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EARLY PLEISTOCENE GLACIATION AND DRAINAGE IN SOUTHWESTERN OHIO, SOUTHEASTERN INDIANA, AND NORTHERN KENTUCKY.

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EARLY PLEISTOCENE GLACIATION AND DRAINAGE IN SOUTHWESTERN OHIO, SOUTHEASTERN INDIANA, AND NORTHERN KENTUCKY

A dissertation submitted to the

Division of Graduate Studies
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by

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I hereby recommend that the thesis prepared under my supervision by James Tobias Teller

entitled EARLY PLEISTOCENE GLACIATION AND DRAINAGE IN SOUTHWESTERN OHIO, SOUTHEASTERN INDIANA, AND NORTHERN KENTUCKY

be accepted as fulfilling this part of the requirements for the degree of Doctor of Philosophy

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ABSTRACT

The sequence of pre-Wisconsinan glacial and drainage events in southwestern Ohio, southeastern Indiana, and northern Kentucky is now established on the basis of: (1) a detailed field study of the glacial deposits, (2) a petrographic examination of 74 samples of till - including heavy, light, and clay mineralogy, pebble counts, till fabric, and size analyses, and (3) a topographic study of abandoned valleys and an examination of the deposits within these valleys.

A truncated paleosol, in till, beneath Kansan till in Decatur County, Indiana, is the first clear evidence of Nebraskan glaciation east of Illinois. This Nebraskan till is herein named the St. Maurice till. Nebraskan glaciation was responsible for the abandonment of the north-flowing pre-glacial (Teays) river system in this area and the establishment of a new, southwest-flowing river system whose course nearly coincided with that of the present Ohio River except in southwestern Ohio. During Aftonian time, this river and many of its tributaries were cut several hundred feet below the old Teays valleys to produce the period of drainage known as the Aftonian Deep Stage.

At least two stadial advances of Kansan ice followed, with one pushing southeastward into westernmost Ohio and across the Ohio River into the northern counties of Kentucky. The surficial Kansan till in this area is named the Cincinnati till. The route of the Aftonian Deep Stage River from Cincinnati to Lawrenceburg (Indiana), which flowed via Hamilton (Ohio), was forced southward at this time so that the ensuing Yarmouthian Deep Stage Ohio River coincided with the present route of

the river except within the city of Cincinnati.

Illinoian ice advanced in two stades from both the northwest and the northeast. West of Cincinnati, the Harrison Lobe advanced southeastward to about the Ohio River valley although it invaded this valley in only two places. This lobe was responsible for the permanent abandonment of the Yarmouthian valley of the Great Miami River in western Ohio and the establishment of a new valley several miles to the southeast. East of Cincinnati, the Clermont Lobe crossed the Ohio River into Campbell County (Kentucky) for a distance of up to two miles and invaded northern and eastern Hamilton County (Ohio). The last change in the course of the Ohio River in this area came about when Clermont Lobe ice permanently diverted the river from its route around northern Cincinnati to one coincident with its present course along the city's southern edge.

INTRODUCTION

Area Under Study

The area under study includes about 3000 square miles in southwestern Ohio, southeastern Indiana, and northern Kentucky (Fig. 1). The area incorporates all of the Ohio River valley between the cities of Cincinnati, Ohio, and Madison, Indiana - a distance of about 70 miles - and the counties adjacent to it. These counties are: Hamilton and eastern Clermont Counties (Ohio), all of Dearborn, Ohio, Ripley, and Switzerland Counties and parts of Jefferson, Decatur, and Franklin Counties (Indiana), all of Boone and Gallatin Counties, and most of Campbell, Kenton, and Carroll Counties (Kentucky).

Objectives

The tills of this area were studied both in the field and laboratory for the following reasons: (1) The glacial deposits of southwestern Ohio, southeastern Indiana, and northern Kentucky have never been studied in detail; (2) the area of pre-Illinoian (Kansan?) drift identified in southwestern Ohio and northern Kentucky (Durrell, 1961) is the most easterly occurrence of surficial drift of this age in the U. S. In fact, buried pre-Illinoian glacial deposits are known from only a few places east of the study area; (3) the age of the surface drift in the southeastern corner of Indiana has never been established.

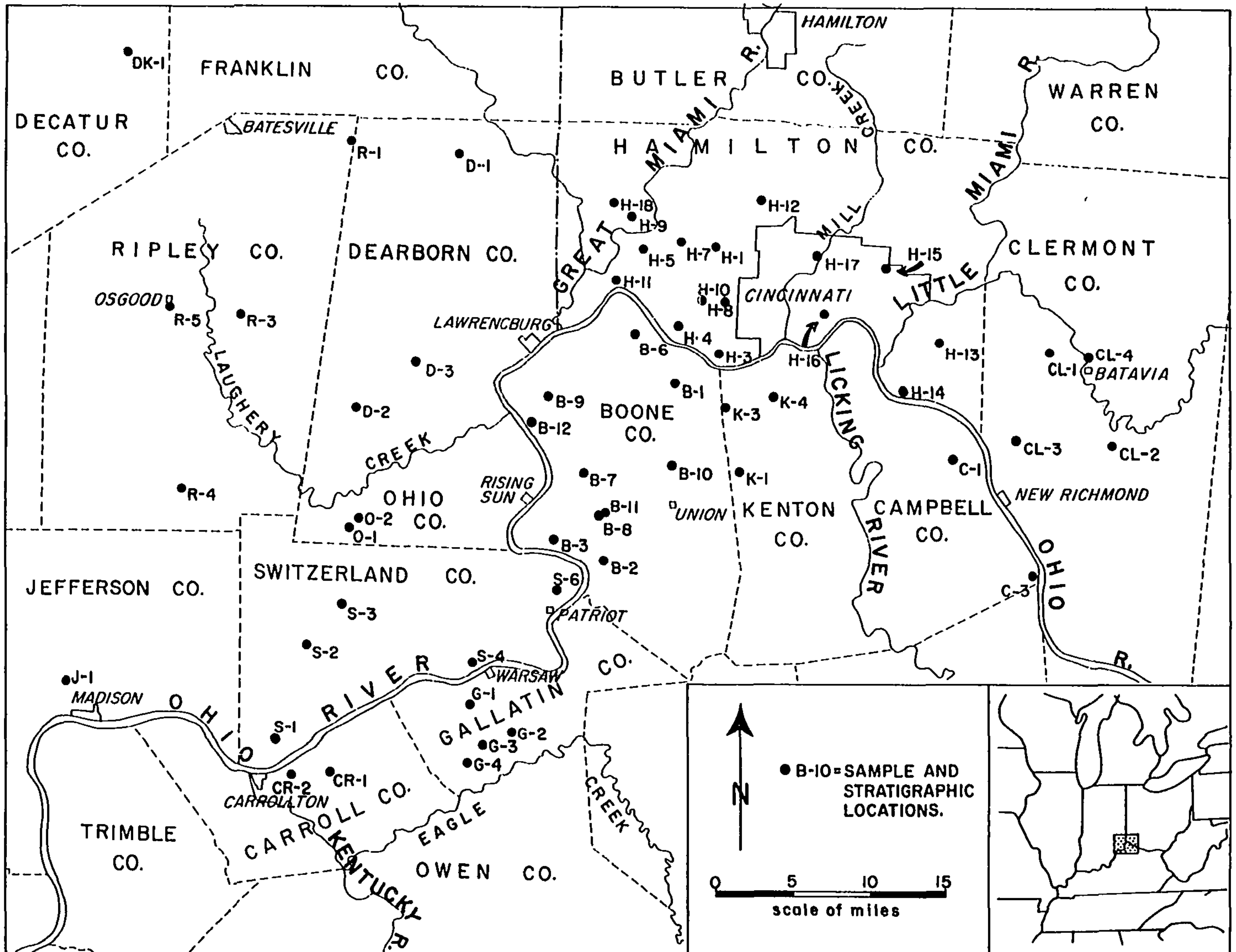

Figure 1 - Area under study showing sample locations.

The objectives of the study were to: (1) map the maximum extent of ice cover (i.e. of till), (2) study the topographic and stratigraphic relations of the pre-Wisconsinan tills, (3) make a detailed laboratory analysis of the tills so that individual till sheets can be identified and correlated empirically, (4) combine the topographic, stratigraphic, and laboratory data to determine the sequence of early Pleistocene glacial and drainage events in the area.

