Origin of Mid-Channel Islands in the Ohio River near Evansville, Indiana

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Abstract

Mid-channel islands in the Ohio River near Evansville have no obvious explanation if they are considered to be products of the modern hydraulic regime of the river. Their size, shape, and occurrence suggest that they did not originate as point bars, scroll bars, or alternate side bars. Analysis of changes in size, shape, and position of these islands laterally along the river, as well as changes through time, suggests that these islands are impediments to flow rather than results of it.

The islands initially form as shoal areas on cutbanks of the river channel. The shoals become detached from the cutbank when channels are eroded between them and the bank. As the shoals aggrade above water level and form islands the newly eroded channels begin to assume an increasing part of the riverflow, and eventually the thalweg shifts to the new channel. The old channel aggrades as the accretionary bank of the river migrates toward the islands, and in time the islands are welded to the accretionary bank and are incorporated into the flood plain.

The surface expression of the islands on the flood plain is one of broad ridges enclosed by much narrower ones that formed as scroll bars on point-bar surfaces. A series of closely spaced auger holes over one such ridge revealed a gravel core that probably was the original impediment to flow that initiated island formation. The gravel core itself probably represents a gravelly braid bar deposited as part of the valley train of the Ohio River that formed during the latter part of the Wisconsinan Age (Pleistocene Epoch).

Introduction

PURPOSE

The Ohio River flows generally westward for more than 1,700 km (1,000 miles) from West Virginia to its confluence with the Mississippi River. Over much of its course the river changes shape along various reaches in response to local variations in discharge, sediment load, gradient, and nature of the substrate over which it flows. Along much of its length, however, the channel is characterized by mid-channel islands.

The islands are variously shaped, and variations in geomorphic expression suggest that they owe their origin to more than one mechanism. Some are evidently remnants of meanders or parts of meanders that have been isolated from the flood plain (figs. 1A, B). Others probably originated by the emergence of scroll bars (fig. 1C) or alternating diagonal side bars (fig. 1D). Shoals at tributary mouths may also aggrade to the point of emergence (fig. 1E), spits of land separating tributaries from trunk streams may be cut off during flood periods, and remnants of these spits may be left as islands.

But the shape of still other islands is not characteristic of any of these modes of formation, nor can the shape of some be easily explained by application of current ideas of flow structure in rivers. Several such islands are found along a broadly meandering reach of the Ohio River downstream from Evansville, Ind. (fig. 2). Several of these islands have existed through historical times along this reach of the river, but others have become emergent only since the early part of this century, and all show some change in size and shape.

The purpose of this paper is to describe the characteristics of the islands in the Evansville area and to propose a model for their formation that takes into account the special features of flood-basin geology that affect their origin and later evolution.

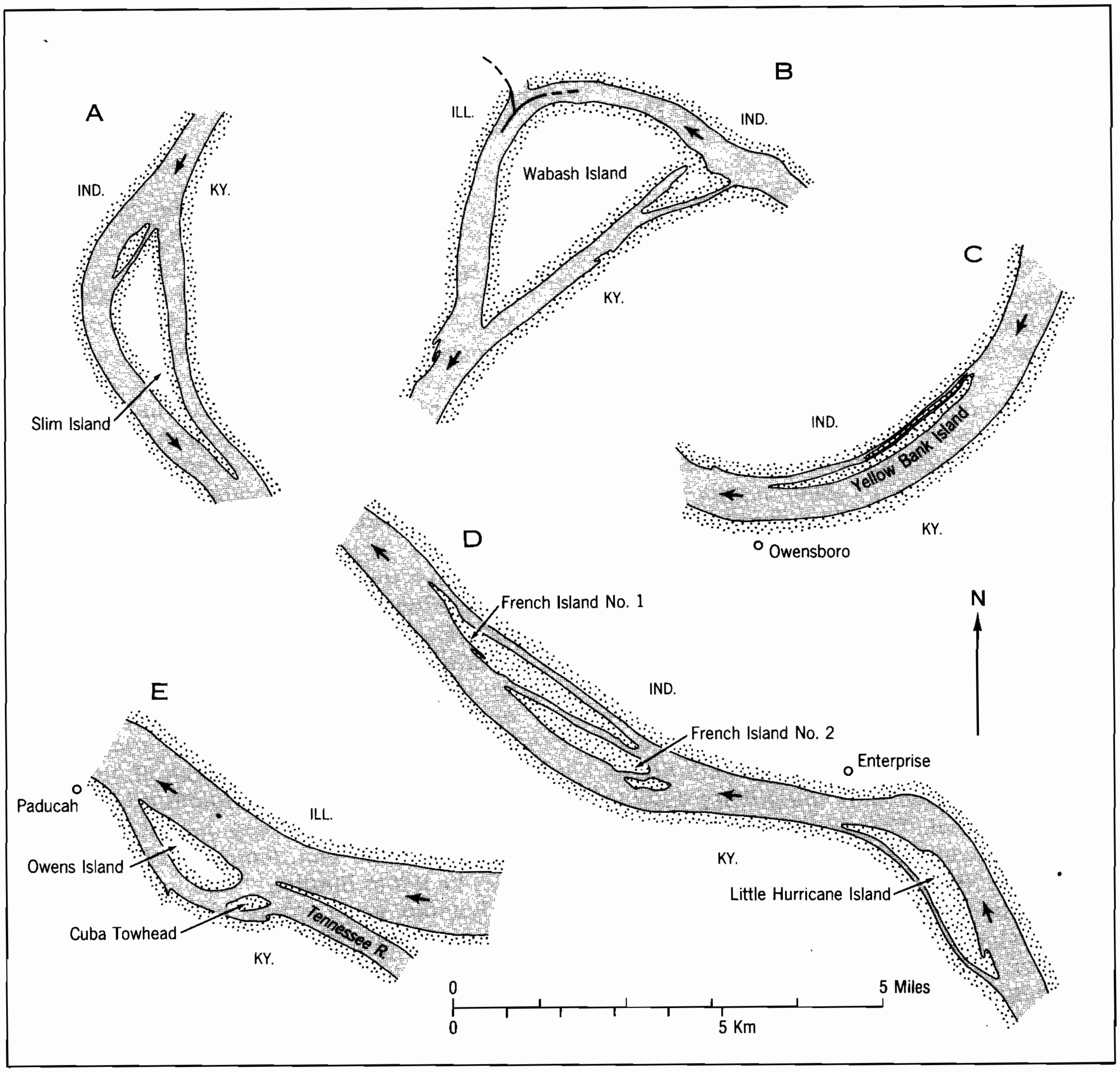

Figure 1. Maps of selected reaches of the Ohio River showing variations in the shape of mid-channel islands having different origins. A and B — chute cutoffs; C — emergent scroll bars; D — alternate side bars; E — deposition at tributary mouth.

METHODS OF INVESTIGATION

Study of these islands took place in two stages. During the first stage their occurrence and physiography were studied by using maps of the Ohio River flood basin prepared in 1966 by the U.S. Army Corps of Engineers. The maps were drawn at a scale of 1:2400 with a topographic-contour interval of 2.5 feet (1.3 m).

