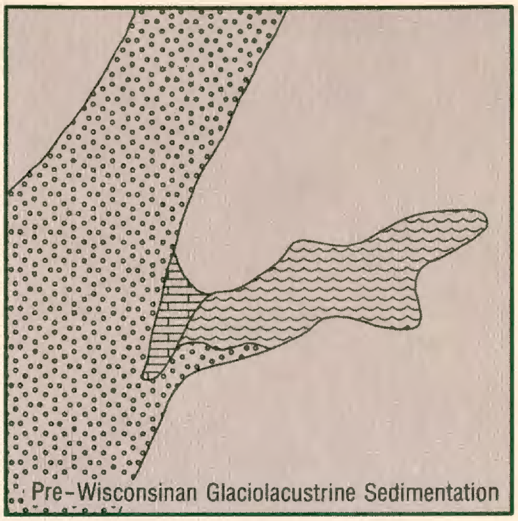
QUATERNARY EVOLUTION OF THE PRAIRIE CREEK LAKE BASIN, DAVIESS COUNTY, INDIANA

Special Report 53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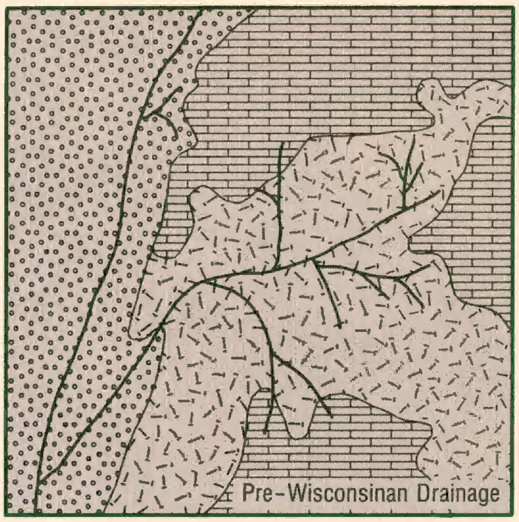
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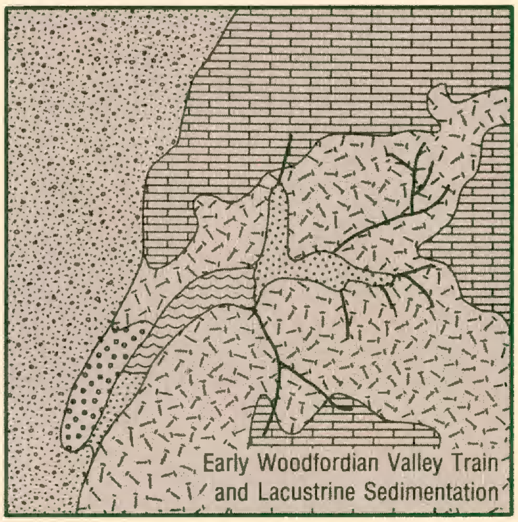
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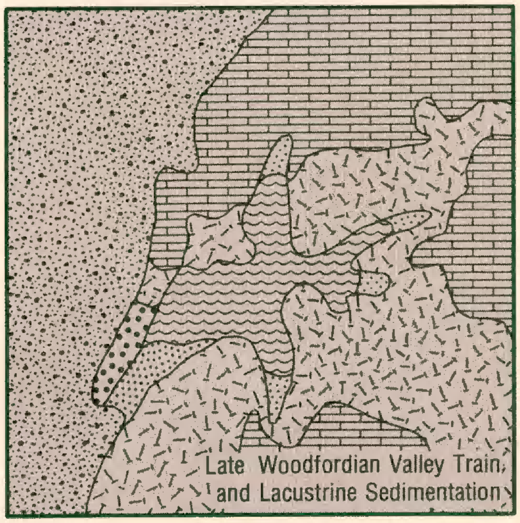
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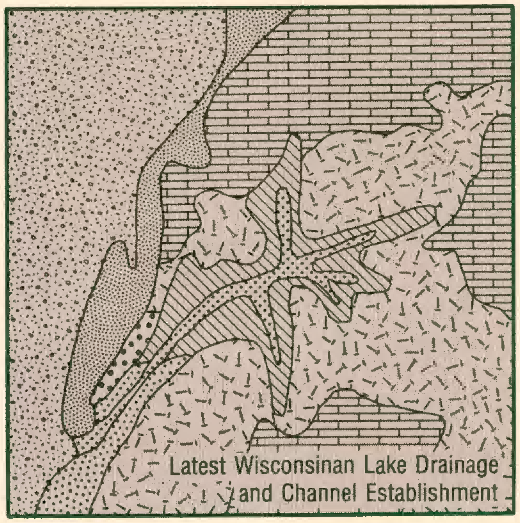
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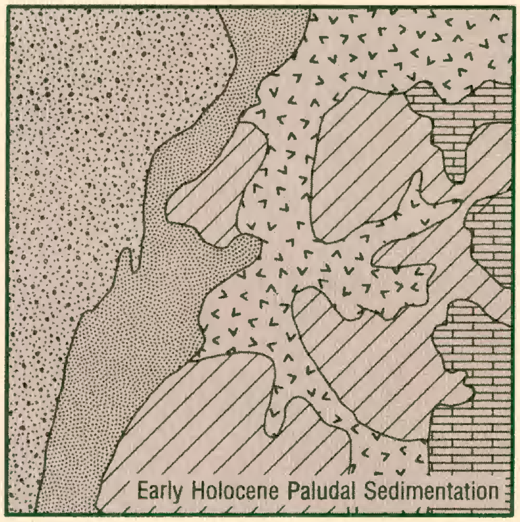
Early Holocene Paludal Sedimentation

State of Indiana
Department of Natural Resources
GEOLOGICAL SURVEY
At Indiana University

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Quaternary Evolution of the Prairie Creek Lake Basin, Daviess County, Indiana

By Gordon S. Fraser and Henry H. Gray

DEPARTMENT OF NATURAL RESOURCES
GEOLOGICAL SURVEY SPECIAL REPORT 53

1816

PRINTED BY AUTHORITY OF THE STATE OF INDIANA
BLOOMINGTON, INDIANA: 1992

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QUATERNARY EVOLUTION OF THE PRAIRIE CREEK LAKE BASIN, DAVIESS COUNTY, INDIANA

By Gordon S. Fraser and Henry H. Gray

ABSTRACT

Broad, nearly level plains occupy large areas in the upland valleys adjacent to the White River in Daviess County, Indiana. These plains are underlain principally by lacustrine muds and fluviodeltaic sands that were deposited during the Woodfordian Age (late Wisconsinan), but a variety of associated sediments, including eolian sands and loess, alluvial sands and muds, paludal muds, and glacial and glaciolacustrine sediments of varying textures are also present. The sediments are arranged in a complex architecture reflecting facies relationships, normal stratigraphic superposition, and inset stratigraphic relationships that reflect the direct and indirect effects of glacial ice in the White River drainage basin.

INTRODUCTION

BACKGROUND

Remnant deposits of lakes that occupied parts of southern Indiana during the Pleistocene Epoch seem first to have been recognized by Siebenthal (1897). He described glacial Lake Flatwoods in Owen and Monroe Counties as having been formed "on the retreat of the ice sheet," that is, as ice marginal (p. 302), and the fining-upward terrace deposits in the valley of Beanblossom Creek as having been deposited "from sluggish waters out of the lime [sic] of the direct current" (p. 303) of meltwater flowing down the presumably ponded valley. Siebenthal's observations were cited by Leverett (1899) and were a point of departure for Marsters's (1902) descriptions of "delta-like" accumulations of clay and sand in the valley of Beanblossom Creek. The "laking," according to Marsters, was caused "by the interference of the ice sheet" (p. 234) at the mouth of the valley.

It remained for Shaw (1911, 1915a), however, to describe fully the more common mode of origin of the glacial lakes as the result of "rapid filling of the channels of master streams so as to form dams across the mouths of the tributaries" (Shaw, 1915a, p. 142). He went on to say (p. 150) that "in order to understand the cause and history of the lakes, it is necessary to look into the history of the large rivers." Most subsequent investigators (Fidlar, 1948; Thornbury, 1950; Pratt, 1960; Straw, 1968; Gray, 1971, 1974; Frye and others, 1972; Heinrich, 1982) have accepted and elaborated on this concept of origin. Many of the later authors, having available to them more detailed subsurface data, have described more complex lake histories.

The Prairie Creek lake basin offered an opportunity to study this type of lacustrine sedimentation in fine detail because of the great quantity of very high quality subsurface information from driller's logs that was supplemented by data from outcrops, auger holes, and split-spoon cores. With this information it was possible to delineate the basin history and the architecture of the lacustrine sequences in greater detail than heretofore possible.

GEOGRAPHIC AND GEOLOGIC SETTING

Daviess County lies in southwestern Indiana about 90 miles (150Km) southwest of Indianapolis (fig. 1). The White River forms its western boundary, and it is bounded by the East Fork White River on the south. Greene and Martin Counties form its northern and eastern boundaries.

The physiography of the county consists of three principal features (fig. 1). Flat alluvial plains in the valleys of the White River and East Fork White River are underlain by a relatively thin veneer of fine-grained alluvium overlying much thicker deposits of sand and gravel. The alluvial plains are bounded by dissected uplands composed of bedrock mantled by till of probable Illinoian age and covered by a variable thickness of loess. Set within basins in the uplands are broad, nearly level plains underlain by muds and fine-grained sands that were deposited in a series of lakes that occupied the tributary valleys of the White River and East Fork White River during the Pleistocene Epoch.

The largest of these lake basins is just north of Washington and is roughly coincident with the Prairie Creek drainage basin. The pre-Pleistocene drainage network of this basin was deeply incised into the bedrock of Pennsylvanian age in the area, but Prairie Creek and its major tributaries are presently low-gradient streams that largely occupy artificial channels excavated into the nearly level surface of the basin-filling sediments.

METHODS OF INVESTIGATION

The character and internal architecture of the deposits in the Prairie Creek basin were determined by analyzing subsurface records from water wells, stratigraphic test wells, petroleum- and coal-exploration wells, and auger holes drilled by the Indiana Geological Survey. The stratigraphic test well data, supplied by Dr. George Otto of Linton, Ind., was particularly useful because of the relatively detailed description of the unconsolidated material overlying bedrock. Water-well records, on the other hand, normally provided information of variable quality and reliability and could only be used in context with other data. Petroleum- and coal-ex-

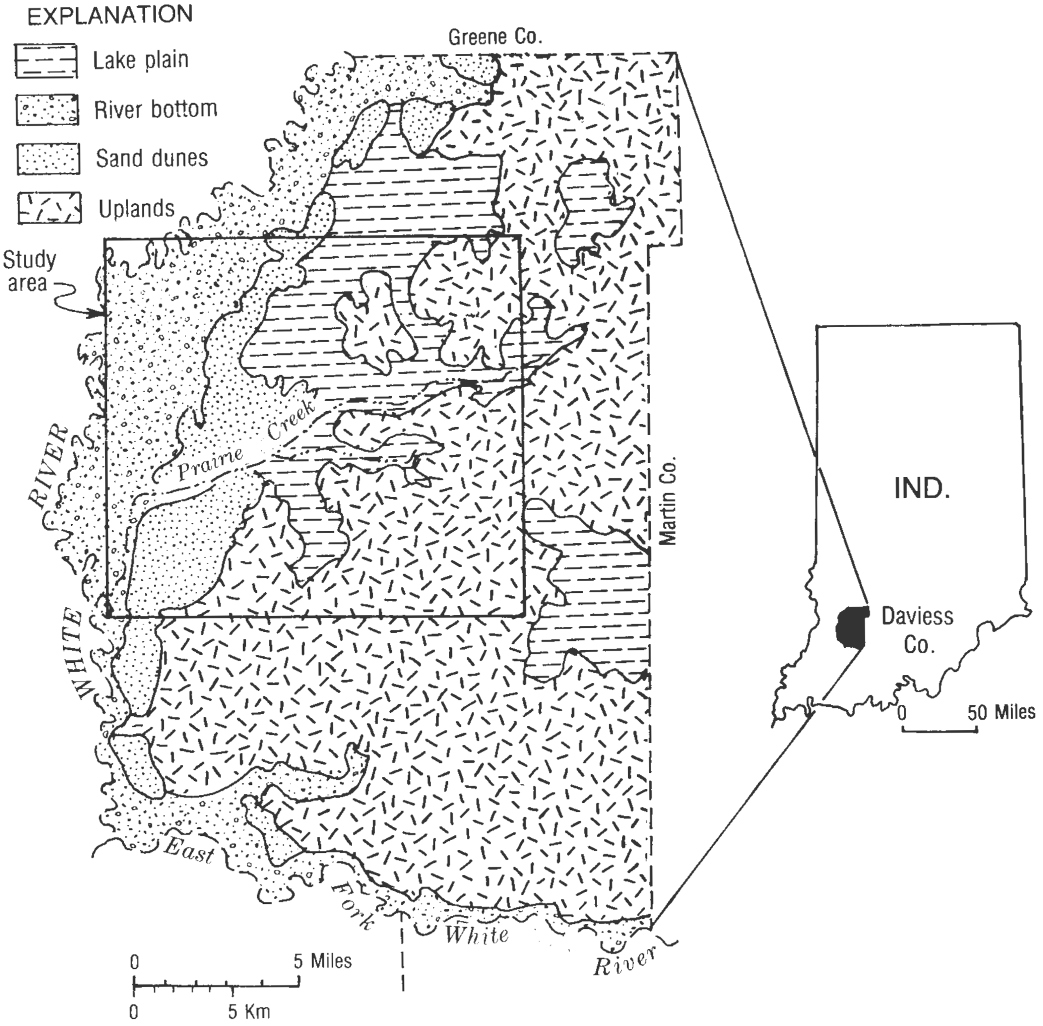

Figure 1. Map of Daviess County showing the location of the Prairie Creek drainage basin and its relationship to the principal physiographic features in the county.

ploration wells provided accurate information only about bedrock elevation and thickness of the overlying unconsolidated deposits.