Bedrock Geology of the Region

Rocks of Paleozoic age form the bedrock surface throughout Ohio, Indiana, and northern Kentucky. The oldest rocks, Middle Ordovician in age, crop out in the deepest river valleys of the study area and along the crest of the Cincinnati Arch in central Kentucky (Fig. 2). To the east and west of this broad anticlinal structure, the age of the exposed rocks becomes younger until Upper Paleozoic sediments are exposed at the surface in eastern Ohio and southwestern Indiana. Northward from the north-central part of Kentucky, progressively younger rocks crop out but, with the considerably lower regional dips along the axis of the Arch, distances to each succeedingly younger outcrop are greater than they are to the east or west.

Within the area under study, rocks range in age from Middle Ordovician to Silurian. The Silurian rocks crop out only along the western edge of this area and are primarily limestones and dolomites. The Ordovician sequence is composed of about equal proportions of

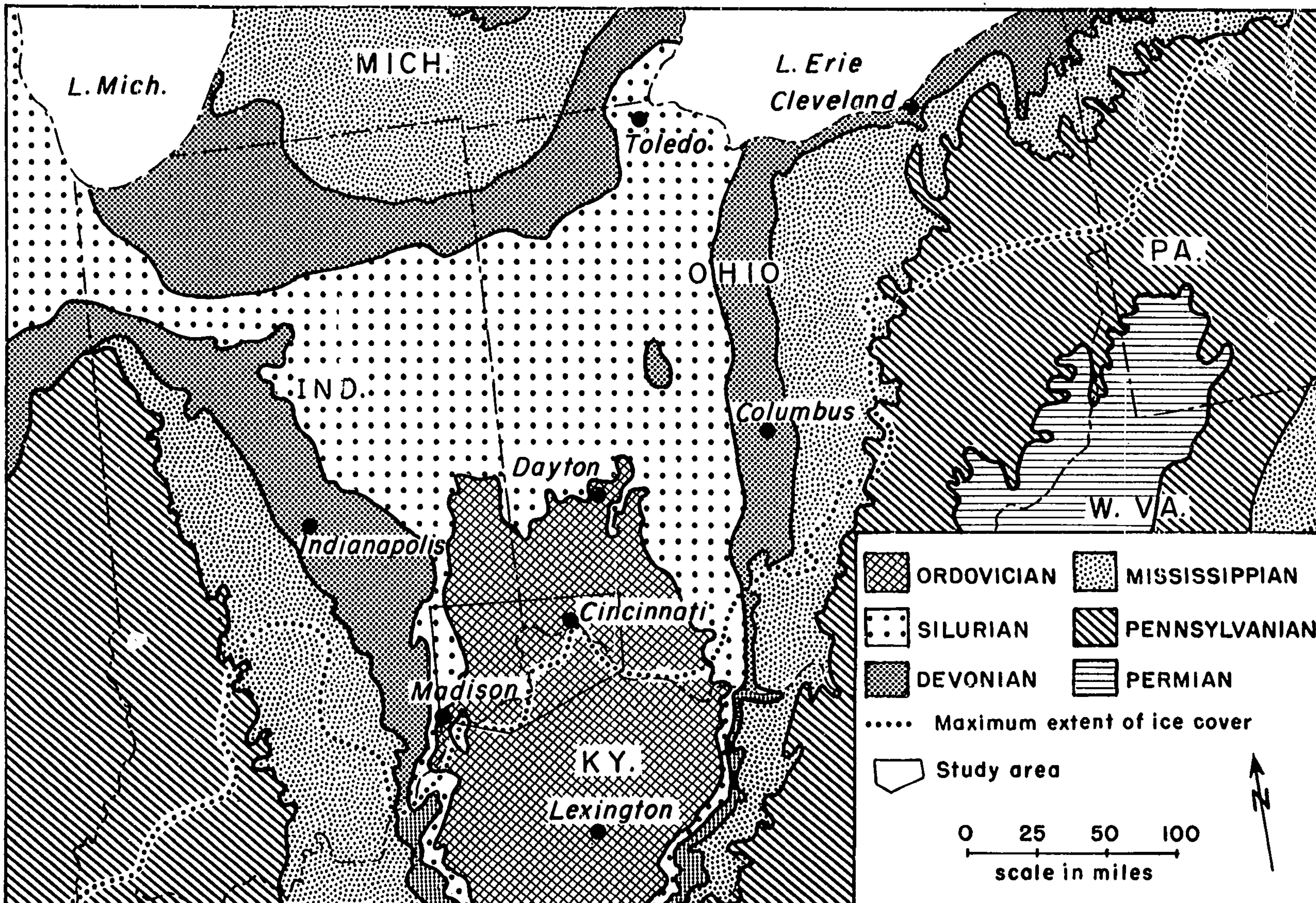

Figure 2 - Bedrock geology of Ohio, Indiana, and northern Kentucky (after U. S. Geological Survey, Geologic Map of the U. S., 1960).

interbedded limestones and shales. In general, the younger rocks outside of the study area contain fewer shale and more siltstone and sandstone units. Dolomite and limestone predominate in the Silurian-Devonian sequence and limestones, shales, and clastic units make up most of the Mississippian-Pennsylvanian sequence.

Previous Work

The earliest glacial studies in southwestern Ohio, southeastern Indiana and northern Kentucky were done for the state surveys in the 1870's (Warder, 1872; Orton, 1873; Sutton, 1876). Wright (1884, 1890) and Leverett (1902) first presented maps of the glacial boundary in the region and further elaborated on the glacial deposits. Many authors have discussed the glacial and pre-glacial drainage conditions of the area and there have been numerous controversies on the subject (see for example, James, 1888; Fenneman, 1914, 1916, p. 113-124; Fowke, 1898, 1900, 1924, 1933; Leverett, 1902, p. 116-118, 1929, p. 19-26; Mallot, 1922, p. 132-138).

Investigation of the ice-laid deposits, however, has been lacking. Except for Durrell (1956, 1961) and Leighton and Ray (1965), no field or laboratory study of the tills in the area has been published since the days of Leverett (1929). Leverett's report still stands as the most comprehensive on the glacial deposits of northern Kentucky and his mapping has been modified in but a few places.

General Review of Regional Pleistocene Stratigraphy

Nebraskan drift

The oldest Pleistocene drift in the east-central U. S. is Nebraskan in age. The nearest to the study area that undisputed Nebraskan deposits are found is in central Illinois (Frye, Willman, and Black, 1965). Deposits of questionable Nebraskan age have been identified in several places in Ohio and Kentucky and include:

(1) Erratics of exotic rock types reported from widely scattered locations in northern Kentucky (Jillson, 1924a, b, 1925; Leverett, 1929) and southeastern Ohio (Patton and Hicks, 1925; Leverett, 1929, p. 50; Ireland, 1943; Merrill, 1953). Most of the erratics are many miles south of the presently drawn glacial boundary and some are apparently of Canadian origin. They generally are small, ranging from a few ounces to several pounds in weight, but two are reported to weigh several tons. Although till has never been found associated with these erratics, some have interpreted them as being the erosional remnants of a very old till sheet and have moved the glacial boundary many miles to accommodate them (Ray, 1969; Thwaites, 1946, Pl. 3).

(2) In a cut ten miles southwest of Cincinnati, a leached, manganese-rich, clayey gravel unit between two tills has been interpreted by Leighton and Ray (1965) as a truncated Aftonian soil profile that is buried by Kansan till.

(3) Deeply weathered outwash, south of the glacial boundary in

extreme eastern Ohio, is interpreted by Lessig (1961, p. 36) as terrace remnants belonging to "the first glaciation of the Allegheny Plateau". Lessig bases this conclusion largely on the fact that the terrace is the highest and most deeply weathered of four terrace levels in the upper Ohio River drainage basin.