Although bathymetric contours are not shown on these maps, lines of depth soundings are displayed. The lines are spaced at 1-mile (1.7-km) intervals along the river and soundings along these lines are spaced at 50-foot (15-m) intervals. These depth soundings were used to construct bathymetric-contour maps of three areas along the river that show the relationship of the islands to the

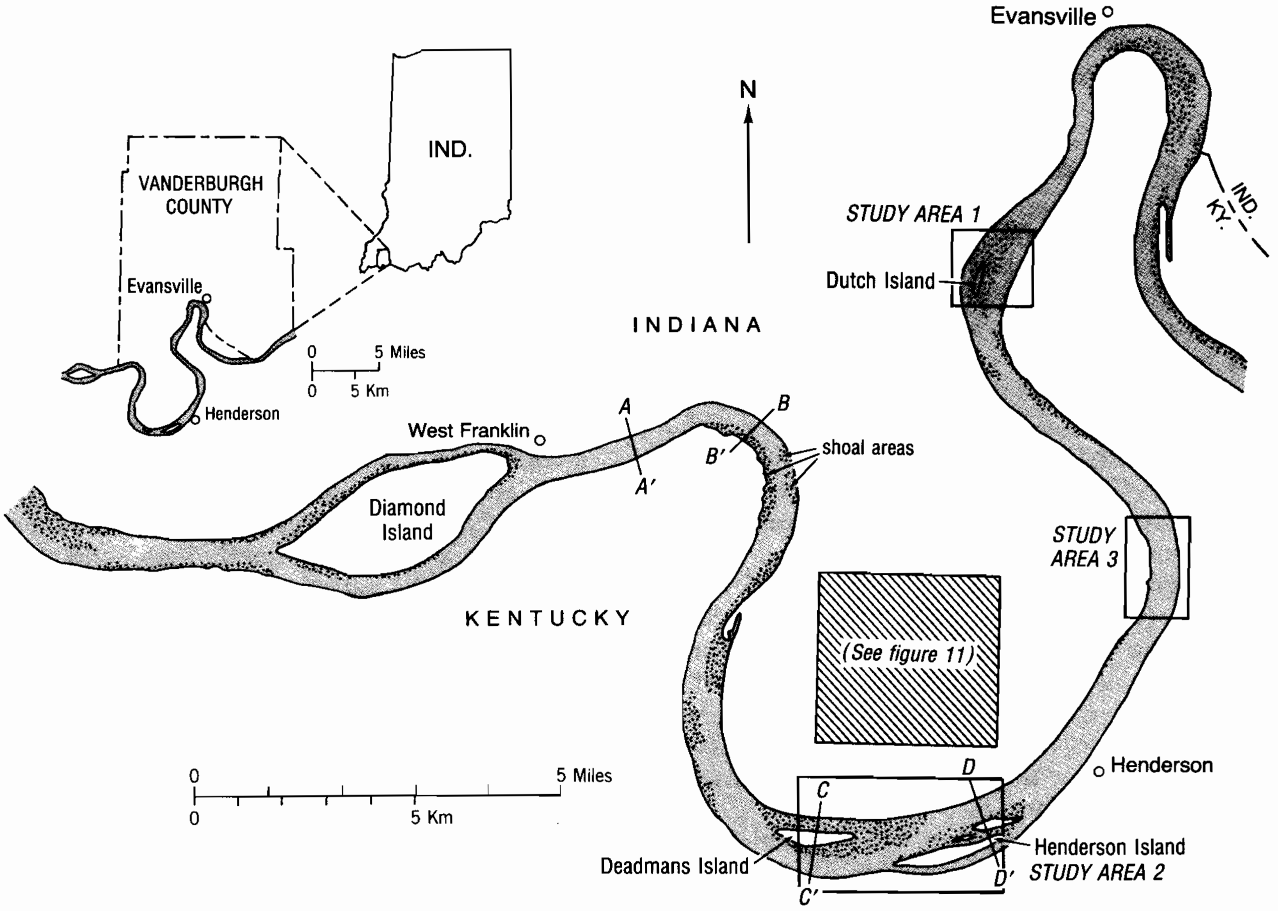

Figure 2. Map showing the part of the Ohio River near Evansville and the locations of the study areas and cross sections.

adjacent banks and, more importantly, to the geometry of the channel in their vicinity.

Historical changes in morphology and position of the islands were determined by comparing maps published in 1966 with maps published by the Corps of Engineers from 1911 to 1914. These latter maps were drawn at the same scale and with the same contour interval, and they also display lines of depth soundings from which bathymetric maps were constructed.

The channel of the Ohio River along the reach downstream from Evansville is migrating at rates of as much as 2 m (6.6 feet) per year (Fraser and Fishbaugh, 1986). As the channel migrates, sediment is eroded from the cutbank of the channel and is added to the accretionary bank, and flood-plain deposits accumulate over former positions of the channel.

Preliminary investigations suggested that the islands remain stationary as the channel migrates, so that, eventually, islands are incorporated into the flood plain behind the accretionary bank. In stage 2 of the investigation this hypothesis was tested by analyzing a series of seven holes drilled across a feature suspected of being one such island. The holes were drilled at an average spacing of 90 m (300 feet) and to an average depth of 12 m (40 feet). Samples were taken at 0.75-m (2.5-foot) intervals to define closely any vertical changes that might occur in the character of the sediment.

Sand (plus gravel), silt, and clay percentages were determined by wet-sieving and pipette analysis. Grain-size distributions of the sand and gravel fraction of each sample were determined by dry sieving on a set of screens at increments of 0.5ϕ. Mean size and standard deviation (sorting) were calculated by the method of moments.

Physiography and Geology

The Ohio River in the Evansville area flows in a valley cut into Pennsylvanian sandstones, shales, and coals that are relatively nonresistant to erosion. The valley is as much as 6.5 km (3.8 miles) wide, and the river meanders broadly over a substrate consisting of unconsolidated Pleistocene and Holocene alluvium. Only a few meanders are broad enough to impinge on the low bedrock hills that form the valley margin.

The river channel ranges between 0.5 and 1.2 km (0.3 and 0.7 mile) wide along this reach. The normal pool elevation of 104 m (342 feet) is controlled by the Uniontown Dam, which was completed in 1975. Before that date the pool elevation was fixed at 103 m (338 feet) by the Henderson Dam, which has since been removed.

Along straight reaches, the channel is narrow, and the cross-sectional shape is roughly symmetrical, although the thalweg tends to be displaced somewhat toward one side of the channel or the other where it erodes to a depth of 15 m (50 feet) below normal pool elevation (fig. 3, cross section AA′). At meander bends where no islands occur, however, the channel is asymmetric. The steep side is at the concave bank, and the gentle side, representing the point bar, is at the convex bank (fig. 3, cross section BB′). The thalweg is near the concave bank, where it may erode to depths as great as 10 m (33 feet) below normal pool elevation. Channels where point bars occur are as much as two times wider than those along straight reaches.

The channel shape along reaches where islands occur is irregular. A thalweg, eroding to depths of about 6 to 10 m (20 to 33 feet) below normal pool elevation, can normally be identified near the cutbank of the channel (fig. 3, cross sections CC′ and DD′). The islands are commonly flanked by broad shoals with margins that slope shallowly or steeply into adjacent channels. Channel widths are significantly greater than those where point bars occur, apparently to maintain the cross-sectional area needed to accommodate the discharge.

The surface of the flood plain is marked by a regular series of concentric ridges and swales that are more or less coincident with the trend of the river channel (fig. 4). The ridges probably formed as scroll bars, and the ridge-and-swale pattern reflects variations in the composition of the Holocene alluvium. The general alluvial sequence under the flood plain consists of a basal layer of medium fine-grained sand overlain by muds consisting of varying proportions of silt and clay. The thickness of the basal sand under the ridges, however, is two to three times greater than that under the swales, and the mud under the swales is consistently more clayey than that over the ridges (fig. 5).

