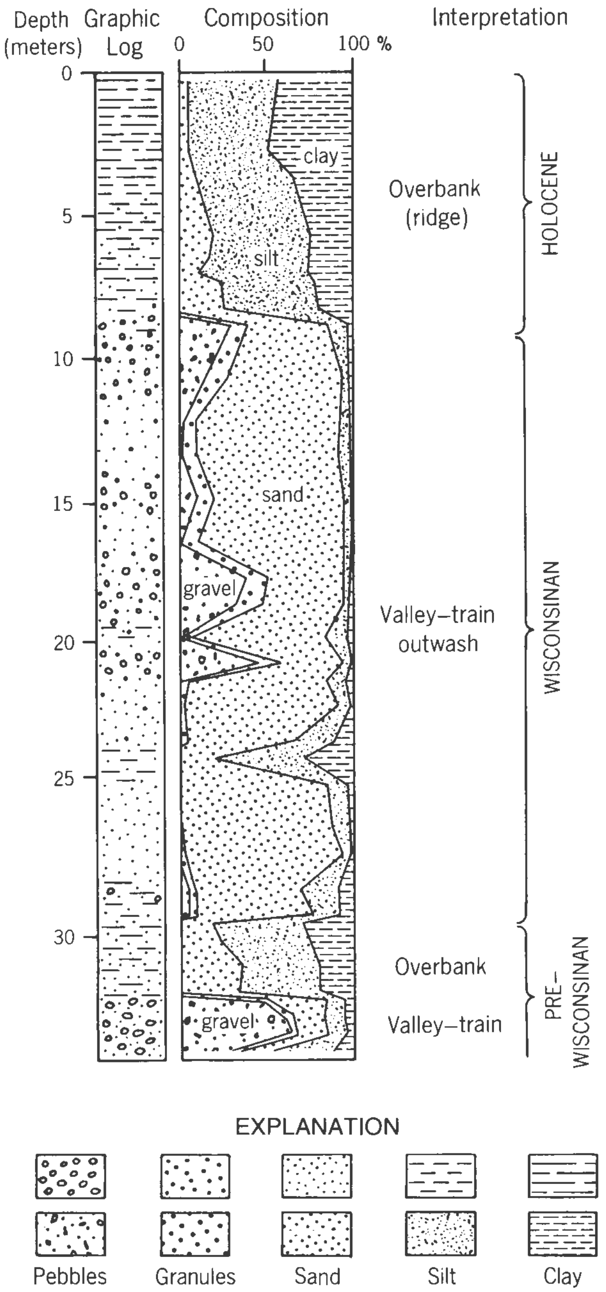


Figure 9. Log of drill hole 7 showing a vertical profile through the alluvium penetrated in a hole drilled on top of a ridge on the flood plain. Location of drill hole 7 is shown in figure 4.

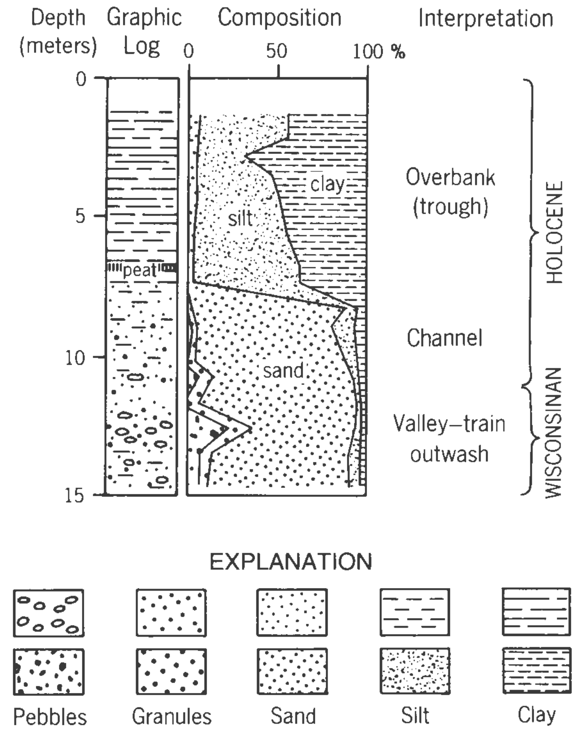


Figure 10. Log of drill hole 8 showing a typical vertical profile through the upper part of the alluvium in a hole drilled in a trough on the flood plain. Location of drill hole 8 is shown in figure 4.

granular sand and pebbly coarse sand with occasional thin layers of muddy sediments. At the base of the section is a unit of highly consolidated sandy mud and coarse-grained sand and pebbles. Clast size of the pebbles in this basal unit is appreciably coarser than that of the pebbles in the overlying unconsolidated pebbly sand. These sediments were easily recognized during drilling because of their density, high resistance to the shearing action of the auger, and pronounced reduction in the rate of penetration. Seismic surveys through this area mistakenly identified these sediments as bedrock because seismic velocities (~8,000 fps) through them approach those of weathered shale.

The muddy sediments at the top of the sequence in holes drilled in swales on the flood plain (fig. 10) do not show the characteristic fining-upward trend of sequences under ridges. Instead, the muds tend to contain more clay and little sand. The base of the fine-grained unit generally contains abundant organic debris and in places a thin peat bed. Also, the muddy sediments do not rest directly on pebbly sand but instead overlie medium-grained sands with granules and rare fine pebbles.

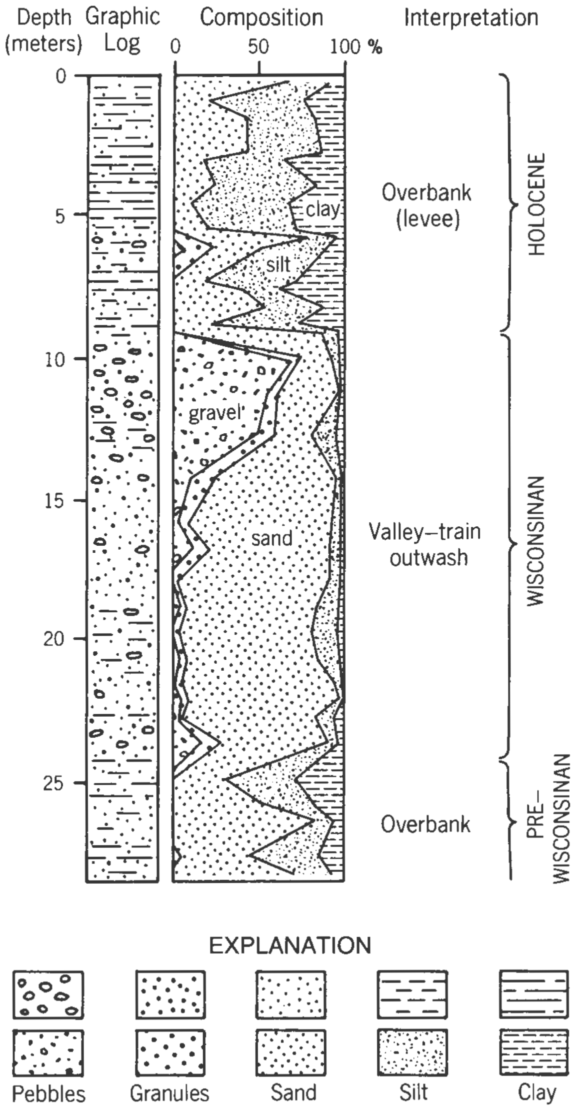


Figure 11. Log of drill hole 3 showing a vertical profile through the alluvium penetrated in a hole drilled on top of a levee. Location of drill hole 3 is shown in figure 4.

The upper part of the sequence under levees is considerably coarser grained than that found in the interior of the meander loop. Appreciable amounts of sand are found throughout the sequences (fig. 11), and occasional layers of sand and granules intercalated with sandy muds and muddy sands are also found. These relatively fine grained sediments rest with an abrupt contact on the underlying sand and gravel.