Kansan drift

Drift attributed to Kansan glaciation is recognized over a wide area of the mid-continent from Iowa to Pennsylvania (Reed, et al., 1965; Wright and Ruhe, 1965; Frye, Willman, and Black, 1965; Wayne and Zumberge, 1965; Goldthwait, et al., 1965; Durrell, 1961; White, Totten, and Gross, 1969). The southernmost edge of Kansan till extends into southern Illinois, southwestern and southeastern Indiana, northern Kentucky, and southwestern Ohio (Flint, et al., 1959). Between southwestern and northeastern Ohio, Kansan drift is unknown. All Kansan deposits east of Illinois are buried beneath younger drift except those in southwestern Ohio and northern Kentucky. Two Kansan ice advances, stades, are recognized in southeastern and western Indiana (Table 1) but nowhere is there an interstadial episode indicative of more than a brief northward retreat in the ice (Gooding, 1966).

Illinoian drift

Illinoian till is exposed at the surface in a two- to more than

Table 1 - Classification of Pleistocene stratigraphic units in southwestern Ohio, southeastern Indiana, and northern Kentucky (Gooding, 1963, 1966; Goldthwait, et al., 1965; Goldthwait, 1969). Names used for the first time in this report are underlined.

GLACIAL-INTERGLACIAL	STADIAL-INTERSTADIAL	NAMED UNITS
Wisconsinan Glacial	"Late" Wisconsinan (±Woodfordian)	-
	Mid? Wisconsinan	-
	"Early" Wisconsinan (±Altonian)	-
Sangamonian Interglacial	---	
Illinoian Glacial	Richmond Stade	?>Danville till?
	Abington Interstade	
	Centerville Stade	
Yarmouthian Interglacial	---	
Kansan Glacial	Columbia Stade	?>Cincinnati till?
	Garrison Creek Interstade	
	Alpine Stade	
Aftonian Interglacial	---	
Nebraskan Glacial	---	St. Maurice till

fifty-mile wide belt beyond the Wisconsinan drift border across the southern parts of Illinois and Indiana and into central Ohio (Flint, et al., 1959). Two Illinoian ice advances are recognized in many places in Indiana and Ohio (Gooding, 1963; Durrell, 1961, p. 57; Goldthwait, 1969; White, 1969, p. 141). The till of these advances is separated by silt or outwash which is thought to represent a short, interstadial, period of ice retreat (Table 1).

Wisconsinan drift

"Late" Wisconsinan (Woodfordian) till is exposed along the northern edge of the study area. In places, north of the Wisconsinan terminal moraine, "Early" Wisconsinan (Altonian) deposits are exposed. South of this, the only Wisconsinan drift is outwash in the major valleys (Goldthwait, et al., 1965; Wayne and Zumberge, 1965). Drift of this age was not included in the present study.

Acknowledgments

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FIELD EXAMINATION OF GLACIAL DEPOSITS

Thickness and Topographic Setting of the Tills

North of the glacial boundary of the region (Fig. 15), till is found scattered across the uplands and in many of the larger valleys. Upland thicknesses rarely exceed 20 feet in southwestern Ohio and northern Kentucky and 10 feet in southeastern Indiana. In many of the early glacial drainageways (Deep Stage valleys), till extends well below the present floodplain reaching thicknesses of more than 100 feet.

Southeast of Cincinnati, many of the tributaries to the present Ohio River are cut in till rather than bedrock and till is exposed in the Ohio River valley at the present river level. From the mouth of the Little Miami River in eastern Cincinnati to about the mouth of the Great Miami River near Lawrenceburg, Indiana (Fig. 1), no till occurs below the uplands along the present course of the Ohio River.

Along the Ohio River from Lawrenceburg to Madison, Indiana, till is commonly exposed within the main valley and in some of its tributaries at the level of the present valley bottom. In only two places, however, is till exposed at elevations between the present valley bottoms and the floors of the abandoned Teays-age valleys, more than 200 feet higher. These two locations are (Fig. 1), (1) near Warsaw, Kentucky (location S-4), and (2) east of Carrollton, Kentucky (location CR-1). The elevations of all sample locations are given in the Appendix. Contrary to the concept of Rich (1956), there is not a complete absence of till below the upland level along the Ohio River between Lawrenceburg to Madison, Indiana.

Because the study area is located near the Ohio River, there has been considerable erosion of Kansan and Illinoian drift and much of the original thin till cover has been removed. As a result, many cuts expose only bedrock or bedrock residuum.

There is little topographic expression of the Kansan and Illinoian till as there is in areas of Wisconsinan drift cover to the north. Except for a small area of hummocky Kansan drift in northern Boone County, Kentucky, all relief in the area is the result of destructional, rather than constructional, processes. For the above reasons, a precise glacial boundary for both the Illinoian and Kansan till sheets is difficult to define.

Depth of Leaching

Southwestern Ohio, southeastern Indiana, and northern Kentucky can be divided into three regions on the basis of the depth of leaching in till. These are: (1) where leaching ranges from 12 to 17 feet in northern Kenton and Boone Counties, Kentucky, and southwestern Hamilton County, Ohio; (2) where leaching ranges from 6 to 8 feet in northeastern Hamilton and Clermont Counties, Ohio; and (3) where leaching ranges from 6 to 12 feet in the counties of southeastern Indiana, Gallatin and Carroll Counties, Kentucky, and northwestern Hamilton County, Ohio. The boundaries between these areas are not well-defined largely due to the considerable amount of post-glacial erosion which has produced many aberrantly shallow leaching depths, particularly near the Ohio River.

The depths to carbonates in sand and gravel almost always exceed those in the adjacent tills. On the uplands of northern Kentucky, southwestern Ohio, and in parts of the abandoned Old Kentucky River valley in Gallatin County, Kentucky, these leaching depths are in excess of 18 feet. The greatest known depths of leaching are in the outwash sands in northern Kenton County, Kentucky. There, carbonates are found at depths between 34 and 44 feet (Schaber, 1962).

Throughout southwestern Ohio, till that is leached to a depth of 6 to 8 feet is considered Illinoian in age (Durrell, 1961, p. 56; Teller, 1967). On this basis, the till in northeastern Hamilton and Clermont Counties is Illinoian. In Kenton, Boone, and southwestern Hamilton Counties, where till is leached more than 12 feet and outwash more than 18 feet, a pre-Illinoian age is strongly indicated.

Within the study area in southeastern Indiana, leaching depths commonly are greater than those in the Illinoian till of southwestern Ohio, but seldom reach the great depths found in the area of pre-Illinoian drift. Although the total carbonate percentage of the till in southeastern Indiana is generally lower than it is in tills to the east (Table 9 in Appendix), the greatest leaching depths - 10 to 1? feet - frequently coincide with an increased silt content of the till. However, the author feels that more evidence is needed in order to correlate the till of southeastern Indiana with either the Illinoian or pre-Illinoian tills of adjacent Ohio and Kentucky.

Loess Thickness

The thickness of loess cover in the study area is quite variable. In places, loess is absent, probably due to erosion, but in others may be as thick as six feet. The area of thickest cover is in southwestern Hamilton County (Ohio), Boone and Gallatin Counties (Kentucky), and eastern Switzerland County (Indiana), where the till and bedrock surface is generally buried by about 4 feet of loess. This may be due to its close proximity to the source of much of the windblown material in the Ohio River valley and/or to the greater age of the surface in that area.

On the Illinoian drift of Hamilton and Clermont Counties (Ohio), loess varies from two to three feet in thickness. Goldthwait (1968, Fig. 1) shows the loess cover on the Illinoian till plain of southwestern Ohio to range in thickness from about two feet to more than four feet.

In most of southeastern Indiana, the loess averages about three feet in thickness. In that area, the loess commonly <u>grades</u> downward from silt (loess) to pebby silt (± loess) to silty and pebbly clay (till), and finally into a clay loam till. This is in contrast to the generally abrupt loess/till contact found in Ohio and Kentucky. The gradation may indicate that the ice sheet stagnated, was covered by windblown material, and then melted, allowing the loess to mix with the upper surface of clayey debris in the ice during melting. Where an abrupt loess/till contact is found, loess deposition probably post-dates the melting of the ice sheet.

South of the Illinoian glacial boundary in northern Kentucky and southwestern Ohio, two loesses, of nearly equal thickness, appear to be present. This distinction is based only on a color difference (see for example, stratigraphic section K-3 in Appendix). Since Goldthwait (1968) has shown that loess on the Illinoian till plain of southwestern Ohio is composed of Woodfordian (Peorian) and Altonian (Roxana) loesses, and in places also of Illinoian (Loveland) loess, it seems likely that loess of two, and probably more ages was deposited over most of southwestern Ohio, southeastern Indiana, and northern Kentucky.