This pattern of sediment distribution suggests that sedimentary processes differed markedly over ridges and in swales. During overbank flooding, water depths were presumably shallower over the ridges than in the troughs, which allowed mud to accumulate in the troughs and sand and silt to be deposited over ridges. Exceptionally deep troughs may also have remained as shallow ponds after recession of floodwaters because peat and organic clays have been found in two holes drilled in troughs eroded into the Pleistocene substrate.

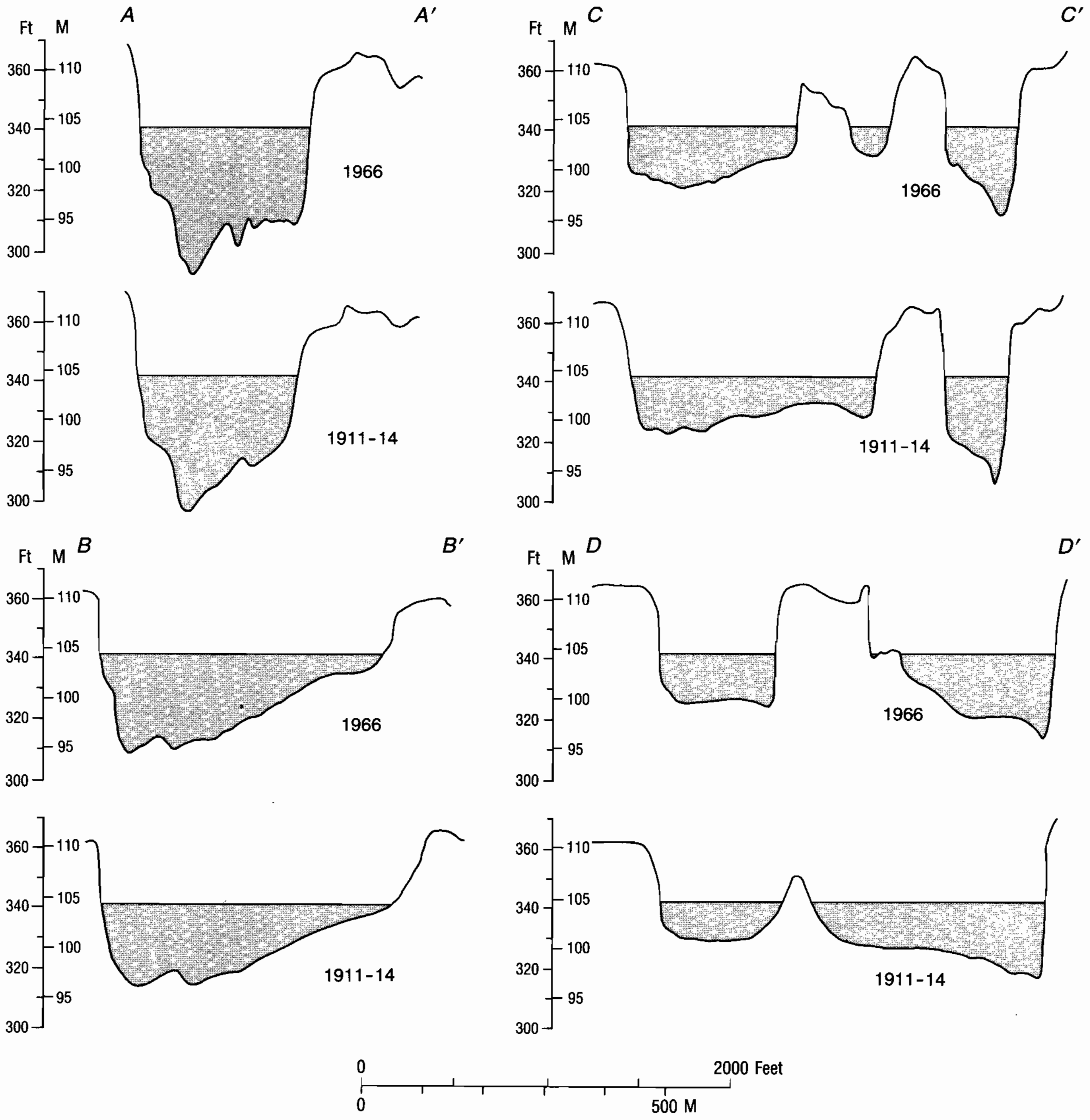

Figure 3. Representative cross sections showing channel profiles of the Ohio River near Evansville during the 1911-14 and 1966 surveys. Locations of the cross sections are shown in figure 2. Water levels have been adjusted to 1966 pool elevation.