The truck-mounted auger rig of the Indiana Geological Survey was used to drill a series of 16 holes in the Prairie Creek basin and in the valleys of the White River and East Fork White River. Samples from 4-inch solid-stem augers and 2-inch split-spoon tubes were used to determine primary sedimentary structures, grain-size characteristics, and mineralogy of the deposits. More than 200 samples were collected during the drilling operations, and an additional 50 samples were collected from natural outcrops along stream banks and in backhoe trenches.

Sand (plus gravel), silt, and clay percentages were determined for all samples by wet-sieving and pipette analysis. The grain-size distributions of the sand and gravel fraction were determined by dry sieving on a sieve set with 0.5 ϕ increments. The heavy-mineral fraction was separated from 11 samples, and clay-mineral analyses of about 100 samples were made to determine provenance of the sediments.

CHARACTER AND ORIGIN OF THE BASIN-FILLING SEDIMENTS

The unconsolidated sediments in the Prairie Creek basin consist of four basic textural types as defined by their varying percentages of sand (plus gravel), silt, and clay (fig. 2). These deposits are further subdivided by their occurrence in the basin and their probable mode of origin. These include two mud lithofacies consisting dominantly of varying proportions

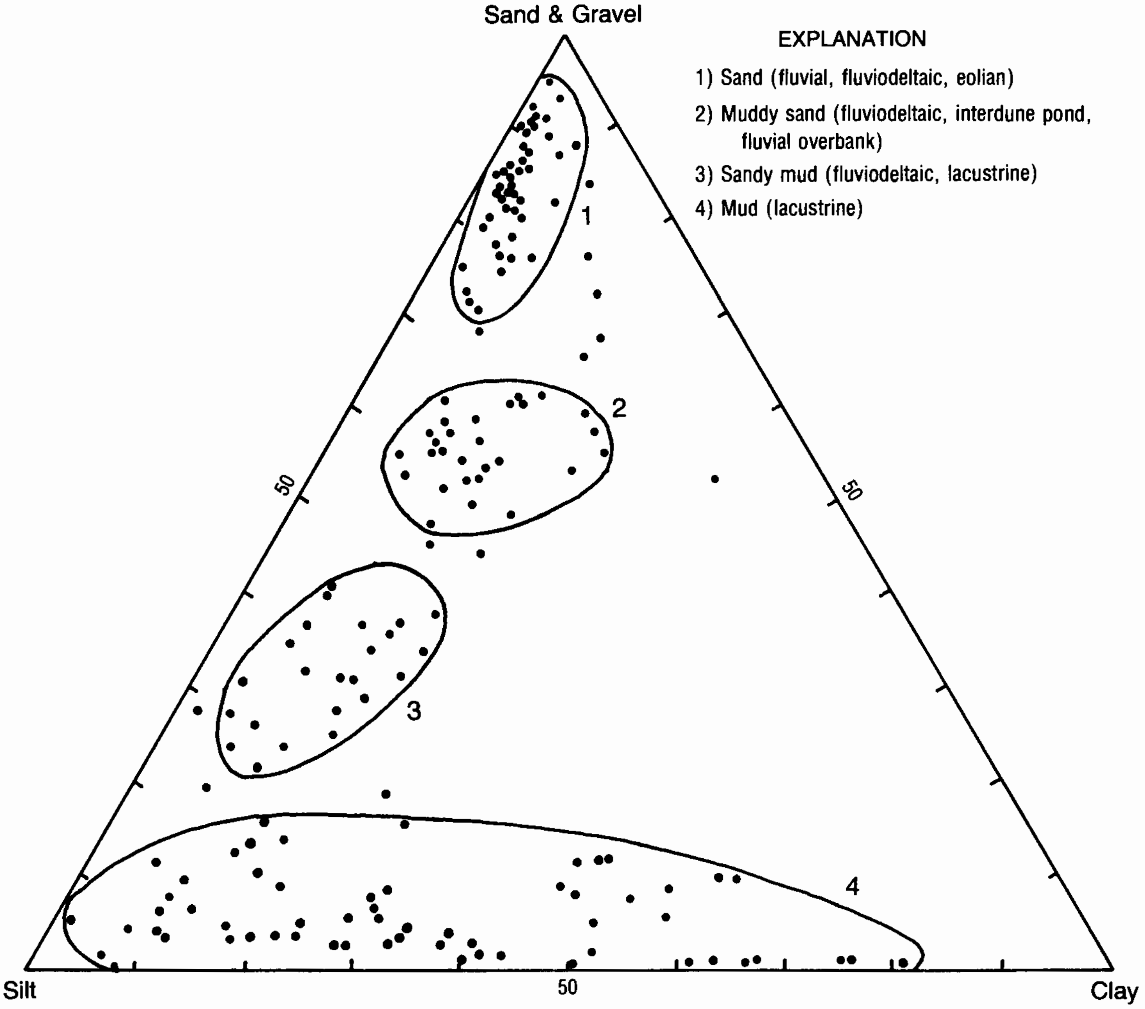

Figure 2. Ternary diagram showing the classification of the Quaternary sediments in the Prairie Creek basin by their relative proportions of sand and gravel, silt, and clay.

of silt and clay, two sandy mud lithofacies with as much as 50 percent sand, four muddy sand lithofacies consisting of sand mixed with 25 to 50 percent mud, and four sand lithofacies with less than 25 percent silt and clay (table 1).

MUD LITHOFACIES

Two types of mud lithofacies occur in the Prairie Creek basin (table 2). They contain less than 20 percent sand, and most contain less than 10 percent. Bulk samples consist of a mixture of silt and clay that varies in composition from dominantly silt to dominantly clay. Normally, however, these two components are segregated into silt-rich or clay-rich laminae 1 to 2 mm thick that are grouped into beds consisting dominantly of one or the other.

Muds are medium gray to black depending on texture and organic content. Clay-rich muds or those with a large organic content tend to be darker, but silt-rich muds are somewhat

Table 1. Textural characteristics of the four primary sediment types in the Quaternary deposits of the Prairie Creek basin

Sediment type	Sand (plus gravel) (pct)	Silt (pct)	Clay (pct)
Mud	7.7	58.6	33.7
Sandy mud	31.8	50.9	17.3
Muddy sand	58.4	28.3	13.3
Sand	85.0	9.9	5.1

Table 2. Textural characteristics of the two principal lithofacies comprising the muds in the Prairie Creek basin

Lithofacies	Sand (pct)	Silt (pct)	Clay (pct)
Paludal	7.8	40.0	52.2
Lacustrine	7.3	58.3	34.4

lighter. Organic material consists primarily of macerated plant material that includes debris from arboreal species, herbaceous pollen, and aquatic plants, such as pond lily, pond weed, and algae (Whitehead, written communication). Significant amounts of shell material including small bivalves and aquatic snails, are also present in the muds.

One mud lithofacies, which is at the top of the basin-filling sequence, is dark gray to black, has a high content of organic debris, and consists mainly of clay-sized material composed of as much as 90 percent Ca-smectite (fig. 3). This upper mud is devoid of structures except for orange mottling and root traces. It was deposited when the lake in the Prairie Creek basin was at its widest extent, but its texture, composition, high organic content, and lack of structures indicate that it was deposited in an environment ranging from shallow lacustrine to paludal.

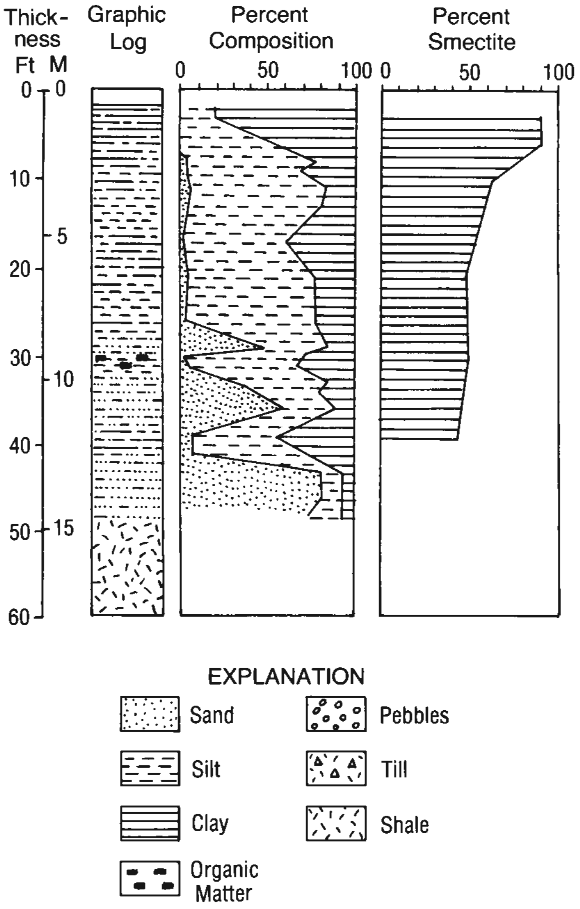

Figure 3. Diagram showing the graphic log, percent composition, and smectite content of sediments penetrated by an auger hole in the eastern part of the Prairie Creek basin. The lacustrine muds low in the sequence consist mainly of silt, and the small proportion of clays present consist of 50 percent or less smectite, but clay content and smectite content increase markedly at the top of the sequence. The auger hole is in the NE$^{1}/_{4}$NE$^{1}/_{4}$NE$^{1}/_{4}$ sec.31, T. 4 N., R. 6 W. The explanation of symbols shown here also serves for figures 4 through 8.

The other mud lithofacies has a significantly higher silt content and concomitantly lower clay content (table 2). In contrast with the paludal clay, it is finely laminated with silt-rich and clay-rich laminae as well as occasional laminae of very fine grained sand. Abundant disseminated plant material imparts a dark-gray to black color to much of this lithofacies, and fibrous plant material is abundant in places. Some horizons within this lithofacies contain concentrations of shelly material.

The delicate laminations characteristic of this lithofacies and the fine-grained nature of the sediment indicate deposition in a relatively deep water lake where the deposition of silt and very fine grained sand from slow-moving density currents alternated with the deposition of clay from suspension. Alternating beds consisting dominantly of silt-rich and clay-rich laminae probably reflect seasonal variations in density-flow frequency, and beds rich in plant material or shell debris probably represent periods of slow sediment influx, shallow lake depth, or seasonal variations in the rate of organic production.

This mode of deposition is also suggested by the pronounced textural variations that occur in the lacustrine muds in a direction perpendicular to the basin axis. Muds closest to the basin axis have a higher proportion of sand than those farther away, and the silt content is enriched at the expense of clay (fig. 4). This textural pattern is typical of mid- and upper-latitude lakes where sediment-laden waters enter lake basins as underflows that are generally confined to axial parts of the lake (Reineck and Singh, 1980). Marginal areas receive sediment settling out of suspension and only occasionally have spillover from especially thick underflows. Lacustrine muds in the axis of the basin, where the basin-filling sequence is thickest, are dominantly in the middle part of the succession where they are bounded at the top and at the bottom by sandier lithofacies (fig. 5). At the margins of the basin, however, the muds may make up almost the entire sequence.

SAND (PLUS GRAVEL) LITHOFACIES

The four sand lithofacies consist of 75 percent or more sand and gravel with varying admixtures of silt and clay. Sandy sediments are further differentiated by their occurrence and relationship to enclosing sediment bodies, shape of sand bodies, textural variations among the lithofacies, and variations in primary sedimentary structures.