Description of Glacial Deposits

Water-laid deposits

Outwash terraces are found in most of the major valleys of the area. In the Ohio River valley, near Cincinnati, the Wisconsinan terrace level is at 540 feet and the Illinoian level at 600 feet. Pre-Illinoian outwash is recognized only on the uplands of the area, primarily in northern Kenton County (Schaber, 1962), northern and western Boone County (Durrell _in_ Ray, 1965, p. 62-63; Swadley, 1969a) and along the northern bluff of the Ohio River in southwestern Hamilton County.

Lacustrine deposits of bedded silts and bedded or color banded clays are exposed in many of the Teays-age and Deep Stage-age valleys and in subsummit positions on the uplands of southwestern Hamilton County, Ohio, and northern Kentucky (Durrell, 1961, p. 55; Durrell in Durrell, Forsyth, and Goldthwait, 1961, p. 67; Durrell in Gooding and Wayne, 1961, p. 129-30; this report, stratigraphic sections H-7, H-8, and H-10 in Appendix). Most of these deposits are Illinoian and pre-Illinoian although Wisconsinan lacustrine material is exposed along the northern edge of the study area. Outwash and till are commonly interbedded with the lacustrine sediments.

Deeply weathered fine grained sands, 10 to 30 feet in thickness, are scattered across the uplands of northern Campbell County, Kentucky (Teller, 1962). Although a glacial origin for these sands has been proposed (Brand, 1934), no evidence is available to support this conclusion. A similar deposit was discovered on the uplands of eastern Carroll County, Kentucky, along SR 1112 (3.4 miles south of Ghent and 1.4 miles northeast of Easterday). Exposed at this location is 13 feet of leached sand which grades upward into silt. Small quartz and chert pebbles are scattered throughout the sand. No bedding was observed. This sand, like that in Campbell County, overlies a clayey material resembling the local bedrock residuum. This deposit extends along the uplands for several tenths of a mile and local farmers indicate that similar deposits are found on other nearby ridge tops. Because the sand here and in Campbell County is found at the highest elevations of the area, it seems unlikely that it is related to the Teays-age drainage. It may be interpreted as (1) a pre-Teays (Cenozoic) drainage remnant, (2) an upper Paleozoic channel remnant like that described by Hrabar and Potter(1969), or (3) an outwash or ice contact deposit.

Ice-laid deposits

Most cuts in the area expose only one till sheet. In eastern Hamilton and Clermont counties, however, within the Illinoian Clermont Lobe of Durrell (1961, p. 57) (Fig. 4), two till sheets, separated by one to ten feet of gravel, are often exposed. In only two places within the Clermont Lobe is there a non-calcareous zone between these tills. These are (Fig. 1): (1) in the George Rack gravel pit in the Mill Creek valley (location H-17) where there is 13 feet of leaching in a sand between two calcareous tills (Durrell, 1961, p. 57; Durrell in Durrell, Forsyth, and Goldthwait, 1961, p. 80), and (2) in southeastern Hamilton County (location and stratigraphic section H-13) where there is three inches of non-calcareous silt at the top of a silt, sand, and gravel unit which lies between two tills.

The two-till sequence in eastern Hamilton and Clermont Counties may represent Illinoian and pre-Illinoian ice advances. However, except for the leaching at H-17, which Durrell (1961, p. 57) indicates may be a truncated Yarmouthian soil profile, no significant weathering zone has been found between the tills in southwestern Ohio. For this reason, the two tills in eastern Hamilton and Clermont Counties are thought to represent fluctuations in the Illinoian ice of the Clermont Lobe. The three-inch non-calcareous zone at H-13 either accumulated (accreted) on the surface or was weathered in situ when the Illinoian ice temporarily retreated northward. If this retreat was of stadial rank, the tills probably are equivalent to the Illinoian stades in southeastern Indiana described by Gooding (1963); the lowest till being deposited during the Centerville Stade and the upper one during the Richmond Stade.

In southeastern Indiana, Gooding (1963, 1966) has described several sections where two units of Illinoian till are exposed. The only one of these which is within the study area, is important because it is the southern most outcrop where there is good evidence for two Illinoian ice advances. This section is located 3.5 miles east of Osgood in Ripley County and the lowest of the two Illinoian tills overlies a Yarmouthian soil developed in till. Gooding (1966) assigns the lowest Illinoian till at that located to the Centerville Stade and the upper till to the Richmond Stade.

South of Ripley County, only one cut exposes more than a single till; it is located in western Ohio County, Indiana (location and stratigraphic section O-1). Both tills at that location may be Illinoian in age or, even though there is not now a zone of weathering in the buried till or the gravel between the tills, the lowest till may be much older than the overlying one.

In addition to the Kansan till exposed near Osgood in Ripley County (Gooding, 1966), buried pre-Illinoian tills are identified in two other places within the southeastern Indiana study area. One is located in southeastern Decatur County (location DK-1) where five tills are exposed. The upper (surface) till is leached seven feet and is considered to be Illinoian. Underlying this (Fig. 3) is a 9-foot soil, developed largely in till, which is interpreted to be Yarmouthian in age. Below the Yarmouthian paleosol are four distinct calcareous tills. The upper two are separated from each other by a thin calcareous gravel and the middle two by thin silty beds which are, in part, non-calcareous (Fig. 3). The upper five feet of the lowest till is oxidized and distinguished from the overlying till by this oxidation and its high content of chert.

Of greatest significance in this exposure is the 5-foot oxidation in the upper part of the lowest till. Since the oxidation almost certainly developed as a surface weathering phenomenon, it is interpreted as being the vestiges of a pre-Kansan, Aftonian, soil that was truncated by Kansan ice. Therefore, the till in which this soil developed is Nebraskan in age. The till is herein named, informally, the St. Maurice till after a small town by that name just to the east. This is the first positive evidence of Nebraskan glaciation east of the state of Illinois.

The three tills between the truncated Aftonian paleosol and the Yarmouthian paleosol in the Decatur County outcrop are correlated with the type Kansan section of Gooding (1966) in Fayette County in the