This site-specific textural differentiation of overbank sediments contributes to the striking topographic pattern of concentric ridges and swales. The ridges probably originate as scroll bars superimposed on point-bar surfaces or as linear positive features that form in the channel itself. Because the sediments in the troughs are clayey and organic, they tend to compact more than the siltier sediments on the ridges. This process of differential compaction serves to maintain the original relief of the scroll bars producing the well-defined ridge and swale pattern seen on the flood plain.

Two types of sequences occur in the terraces. The most common sequence consists of an upper interval that includes mud at the top overlying fine-grained well-sorted sand (fig. 12). The mud is similar in texture to that under the flood plain, but it lacks fine laminations except near the base of the sequence. The sand under the high terrace is similar in size to that underlying the mud of the flood plain, but it tends to be better sorted. The lower part of this type of sequence consists of sand and gravel that are similar to those making up most of the valley fill under the flood plain.

The second type of sequence occurs near the valley walls at the mouths of tributary valleys. The upper part of the sequence consists of mud overlying fine-grained well-sorted sand (fig. 13). The lower part of the sequence, however, contains relatively little sand and gravel and consists, instead, of mud and sandy mud that tend to be finely laminated. In both types of upper terrace sequences the fine-grained sand rests directly on sand and gravel without the intervening unit of medium sand and granules characteristic of the sequence underlying the flood plain.

INTERNAL STRUCTURE OF THE MEANDER LOOP

The internal distribution of these textural units can be seen in a radial cross section along a north-south line through the meander loop (fig. 14). Six structural features are most readily apparent.

1. The consolidated sediments at the base of the alluvium fill in a highly irregular topography on the bedrock surface. The

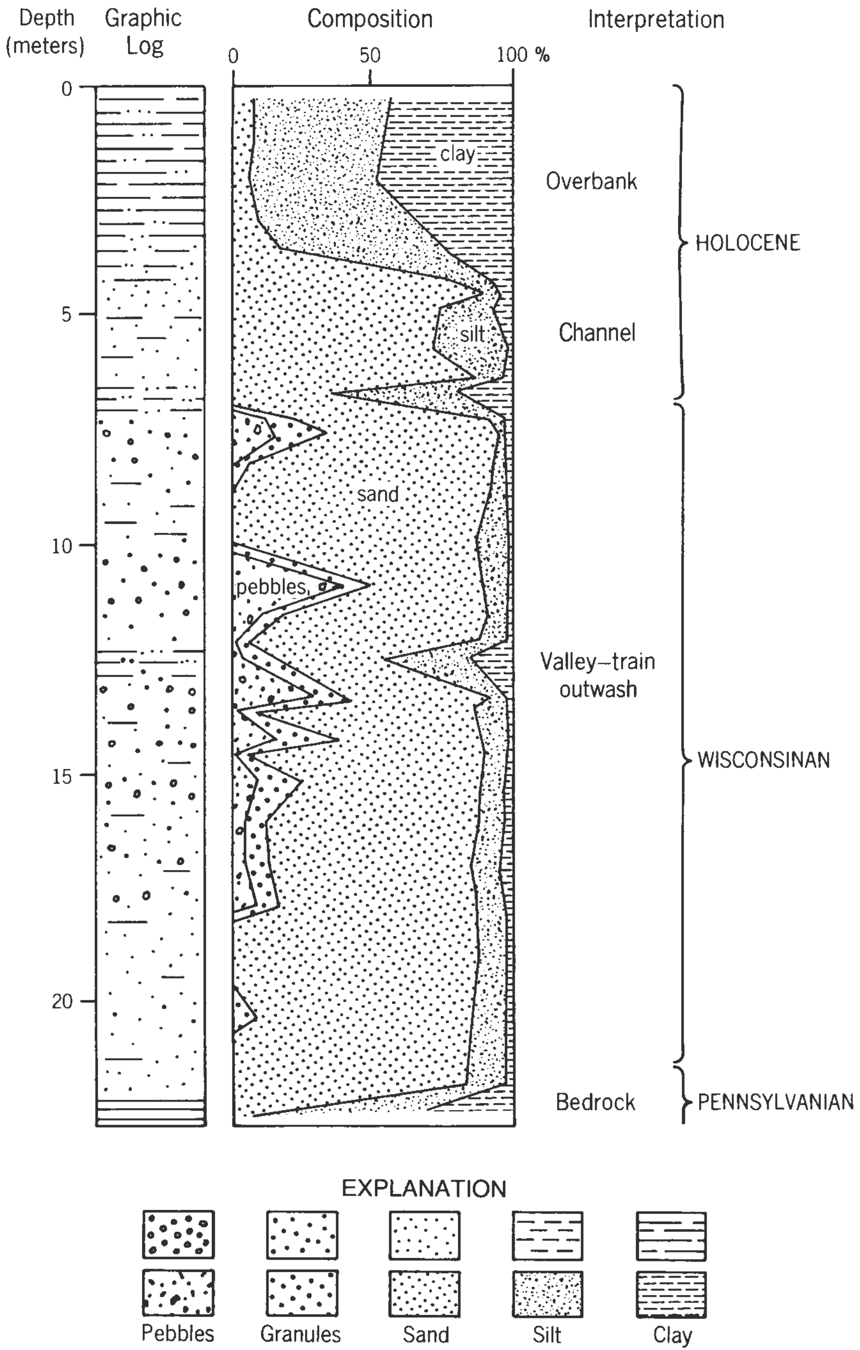


Figure 12. Log of drill hole 4 showing a vertical profile through the alluvium penetrated in a hole drilled in the upper terrace. Location of drill hole 4 is shown in figure 3.

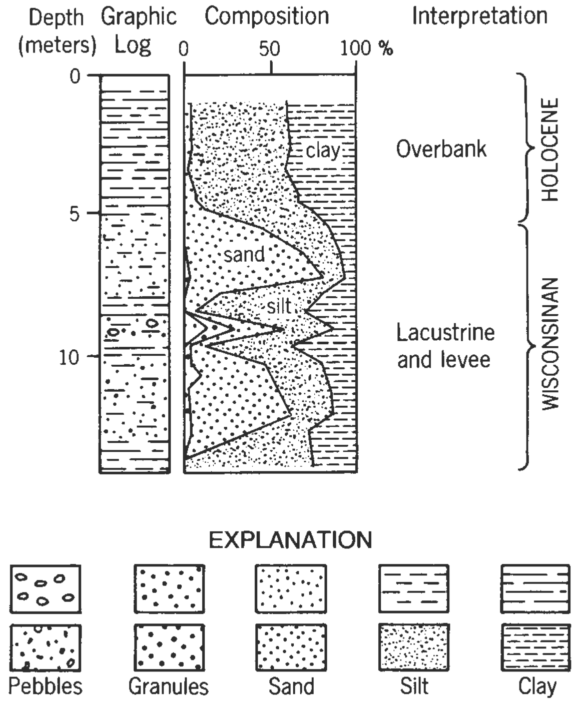


Figure 13. Log of drill hole 1 showing a vertical profile through the upper part of the alluvium penetrated in a hole drilled in the upper terrace near the mouth of a small tributary valley. Location of drill hole 1 is shown in figure 3.

upper surface of the consolidated sediments, however, is relatively level.

2. The beds of coarse sand and pebbles are not uniformly distributed in the middle part of the alluvial fill. They are best developed toward the center of the valley and become interbedded with granular sands toward the margin of the valley.

3. The upper surface of the sand and gravel varies in elevation. It is at an elevation of about 350 feet (107 m) near the valley walls and slopes gradually downward to an elevation of 335 feet (102 m) under the low terrace. Under the flood plain the surface is undulatory and has a high elevation of about 330 feet (100 m) and a low elevation of 310 feet (95 m), roughly the elevation of scour of the present river.

4. A prism-shaped body of medium-grained granular sand is found along the flood plain where it fills in the irregular upper surface of the sand and gravel unit. The granular sand, however, does not occur under the terraces. Instead, a unit of fine-grained well-sorted sand occupies the equivalent stratigraphic position.