Eolian sands are the finest grained and best sorted of the sand lithofacies (table 3). They are at the top of the basin-filling sequence along the south side of the basin and at the mouth of the basin near the White River. Eolian sands form a broad sheet in these areas, and in places they have accumulated into dunes as much as 30 feet high (fig. 6).

Two types of fluvial sands occur in the basin-filling sequence. Both are also medium fine grained, but they are

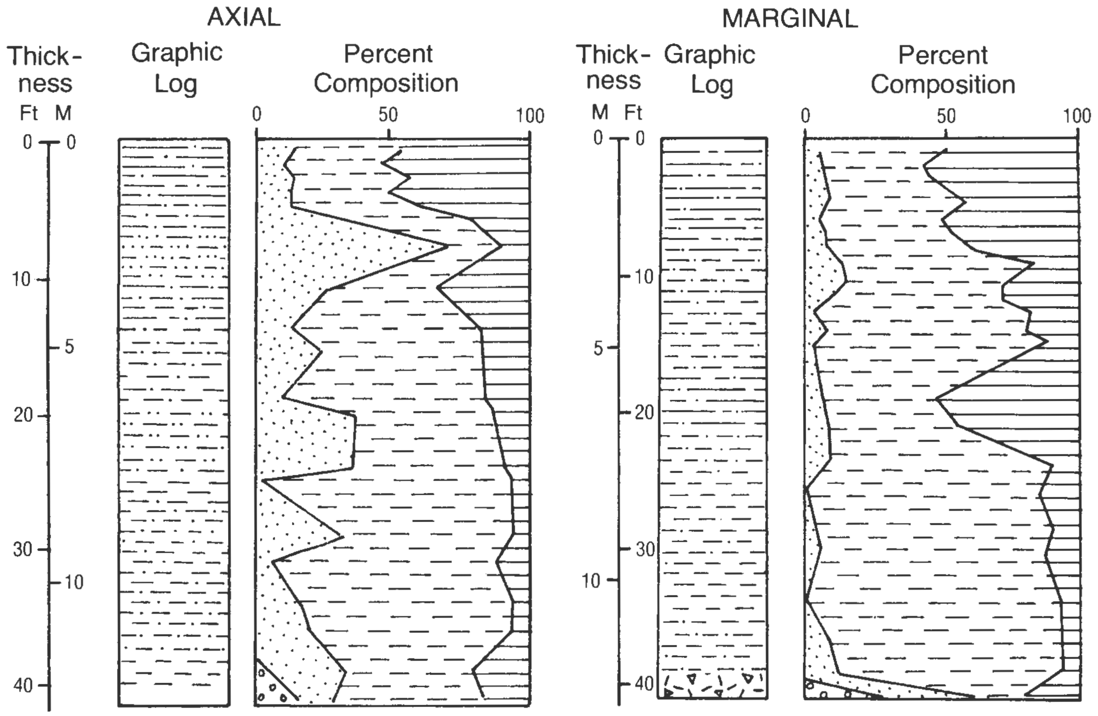

Figure 4. Diagram showing the textural variations between the lacustrine sediments deposited near the axis of the Prairie Creek basin and those deposited at the margin. The samples of lacustrine muds collected from an auger hole drilled near the basin axis have a higher sand and silt content than those from an auger hole drilled near the margin, and they are also interbedded with sandier lithofacies. The auger-hole locations are NE^1/4SE^1/4SE^1/4SE^1/4 sec. 2, T. 3 N., R. 7 W. (axial), and SE^1/4SE^1/4SE^1/4SE^1/4 sec. 2, T. 3 N., R. 7 W. (marginal). The explanation of symbols used is shown in figure 3.

considerably less well sorted than eolian sands (table 3). One of these types is at the base of the Wisconsinan sequence where it fills paleovalleys (fig. 5). These sands contain abundant granules including coal, sandstone, and mudstone intraclasts indicative of a local origin. They also have a relatively large component of silt and clay. Some of the mud fraction is disseminated in the sands and is probably the result of postdepositional infiltration from overlying sediments. Muds also occur as thin laminae and discontinuous stringers, and these were probably deposited from suspension during periods when active sediment transport was not taking place.

These basal fluvial sands occur in pronounced fining-upward sequences. Such an occurrence may be the result of deposition on the point bar of a meandering stream where sands become finer grained in shallower water in response to progressive reduction in shear stress. But the range in grain size from coarsest to finest displayed in these sequences is greater than that normally derived from such a process. The fact that the sands are overlain rather abruptly by lacustrine muds and sandy muds (figs. 5 and 7) indicates that the pronounced fining-upward sequences they display result from a reduction in stream gradient caused by rising base level during lacustrine onlap.

The second type of fluvial sand lithofacies occurs at the top of the basin-filling sequence where it overlies fluviodeltaic sands with an erosional contact and is in lateral erosional contact with eolian sands. These sands are also medium to fine grained and moderately sorted, although they tend to be somewhat finer grained than basal fluvial sands, especially in the coarsest 1-percentile fraction (table 3). Primary sedimentary structures include horizontal laminae, trough and tabular crossbedding, and cut-and-fill structures where crossbedded sands fill broad shallow channels with scoured bases (fig.8).

Two separate episodes of channel erosion and in-filling are evident in the upper fluvial sands. Radiocarbon dates of abundant plant and animal macrofossils associated with the deposits indicate that the first of these episodes occurred sometime after 14,000 years before the present (bp). The faunal remains consist of a diverse assemblage that includes both terrestrial and aquatic species characteristic of a cold climate (Munson, written communication). That the plant macrofossils are dominantly spruce also indicates a boreal climate (Jackson and Whitehead, written communication). Other plant fossils include pollen and macrofossils of larch and fir indicative of moist soil conditions, *Myriophyllum* and *Charra* that grew in perennially flooded areas, such shoreline species as *Carex* and *Eleocharis acicularis*, and *Chenopodium* and *Eupatorium* that probably colonized newly exposed mudflats. Large peat clasts are also in the sands. These data indicate that the first episode of deposition of the upper fluvial

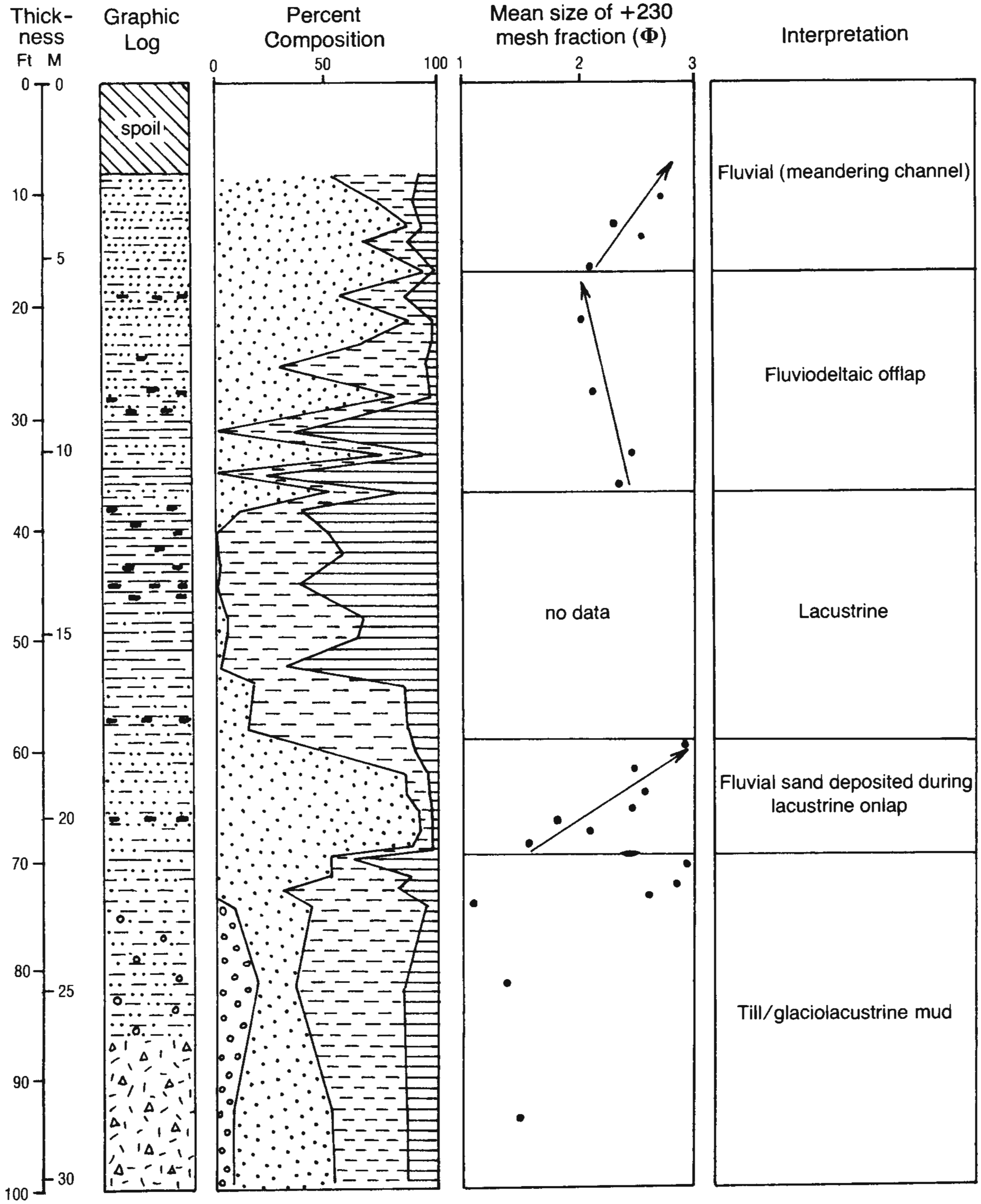

Figure 5. Diagram showing the graphic log, textural parameters, and inferred environments of deposition of sediments penetrated by an auger hole drilled in the axis of the Prairie Creek basin. The till and glaciolacustrine muds in the basal 40 feet of the succession are of probable Illinoian age. They are overlain by fluvial sands deposited during a phase of lake expansion that culminated in the deposition of a thick sequence of lacustrine muds. The lacustrine muds are overlain by sandier fluviodeltaic lithofacies deposited during a period of fluctuating lake level, and the succession is capped by a fining-upward fluvial sequence. The auger hole is in the N1/2NW1/4NE1/4NE1/4 sec. 10, T. 3 N., R. 7 W. The explanation of symbols is shown in figure 3.

Table 3. Textural characteristics of the principal lithofacies comprising the sands in the Prairie Creek basin

Lithofacies	Sand (pct)	Silt (pct)	Clay (pct)	Mean size (ϕ)	Coarsest 1 percentile (ϕ)
Eolian	88.1	8.0	3.9	2.40	1.10
Fluvial (upper)	90.1	7.1	2.8	2.26	1.14
Fluvial (lower)	82.2	10.7	7.1	2.33	0.78
Fluviodeltaic	81.9	14.6	3.5	2.31	1.06

lithofacies occurred in channels cut into the exposed lake bottom soon after it drained.

Radiocarbon dates derived from samples of transported woody material included in the channel-sand deposits indicate that the second episode of fluvial deposition began as early as 4,000 years bp and ended as late as 3,000 years bp. These fluvial sediments consist of crossbedded medium- to coarse-grained sands in relatively thin fining-upward sequences. The coarser sands at the base of the channels grade upward to medium fine grained sands with silt and clay in abundant stringers and laminae (fig. 8). The sands in the lower part of the sequence fill shallow imbricate channels that were apparently cut and filled by a laterally migrating stream (fig. 8). The sediments in the upper part of the sequence were probably deposited in a proximal overbank setting where active bedload transport was periodically interrupted by slack-water periods when mud settled out of suspension. The relative thinness of the deposits, the evidence of lateral accretion in the pattern of channel scours, and the pronounced fining-upward tendency of the deposits indicate that these uppermost fluvial sands were deposited by a shallow meandering stream.