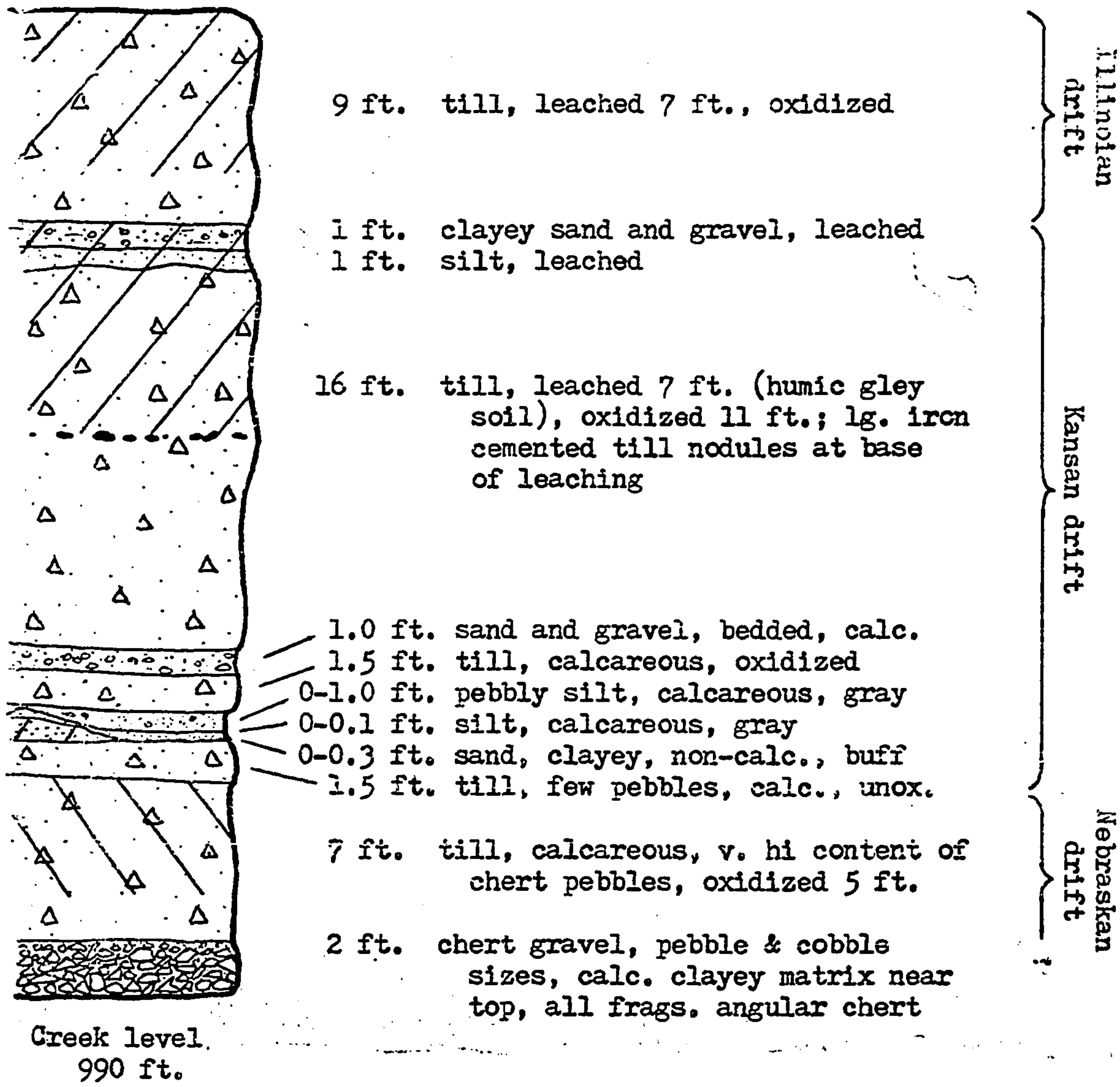

Figure 3 - Type section of Nebraskan St. Maurice till in Decatur County, Indiana; 0.7 miles west of St. Maurice where 200 North Rd. crosses small creek (SW 1/4 SW 1/4 sec. 30, T. 11 N., R. 11 E.). More detailed description in Appendix.

following way: (a) The basal Kansan till is considered equivalent to the till deposited during the first or Alpine Stade because it is separated from the overlying tills by a thin non-calcareous sand. This non-calcareous sand is interpreted as representing the Garrison Creek Interstade. (b) The upper two Kansan tills probably were deposited during the second or Columbia Stade although it is possible that each till represents a separate, stadial advance.

The second new exposure of pre-Illinoian till in southeastern Indiana is in Dearborn County, about 5 miles west of the Ohio River (location and stratigraphic section D-3), where there is a 3-till sequence. The lower till is leached four feet and is overlain by calcareous till. The calcareous middle and upper tills are distinguished from each other by their color and gross lithology. The upper till is buried by three feet of silt (loess) and this loess/till unit has a 9-foot leached zone developed in it. The upper till is interpreted, because of its leaching depth, to be Illinoian in age. The middle till probably is either an earlier Illinoian till or the basal portion of the upper unit. The leaching in the lower till is interpreted as a truncated Yarmouthian soil profile developed in Kansan till.

Direction of Ice Movement

Till fabric

Till fabric measurements were made at 18 locations in the study area. The procedure used in measuring the fabric was much like that advocated by Drake (1968). The azimuth of 33 to 50 pebbles, with a maximum length of one to three inches, was measured in place on the outcrop. The azimuth reading was plotted in the northern hemisphere of a rose diagram if the dip of the pebble's long axis was in a northerly direction; if not, the azimuth value was placed in the southern hemisphere of the rose diagram. Only pebbles that had an A axis/B axis (longest axis/intermediate axis) ratio of 1.7/1 or greater were recorded. Drake shows that by using this axial ratio, as few as 20 long axis measurements are representative of any strong pebble orientation at any one locality.

When the till fabric measurements are divided into geographic areas based on their age, as determined by the study of leaching depths, the following ice flow patterns emerge (Fig. 4):

(1) In the pre-Illinoian area of northern Kentucky and extreme southwestern Ohio, all fabric orientations are northwest-southeast. Pre-Illinoian ice, therefore, flowed from the northwest.

(2) In the Illinoian area of Clermont and eastern Hamilton Counties, Ohio (the Clermont Lobe), one of the two fabric measurements (CL-1) supports the earlier findings of Durrell (1961, p. 57) that the ice sheet flowed from the northeast. The other fabric measurement (CL-3) was taken from a deep early Pleistocene valley that is oriented northwest-southeast and, therefore, its orientation probably reflects only the local ice-flow direction in that valley.

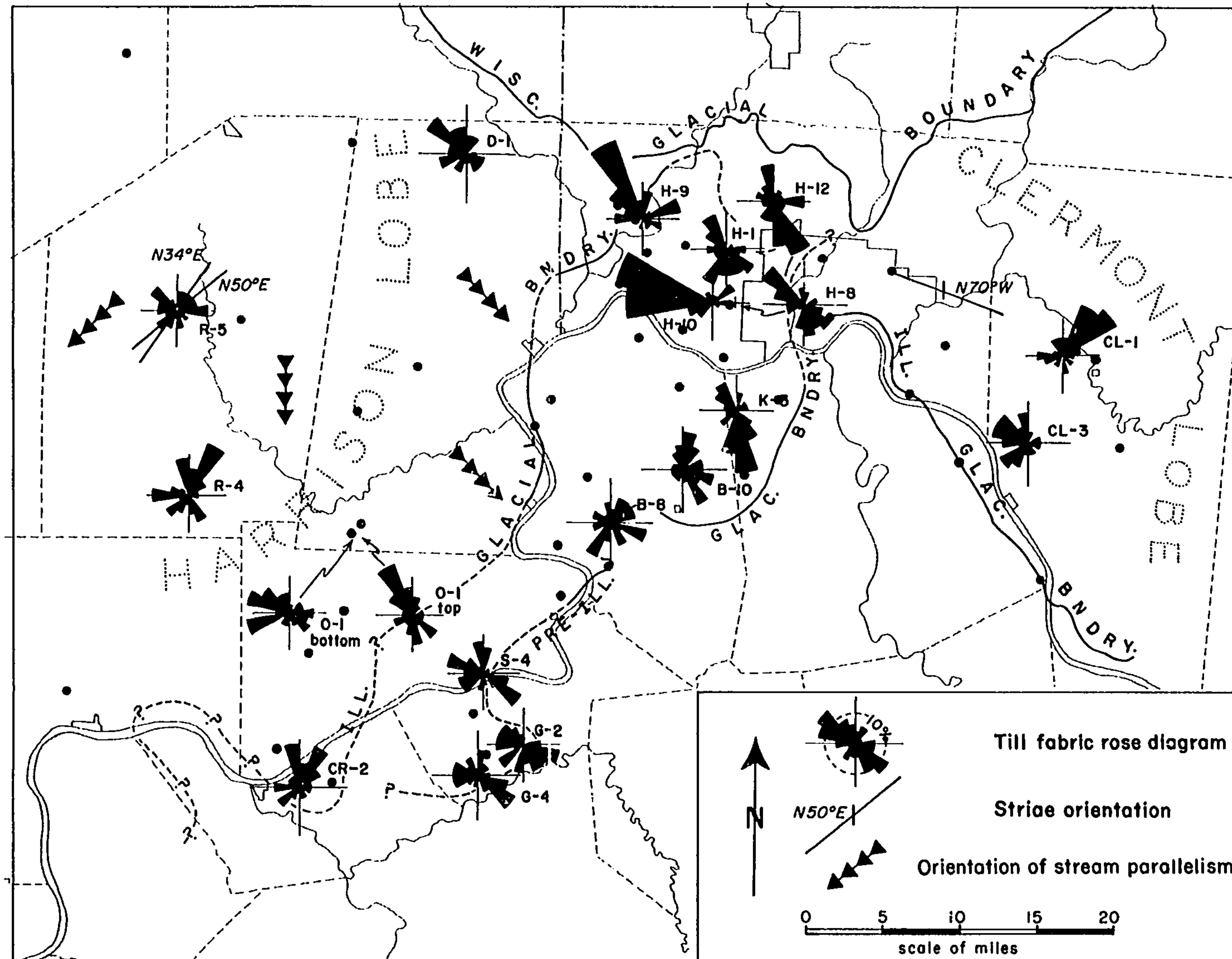

Figure 4 - Map showing till fabric measurements and other directional indicators of ice movement. Glacial boundaries based on both field and petrographic evidence (Fig. 15).