5. Under the flood plain a thin unit of fine-grained sand lies immediately beneath the uppermost muddy sediments. This sand is dissimilar to those sands under the terraces in its coarser grain size and poorer sorting, and it is also texturally distinct from the underlying granular sand.

6. Near the valley wall muddy sediments that are intercalated with thin sand and gravel beds are found at the mouth of a minor tributary of the river. These beds are laterally equivalent to the sand and gravel near the center of the valley.

AGE RELATIONSHIPS

Datable material from four locations has been found in the meander loop, and three of the locations are along the line of cross section (fig. 14). Archaeological artifacts (primarily spearpoints) were found near the valley margin in the sediments of the high terrace. The material was at a depth of about 1 foot (0.3 m) and was dated culturally at 10,000 to 12,000 ybp (C. A. Munson, oral communication, 1981). Other archaeological material, also consisting predominantly of spearpoints, was found on the surface of the low terrace on the west side of the meander loop. This material was dated culturally at 6,000 to 8,000 ybp (C. A. Munson, oral communication, 1981).

Peat was encountered in two holes drilled along the line of cross section. Hole 8, drilled in the flood plain near the scarp separating the flood plain from the low terrace, encountered peat near the base of the upper muddy unit. This peat (ISGS 639) was dated by C^{14} methods at 3,980 ± 75 ybp. Hole 15 was drilled in the middle of the flood plain, and a second peat layer was found, also near the base of the upper muddy unit. This peat (ISGS 640) was dated at 2,140 ± 100 ybp.

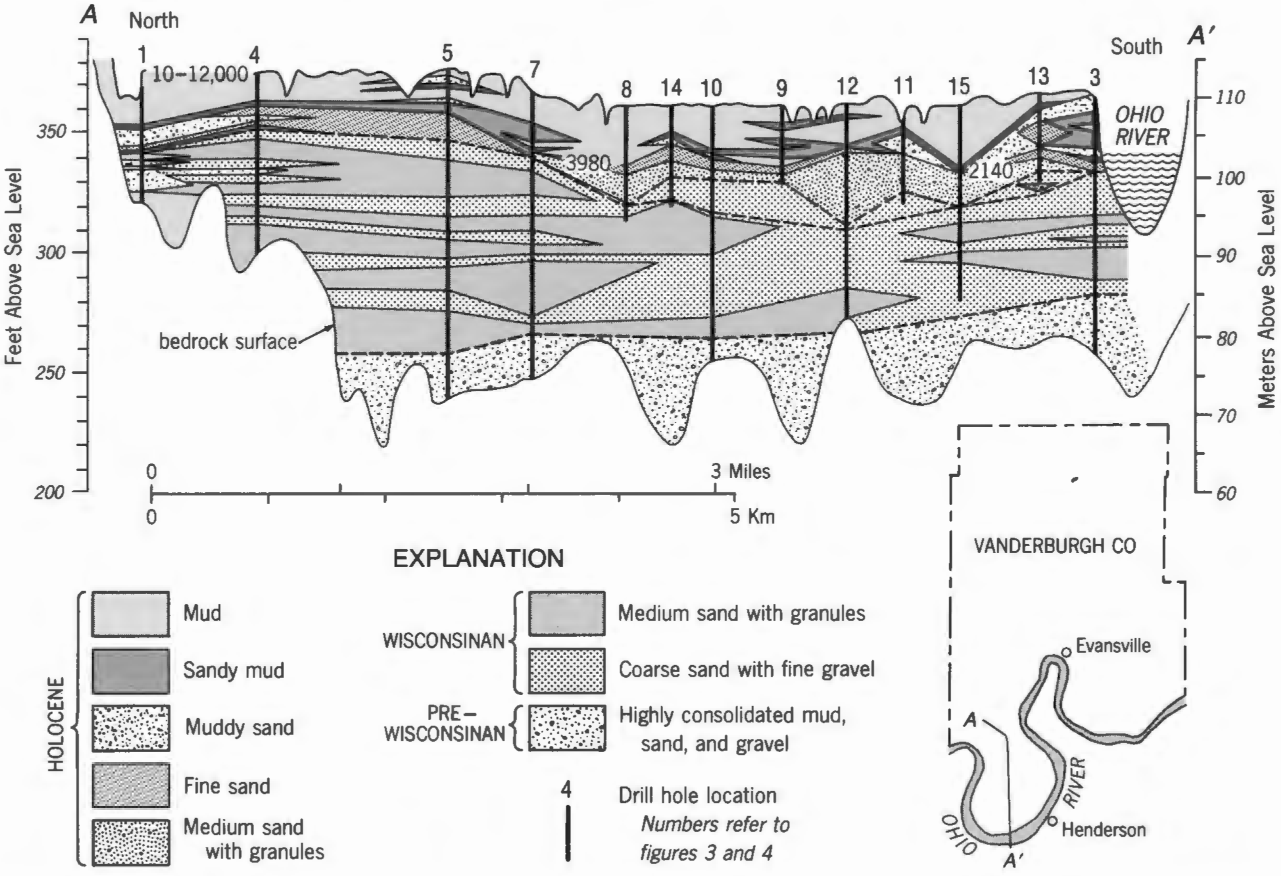


Figure 14. Cross section showing the architecture of the alluvial fill in the Ohio River valley near Evansville. Dashed lines mark the boundaries separating sediments of Holocene, Wisconsinan, and pre-Wisconsinan age.

History of Alluviation

The various geomorphic, textural, and stratigraphic units that have so far been defined represent discrete stages in the alluviation of the valley. The alternating episodes of erosion and deposition during this period produced a complex distribution of sediments in the valley.

PRE-PLEISTOCENE EVENTS

The bedrock surface on which the alluvium rests appears to have been shaped by at least two and perhaps three erosional episodes. The eastern and central parts of the midcontinent were apparently once occupied by an extensive surface variously named the Lexington, Highland Rim, or Cumberland Plain. (See Ray, 1966, for a review of this feature.) Remnants of this surface are in the uplands along the Ohio River upstream from Rockport, but evidence of the surface is lacking in the soft Pennsylvanian strata underlying the area downstream from Rockport.

Intermittent stream rejuvenation initiated by uplift during the latter part of the Tertiary Period caused dissection of the plain (Ray, 1966), and a series of gravel-capped steps in the bedrock leading down to the present Ohio River was formed. In the Evansville area such a step may be represented by the accordant hill crests at 470 feet (143 m), and the bedrock terraces below the alluvium at 240 to 260 feet (73 to 79 m) and 260 to 280 feet (79 to 85 m) may represent two more such steps.

The terrace at 260 to 280 feet (79 to 85 m) correlates with a bedrock bench at a similar topographic position in the Owensboro area

(Ray, 1966), but the lower terrace does not appear to have correlative levels elsewhere along the river. Theiss (1922) reported a bedrock bench at 300 feet in Henderson County by means of a few datum points, but recent mapping by the U.S. Geological Survey (Ball, 1973; Smith and Ball, 1973, 1974; Norris, 1974) does not show a well-developed terrace at that elevation.

A deep channel is incised in the bedrock-valley floor to an elevation of 200 feet (60 m) about 160 feet (50 m) below the low bottoms and 140 feet (42 m) below the present level of the river. This deep channel has been noted elsewhere in the Ohio River (Ray, 1966) and in other major pre-Pleistocene drainage systems (Fisk, 1944; Horberg, 1945; Wayne, 1952).

The age and the cause of this deep incision are open to speculation. The erosional episode obviously postdates the development of the Lexington surface and predates the age of the oldest alluvium in the valley, which can only be confidently dated as Pleistocene in age. Ray (1966) believed that the rapid downcutting of the deep valley was the last in a series of erosional episodes caused by uplift during the late Tertiary. Wayne (1952) believed that the deep stage formed during the Pleistocene (after the so-called "Nebraskan" Age) when diversion of the upper reaches of the Teays-Mahomet drainage system into the Ohio River valley caused static rejuvenation. It may also have formed with the inception of through-flowing drainage in the Ohio River. N. K. Bleuer (oral communication, 1983) believed that this may have occurred about 0.7 to 0.8 my ago (marine isotope stage 22) with blockage of the Teays River valley in east-central Indiana by ice. In the Evansville area there is no evidence presently available to support any of these views.