The fourth sand lithofacies in the basin-filling sequence consists of fluviodeltaic sands deposited during those times

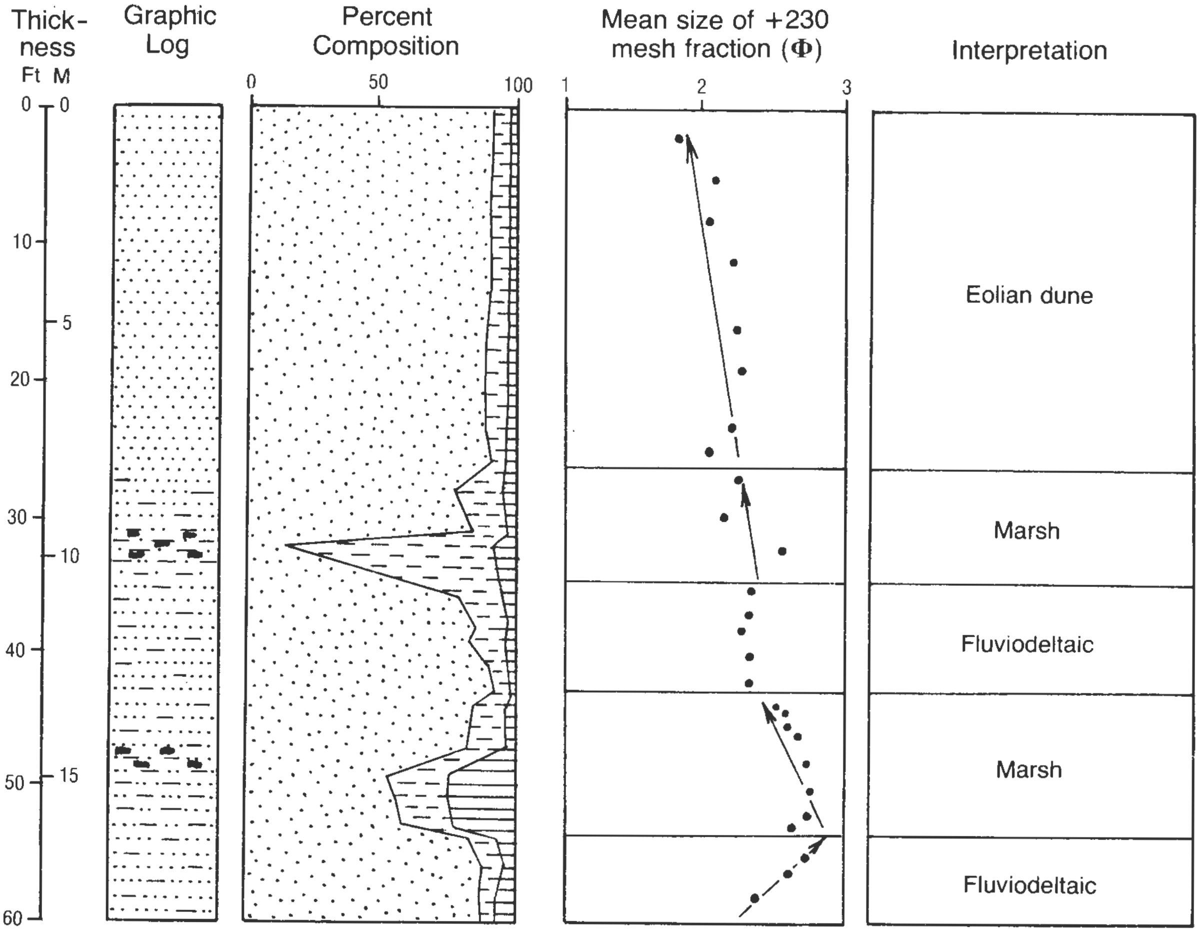

Figure 6. Diagram showing the graphic log, textural parameters, and inferred environments of deposition of sediments penetrated by an auger hole drilled in the western part of the Prairie Creek basin. The lower part of the sequence consists of fluviodeltaic sands interbedded with muddier marsh sediments deposited during a period when the Prairie Creek basin was in the process of being blocked by encroaching dunes. The succession was capped by eolian sands that cover most of the western part of the basin. The auger hole is in the SE$\frac{1}{4}$NE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 31, T. 4 N., R. 6 W. The explanation of symbols is shown in figure 3.

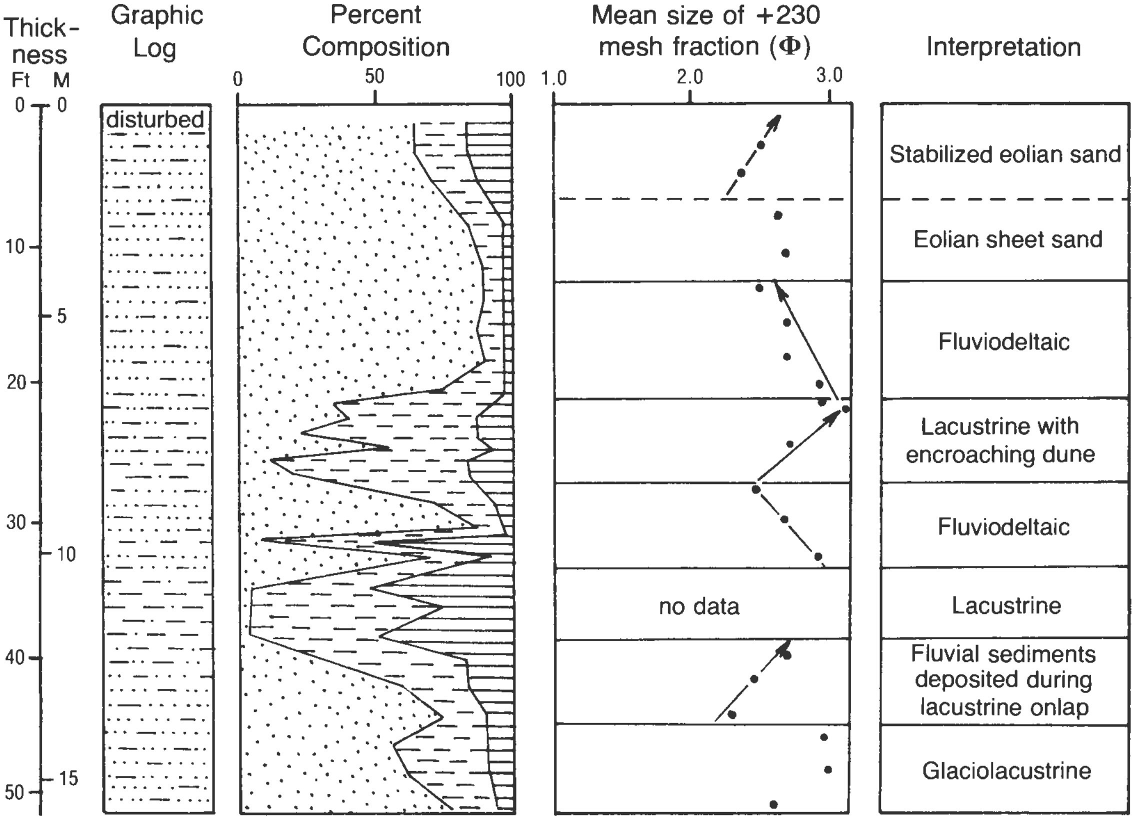

Figure 7. Diagram showing the graphic log, textural parameters, and inferred environments of deposition of sediments penetrated by an auger hole drilled in the central part of the basin north of the basin axis. Glaciolacustrine sediments of Illinoian age are overlain by a fining-upward fluvial sequence deposited during a period of lake expansion that culminated in the deposition of lacustrine muds. The lacustrine muds are separated into a silt-rich upper unit and a clayier lower unit by a sandy fluviodeltaic unit probably deposited during a time of low lake level. The lake muds are overlain by a coarsening-upward sequence of fluviodeltaic sediments that is capped by eolian sands. The auger hole is in the SE1/4SE1/4NE1/4 sec. 2, T. 3 N., R. 7.W. The explanation of symbols is shown in figure 3.

when a lake occupied the basin. The sands are medium fine grained and moderately sorted, and they occur in well-developed coarsening-upward sequences (figs. 5 and 7). They are among the muddiest of the sand lithofacies, but the mud component consists chiefly of silt (table 3) that was probably deposited as bedload from very slow flowing streams crossing a low-gradient delta plain. The occurrence of these sands in coarsening-upward sequences is consistent with their interpretation as deposits of delta wedges prograding into the lake basin.

The fact that fluviodeltaic sands are best developed in the western part of the basin (fig. 9) indicates that they were transported into the basin from the White River. Material derived locally from the drainage basin developed only minor deltaic sequences, probably because most of the locally derived sediment was trapped in stream valleys where alluviation occurred in response to rising base level as lakes were established in the basin.

Near the White River, at the mouth of the basin, fluviodeltaic sands are as much as 40 feet thick, but farther east, at the distal end of the delta lobe, the sands are in beds 5 feet thick or less that are interlayered with lacustrine muds and muddy sands. This interbedding probably occurred as a result of lateral migration of the delta margin in response to fluctuations of the water level in the lake.

SANDY MUD LITHOFACIES

Two types of sandy muds are closely associated with lacustrine muds either where they are interbedded with the muds or where they are transitional beds between the muds and sandier lithofacies (muddy sands and sands). Despite their different occurrences these two types of sandy mud lithofacies have virtually identical textural characteristics (table 4), and both display similar sedimentary structures. The various grain-size fractions are not intimately mixed but are instead segregated into layers that impart a fine lamination to these lithofacies along with delicate layers of macerated organic material.

The clay and silt laminae and the thin layers of finely divided organic material indicate that both these sandy mud lithofacies were deposited in a subaqueous environment that

Table 4. Textural characteristics of the principal lithofacies comprising the sandy muds in the Prairie Creek basin.

Lithofacies	Sand (pct)	Silt (pct)	Clay (pct)	Mean size (ϕ)	Coarsest 1 percentile (ϕ)
Transitional	33.8	52.3	13.9	2.98	1.40
Interbedded	36.0	49.7	14.3	3.01	1.30
Pre-Wisconsinan	36.0	44.1	19.9	2.23	-1.53

had episodes of traction transport alternating with periods of deposition from suspension. Therefore, the fact that the depositional setting was probably similar to that of lacustrine mud, except for closer proximity to sediment sources, accounts for the greater proportions of sand and silt in the lithofacies. The sandy muds that are closely associated with lacustrine muds, therefore, probably represent deposition by underflows at the distal ends of deltaic wedges. Their virtual restriction to axial parts of the basin (figs. 4 and 10) also supports this interpretation.

Other sandy muds, however, are deep in bedrock valleys in the lower part of the basin-filling sequence (fig. 5). These sandy muds consist of subequal amounts of sand and silt with lesser admixtures of clay (table 4). The primary difference between these sandy muds and those associated with lacustrine muds higher in the section is their greater degree of consolidation. Although they are not lithified, sandy muds low in the sequence are so highly consolidated that in some places they could not be penetrated either by augers or by