(3) In southeastern Indiana and some adjacent portions of Kentucky and Ohio, in the area considered uncertain in age on the basis of depth to carbonates, there is a radial pattern of till fabric orientations. This pattern is interpreted as indicating that the ice, the Harrison Lobe (Durrell, 1961, p. 57), flowed southward as a narrow tongue into the southeastern corner of Indiana.

Distinction between till deposited by the Clermont Lobe and that deposited by the Harrison Lobe can probably be made on the basis of till fabric data. All till fabric measurements taken within the area of pre-Illinoian drift in northern Kentucky and southwestern Ohio, however, have a northwest-southeast orientation and, therefore, cannot be distinguished on this basis from till deposited by the Illinoian Harrison Lobe of ice which also has this fabric orientation in adjacent southeastern Indiana (Fig. 4).

Striae

Glacial striae are known at two locations in the study area. One of these is near Osgood in Ripley County, Indiana (location R-5, Fig. 4). Here, along the western edge of the Harrison Lobe, numerous striae are oriented N 50° E and N 34° E supporting the till fabric evidence that the ice flowed from the northeast in that area. These striae are found on the Silurian (Niagaran) limestone surface beneath 8 to 12 feet of loess/till. The glacial drift is leached seven feet and, therefore, is probably Illinoian in age. The N 50° E striae are cut more deeply than the N 34° E direction.

The second location where striae have been found is in eastern Hamilton County, within the Clermont Lobe, in a small valley behind the school at the end of Roe Street, 1.0 miles north of the Little Miami River and 0.7 miles directly north of the downtown square in Mariemont (Maderia 7 1/2-minute topographic map), (Durrell, unpublished data). The striae are cut into Ordovician (Cincinnatian) limestone and oriented N 70° W (Fig. 4). Because these striae are in an old pre-glacial valley, with an orientation roughly parallel to that of the striae, and because most other evidence in that area suggests a northeast to southwest ice movement in the Clermont Lobe, these striae are considered aberrant.

Stream parallelism

An additional feature in southeastern Indiana, stream parallelism, may also be indicative of the ice flow direction in that area. This parallelism is best displayed in eastern Ohio County, west of Rising Sun, and in Dearborn County, northwest of Lawrenceburg, where the majority of valleys strike about N 45° W. This preferred stream orientation can be clearly seen in these areas on the Aberdeen and Guilford 7 1/2-minute topographic maps. West of this area, a less obvious stream parallelism occurs which shifts from the northwest-southeast orientation near Lawrenceburg to a northeast-southwest orientation in Ripley County. The overall pattern of the streams across this area is a radial one which roughly parallels the ice movement directions as determined from striae and till fabric measurements (Fig. 4).

A detailed field study was not made on the valleys exhibiting the preferred orientation. At this time, two possibilities seem to best explain the parallelism; they are:

(1) The streams developed along an ice-produced, mega-fluted pattern in the surface of the area. The radiating pattern, coinciding with fabric and striae information, supports this hypothesis.

(2) A well-developed jointing pattern in the bedrock of the area may have produced a parallelism of streams that was not obliterated during glaciation. Hofmann (1966) found the major joint orientation in the Upper Ordovician of southwestern Ohio to be northwest-southeast. He also notes that related to these joints are small folds, faults, and broad undulations and concludes (p. 546-547), "... The northwest direction of the older (preglacial) drainage may itself have been controlled initially by topographic irregularities, reflecting subsurface structural features...."

PETROGRAPHY OF THE TILLS

Introduction

The purpose of the laboratory analyses was to characterize the tills whose ages were known so that they could be empirically correlated with tills whose ages were uncertain. Willman, Glass, and Frye (1963) and others have successfully done this in Illinois. In addition, important differences might be discovered between individual Illinoian or pre-Illinoian stades.

The samples were divided into three groups based on the depth of leaching in the area from which they were collected. These groups are: (1) eastern Hamilton and Clermont Counties (Ohio) where leaching is consistently between 6 and 8 feet (Illinoian samples), (2) the uplands of Kenton and Boone Counties (Kentucky) and southwestern Hamilton County (Ohio) where leaching generally exceeds 12 feet (pre-Illinoian samples), and (3) all areas where the leaching depth does not fall into one of the above categories - primarily the counties of southeastern Indiana, northwestern Hamilton County (Ohio), and Gallatin and Carroll Counties (Kentucky). The last group is referred to as the uncertain-age samples.

After every petrographic analysis, each uncertain sample was assigned an Illinoian or pre-Illinoian age if possible. A summary of these assignments is shown in Figure 15. However, since till fabric data (Fig. 4) indicate that till in both the pre-Illinoian and uncertain areas were deposited by ice moving from the northwest, a similarity of properties does not necessarily mean that they were deposited by the same ice sheet. A difference in properties between the pre-Illinoian and uncertain samples, however, would be a strong indication that they were deposited by two different advances of ice.

Procedure

All samples of till analyzed in the laboratory were calcareous - reacting strongly with dilute (3:1) hydrochloric acid - and many were oxidized. In general, the following steps were used in the analyses (modified after Willman, Glass, and Frye, 1963).

(1) 100 grams of till were disaggregated by adding tap water and hand shaking.

(2) The slurry was wet sieved through a 62μ (#230) sieve until the wash water was clear. The wash water was not retained.

(3) The >62μ material was dried and then sieved through whole phi interval sieves.

(4) Each fraction was weighed.

(5) the 3ϕ and 4ϕ (fine and very fine grained sand) fractions were boiled in 33% hydrochloric acid for two minutes to remove the carbonates and the iron staining on the grains.

(6) The acidized sample was washed, dried, and weighed.

(7) The heavy minerals were separated in Bromoform (S.G. 2.86 at 25°C).

(8) A split of the heavy minerals was mounted with Aroclor (Monsanto #4465; n=1.665) and 200-400 grains on each slide were identified by a line count.

(9) A synthetic rock was made with the light minerals by adding an equal portion of clear "bakelite" powder (Transoptic Powder, Buehler No. 20-3400AB) and molding the mixture under temperature and pressure (in a Buehler Metallurgical Apparatus) into a 1 1/4-inch diameter disc.

(10) A thin section was then made from this synthetic light-mineral rock and the potassium feldspars were etched with hydrofluoric acid vapors and stained by emersing in sodium cobaltinitrite (Bailey and Stevens, 1960).

A second sample of till, 20 grams, was used for size analysis of the <62μ fraction and determination of the clay mineralogy. The following is an explanation of the reason for using a second sample for this. In order to obtain enough of the fine and very fine sand grains for analysis, 100 grams had to be used. Since pipette analysis requires a maximum of 1000 milliliters of liquid, the wash water used during wet sieving had to be kept below this volume. Experiments showed that, because the tills contained high percentages of clay and silt, it was extremely difficult to keep the volume of water that small for 100 grams of sample. In addition, the <62μ weight recommended for pipetting is 10 to 15 grams, so the initial sample weight had to be kept to about 20 grams (Folk, 1965, p. 37). It was reasoned that if any samples are considered representative, all fractions of it should be comparable in mineralogy, grain size, etc. Experiments confirmed this. The procedure for examination of the 20 gram sample was as follows:

(1) The sample was disaggregated by adding distilled water with 2.5 grams/1000 milliliters of Calgon dissolved in it.

(2) It was then wet sieved through a 62μ sieve, using the same Calgon and water solution. All <62μ material was retained and placed in a 1000 milliliter graduated cylinder.

(3) The solution was pipetted according to the standard procedure given in Folk (1965, p. 37-40).

(4) About 20 milliliters of liquid containing <2μ particles was removed, concentrated by centrifuging, and placed on frosted petrographic slides.