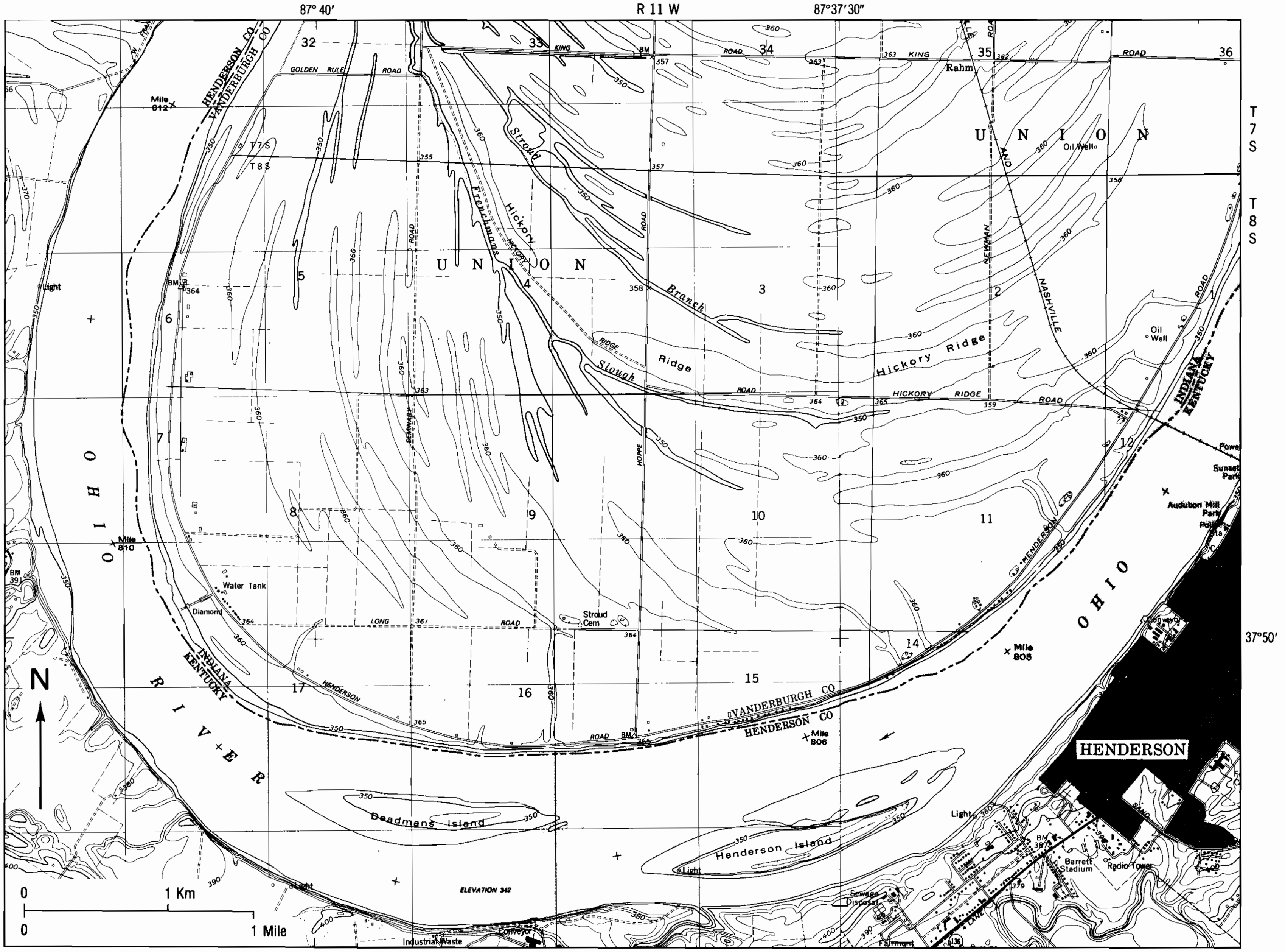

Figure 4. Topographic map of a part of the flood plain of the Ohio River near Evansville showing the ridge-and-swale topography characteristic of the flood plain. (See fig. 2 for approximate location.)

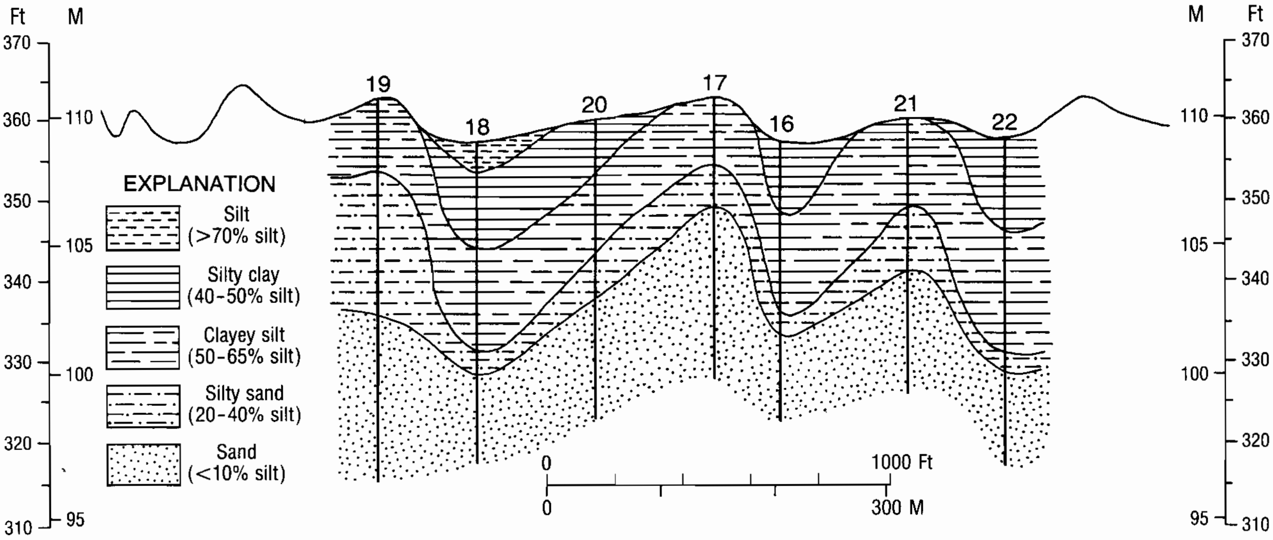

Figure 5. Cross section across a part of the flood plain of the Ohio River showing the internal architecture of the modern alluvium. Location of the cross section is shown in figure 11.

Characteristics of the Mid-Channel Islands

Three areas along the reach of river immediately downstream from Evansville were chosen for study (fig. 2). Two of the areas (1 and 2) contain mid-channel islands, and the third (3) contains a feature on the convex bank that probably represents an island in the process of being incorporated into the flood plain.

Study area 1 is about 4 km (2.4 miles) downstream from Evansville and contains a small island near the concave side of the river channel. The island is about 1 km (0.6 mile) long and 0.3 km (0.2 mile) wide. The island is elongate parallel to the channel axis, and it occupies the south (downstream) end of a bulbous shoal area that extends for about 2 km (1.2 miles) near the concave side of the channel (fig. 6). The shoal is separated from the bank by a shallow trough, and it is bounded on the concave side by the thalweg. Adjacent to the shoal, the thalweg is at an elevation of about 98 m (322 feet), but immediately upstream and downstream from the shoal, thalweg elevations are as low as 94 m (310 feet) and the channel width is somewhat narrower.

At the time of the earlier mapping (1911-14) the shoal area was smaller than at present, and an island had not yet emerged (fig. 6). The shoal was connected to the concave bank, although reentrants occurred at both upstream and downstream margins and therefore presaged the eventual separation of the shoal from the channel bank. The thalweg had the same approximate configuration at that time, but it was nearer the convex bank. Therefore, the principal change during the 50-year period was the emergence of the island from the shoal and its aggradation to the level of the flood plain at about 110 m (360 feet). In addition, a shallow channel separating the shoal from the concave bank was established.

Study area 2 is at the south end of the meander loop and consists of four islands (fig. 7). These islands are also in a shoal area that is near the concave bank of the channel, but here the shoal is separated from the bank by the thalweg, which descends to an elevation of about 95 m (310 feet). Two large islands, separated by a shallow channel, are en echelon along the shoal, and two small islands are on the northern flank of the easternmost (Henderson) large island. These islands are also arranged en echelon, and the three are separated by shallow (< 1 m deep) channels.

The islands also existed during the early mapping period, but their shape differed