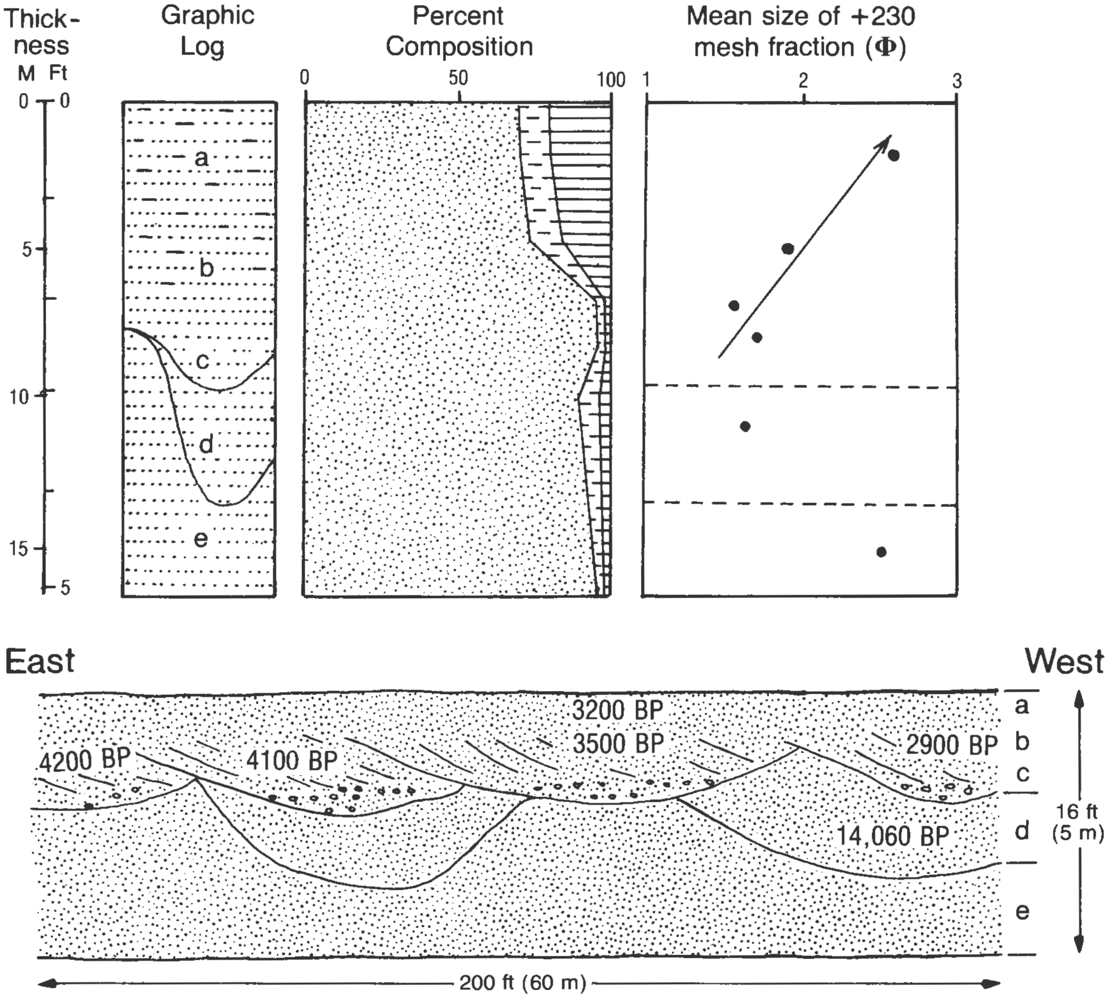

Figure 8. Diagram showing a composite graphic log, textural parameters, and a cross-section of an outcrop of fluvial and fluviodeltaic sands in the basin axis near the basin outlet. Fluviodeltaic sands of unit e are erosionally overlain by fluvial sands of unit d that were deposited following the draining of the lake sometime after about 14,000 years bp. These sands are overlain by a fining-upward fluvial sequence (units c, b, and a) deposited by a shallow meandering stream that occupied the basin axis during the latter half of the Holocene. Numbers refer to the time, in years before present, of deposition of the units. The outcrop is in the NW1/4NE1/4NE1/4 sec. 10, T. 3 N., R. 7 W. The explanation of symbols is shown in figure 3.

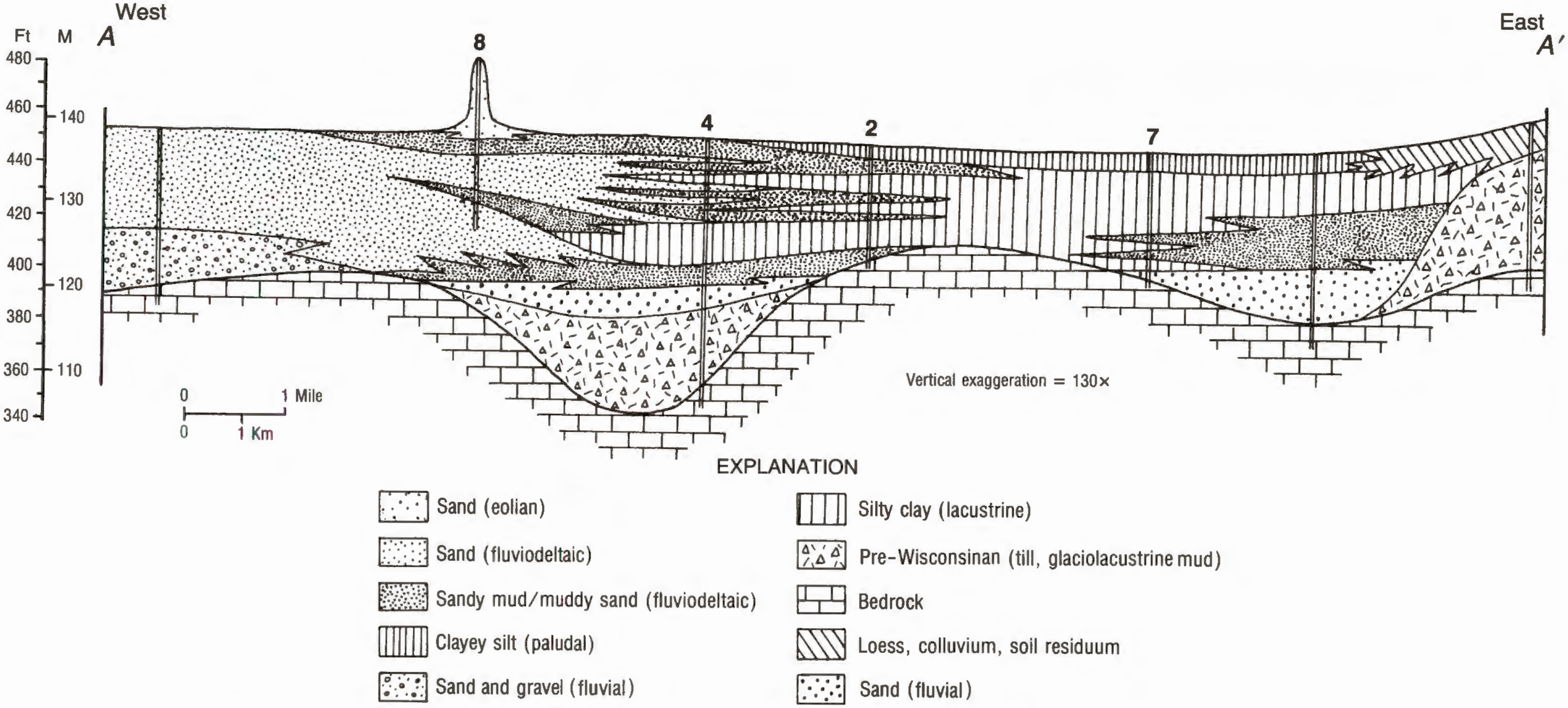

Figure 9. West-east cross-section, based primarily on data from auger holes, showing the facies architecture along the axis of the Prairie Creek basin. The White River was the primary source of sediment as indicated by the thick wedge of fluvial and fluvio-deltaic sands prograding into the basin from the west. The smaller sediment wedge entering the basin from the east was derived from the local drainage basin, and both wedges thin and become interbedded with lacustrine muds which dominate the central part of the basin. Paludal sediments capping the succession in the central part of the basin are bounded on the west by eolian sands and on the east by muds that probably represent colluviated loess that was eroded from the adjacent uplands. Locations of drill holes used to construct the cross-section are shown by vertical double lines. Location of the cross-section is shown in Figure 15.

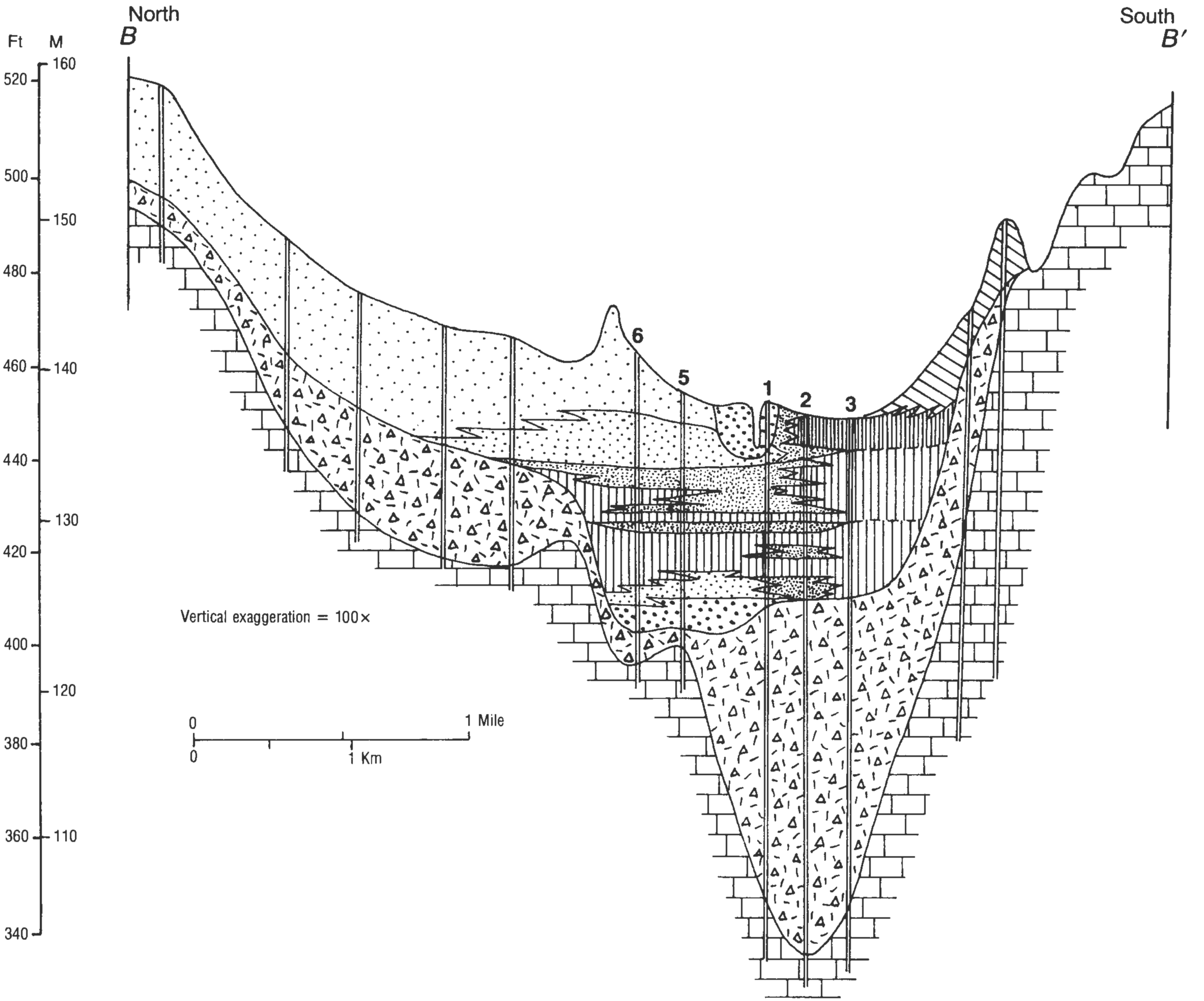

Figure 10. North-south cross-section showing the facies architecture in a direction oriented perpendicular to the basin axis. The bedrock valley is filled with Illinoian-age till and glaciolacustrine sediments to an elevation of about 440 feet. Wisconsinan-age sediments are inset within these older sediments. They consist of lacustrine muds that dominate the successions marginal to the axis, and sandier lithofacies that were deposited by underflows along the basin axis. The lacustrine sediments may be divided into two units that are separated by a fluvial (?) channel-fill sand at an elevation of about 430 feet. Fluvio-deltaic sands near the top of the succession are capped by eolian sands to the north and are channeled by fluvial sands at the basin axis. Locations of drill holes used to construct the cross-section are shown by vertical double lines. The explanation of symbols is shown in figure 9 and the location of the cross-section is shown in Figure 15.

split-spoon tubes. Those higher in the section, on the other hand, commonly liquified when disturbed by drilling.

The degree of consolidation of these sediments and their position low in valley-fill sequences indicate that they are probably pre-Wisconsinan in age and are equivalent to the glacigenic sediments of probable Illinoian age (Miller and others, 1987) that occur in the uplands surrounding the Prairie Creek basin.

Although their gross textural parameters are similar, pre-Wisconsinan sandy muds also differ from their Wisconsinan counterparts in several important textural characteristics (table 4). For example, the sand fraction is coarser grained. This is especially evident in the value of the coarsest 1 percentile, which contains a significant amount of granular material and some pebbles in most samples of this lithofacies. An inspection of the gravel fraction reveals that a substantial proportion of the clasts are of exotic rock types indicating that these sediments had a direct glacial origin.

The textural, compositional, and structural differences between the Wisconsinan and pre-Wisconsinan sandy muds indicate somewhat different modes of deposition. Some of the pre-Wisconsinan sandy muds are massive, have a blocky fracture, and have a random distribution of their textural components. These were probably deposited directly from glacial ice as till. Other samples of this lithofacies are laminated, and in some samples pebbles deform the surrounding laminae. The segregation of textural components into fine laminations indicates a lacustrine origin not unlike that postulated for the younger sandy muds, but the pebbles were probably deposited as dropstones from floating ice. Their occurrence in the pre-Wisconsinan sandy muds indicates deposition in a glaciolacustrine setting in proximity to glacial ice. This is a reasonable interpretation given the presence of till in the basin and in the surrounding uplands.

MUDDY SAND LITHOFACIES

Muddy sands consist of 50 to 75 percent sand-sized material and admixtures of varying amounts of silt and clay (table 1). The mud component is incorporated in part as matrix in the sand fraction, but the bulk of it is discrete laminae within the sand. Organic debris is abundant in some occurrences of muddy sand where it is primarily in discrete layers. The sand fraction is medium to medium fine grained and tends to be moderately well sorted.