PLEISTOCENE EVENTS

Most of the alluvial fill is Pleistocene in age. The basal material consists of highly consolidated gravel, sand, and mud. The contact between the basal material and the overlying unconsolidated pebbly sand is a nearly level surface about 80 feet (24 m) below the present flood plain. Nowhere has a complete section of this material been penetrated, but the holes that have been drilled into the upper part suggest that the sediments are in a fining-upward sequence of gravels at the base passing upward into interbedded sand and mud. Because of poor sample recovery from these holes, the detailed nature of the fining-upward sequence is uncertain, but except in the degree of its consolidation it appears to differ little from the overlying sequence, and it may have formed in an analogous manner.

The gravel was probably deposited during a period of glacial advance, and the mud and sand were possibly deposited during an interglacial period in response to a reduced transport capability. Crystalline rock fragments in the gravels confirm a Pleistocene age, and the highly consolidated nature of the sediment suggests that it is at least pre-Wisconsinan, but there is no evidence presently available to attribute the material to a particular advance.

Several ice sheets advanced into Indiana during the Pleistocene, and any of them could have influenced sedimentation in this area. A pre-Wisconsinan ice sheet reached at least the northern part of Vanderburgh County and may have extended as far south as the Ohio River (Wayne, 1963). Even if the ice had reached only the headwaters of Pigeon Creek, meltwater could have been routed down that drainageway into the Ohio River. The apparent absence of gravels in the Pigeon Creek valley, however, argues against this possibility. Deposits of at least two pre-Wisconsinan ice advances lie along the Ohio River in the eastern part of Indiana, and either of these ice advances could also have been the source of the basal alluvium.

Most of the alluvium in the valley consists of sand and gravel of Wisconsinan age. These sediments are as much as 90 feet (27.5 m) thick in the Evansville area, and they extend across the entire width of the valley. The sediments underlie two terrace levels in the Evansville area that can be correlated with terraces up the Ohio River valley as far as the outlets of the Miami and Whitewater Rivers, which suggests that the material was derived from ice that advanced into the Miami-Whitewater basin during Woodfordian (late Wisconsinan) time. Correlation of pebbly beds across the valley indicates that deposition occurred during two aggradational episodes that were separated by an erosional event. The first aggraded the valley floor to an elevation of about 380 feet (116 m) and filled the valley with interbedded pebbly and granular sands. These sediments are preserved under the high terrace where remnant bars are discernible in the Owensboro area (Ray, 1966) as well as in the Evansville area. The shape of the remnant forms indicates that during at least the last stage of this phase of deposition the valley was occupied by a braided stream with flow confined to channels during low-water stage and with flow unconfined during flood stage.

Pebbly sediments concentrated in the central part of the valley indicate that strongest flow was maintained there during this period, and muddy sediments in tributaries indicate that the valley floor aggraded quickly and dammed the tributaries of the river and that lakes were formed where fine-grained sediments accumulated (fig. 14).

After this initial period of deposition a channel as much as 30 feet (9 m) deep was cut into the alluvium forming the high terraces. This channel was filled later in the Woodfordian by sediments that are significantly finer grained than those deposited earlier. The finer grained sediments are preserved under the low terrace where relict bar forms indicate that deposition occurred in a braided meandering channel characterized by relatively low flow velocities. The low-terrace level can be correlated with a similar level described by Theiss (1922) in Henderson County and Ray (1966) in the Owensboro area. Ray also noted the meandering channel pattern preserved on the terrace surface and the relatively fine grained nature of the sediments underlying it.

The two periods of deposition can possibly be related to two Woodfordian ice advances into the Miami-Whitewater basin that were recognized by Gooding (1957; 1973). The first, in the early Woodfordian, advanced midway into the basin. The second advance occurred in the late Woodfordian and reached only the northern margin of the basin. Meltwaters of this advance initiated a primarily erosional event in the Whitewater system (Gooding, 1957), but the reworked sediment from the Whitewater was added to the alluvium of the Ohio River. The two advances probably resulted in the two depositional episodes in the Evansville area that were separated by an erosional event that probably occurred during the intervening temporary ice retreat.

POST-PLEISTOCENE EVENTS

Any definition of the Pleistocene-Holocene contact must be somewhat arbitrary. A rock-stratigraphic definition is based on the supposed effects caused by withdrawal of the midcontinent ice sheets. Timing of the withdrawal varies locally, however, and so a time-transgressive boundary is produced. Time-stratigraphic definitions are based on establishing a date for a widespread climatic event. Such a definition might be universally applicable, but it may be difficult to establish locally where the effects may not be manifested or where they may be manifested in a radically different way.

In any case, a time-stratigraphic definition of the boundary is difficult to establish where closely spaced absolute dates are not available, and this is true of the alluvial deposits in the Evansville area. A boundary can be established in parts of the valley where a pronounced textural break occurs between deposits known to be of the modern river and those that can be assigned, with relative confidence, to the Pleistocene river. In other parts of the valley, however, there is no pronounced textural break, and the boundary can only be approximated.

Most of the fine sand and mud overlying the gravelly sediments probably was deposited during the Holocene Age, but because some of these sediments may well have been deposited during the late Woodfordian, placement of the Pleistocene-Holocene boundary within the sequence is somewhat difficult.

Dates for cultural material near the surface of the high terrace indicate that most of the fine-grained material there accumulated before 10,000 to 12,000 ybp. These deposits may originally have been overbank deposits formed during flood stages of the late Woodfordian ice advance. The sand is texturally similar to that in dunes found