(5) The slides were air dried and the clay minerals analyzed by x-ray diffraction on a General Electric XRD-5 unit. Slides were irradiated with copper radiation (1) untreated, (2) glycolated (for at least 48 hours in a room temperature vapor bath of ethylene glycol), and (3) heated (to 340°C for one hour). A semi-quantitive analysis of the clay minerals was obtained by using the following procedure (Glass, 1969, written communication):

$$\text{Expandable clays} = \left\{\begin{array}{l}\text{intensity of } 8.8^\circ \text{ peak}\\ \text{after heating to } 340^\circ\text{C}\end{array}\right\} - \left[\begin{array}{l}\text{intensity of } 8.8^\circ \text{ peak}\\ \text{after glycolation}\end{array}\right] = X$$

Kaolinite and Chlorite = intensity of 12.4° peak after glycolation = Y

Illite = intensity of 8.8° peak after glycolation = Z

$\frac{X}{X+Y+Z}$ = % Expandable clays (includes all clay minerals that expand to about 17A° with ethylene glycol)

$\frac{Y}{X+Y+Z}$ = % Kaolinite and Chlorite (chlorite includes all nonexpandable 14A° material)

$\frac{Z}{X+Y+Z}$ = % Illite

The relative percentages of kaolinite and chlorite can often be determined by comparing their third order peaks at 24.9° and 25.1° but those peaks were not well enough defined for this in the present study. In nearly all cases, however, it could be determined which of the two were present in the "Kaolinite and Chlorite" (12.4° peak) group. This was done by first determining if a chlorite peak (5.9°) was present. If it was not, then all, or most, of this group must be kaolinite. If there was a 5.9° peak, indicating that at least some chlorite was present, then the slide was heated to 500°C for 1 hour to destroy all kaolinite. If kaolinite was present along with the chlorite, the 12.4° peak would be reduced in amplitude; if it was not reduced, only chlorite was present.

Grain-Size Distribution

Many studies have analyzed the distribution of particle sizes in tills and some have found this criterion useful in distinguishing one till sheet from another. Shepps (1953), Forsyth (1965), and Goldthwait (1969, p. 3) have differentiated some of the Wisconsinan tills in Ohio on this basis. Many till studies, however, have shown that the mechanical composition within one till sheet can be as variable within itself as it is from one till sheet to another. Field observations indicate that the particle size distribution in the basal part of a till sheet is often more similar to an underlying unconsolidated unit than to the upper portions of the same till sheet. Therefore, unless sampling is always from the same (preferably non-basal) position in the till, it seems unlikely that size distribution will ever become a widely used correlation tool.

Size analysis data from this study is presented in Table 7 in the Appendix and also is plotted on triangular diagrams (Figures 5 and 6). When the pre-Illinoian percentages from location DK-1 (Fig. 1) - exposed beneath a Yarmouthian soil in the extreme northwestern corner of the study area - are excluded, the 90% confidence limits define two distinct, but closely spaced and slightly overlapping, areas on the diagram for the Illinoian and pre-Illinoian. Computation of the arithmetic means for these two groups again allows the distinction to be made (Table 2).

Table 2 - Arithmetic means (and standard deviations) for mechanical analyses of Illinoian and pre-Illinoian tills (excluding Decatur County samples).

	Sand and Granules (%) (.062-2.0 mm)	Silt (%) (.004-.062 mm)	Clay (%) (<.004 mm)
Illinoian till (13 samples)	34.3 (±6.8)	35.9 (±3.5)	29.9 (±4.1)
pre-Illinoian till (16 samples)	26.7 (±4.8)	34.7 (±3.3)	38.6 (±4.1)

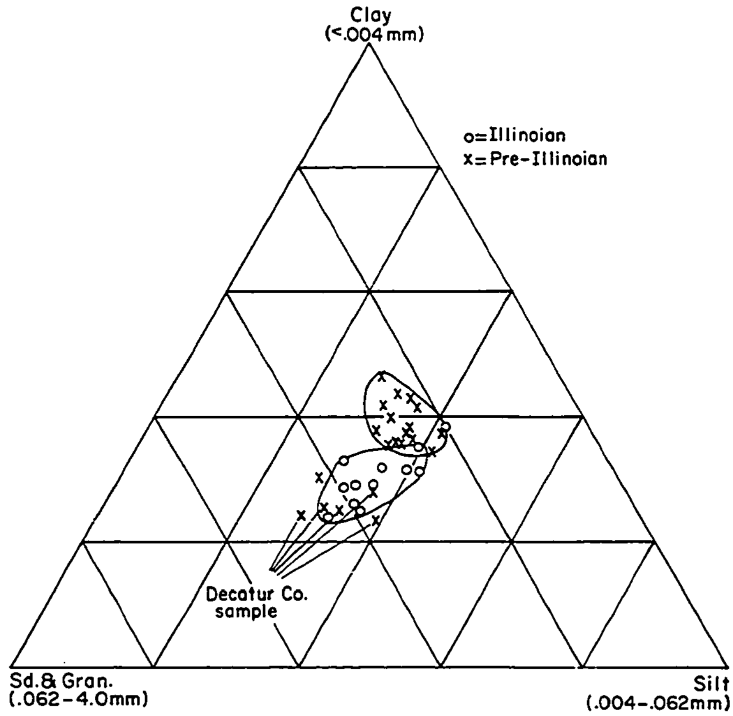

Figure 5 - Grain-size distribution of Illinoian and pre-Illinoian tills; 90% confidence limits outlined.

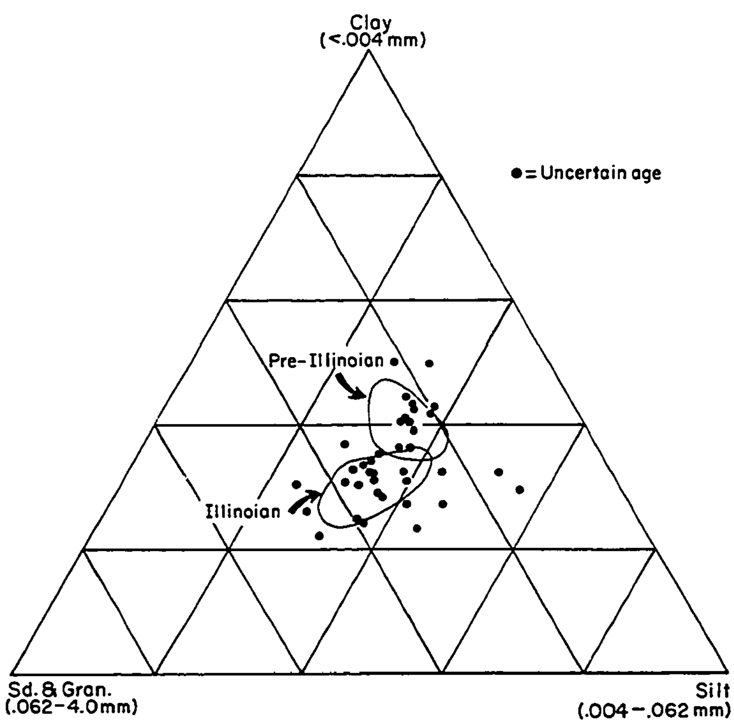

Figure 6 - Grain-size distribution of uncertain-age till plotted with outlines of grain-size limits of Illinoian and pre-Illinoian tills.

These analyses show that, as a rule, tills deposited by Illinoian glaciers are more sandy and less clayey than those deposited by the pre-Illinoian ice sheet.

When the sand-silt-clay percentages of the uncertain-age tills were plotted on a triangular diagram showing the confidence limits of the Illinoian and pre-Illinoian mechanical analyses (Fig. 6), about 60% of the uncertain group falls within, or closest to, the 90% confidence limits of the Illinoian till. This 60% includes the majority of the samples from southeastern Indiana. The uncertain samples falling into the pre-Illinoian group are primarily those from the uplands of Gallatin County (Kentucky) and northwestern Hamilton County (Ohio).

On the basis of mechanical analyses, the surface till throughout the southeast Indiana study area is most like that of the Illinoian samples of the Clermont Lobe and therefore is considered Illinoian in age. Pre-Illinoian till is restricted to the uplands of Kenton, Boone, Gallatin, and western Hamilton Counties.

Clay Mineralogy

Quantitative analyses of clay minerals has been used successfully to distinguish till sheets in Illinois (Willman, Glass, and Frye, 1963; Johnson, 1964; Frye, et al, 1969). Elsewhere in the east-central U.S. this approach has been little used except as a tool in discerning the stage of development of weatherin in tills (Bhattacharya, 1962, for example).