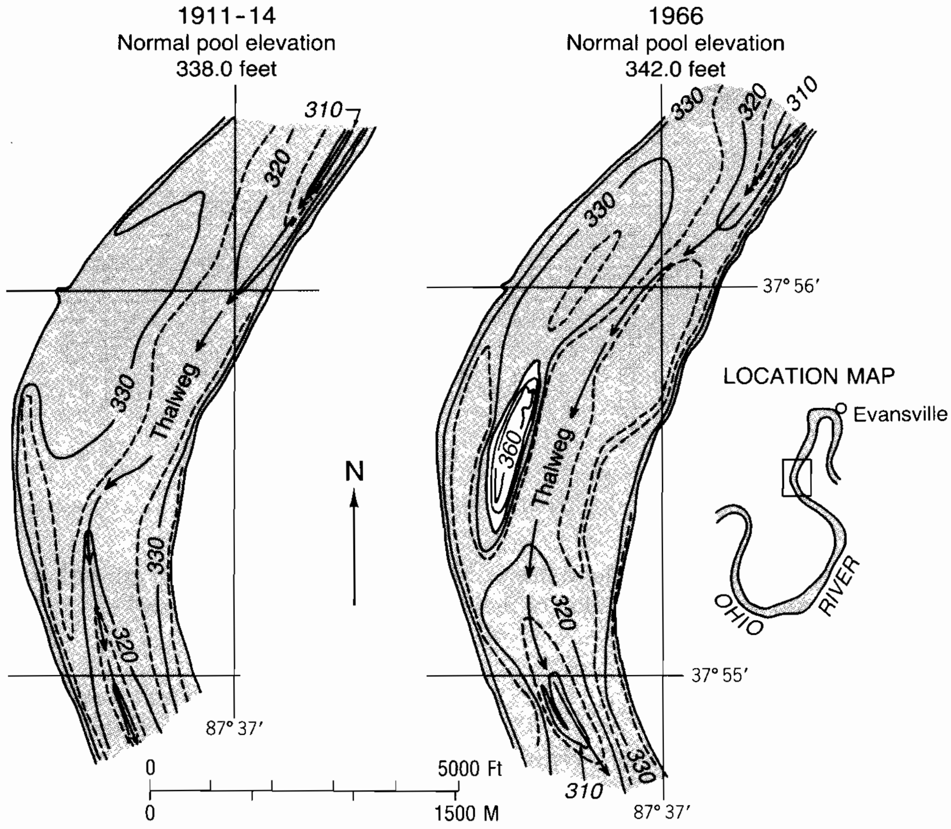

Figure 6. Map showing bathymetry of the channel in study area 1 drawn from depth soundings taken in 1911-14 and in 1966 by the U.S. Corps of Engineers. Contour interval is 10 feet. Datum is mean sea level. (See fig. 2.)

markedly from the present shape, and the bathymetry of the channel has also changed considerably. The westernmost island (Deadmans), especially, has grown during the 50-year interval, and the channel separating the two islands has aggraded from an elevation of about 97 m (320 feet) to its present elevation of 100 m (330 feet).

Most of the growth of Deadmans Island has occurred parallel to flow, both upstream and downstream, and to the south, transverse to flow (fig. 7). To accommodate the rapid growth of the island and to maintain the equilibrium cross-sectional area, the channel immediately south of the island has been deepened (figs. 7 and 3, cross section CC′).

The two small islands that appear on the 1966 map were not on the earlier map, but there was a shoal area on the north side of Henderson Island, and the two islands probably emerged from that shoal.

The major changes during the 50-year mapping interval were substantial growth of Deadmans Island, emergence of two islands on the north flank of Henderson Island, infilling of the channel north of the islands and of the shallow channel separating the two islands, and a concomitant deepening of the channel south of the islands.

Study area 3 is about midway between study areas 1 and 2 along a north-south reach of the river on the east side of the meander loop (fig. 2). There are no islands presently occupying the channel in the area, but the

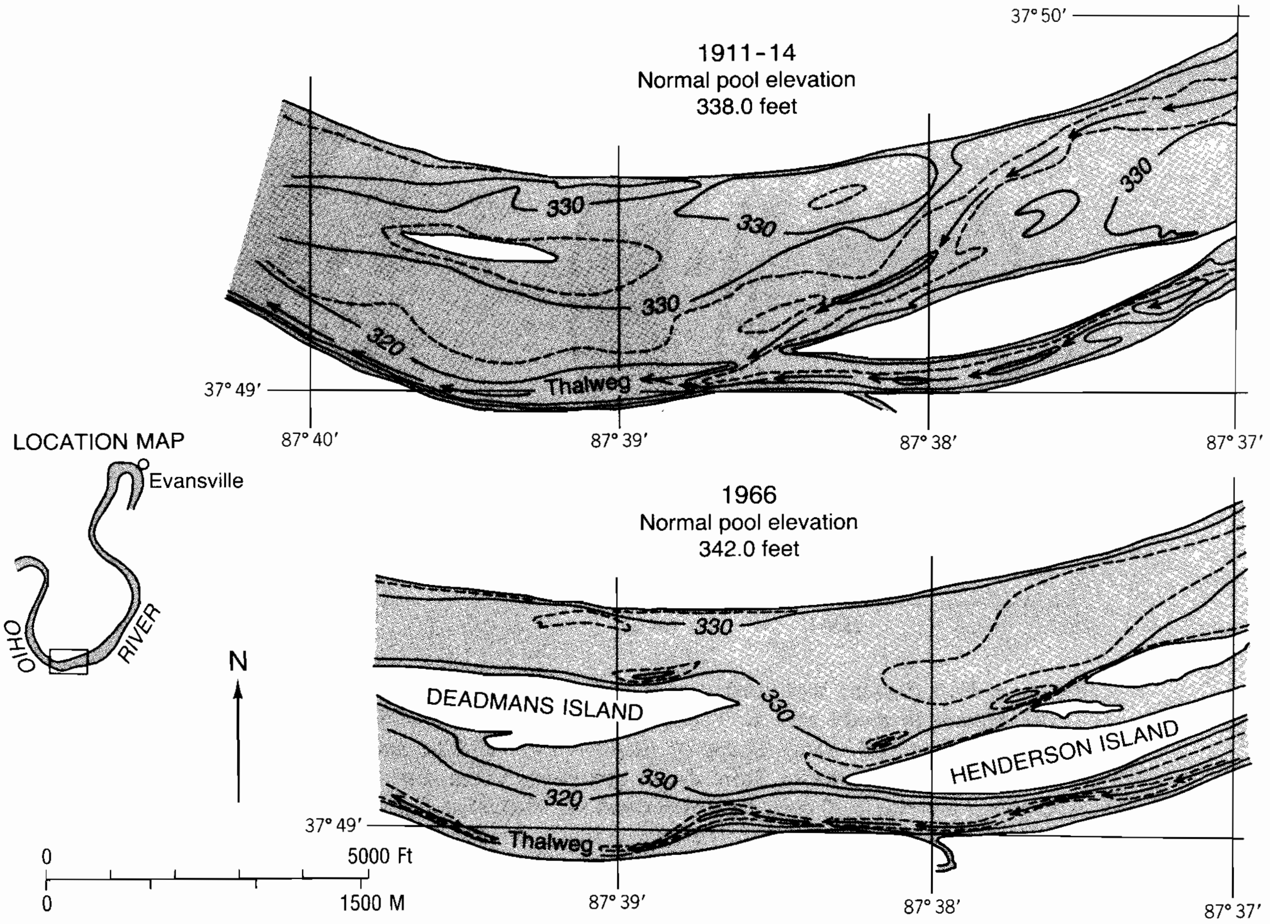

Figure 7. Map showing bathymetry of the channel in study area 2 drawn from depth soundings taken in 1911-14 and in 1966 by the U.S. Army Corps of Engineers. Contour interval is 10 feet. Datum is mean sea level. (See fig. 2.)

characteristics of a feature on the convex bank of the channel suggest that there was an island at one time.

Landward of the convex bank in the study area at the time of the first mapping, the flood plain rose to an elevation of about 110 m (360 feet) (fig. 8). A slope break occurred about 400 m (1,300 feet) west of the river's edge, and the land surface descended to an elevation of 107 m (350 feet) to form a shelf that separated the flood plain from the river. A narrow trough, descending to an elevation of about 103 m (340 feet), occurred at the toe of the slope break and separated the shelf from the flood plain. The southern part of the trough was occupied by a reentrant of the river channel that extended northward into the trough about 0.8 km (0.5 mile).

By 1966 the shelf had aggraded to the level of the flood plain, the trough was filled almost completely, the reentrant was cut off from the river, and only a narrow pond was left.