Two of the muddy sand lithofacies are closely associated with lacustrine muds. They are remarkably similar in texture and are finer grained and enriched in silt at the expense of clay relative to the other muddy sands (table 5). Of the two, those at the base of lacustrine deposits are a thick sequence of transitional beds between fluvial sands and more muddy lacustrine lithofacies. This transition is expressed not only as an increase in mud content but also as a decrease in grain size of the sand fraction (figs. 5 and 7).

The well-defined clay laminae and organic layers within the lithofacies indicate that although active traction transport was the dominant depositional process, it was interrupted by periods of quiescence when suspension settling of mud and water-logged organic debris occurred. Such a combination of processes could occur within a fluvial setting when stream competency and capacity declined in response to rising base level caused by lake formation and expansion. The change in depositional processes that would accompany such an event could account for the observed textural and structural characteristics in basal muddy sand lithofacies.

Unlike the muddy sands at the base of the lacustrine sequences, those that are interbedded with lacustrine muds and sandy muds form relatively thick beds. But the close similarity of their textural and structural characteristics indicates a similar mode of deposition. These interbedded muddy sands probably represent the leading edges of the subaerial parts of deltaic wedges that prograded rapidly into the lake basin during periods of lake lowering or that prograded more slowly into the basin during the normal process of facies expansion as the basin filled. Because the bases of these units have relatively sharp contacts with the underlying muds, the former interpretation is the more likely.

Other muddy sands are interbedded with sands of probable fluvial origin (fig. 5). This lithofacies is enriched in clay relative to fluviodeltaic muddy sands (table 5), but the mean size of the sand component is slightly coarser grained. The mud component may be matrix material where the muddy sands are massive, but more commonly the mud is segregated through the sand.

The environment indicated by these characteristics is one where sands could be deposited by traction transport and mud and organic debris could settle from suspension during periods of quiescence. Within a fluvial setting, such an environment could occur in a flood plain adjacent to channels where flood events alternated with slack-water periods. It would also occur within the channels themselves if they were blocked or abandoned. Such channels would be in a position to receive sand during flood stage but would be inactive during periods of low flow when mud and organic debris could settle from suspension. The repeated occurrence of muddy sands within thick sequences of channel sands (fig. 5) indicates that their deposition might also be the result of periodic changes in base level associated with alternate expansion and contraction of the lake.

The remaining muddy sand lithofacies occurs at the top of the eolian sand sequences (fig. 7). These muddy sands are massive, the mud fraction is matrix, and the sands are characteristically mottled and marked with root traces. The textural parameters of the sand fraction are similar to those of eolian sands (table 5), and a downward transition into the underlying eolian sands through the gradual elimination of silt and clay is evident. This lithofacies probably formed as a product of soil-forming processes on stabilized dunes and sand sheets

Table 5. Textural characteristics of the four principal lithofacies comprising the muddy sands in the Prairie Creek basin.

Lithofacies	Sand (pct)	Silt (pct)	Clay (pct)	Mean size (ϕ)	Coarsest 1 percentile (ϕ)
Basal fluviodeltaic	58.7	32.2	9.1	2.81	1.38
Interbedded fluviodeltaic	60.1	29.5	10.4	2.82	1.35
Fluvial	60.0	24.3	15.7	2.68	1.36
Soil	65.7	18.3	16.9	2.33	1.21

when windblown silt and clay were trapped by vegetation and translocated downward into the soil.

SUMMARY

Four principal sediment types were deposited during the evolution of the Prairie Creek basin, and their characteristics reflect the processes active in the various depositional systems that occupied the basin. Laminated muds were deposited in lakes and marshes, and sandy muds were deposited by prodelta underflows and in proglacial lakes where muds mixed with coarser sediment raining down from floating ice. Muddy sands were deposited at lacustrine delta margins, in rapidly aggrading fluvial channels during episodes of lake expansion, and on stabilized dunes through a process of translocation during soil formation. Sands were deposited on eolian dunes and sheet sands, in fluvial channels, and on lacustrine delta plains.

EVOLUTION OF THE PRAIRIE CREEK BASIN

The Prairie Creek basin began its development as a small tributary basin of the White River bedrock valley. Dating of this period is uncertain, but the development of this basin was probably part of the development of the drainage basin of the bedrock valley of the lower Ohio River during the later Terriary (Wayne, 1952). The bedrock valley of the White River was a tributary of the bedrock valley of the lower Ohio River.

Early Pleistocene integration of a number of streams into the Ohio River system and the subsequent entrenchment of the streams created the so-called "deep stage" in the Ohio and Wabash bedrock valleys (Wayne, 1952; Bleuer, 1991). The "deep stage" is evident in the bedrock valley of the White River near the Prairie Creek basin where the floor of a narrow and divided valley is at an elevation of about 320 feet (fig. 11). The bottom of the bedrock valley of Prairie Creek is also at an elevation of 320 feet, at least near its confluence with the White River valley. This indicates that the basin also responded to early Pleistocene erosion in the White River valley, which served as its local base level.

A dendritic drainage pattern developed in the basin during these initial stages of its evolution (fig. 12a). High-order tributaries are in the upper reaches of the basin, but the fact that these tributaries are notably lacking in the lower reaches indicates that the basin had developed to the abstraction phase of drainage-basin evolution.

Initial deposits within the bedrock-valley system must have been fluvially derived. No such sediments were recovered, however, during the drilling program, and none are recorded in driller's logs of wells in the area. That basal deposits throughout most of the basin, instead, consist of glacigenic sediments indicates that all earlier sediments in the valleys were eroded before or as a result of the advance of glacial ice into the area.

The magnetically reversed glaciolacustrine sediments containing a fauna bearing relatively young amino-acid racemization dates south of Daviess County (Miller and others, 1987) indicate that the glacigenic sediments at the base of the Pleistocene sequence in the Prairie Creek basin are Illinoian in age. Ice must have covered the area at that time because the hills surrounding the basin are covered by till. But the White River valley must have remained open as an intra-ice channel because pre-Wisconsinan gravels are in the valley. Likewise, the Prairie Creek basin also was open, at least part of the time, because it was the site of a proglacial lake that formed as the White River valley filled with outwash and blocked the outlet (fig. 12b). Glaciolacustrine sediments consisting of laminated muds with dropstones accumulated in this lake. Because the ice was so near the lake, subaqueous debris flows must also have occurred, but their identification is problematic because of the poor quality of samples from deep in the basin. Glacial and glaciolacustrine sediments fill the bedrock valley of Prairie Creek to an elevation of about 440 to 460 feet (figs. 10 and 13), which indicates the minimum elevation of alluviation of the White River valley by Illinoian valley-train sediments.

During the Sangamon Interstade the outwash in the White River was eroded to an elevation of about 400 feet, and the Illinoian glacigenic sediments were left perched as a terrace along the eastern margin of the valley (fig. 14). The lowering of its local base level caused Prairie Creek and its tributaries to entrench themselves into the glacigenic sediments filling the basin (fig. 15). As much as 60 feet of sediment was eroded in the trunk valley (figs. 10 and 13), and a low-density dendritic drainage network was established in the basin (fig. 12c).

Ice once again entered the White River drainage basin during the late Wisconsinan. It did not extend as far south as Daviess County, but it did affect the Prairie Creek basin because the White River served as one of the major sluiceways for meltwater from this ice mass. Outwash from glaciers in the northern half of Indiana once again aggraded the valley during this period and served to dam the mouth of Prairie Creek and reestablish a lake in the basin (fig. 12d).

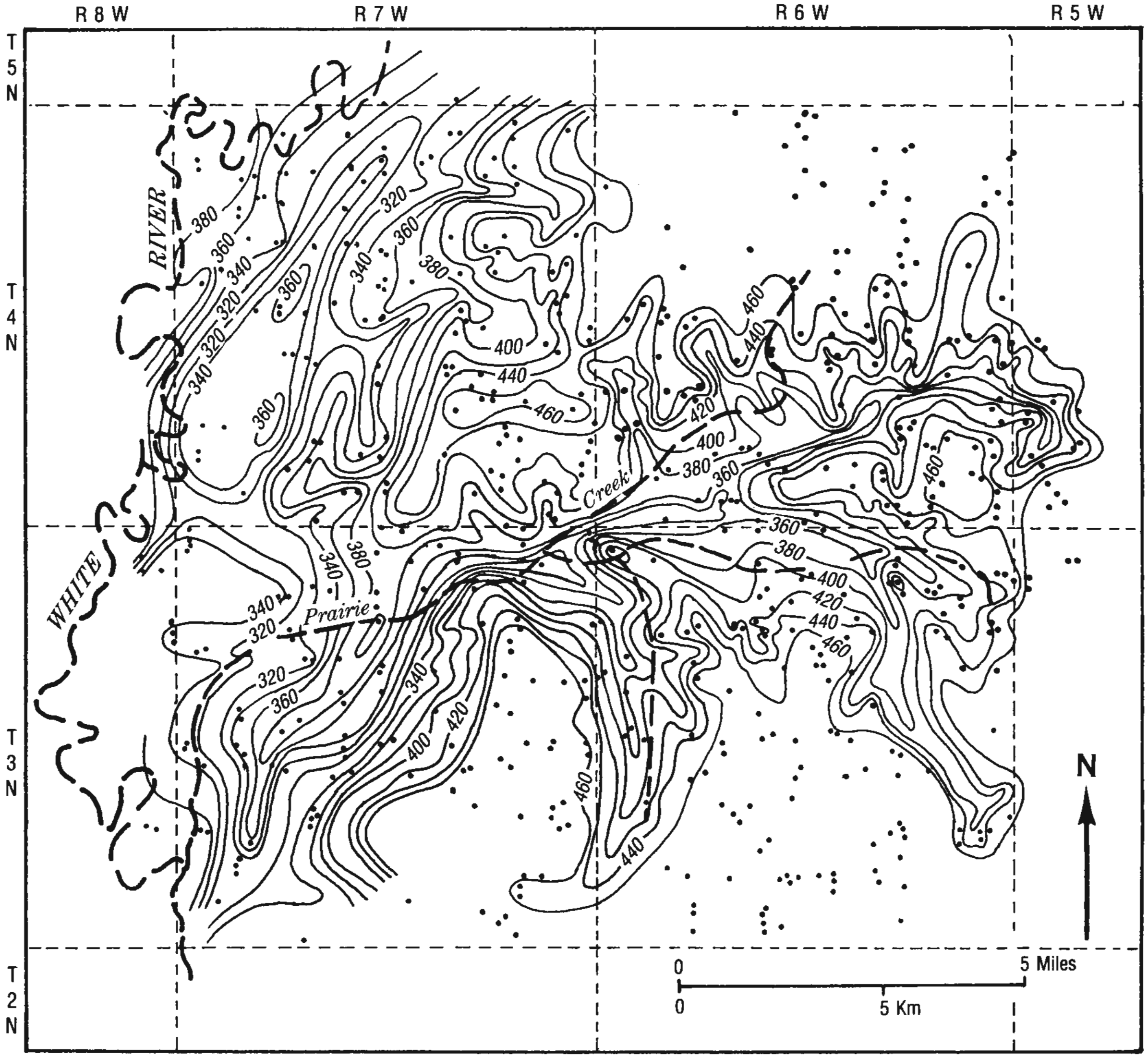

Figure 11. Map showing the bedrock topography of the Prairie Creek basin. The contour interval is 20 feet, and only those elevations below 460 feet are shown. The Prairie Creek basin was drained by a dendritic stream that was graded to the trunk stream in the White River bedrock valley. The location of present-day drainage is shown by dashed lines. Dots show the locations of data points.

The initial deposits during the early phases of lake establishment consisted of pronounced fining-upward alluvial sequences that were deposited in response to rising local base level. Eventually the lake was fully established in the basin, and a pattern of lacustrine sedimentation prevailed. This pattern consisted of sandy subaerial deltaic wedges entering the basin primarily from the White River and secondarily from upstream reaches, underflows at the prodelta slope depositing sandy muds along the lake axis, and laminated muds settling from suspension along the lake margins and over the prodelta plain.

Sediment influx from the White River valley did not enter the basin directly from the west. Although most of the basin is oriented along an east-west axis, it is separated from the White River valley by a north-south oriented ridge that deflects the axis of the basin to the south (fig. 15). Sediment actually entered the basin from the south, and momentum probably carried it to the north side of the central basin before it was redirected eastward along the axis. Therefore, fluviodeltaic sands are best developed along the north side of the basin (figs. 10 and 12e).