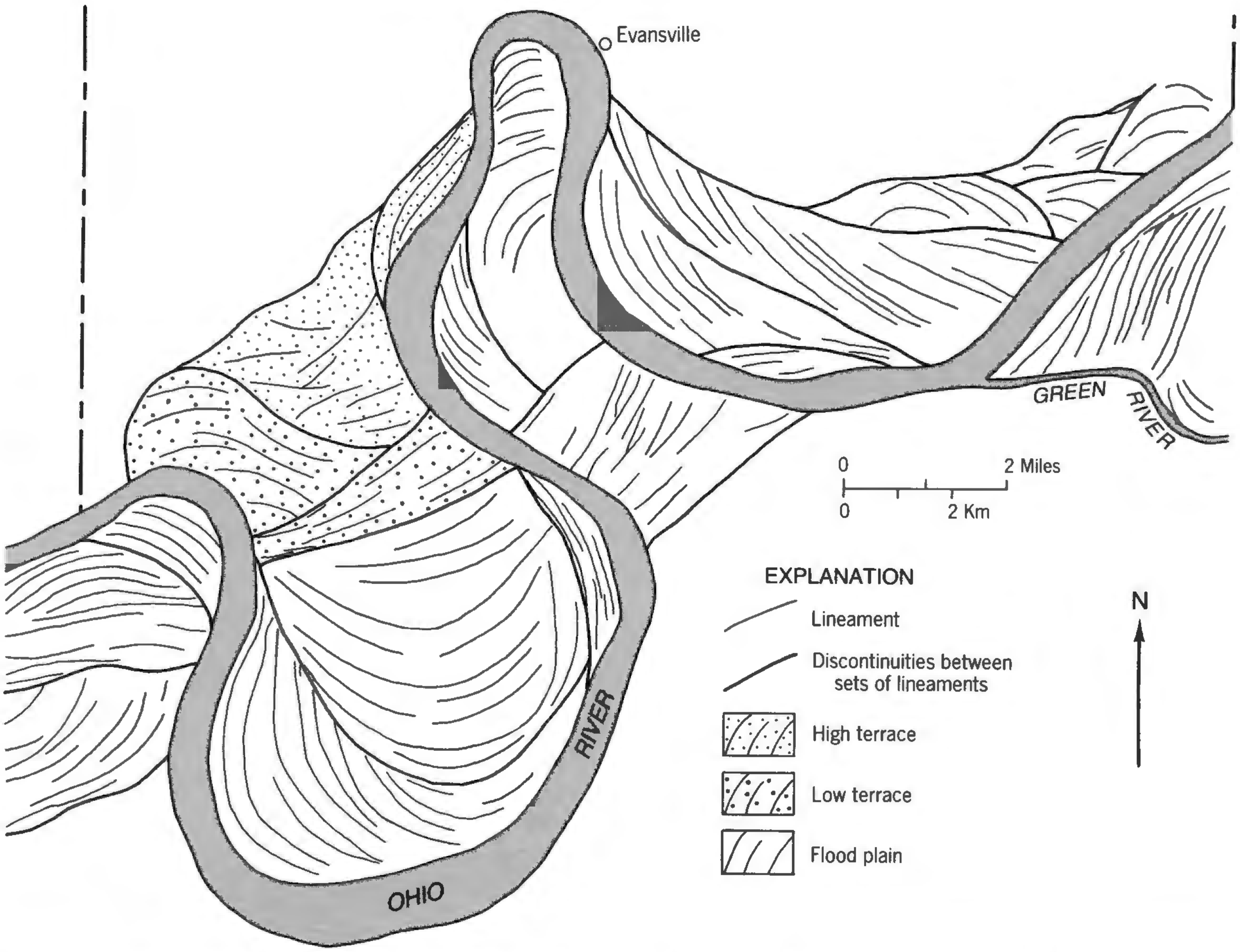


Figure 15. Map showing the trends of the surface lineaments on top of the alluvium produced in response to the channel migration of the Ohio River.

elsewhere in the Evansville area, however, and the muds are similar to the loess deposits mantling the uplands. They may, therefore, be the result of wind deposition that occurred after ice retreat from the Miami-Whitewater basin. Both sands and muds, however, are finely laminated in the lower part of the sequence, and so they are more analagous to the flood-plain and levee deposits of the modern river. These sediments, therefore, probably accumulated as overbank deposits of the late Woodfordian river, and relatively little sediment was added to the high terrace after the withdrawl of the ice sheet.

The prism of modern channel and overbank sediments under the flood plain began to accumulate after 4,000 ybp, an assumption based on a C^{14} date for peat found near the scarp separating the flood plain from the low terrace. Earlier Holocene sediments were probably deposited in the meander loop, but they have since been eroded as the channel has migrated across the valley bottom. Evidence of these earlier deposits can be found in other meander loops in the area where older sets of concentric scroll-bar patterns have been truncated by more recent channel configurations (fig. 15). Overbank deposits of these earlier Holocene channels may also occur on the low terrace where artifacts dated 6,000 to 8,000 ybp are found at the top of a sequence of muds. These deposits accumulated after deposition of the gravels underlying the low terrace (that is, after the withdrawal of the late Woodfordian ice sheet) but before deposition of the artifacts. Their fine-grained laminated character suggests deposition as overbank deposits, but since growth of the meander began about 4,000 ybp, these overbank deposits must be related to an earlier period of Holocene alluviation.

The sediments overlying the sand and gravel under the low bottoms characteristically consist of a basal granular sand layer overlain by muddy sediments that in places are somewhat sandy over ridges. The basal sand layer is 3 to 29 feet (1 to 9 m) thick. Some of this variation may be accounted for by a slightly irregular upper surface, but most of the variability is caused by the highly irregular lower contact (fig. 14) with the Wisconsinan valley-train deposits.

There are three lines of evidence suggesting that the granular sands are channel and point-bar deposits of Holocene age. First, the maximum age of the overlying muds is established at about 4,000 ybp by C^{14} dating. This date also establishes the minimum age of the sands, and since there is no indication of a significant break in the depositional record between sands and muds, that date probably approximates the actual time of sand deposition as well.

Second, the textural change that occurs between the granular sands and the underlying pebbly sands suggests quite different modes of deposition. Such a textural change in bedload material would be the expected response to the change in hydraulic regime undergone by the river as it adjusted to new conditions of climate in the Holocene. The sand and the gravel underlying these sediments are, by correlation with similar materials under the terraces, of late Woodfordian age. By analogy the granular sands overlying the sand and the gravel under the flood plain are the expected finer grained products deposited by the meandering stream of Holocene age.

Finally, the nature of the contact between the granular sands and the underlying pebbly sands suggests that the sediments above the contact were deposited by a stream substantially the same as the present one. The contact is highly irregular with as much as 20 feet (6 m) of relief. Because low points along the contact are coincident in elevation with the depth of the modern channel, these lows may have been sites of former channels occupied by a river of substantially the same hydraulic characteristics as the present river. It is probable, therefore, that the granular sands are the basal channel and point-bar components of the kind of fining-upward sequence normally associated with meandering streams, such as the present Ohio River.

There are three site-specific vertical sequences developed on the flood plain. Mud, generally highly organic, is deposited in troughs of the ridge and swale system. Mud with minor amounts of sand accumulates on ridges, and mud with appreciable amounts of sand is deposited on levees.

The fine-grained sands and muds that form the topmost part of the Holocene flood-plain deposits were formed by overbank processes. Channel sands are deposited on subaqueous parts of the point bar. But the part of the point bar near the bank is at an elevation above mean low-water stage, and it is this part that is the site of overbank rather than channel processes of deposition. Basal overbank sediments contain significant amounts of sand as thin lenses, but as aggradation continues silt and clay almost exclusively make up the sediments.

Aggradation of a flood plain is initially rapid. When the point-bar surface is newly emergent, it may be inundated numerous times during the year by storm-induced flood events of relatively small magnitude. As the surface elevation increases, however, it becomes less susceptible to flooding and the rate of aggradation slows. As the surface approaches the elevation of the flood plain the frequency of flooding decreases even more, and at this point sediment is added slowly.

The slowing rate of aggradation affects the preservation potential of internal sedimentary structures in the overbank deposits of the meander loop. Low in the sequence, where aggradation was rapid, the sediment is finely laminated. Higher in the sequence, however, internal primary structures have been destroyed by the rooting activity of plants that

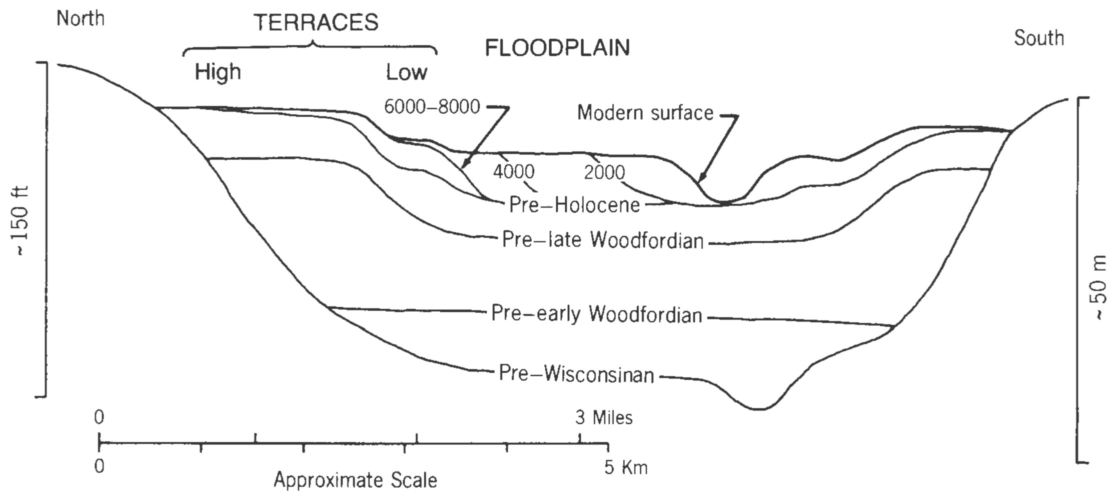


Figure 16. Diagram showing the arrangement of time lines in the alluvial fill of the Ohio River valley near Evansville.

have had time to thoroughly homogenize the sediments because of the slow accumulation rates.