The shelf could represent a point bar that aggraded above water level, but because it is separated from the flood plain by the trough, the shelf more probably represents a former mid-channel island that became welded to the

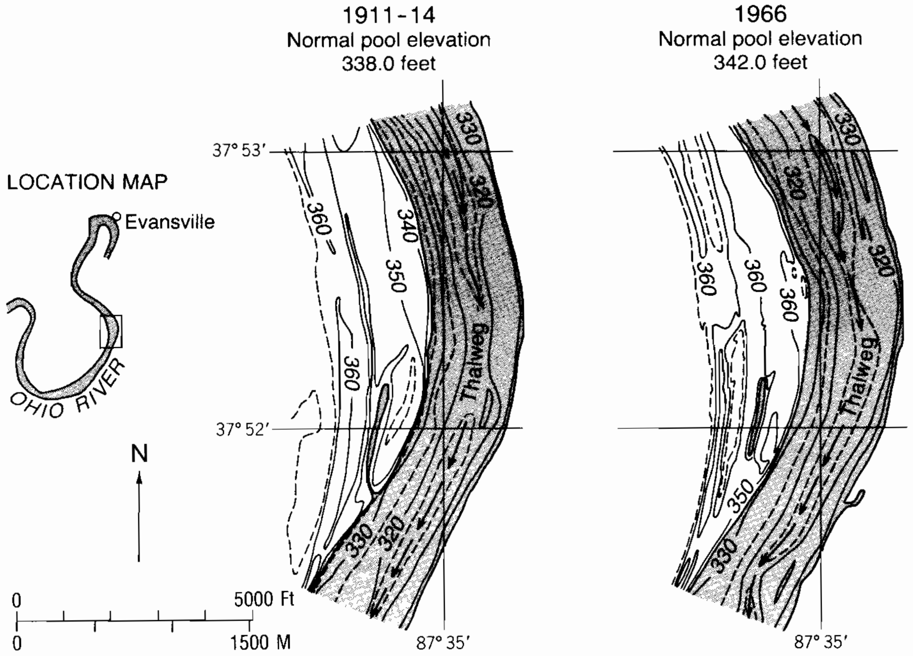

Figure 8. Map showing bathymetry of the channel and topography of the adjacent flood plain in study area 3. Topographic contours were taken from maps prepared by the U.S. Army Corps of Engineers in 1911-14 and in 1966. Bathymetric lines were drawn from depth soundings taken during the same years. Contour interval is 10 feet. Datum is mean sea level. (See fig. 2.)

flood plain as the convex bank advanced to the east. This implies that the island remained stable as the channel moved laterally.

Evolution of the Mid-Channel Islands

A complete evolutionary sequence cannot be seen because the time interval available for study is too short. The three study areas, however, can be taken to represent an ergodic sequence, so that spatial variations substitute for temporal ones. The data available to this study are not adequate to prove that differences in the characteristics of the channel, bank, and island morphologies among the three study areas represent stages in the evolution of mid-channel islands, but such an explanation is plausible. Therefore, Dutch Island in area 1 represents initial stages of island emergence, the islands in area 2 represent intermediate stages of island growth and channel diversion, and area 3 represents the ultimate inclusion of the islands into the accreting flood plain. If this premise is correct, a model for island evolution can be developed (fig. 9).

At the inception of island development (stage 1) a shoal area develops on the concave bank of a meander bend. Reentrants form at both upstream and downstream ends of the shoal (stage 2), and during stage 3 the shoal is detached from the bank and an island emerges. At some point (stage 4) a deep channel develops between the island and the concave bank, and the channel on the opposite side of the island aggrades as progressively more flow is diverted into the new thalweg.

During stage 5 the convex bank begins to accrete in the direction of the island, and by stage 6 the process of incorporation of the island into the accreting flood plain has begun. At stage 7 the island is welded to the flood plain, and its surface has aggraded to the level of the flood plain.

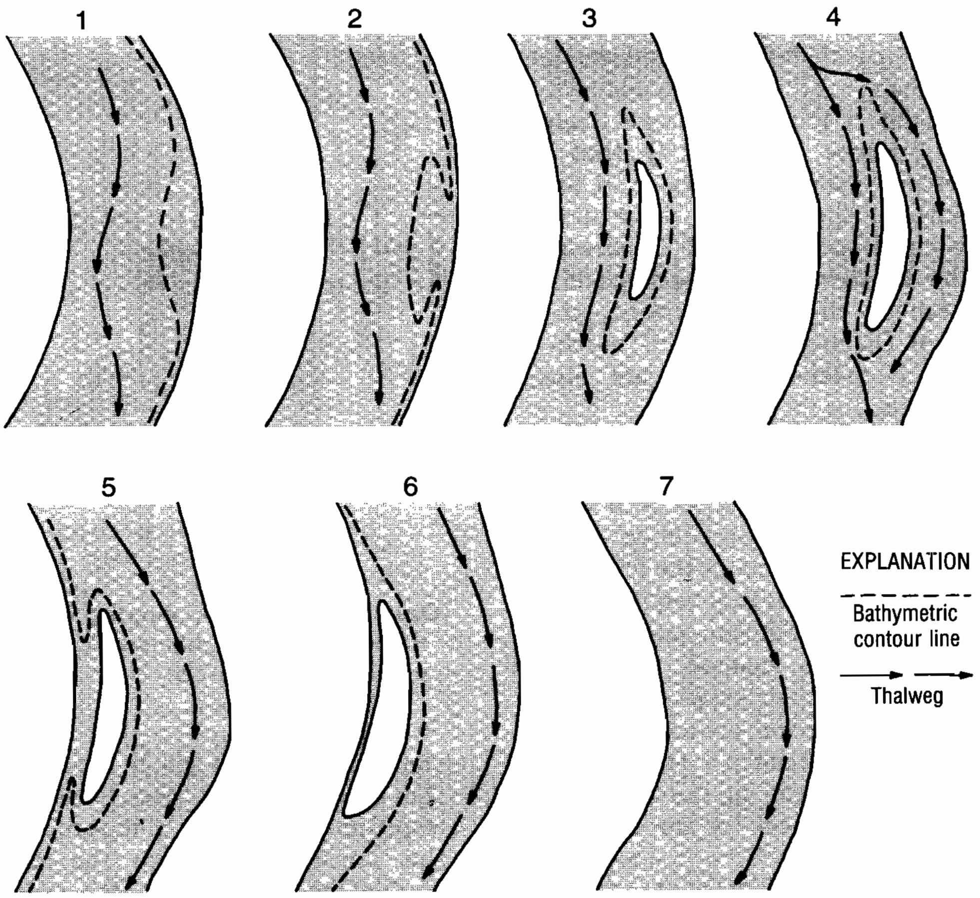

Figure 9. Model showing stages in the evolution of mid-channel islands.

The proposed model accounts for the development of mid-channel islands but does not account for the origin of the shoals. The simplest explanation involves the action of intrinsic processes within the stream to mold a shoal onto the channel. Flows on straight reaches or around large meanders commonly display a structure that consists of a lateral waveform that alternately impinges on one or the other bank of a channel and then swings away. Length of the wave has been established empirically to be about five to seven times the channel width, and this waveform appears to be the main cause of the rhythmic chute and pool topography found in most channels (Keller, 1971; Yang, 1971; Keller and Melhorn, 1973; Dietrich and Smith, 1984; Davies and Tinker, 1984). This mode of formation may, in fact, be the cause of some islands in the Ohio River (fig. 1D, for instance), and it is possible that this mechanism worked to form at least some of the islands near Evansville. By this method pools form where flow impinges on a bank, and shoals (or side bars) occur at points of flow divergence. Alternate side bars are common along the Ohio River, and some have emerged to form low-amplitude meanders (Gray, 1984).