Two major episodes of lake expansion are recorded in the lacustrine sediments of the basin where the onlap of prodelta muds and sandy muds over sandy delta-plain lithofacies has produced two fining-upward sequences. A similar history of late Wisconsinan lake sedimentation has been described for Lake Saline in southern Illinois (Frye and others, 1972) and for Salt Creek near Bedford, Indiana (Gray, 1974). For both places the two phases of lake expansion were thought to be caused by separate advances of glacial ice into the upstream reaches of the drainage basin of the trunk streams. The intervening episode of glacial retreat from the drainage basins resulted in the erosion of the outwash sediments in the valley

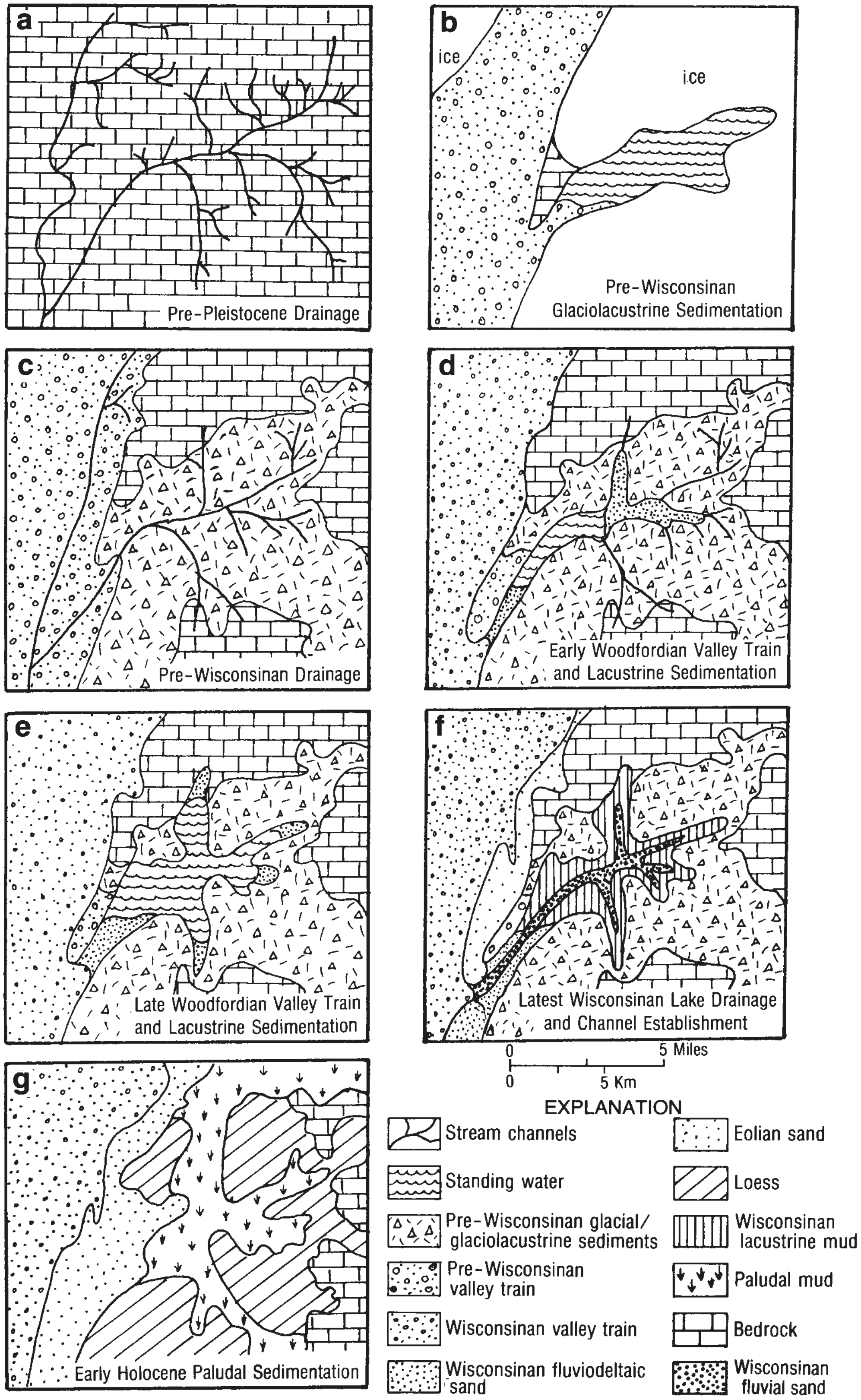

Figure 12. Diagram showing various stages in the evolution of the Prairie Creek basin beginning with the formation of the bedrock drainage basin and culminating with the establishment of the modern drainage.

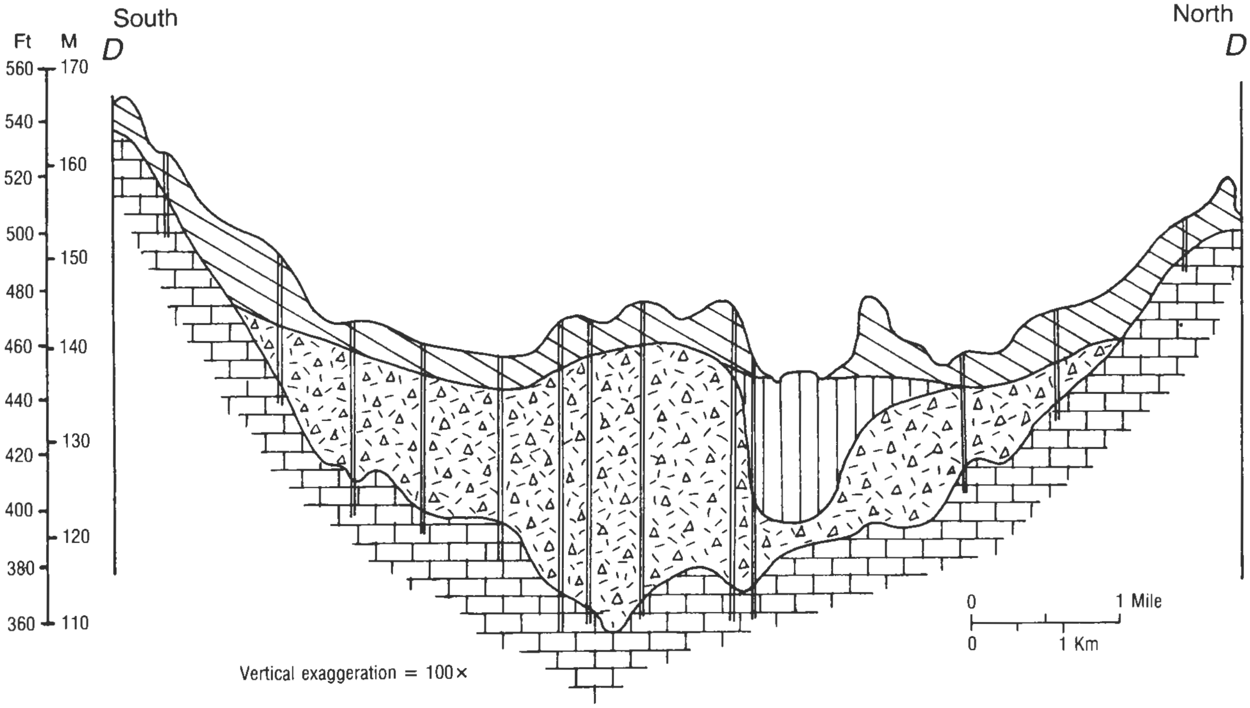

Figure 13. South-north cross-section oriented perpendicular to the basin axis showing the facies architecture in the eastern part of the Prairie Creek basin. Pre-Wisconsinan (Illinoian) glacigenic sediments fill the bedrock valley to an elevation of about 460 feet. Lacustrine and paludal sediments of Wisconsinan age are inset within these older sediments, and the sequence is capped by loess, colluvium, and soil. Locations of drill holes used to construct the cross-section are shown by double vertical lines. The explanation of symbols is shown in figure 9 and the location of the cross-section is shown in figure 15.

of the trunk stream, and this erosion allowed the lake in the tributary valleys to drain.

The same basic mechanism probably caused the two phases of lake expansion in the Prairie Creek basin because the drainage basin of the White River was subject to two principal episodes of advance of Huron-Erie Lobe ice during the late Wisconsinan (Wayne, 1968). The first reached its maximum extent about 21,000 years bp (Wayne, 1968; Bleuer, 1991) and deposited the sediments of several members of the Trafalgar Formation. The second reached its maximum extent about 16,000 years bp and deposited till of the Lagro Formation. Ice of the first advance, however, was still in the basin during the second glaciation (Wayne, 1968; Ballard, 1985), so that meltwater probably continued to be supplied to the White River and a major phase of valley-train degradation did not occur during the interval between the two advances.

Meltwater discharge must have slowed, however, during the latter stages of disintegration of the Trafalgar ice sheet. Minor degradation of the valley-train surface in the White River probably occurred, and the lake in the Prairie Creek basin drained partially. Significant erosion of the lake-plain surface did not take place at this time, although subsurface evidence indicates that a minor amount of channelization along the valley axis did occur (fig. 10). The amount of erosion did not exceed 5 feet, however, and the sediments filling the "channel" bear a greater resemblance to fluviodeltaic sediments than to fluvial ones.

Large-scale erosion of valley-train sediments in the White River valley occurred after the final withdrawal of ice from the drainage basin about 13,000 years bp. The lake in the Prairie Creek basin drained, and a channel system was established on the exposed lake plain (fig. 12f). Abundant organic material,

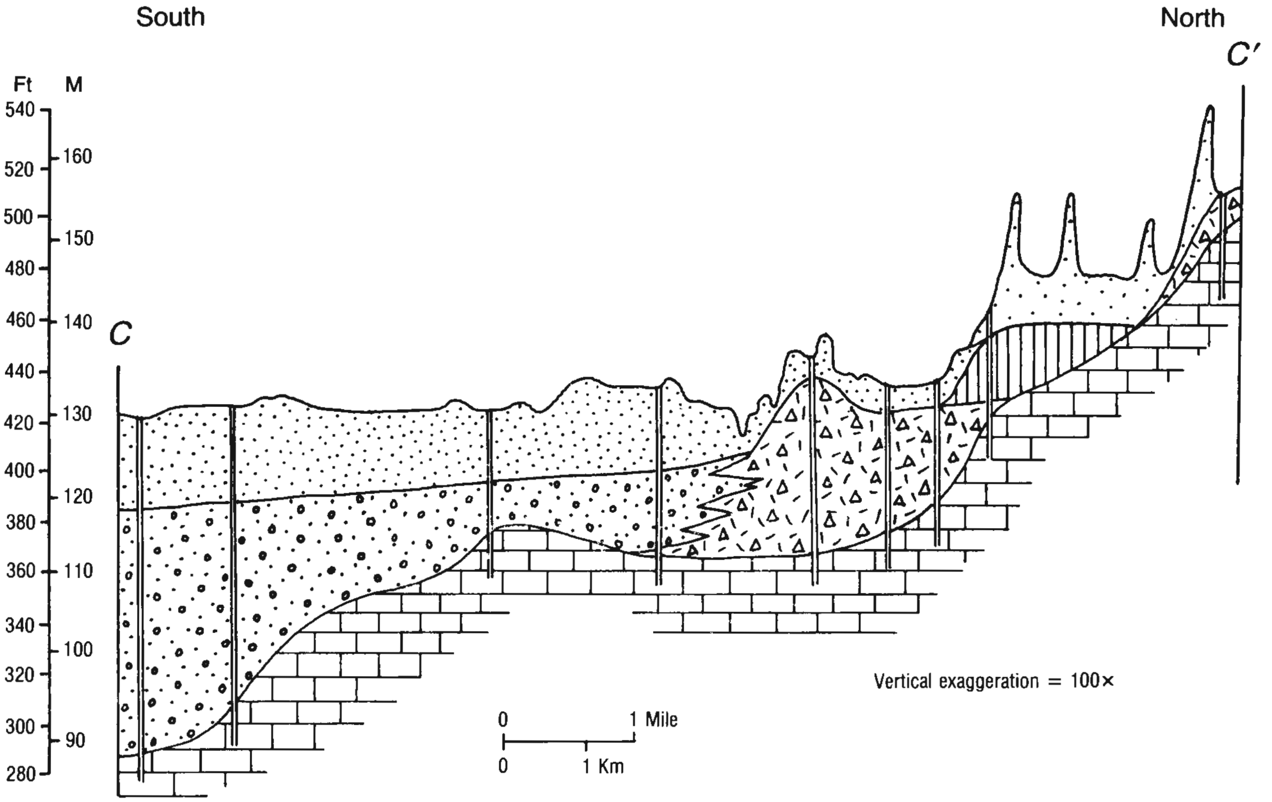

Figure 14. South-north cross-section showing the relationship of the basin-filling sediments at the west end of the basin to the alluvial fill in the White River valley. Sand and gravel of Illinoian age in the White River valley are overlain by sands deposited during the late Wisconsinan. Glaciolacustrine and lacustrine sediments capped by eolian sands are terrace remnants along the eastern margin of the valley. Locations of drill holes used to construct the cross-section are shown by double vertical lines. The explanation of symbols is shown in figure 9 and the location of the cross-section is shown in figure 15.

including plant and animal macrofossils, plant microfossils, and peat clasts eroded from the lake plain, formed a part of the alluvium filling these channels. Faunal and floral remains indicate a cold climate (Jackson and Whitehead, written communication), and a date of about 14,000 years bp derived from some of this material is consistent with the interpretation that the lake existed when ice occupied the White River drainage basin. Radiocarbon dates of about 13,000 years bp on the Fort Wayne Moraine (Fullerton, 1980) give the minimum date for withdrawal of the ice from the drainage basin and also set the time for the establishment of a drainage network on the exposed lake plain.