Comparison of maps drawn in 1911-14 and 1966 by the U.S. Army Corps of Engineers gives some indication of the absolute rate of aggradation. Midchannel islands can be seen to aggrade to the level of the flood plain within 50 years after initial formation, and as much as 20 feet (6 m) of sediment has accumulated on the leading edge of the prograding part of the meander loop in the same 50-year period. Even single flood events can add significant amounts of sediment to the flood plain. Mansfield (1938) reported that as much as 1.5 feet (0.5 m) of sediment was deposited along parts of the Ohio River during the record flood of 1937.

ISOCHRONS

Seven isochrons, including the present depositional surface, can be defined within the valley (fig. 16). The contact between bedrock and alluvium is probably time synchronous. The date of the origin of the contact is uncertain, but the valley was likely cut in the late Tertiary or early Quaternary. The immediately overlying deposits are of pre-Wisconsinan age and were probably deposited rapidly enough across the valley that their contact with the bedrock surface is an isochronous surface of indeterminate age.

The contact between the Illinoian? and Wisconsinan sediments is probably also an isochronous surface of erosional origin. The immediately overlying sediments are likely of early Woodfordian age, which indicates that the surface represents an erosional interval that ended in early Woodfordian time.

Within the valley-train sediments is an apparent break in the depositional record where an abrupt change in texture and depositional style occurs. The break may be correlated with a minor ice retreat from the Miami-Whitewater basin in the latter part of the Woodfordian, and the succeeding deposits may be correlated with a late Woodfordian readvance into the basin. The surface formed during the break in deposition, therefore, is of probable pre-late Woodfordian age.

The fourth surface separates Pleistocene sediments from Holocene sediments. The surface is partly erosional where post-Pleistocene scour cut a channel in which Holocene alluvium was deposited. Where erosion has occurred, the surface can be relatively well defined. But on the upper terrace late Woodfordian overbank deposition probably merged into Holocene overbank deposition, and therefore the surface can only be approximated. Given the known rapid rate of accumulation of overbank sediments and the 10,000 to 12,000 ybp date on artifacts recovered near the surface on the upper terrace, it is likely that most of the deposits are pre-Holocene. Therefore the Pleistocene-Holocene boundary can be paced near the surface on the upper terrace.

On the lower terrace, however, surface artifacts dated 6,000 to 8,000 ybp indicate that most of the overbank deposition here occurred during the early Holocene. The Pleistocene-Holocene boundary probably occurs near the base of the overbank sediments under the low terrace.

Two time lines can be approximately defined within the Holocene section. Dates of 4,000 and 2,000 ybp for peats at the base of the overbank deposits under the flood plain suggest that the prism of Holocene sediments can be divided into three sections. Holocene deposits over the low terrace accumulated mostly before 6,000 to 8,000 ybp. Holocene deposits under the flood plain, however, accumulated after 4,000 ybp, and a near-vertical time line must separate the two sediment bodies (fig. 16). Because the meander began to prograde away from the low terrace at about 4,000 ybp, the time line can be ascribed to that date. The time line must then descend under the channel deposits of the modern river where it becomes coincident with the boundary separating Pleistocene and Holocene alluvium.

From 4,000 to 2,000 ybp the meander prograded 2.5 miles (4.1 km) southward at an average rate of 6.6 feet (2.0 m) a year. At about 2,000 ybp it changed direction and prograded 1.9 miles (3.0 km) southwestward to its present position. Each progradational episode is represented by a package of sediments separated by a sigmoidal time line dated 2,000 ybp. The upper and lower parts of the sigmoidal line asymptotically approach the upper and lower bounding surfaces of the Holocene deposits, and the middle part of the line represents the steep slope of the prograding bank (fig. 16). Therefore, the time line approximates the shape of the present cross-sectional profile of the flood plain. If the absolute dates were available, an infinite number of similarly shaped time lines could be drawn to represent the various stages in the progradation of the meander loop.

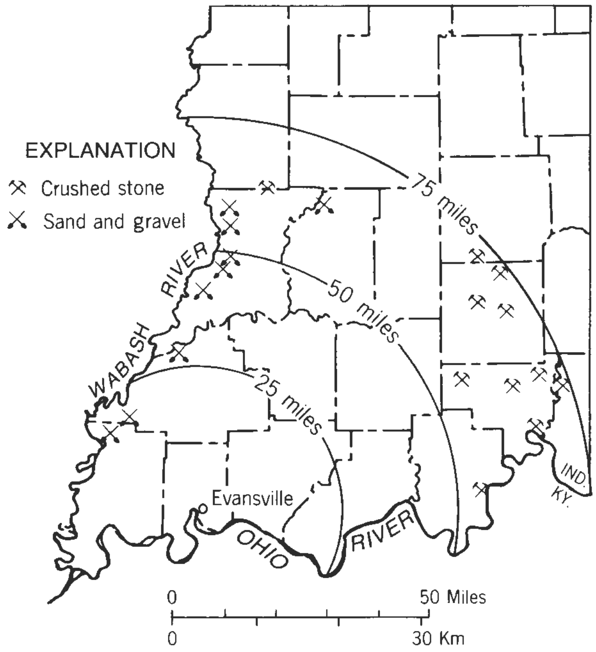


Figure 17. Map of southwestern Indiana showing the distance (in miles) from Evansville to presently available sources of aggregate.

Sand and Gravel Resources

INTRODUCTION

Among the factors that contribute to the economic development of an area is access to a cheap, plentiful source of construction materials, especially those used in producing concrete. Sand and gravel are used as aggregate in concrete, and they make possible the construction of all types of public and private buildings and roads.

Unfortunately southwestern Indiana lacks readily exploitable sources of crushed stone and has few commercial sand and gravel resources (fig. 17). Concrete aggregate is currently supplied to Vanderburgh County by both water and overland transportation, but a local source of aggregate near the rapidly expanding urban area around Evansville would be highly desirable.

This part of our report is intended to supplement an earlier publication concerning the environmental geology of the Evansville