Alternate side bars do occur along the reach of the river near Evansville and some have islands on them. But the features they display suggest that their occurrence is controlled by the islands and not that they are initial stages in the formation of islands. There is a weakly developed set of side bars downstream from Dutch Island, for instance, and there is a much better developed set downstream from Henderson Island (fig. 2). The occurrence of islands at the head of the two groups of alternate side bars suggests that the islands themselves initiated the laterally structured flow. In fact, because side bars do not occur upstream of the bars and because the side-bar configuration is lost downstream over a short distance, it is likely that a laterally structured flow is not stable in this reach. In addition, the presence of a deep channel between Henderson and Deadmans Islands and the adjacent bank is incompatible with the hypothesis, and the occurrence and characteristics of Diamond Island, just downstream from the meander bend, are also inconsistent with it.

Perhaps a more telling argument against the origin of the islands as emergent alternate side bars is the stability of the islands. Side bars are topographic elements constructed from sediment undergoing transport in the channel. As such, they are in hydraulic equilibrium with normal riverflow, and the topography should migrate with the channel. Although the islands may change their shape (primarily through accretion), they are elements in the channel, and any hypothesis for their origin must consider that material in the islands is apparently not transportable by the modern river.

Some islands in the Ohio River are cored by bedrock, but the channel downstream from Evansville flows in a valley that is thickly aggraded with alluvium of the Pleistocene Series and bedrock lies as much as 30 m (100 feet) below the level of the present channel floor (Fraser and Fishbaugh, 1986).

The Pleistocene sediments over which the channel flows, however, consist of interbedded sand and gravel deposited probably in braided-stream systems (Fraser and Fishbaugh, 1986). Deposition of gravel occurred on large bar forms, some of which are still visible on the surfaces of terraces that line the river valley (Ray, 1965; Fraser and Fishbaugh, 1986), and this material is much coarser than that currently being transported by the river. Gravels are laterally discontinuous, however, and the intervening channel deposits consist mainly of sand not significantly different from the bedload of the modern river.

The implication of the variation in grain size of the Pleistocene substrate is that the modern river can transport the Pleistocene channel sediments but is incapable of moving the gravels in the bars, which then act as impediments to flow. Supporting evidence for this contention lies in the nature of the contact between Pleistocene valley-train sediments and modern alluvium of the Holocene Series. A channel that has established an equilibrium profile erodes a nearly level surface as it migrates across a homogeneous substrate. Relief on the Pleistocene-Holocene contact of as much as 4 m (13 feet) (Fraser and Fishbaugh, 1986), therefore, suggests that the valley-train deposits are laterally heterogeneous.

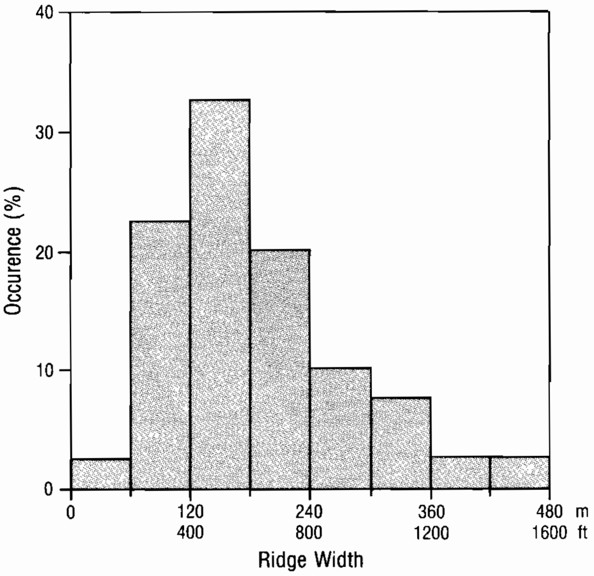

Figure 10. Histogram showing the distribution of ridge widths in the meander loop of the Ohio River southwest of Evansville.

Mid-channel islands form when the migrating channel of the modern river encounters Pleistocene gravel bars composed of sediments that it is incapable of transporting. Pleistocene bars are detached from cutbanks and form shoals as they split the flow. The shoals eventually aggrade above water level and form islands, and thalwegs shift from one side of the bar to the other. Because they are immobile, the islands are eventually incorporated into the flood plain of the accreting bank.

To test this hypothesis the second phase of the program was initiated to find such an