Fluvial activity ended at some point, and a marsh was established in the basin (fig. 12g). Direct evidence setting the time for this event is not available, but indirect evidence indicates that it occurred sometime before about 10,000 years bp. The formation of the marsh was probably the result of dune formation that dammed Prairie Creek at the mouth of the basin. Sand for these dunes was stripped from exposed sand flats in the valley of the White River and deposited against the east valley wall by the prevailing westerlies. As the climate changed, however, the valley floor became vegetated, the supply of sand was cut off, and the dunes were stabilized. The crests of stabilized dunes became sites for occupation by prehistoric Native Americans. The archeological material they left indicates that this occupation occurred about 10,000 to 11,000 years ago (P.J. Munson, written communication) and therefore gives a minimum age for dune stabilization and marsh formation. In addition, as the marsh was established it caused the extinction of a forest that occupied the basin. The resulting forest bed, now covered with organic muds, has not been dated, but because the flora consists predominantly of deciduous trees, the forest was undoubtedly established sometime after about 11,000 years bp when deciduous forests were first established on a continuous basis in the region (King, 1981; Shane, 1987).

The marsh was unlike the lakes that previously occupied the basin in that after its establishment it received an increasingly greater amount of sediment from the local drainage. By the end of marsh sedimentation, the predominant material being deposited consisted of smectitic clays (fig. 3). The muds in the underlying lacustrine sequences, on the other hand, consisted mainly of silt, and the included clays consisted mainly of illite and chlorite. The fact that this latter assemblage is similar to the assemblage of Huron-Erie Lobe tills indicates that most of the sediment in the lacustrine sequences

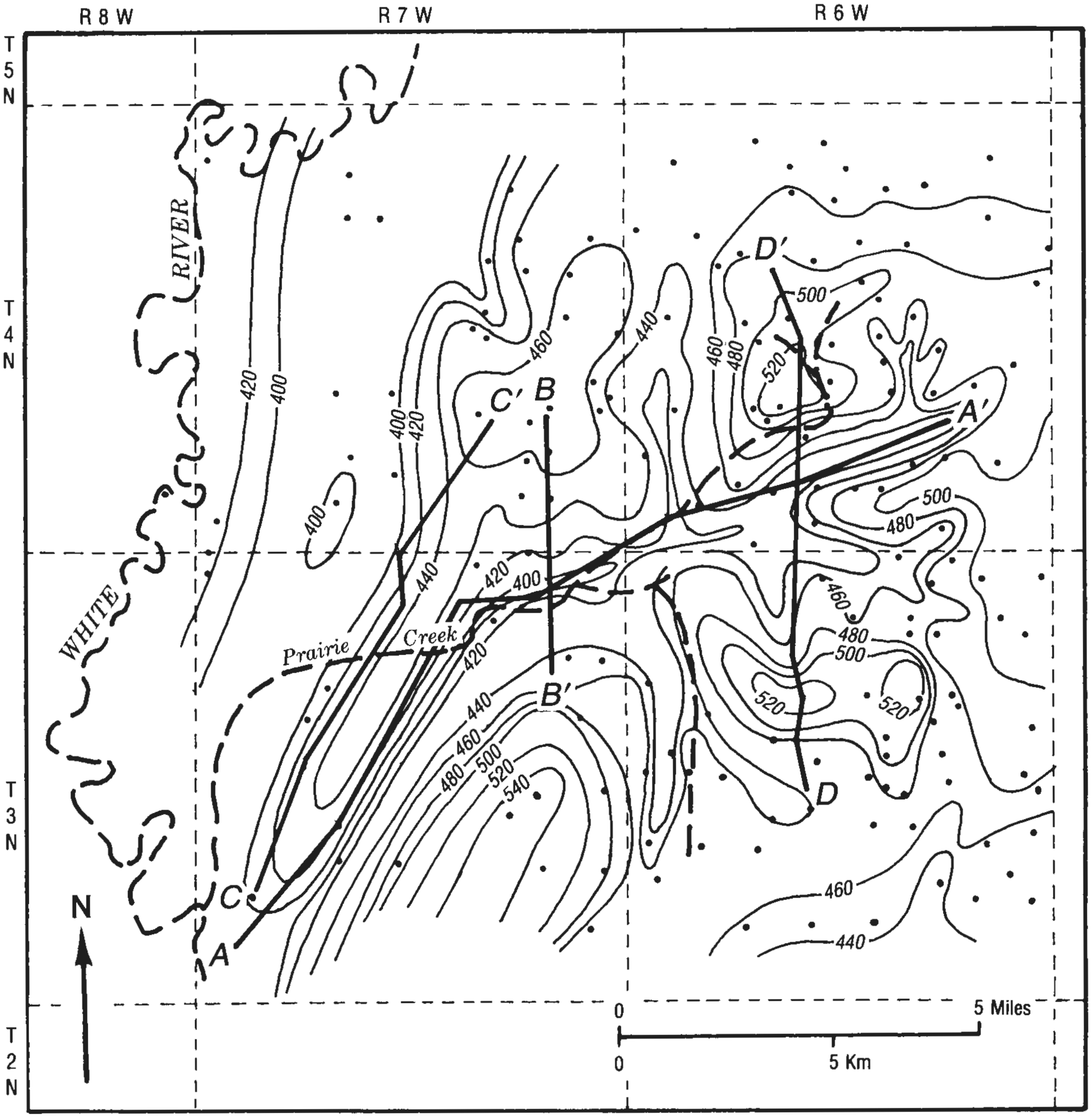

Figure 15. Map showing the topography on the top of the glacial and glaciolacustrine sediments in the Prairie Creek basin and the locations of the cross-sections shown in figures 9, 10, 13, and 14. The shape of the drainage basin that developed on these sediments during the Sangamon Interstade closely parallels that of the bedrock basin (fig. 11). The location of present-day drainage is shown by the dashed lines. Dots show the locations of data points.

was washed into the basin from the White River. Smectitic clays are not abundant in the parent material underlying the uplands surrounding the Prairie Creek basin, but small amounts, along with more abundant randomly interstratified mixed-layer clays, do occur in the soils developed on pre-Wisconsinan tills in the area. These smectitic clays probably compose part of the clay-mineral assemblage in the upper part of the basin-filling sequence, but the high degree of crystallinity shown by the smectites in the basin indicates that most of them were probably produced in situ by neomorphic alteration of degraded clays from the soils.

The increasing proportion of these clays upward in the sequence indicates that the supply of sediment from the White River slowed and locally derived sediment was allowed to predominate. The presence in the marsh sequence of at least some sediments derived from the White River is difficult to explain because the marsh supposedly formed after drainage from the basin was blocked by encroaching dunes, and this blockage should have prevented sediment from entering the marsh from the White River. This apparent anomaly can be explained in two ways. First, the blockage of Prairie Creek may have occurred during a long period of time and therefore a continuous, although decreasing, supply of material would have been allowed to enter the basin during the process. The White River, however, was in an erosional phase after the withdrawal of ice from its drainage basin, and so its ability to supply sediment to the basin, even during flood stage, was probably slight.

More likely, the sediment derived from the White River in the lower part of the marsh sequence was probably transported into the basin by wind. The decreasing proportion of this sediment upward in the sequence may have been the result of the same change in climate and vegetation that caused stabilization of the dunes at the mouth of the basin. McKay (1979), for example, gave a date of about 10,000 years bp for cessation of loess deposition in Illinois, and that date coincides with the probable date for dune stabilization in the White River valley. Indeed, windblown silt and clay, stripped from the flood plain of the White River, may have been an important part of the sediment supplied to the basin during the whole of the late Wisconsinan.

It is perhaps surprising that heterogeneous, partly lacustrine Quaternary sedimentary sequences of the type described in this report were involved in the controversy about the origin of loess. Today the eolian origin of loess has become so widely accepted, at least in the United States, that it is almost implicit in the definition of the material. It is well to recall, however, that many authorities have considered loess to be of another or of mixed origin. Two collections of papers in which theories on the origin of loess are discussed in some detail are Schultz and Frye (1968) and Swalley (1975).

In the midst of the earlier controversy there appeared a paper by Fuller and Clapp (1903) that argued for two kinds of loess in southern Indiana: common loess and marl-loess. The common loess was said to be nonstratified, noncalcareous, and nonfossiliferous, to be principally silt, and to form an extensive blanket across much of southwestern Indiana. The marl-loess was described as calcareous, stratified, fossiliferous, and limited to a rather narrow belt of land near the Wabash River.

Because the marl-loess was said by Fuller and Clapp (1903, p. 166) to be "an aqueous deposit," it would seem that they had made a distinction between true loess of eolian origin and the calcareous lacustrine sediment that partly fills many of the valleys tributary to the major outwash-carrying streams of southern Indiana. This is not the fact, however; fossils reported as coming from the marl-loess were dominantly nonaquatic and were thought to be "floated or washed" (p. 167) into the silt-laden waters. The patterns of distribution that Fuller and Clapp described make it clear that they grouped as marl-loess all forms of calcareous surficial silt, including both stratified lacustrine sediment and basal unleached loess. Shaw (1915b) flatly rejected Fuller and Clapp's arguments for the marl-loess and found that most of it was "wind-deposited true loess" (p. 108).

Yet Shaw also appears to have missed an important point: there are not just two kinds of surficial sediment to treat here, there are three. Loess, which is nonstratified and where thick is calcareous in its lower part, blankets the low rolling hills. Calcareous laminated silt and clay in the valleys represent deposits of finger lakes. Some of these, as explained by Shaw (1915a), were held in by an aggrading valley train; others were ice marginal. A third material, presently defined and mapped only as a "lowland silt complex" (Gray, 1989), consists of poorly stratified sand and silt of mixed origin. It commonly occupies a low terrace position and overlies, in various places, outwash sand, lacustrine silt and clay, till, bedrock, and possibly other materials. At many sites the underlying material is capped by a strong paleosol or paleosol remnant, but the surficial silt has only a weak soil and in many ways is similar to loess, from which it was undoubtedly derived. This poorly understood material, which only now is emerging as a stratigraphic entity, is the surface material in much of the area discussed in this report.

The marsh apparently occupied the basin for several thousand years, because fluvial channel sands near the mouth of present Prairie Creek contain transported organic debris dated from about 4,200 years bp to 2,900 years bp. These sediments were deposited by a relatively shallow meandering stream that was probably not unlike modern Prairie Creek before it was artificially channeled in the early 1900's.

SUMMARY

The history of lacustrine sedimentation in the bedrock valley forming the Prairie Creek basin spans the latter half of the Pleistocene. The first episode occurred sometime during the Illinoian when glaciers surrounded the basin and supplied sediment directly to it. The second important episode occurred during the Wisconsinan when several advances of glacial ice of the Huron-Erie Lobe entered the White River drainage basin. Outwash from these glaciers caused the aggradation of the valley that blocked the mouths of many of the tributaries of the White River and formed lakes in their drainage basins.

Two principal episodes of lacustrine sedimentation during the late Wisconsinan resulted in deposition of two fining-upward sequences in response to lake expansion. These episodes can probably be attributed to the two principal episodes of glacial advance into the headwaters of the White River.

The lake drained after the final retreat of glacial ice from the drainage basin, but a marsh was established when drainage was blocked by encroaching dunes. After about 4,200 years bp drainage was reestablished, and the Prairie Creek basin assumed the aspect it maintained until the early 1900's, that is, the aspect of a flat, low-lying plain that was probably seasonally inundated during spring floods but that was emergent at least part of the year.

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