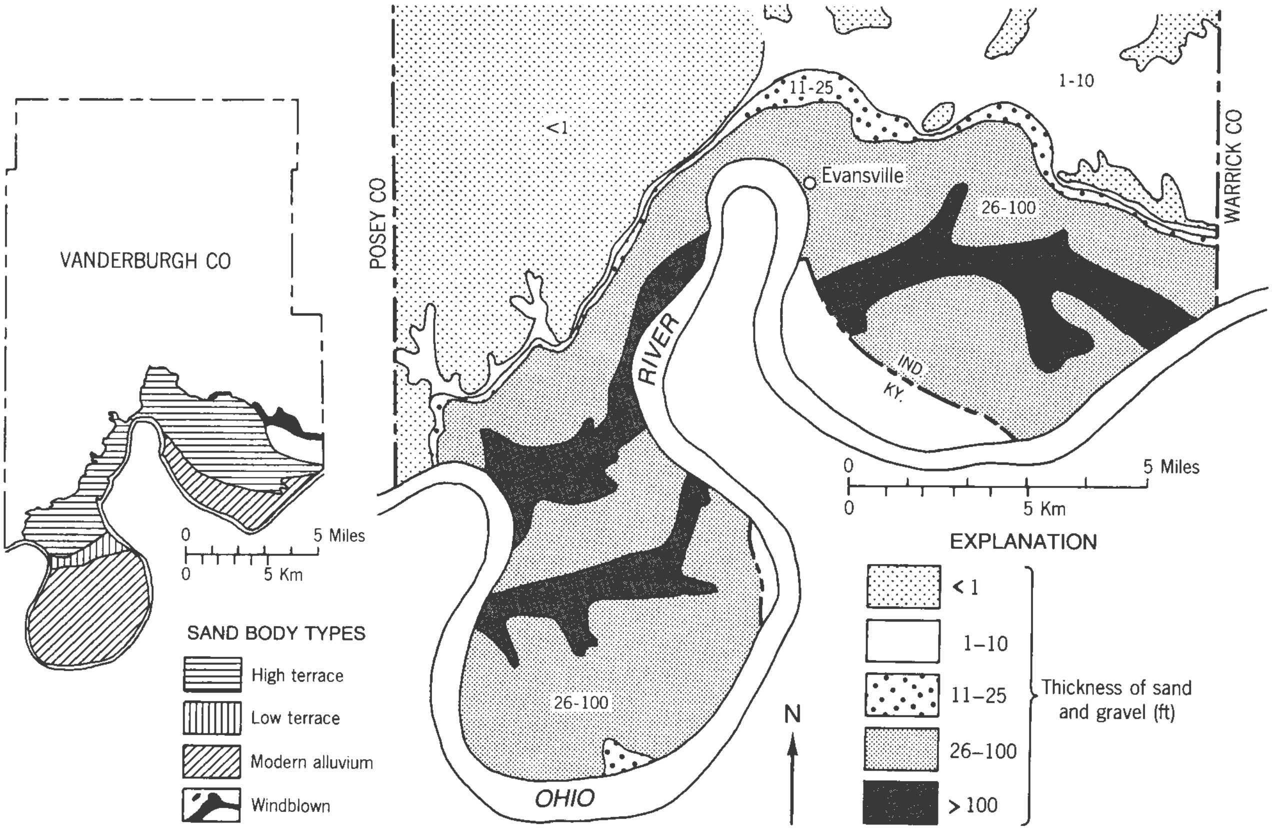


Figure 18. Map showing the thickness of sand and gravel deposits in the Evansville area.

area (Straw and others, 1977) in which the economic resources were identified and mapped. The present report locates the major sand and gravel deposits of the whole county, shows the thickness and the lateral extent of the most important ones, and assesses their economic potential.

OCCURRENCE OF SAND AND GRAVEL

There are four types of sand and gravel deposits in Vanderburgh County. These deposits, in order of importance, are: (1) valley-train deposits; (2) Holocene alluvium of the Ohio River valley; (3) windblown sands; and (4) Holocene alluvium of tributary streams. The first three of these are by far the most important volumetrically, and they are the only deposits with any economic potential.

VALLEY-TRAIN DEPOSITS

Valley-train deposits consist of sand and gravel with minor lenses of gray clayey silt. They fill the deep channel of the pre-Illinoian Ohio River valley and its tributaries and have aggraded the valley to an elevation of about 330 feet (100 m). Nearly all variation in thickness in these sediments (fig. 18) can be attributed to the irregular topography developed on the bedrock surface.

Valley-train deposits may be divided into three units. The basal unit, of pre-Wisconsinan age, is relatively coarse compared with the overlying units, but it is at great depth and is covered by a variable thickness of mud (fig. 9). The two overlying units are Woodfordian in age and have their source in the ice sheet that advanced into the Miami-Whitewater basin. The source of the deposits was, therefore, relatively far from Evansville, and the deposits are correspondingly fine grained. The two gravelly units may be correlated with the two separate advances that reached the basin. The first advance extended midway into the basin, but the second reached only the headwaters of the two rivers. Because the source of the second unit is farther upstream from the Evansville area than the first, its deposits are correspondingly finer grained.

The basal valley-train unit extends across the entire width of the valley. It is as much as 60 feet (18 m) thick, but it varies greatly in thickness because of irregular topography of the surface on which it is deposited. The middle unit also extends across the entire valley. It is as much as 90 feet (27 m) thick primarily because of postdepositional erosion during a minor late Woodfordian ice retreat. The upper unit does not extend across the valley. Instead, it is confined to the trough eroded into the underlying second-phase sediments. It in turn has been postdepositionally eroded, and because of irregularities in both upper and lower bounding surfaces it ranges from 0 to 20 feet (0 to 6 m) in thickness in the valley (fig. 14).

The total thickness of the valley-train deposits exceeds 100 feet (30 m) in the valley of the Ohio River (fig. 18). Over much of the rest of the valley the deposits range from 26 to 100 feet (8 to 30 m) in thickness and thin rapidly toward the margins of the valley. In general, the present valley wall is the lateral limit of the valley-train sediments, but sand and gravel deposits, which were the result of exceptional floods, carried coarse sediments short distances up tributaries. During the period of maximum valley-train alluviation these tributaries were the sites of lakes, and the sand and the gravel found near their mouths are commonly interbedded with lacustrine muds (fig. 14).

Within the valley-train sediments are notable variations in grain size. Coarsest sediments are at the base of the deposits, and relatively coarse sediments are at the top of the middle unit (fig. 9). Within the middle unit relatively coarse sediments are in the center of the valley where there is a core of uniformly gravelly sediments (fig. 14).

The economic potential of a sand and gravel deposit is determined not only by grain size and quantity but also by quality of the material. The quality of aggregate is a measure of its ability to withstand crushing, abrasion, and deterioration under freeze-thaw conditions and its capacity to absorb water and react with the constituents of the cement. Valley-train deposits throughout Indiana typically consist of a wide variety of rock types; some are unsuitable for use as aggregate because of various deleterious properties.

In general, carbonate rocks and metamorphic and igneous rocks produce high-quality aggregate because they are durable and chemically inert. Sandstones and mudstones tend to perform poorly as aggregate because they are soft and easily abraded. Sandstones especially tend to be highly absorptive and perform poorly in freeze-thaw tests. Cherts are hard and nonabsorptive, but some cherts react chemically with cement and therefore cause fracturing and popouts in concrete. The Indiana State Highway Commission classifies all chert with a bulk specific gravity less than 2.45 as potentially deleterious, and more than 5 percent of this chert type seriously reduces the quality of the aggregate.

Pebble counts of three gravelly zones in one test hole reveal a considerable variability in the composition of the valley-train deposits (table 3). Carbonate, igneous, and metamorphic rock types range from 70 percent in the upper part to a low of 56 percent in the middle of the deposit. Potentially deleterious rock types, especially clastic sedimentary rocks, range from 29 to 43 percent.

The pebble counts indicate that the coarse fraction of the deposit contains appreciable amounts of potentially deleterious material, especially soft clastic sedimentary rocks. The finer fraction, however, contains fewer deleterious particles, and quality-control tests run by the Indiana State Highway Commission (table 4) on a composite sample indicate that the sand could serve as Class A aggregate.

The major problem in using these deposits is the thickness of the overburden. The sands and the gravels are covered by overbank silts and clays and windblown sands and silts. As much as 30 feet (9 m) of this material has been deposited, and it would have to be stripped off the underlying sand and gravel before mining operations could begin. The overburden varies considerably in thickness. It

Table 3. Frequency occurrence (in percent) of clasts of various rock types of the +3/8-inch fraction

[Valley-train deposits were sampled from a drill hole in the SE¼SE¼SE¼ sec. 21, T. 7 S., R. 1 W.]

Sample interval (ft)	Probable age	Limestone (pct)	Dolomite (pct)	Chert (pct)	Sandstone/ Mudstone (pct)	Igneous (pct)	Metamorphic (pct)
30— 40	Late Woodfordian	2	47	12	17	21	0
50— 70	Early Woodfordian	4	7	12	31	43	2
105—115	Illinoian?	3	17	13	27	37	3

Table 4. Quality-control tests on a 14-2 sand (Indiana State Highway Commission designation)

[Sand was taken from a composite sample of splits from all borehole samples containing sand and gravel.]

Apparent specific gravity	Bulk specific gravity	Water absorption	Sulfate soundness loss (pct)	Los Angeles abrasion (pct)
2.732	2.544	2.70	2.67	30*

*Estimated.

is as little as 10 feet (3 m) thick along the margins of the valley, and as much as 30 feet (9 m) thick nearer the river.