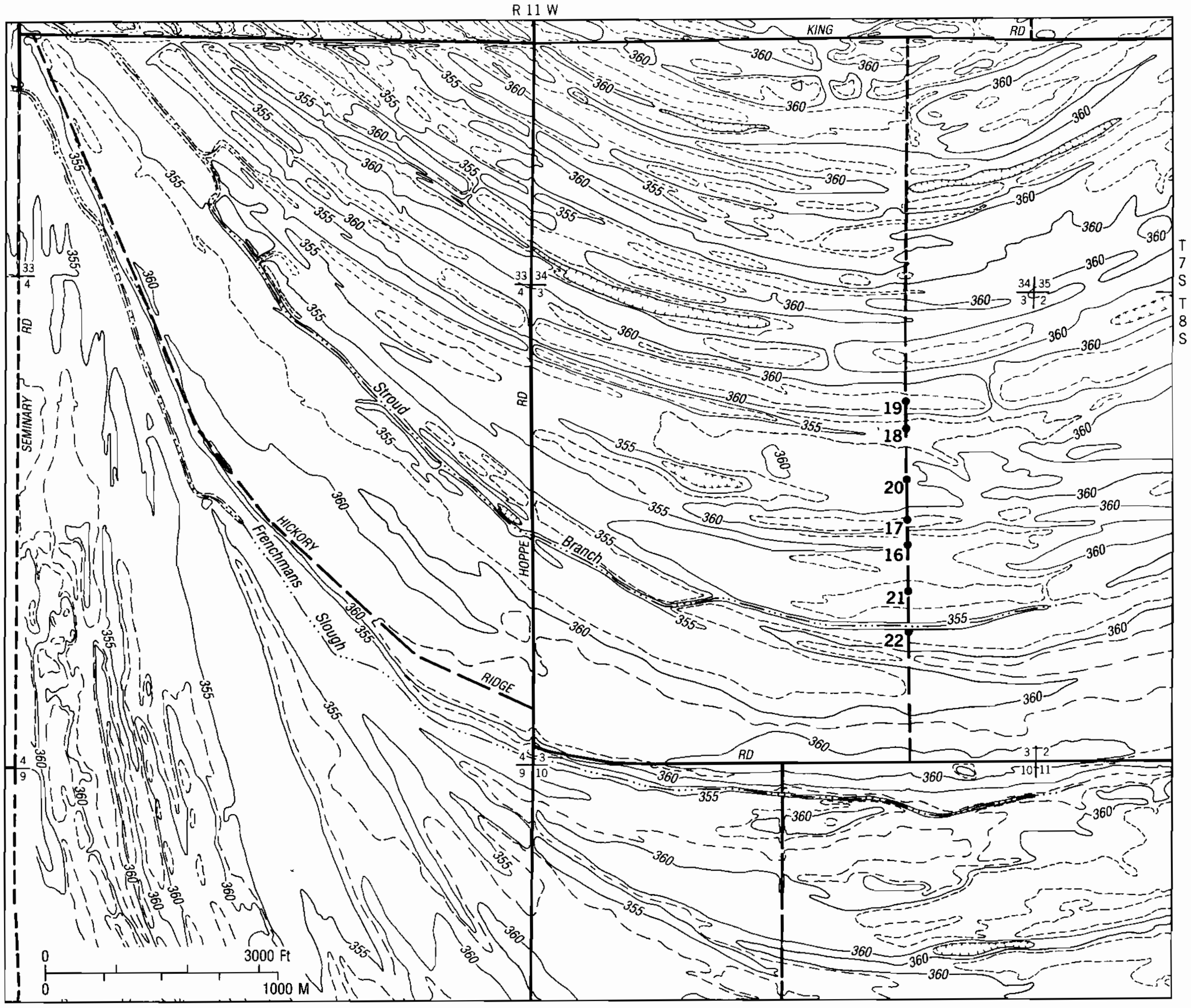

Figure 11. Topographic map of a part of the Ohio River flood plain near Evansville showing sets of long, narrow ridges interspersed with wider, shorter ones. Contour interval is 5 feet. Dashed lines are auxiliary contours. Symbols and numbers indicate drill-hole locations. (See shaded area in fig. 2 for map location.)

island in the flood plain of the meander loop and, through detailed analysis, to determine the nature of the valley-train sediments under the island, the nature of the contact between Pleistocene and Holocene alluvium, and the architecture of the overlying sediments.

The Ohio River flood plain displays a series of rhythmic, concentric ridges and swales in its meander loops that appear on first inspection to be remarkably regular in shape and spacing. Closer analysis, however, reveals that ridges join and bifurcate, are grouped into packets recognized by their angular relationships with adjacent packets, and have a wide range of shapes and spacings. About 80 percent of the ridges are less than 240 m (800 feet) wide (fig. 10), and these ridges probably represent emergent scroll bars formed by transverse flow moving up out of the thalweg onto the point-bar surface. The remaining 20 percent of the ridges are wider than 240 m (800 feet), and about 5 percent of them range from 360 to 480 m (1,200 to 1,600 feet) in width. Because this width is an appreciable

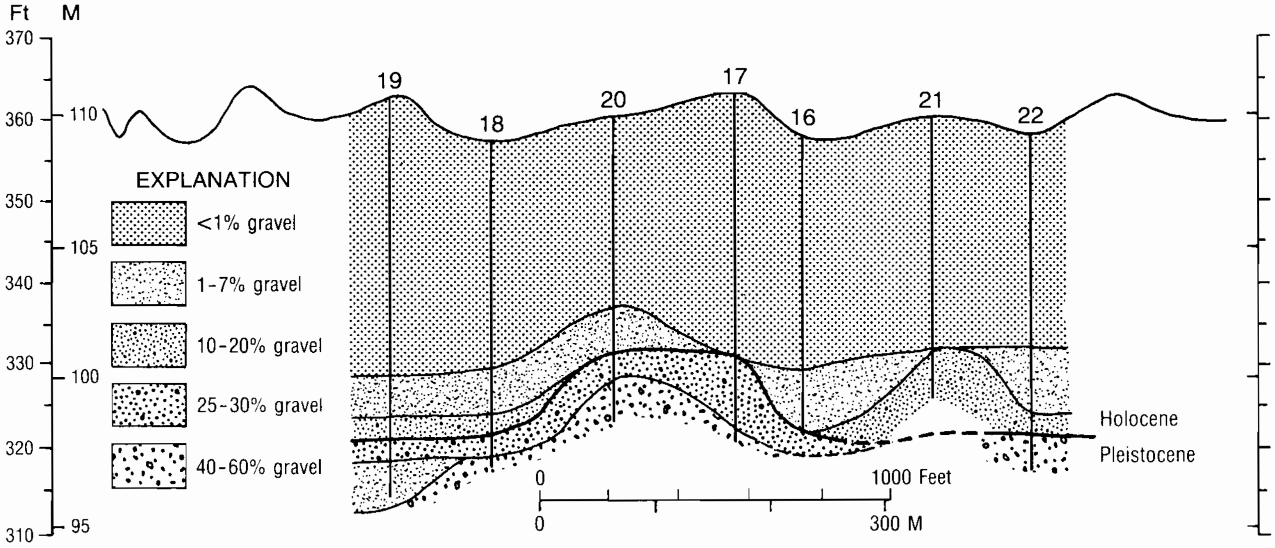

Figure 12. Cross section across a part of the flood plain of the Ohio River near Evansville showing the distribution of gravel within the sediments. Location of the cross section is shown in figure 11.

part of the channel width in the area, it is unlikely that such wide ridges are scroll bars. Although wider than their scroll-bar counterparts, these ridges are not so long, and they form lenticular areas with relatively flat surfaces embedded in a terrain characterized by narrow, highly elongate ridges (fig. 11).

These ridges are similar in shape and size to present mid-channel islands, and they likely represent islands that have been incorporated into the flood plain of the meander loop. One such ridge was chosen for detailed study, and a series of seven auger holes were drilled on a line transverse to the ridge crest (fig. 11). The line extends southward from a narrow ridge, across a broad ridge, and across another narrow one to a trough at the south end of the line.

The contact between the Holocene and Pleistocene alluvium in the valley can be determined by sediment grain sizes (Fraser and Fishbaugh, 1986). Pleistocene alluvium contains as much as 60 percent granules and fine pebbles, whereas the Holocene alluvium consists of sand with less than 20 percent granules and no pebbles. The contact along the line of cross section is at an elevation of about 98 m (321 feet) under the narrow ridges at either end of the cross section. That the contact even remains at that elevation under the troughs suggests that this is the depth of scour of the migrating thalweg (fig. 12). Under the broad ridge, however, the contact rises to an elevation of about 101 m (331 feet) and forms a core of coarse material. Significantly, the difference in elevation is the same as that from the surface of the shoal to the adjacent thalweg in study area 1.

The occurrence of this gravel core under the broad ridge supports the premise that broad ridges in the flood plain originated as islands whose position was controlled by remnant braid bars composed of sediments coarse enough to form impediments to flow in the modern Ohio River.

Discussion

All available evidence indicates that mid-channel islands near Evansville owe their origin to remnant Pleistocene braid bars of late Wisconsinan age that are positive features of the substrate over which the modern channel migrates.

The evidence suggests that:

(1) The islands are not obviously of another origin. They occur near concave banks, so they are not emergent point bars. They are

too wide to be emergent scroll bars, and they appear to be causes of alternate side bars where they occur rather than the result of side-bar formation.

(2) The islands are stable features that do not migrate as the channel shifts laterally. The islands serve as impediments to flow around which the thalweg must shift, and therefore they must be composed of materials resistant to entrainment by flow in the modern river.

(3) The islands eventually become incorporated into the flood plain as the accretionary bank migrates toward them and eventually engulfs them. This process is especially evident at study area 3. In addition, variations in ridge width on the flood plain suggest that not all ridges originated as scroll bars. Narrow ridges are compatible in width to scroll bars presently forming on the river, but wider ones more closely resemble in size and shape mid-channel islands.

(4) The contact between the Holocene and late Wisconsinan alluvium in the area is irregular, and this irregularity reflects the inability of the modern river to erode the substrate uniformly. In at least one example an elevated part of the contact is underlain by gravel and is coincident with a broad ridge on the surface of the flood plain. The elevated part of the contact may represent a remnant braid bar composed of materials too coarse to be transported by the modern river.

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