HOLOCENE ALLUVIUM OF THE OHIO RIVER

The present Ohio River is currently flowing in broad meander loops that have migrated across the valley floor during the Holocene and left a broad, irregular sheet of channel sands at the base of the Holocene deposits. The sands rest directly on a scour surface on the underlying valley-train sediments. The sands are relatively thick in lows on this surface, and they thin markedly over highs (fig. 14).

The use of modern channel sands is limited. The material is fine grained relative to valley-train sands and gravels. It consists primarily of medium-grained sands with granules, and the number of aggregate grades capable of being produced from the material is severely limited. Also, the amount of fine-grained sediments as overburden and as interbeds presents serious problems to efficient exploitation.

WINDBLOWN SANDS

During the withdrawal of the ice from the Miami-Whitewater basin the unvegetated surface of the valley-train deposits was periodically stripped by wind of clay, silt, and fine sand. Clay and silt accumulated on the uplands as loess, and the sand was deposited in eolian dune ridges. One such ridge is in the southeastern part of Evansville where eolian sands as much as 50 feet (15 m) thick lie in a northwest-southeast ridge just south of the state hospital (fig. 18, inset). Several smaller ridges are nearby, and they, along with the larger ridge, rest directly on valley-train sediments.

Although loess was mined in the Evansville area for foundry sand until the mid-1960's, it has little economic potential at present. Dune sand is too fine to be used in bituminous mixes, and the Indiana State Highway Commission specifically prohibits the use of dune sand in asphalt. Although loess is satisfactory for use as a natural molding sand, the market for this product is almost nonexistent.

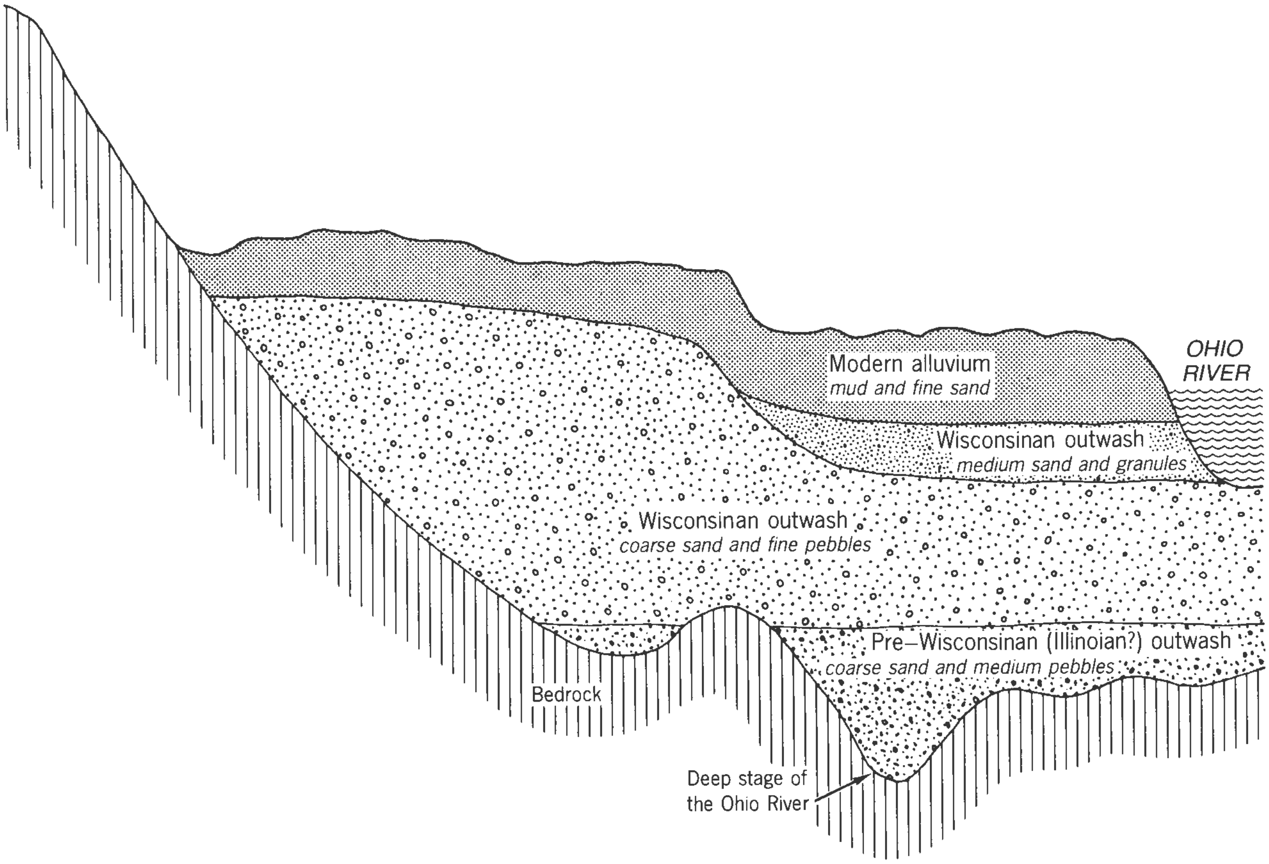


Figure 19. Exploration model showing sand and gravel resources in the Ohio River valley near Evansville.

HOLOCENE ALLUVIUM OF THE TRIBUTARIES

Alluvium has also been deposited in several tributaries of the Ohio River near Evansville. In the smaller streams a thin veneer of sand and locally derived gravels may be found, and in Pigeon Creek as much as 10 feet (3 m) of sand and gravel are present. These deposits have little resource potential because of their small size, generally fine grained nature, and poor quality of the coarse fraction and because of the thick lacustrine muds covering the Pigeon Creek deposits.

EXPLORATION MODEL

The value of a sand and gravel deposit depends not only on the bulk volume present but also on the volume of the material that can be used. To define those parts within a deposit that have the greatest value, an exploration model should be able to predict the places within a deposit that have the greatest concentration and widest range of grain sizes within the medium sand to coarse gravel grades.

In the absence of crushing equipment, clasts larger than 4 inches in diameter are normally considered oversized and therefore a waste product. Fine sand, silt, and clay are normally disseminated throughout even coarse gravel deposits and must be washed from material that is to be used as aggregate. Large concentrations of these fine-grained sediments constitute serious impediments to mining and must be either removed or bypassed as the desirable components of the deposit are extracted. Finally, if the sand to gravel ratio within the deposit is too high, the ability to produce coarser grades of aggregate will be impaired.

Pre-Wisconsinan valley-train deposits are coarse and well graded, but they are commonly interbedded with fine clay and mud. Also, their great depth below the surface probably prohibits economic exploitation (fig. 19).

The coarsest sediments of the Wisconsinan valley-train deposits accumulated during early Woodfordian time. These deposits form the high terraces lining the valley margins at elevations of 365 to 380 feet (110 to 115 m). The sands and the gravels are overlain by 15 to 20 feet (4 to 6 m) of dune sand covered by 5 to 10 feet (1.5 to 3 m) of silt and clay overburden. These high terraces contain the most economically attractive sand and gravel deposits because of the relative coarseness of the material and the thin amount of overburden. Problems, however, may be encountered near valley walls at the mouths of tributary streams where the sand and the gravel are in many places interbedded with lacustrine muds that would impede mining.

In the center of the valley, under the low bottomlands, coarse sand and gravel of early Woodfordian deposition were cut by a channel that was later filled by finer sand and gravel of late Woodfordian deposition and the channel deposits of the present river. Because of the relatively fine grained nature of these deposits, sand and gravel under the low bottomlands are not economically attractive. Also, these deposits are capped by 15 to 25 feet (4 to 7 m) of overbank silts and clays that have to be stripped before sand and gravel can be extracted. One factor favoring this area is that beneath the overburden and fine-grained sand and gravel are uniformly coarse deposits that form a core of gravelly material near the center of the valley.

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