The detailed clay analysis of each sample in the study area is presented in Table 8 in the Appendix. The relative quantities of clay types in the Illinoian and pre-Illinoian samples are shown in Figure 7. Two closely spaced but distinct areas are outlined on the diagram when the 90% confidence limits are drawn. Again, as with the size analysis data, the Decature County, Indiana (location DK-1), quantities were not included in this determination. This distinction can also be made on the basis of the arithmetic means of the clay percentages in both groups (Table 3). The pre-Illinoian, then, can be distinguished from the Illinoian on the basis of its low amount (<10%) of kaolinite and chlorite and associated high amount (>45%) of expandable-type clays.

Kaolinite occurs in all samples. When both kaolinite and chlorite are present, the amount of kaolinite is always greatest. Chlorite is present in 85% of the Illinoian samples but in only 6% of the pre-Illinoian samples. Very few of the uncertain group contain chlorite. The absence of chlorite, in samples of this study, is associated in nearly

Table 3 - Arithmetic means (and standard deviations) for clay mineral components of Illinoian and pre-Illinoian tills (excluding Decatur County samples).

	Kaolinite and Chlorite (%)	Illite (%)	Expandable minerals (%)
Illinoian till (13 samples)	24 (±7)	46 (±5)	31 (±9)
pre-Illinoian till (16 samples)	6 (±3)	39 (±9)	55 (±10)

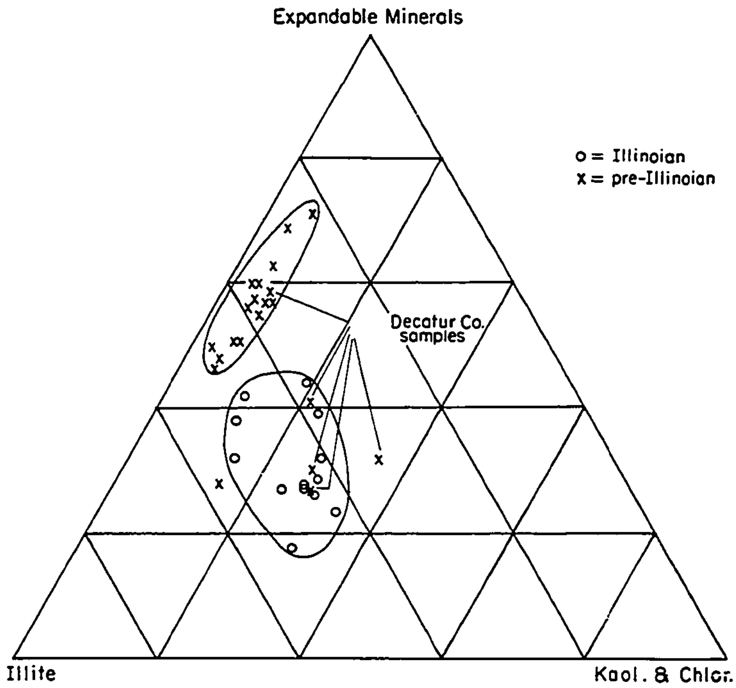

Figure 7 - Clay mineral composition of Illinoian and pre-Illinoian tills; 90% confidence limits outlined.

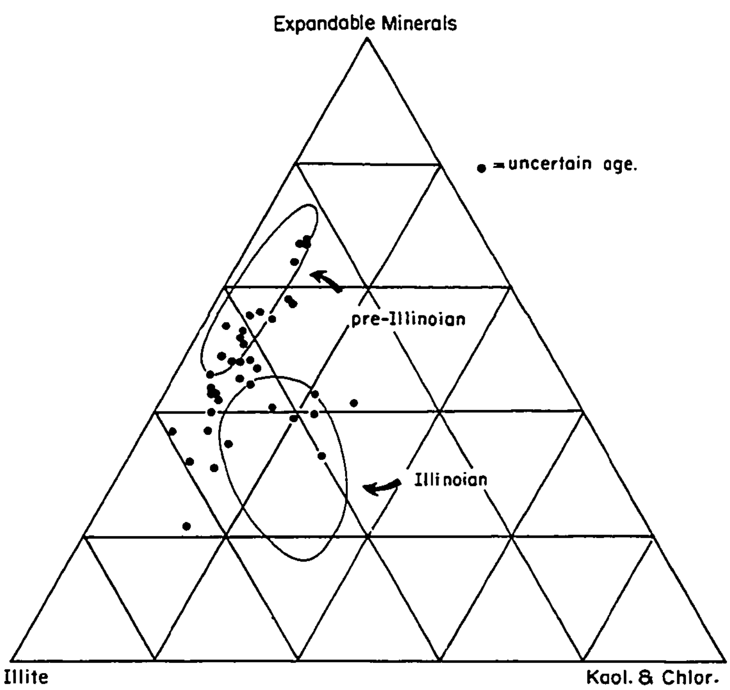

Figure 8 - Clay mineral composition of uncertain-age till plotted with outlines of compositional limits of Illinoian and pre-Illinoian tills.

every case with the presence of oxidation in the unit sampled. This correlation agrees well with the conclusions of Droste (1956), Willman, Glass, and Frye (1966, p. 21), and others that chlorite is one of the most sensitive minerals to weathering, being altered even before the carbonates are removed. The low amount of "Kaolinite and Chlorite" in the pre-Illinoian group, however, is not thought to be entirely the result of destruction of the chlorite by oxidation because the oxidized Illinoian samples still have two to three times as much kaolinite and chlorite as do the pre-Illinoian ones.

When the relative abundances of clays in the uncertain samples are plotted on a diagram showing the confidence limits of the Illinoian and pre-Illinoian abundances (Fig. 8), 60% fall within or closest to the pre-Illinoian. However, the age assignments determined from the clay mineralogy do not divide the uncertain-age till in southeastern Indiana and adjacent parts of Kentucky and Ohio into distinct geographic areas. Instead, both the Illinoian and the pre-Illinoian samples are mixed (geographically) throughout that area (Fig. 15).

The relatively high amounts of expandable minerals in the pre-Illinoian tills of this area (generally >50%) are comparable to what Frye, Glass, and Willman (1963) found in the Kansan till of western Illinois. The Kansan till (as well as the Illinoian till) of eastern Illinois and western Indiana, however, has a relatively low amount of expandable minerals and a high amount of kaolinite and chlorite and therefore is quite different from the pre-Illinoian of this area (Frye, Glass, and Willman, 1963; Johnson, 1964; this report, samples PCM-1a and PCM-1b).

Heavy Mineralogy

Heavy minerals have provided the means to differentiate till sheets in Ontario (Dreimanis, et al, 1957), Illinois (Frye, Glass, and Willman, 1963), and other mid-western states, but, to date, no heavy mineral studies have been published on any of the pre-Wisconsinan tills in Ohio, Indiana, or Kentucky. The percentages of the heavy minerals identified in this study are given in Table 9 in the Appendix and the arithmetic means of the Illinoian and pre-Illinoian groups are shown in Table 4. Perhaps the most notable feature of these means is the similarity between the two age groups. The only mineral types that differ more than a percent or so are total garnet, hypersthene, total pyroxene, epidote, and opaques. When standard deviation is considered, the differences in the percentages of total garnet and the opaques is not significant. The difference between the total pyroxene percentages is largely the result of the variation in the hypersthene percentages. The only significant and consistent variation between the Illinoian and pre-Illinoian heavy mineral suites is in the hypersthene and epidote content.

When a ratio between the hypersthene and epidote percentages is computed, it is generally greater than 1.0 for the Illinoian samples and is less than 1.0 for the pre-Illinoian samples. This information is

Table 4 - Arithmetic means and standard deviations (in percent) for heavy mineral components of Illinoian and pre-Illinoian tills (excluding Decatur County samples).

Heavy mineral	Illinoian till	Standard deviation	Pre-Illinoian till	Standard deviation
Garnet, colorless	7.3		8.8	
Garnet, pink, etc.	7.8		9.4	
total Garnet	15.2	2.9	18.3	3.7
Hornblende	35.8		36.4	
Tremolite-Antinolite	2.9		3.1	
total Amphiboles	38.8		39.5	
Augite-Diopside	4.5		3.4	
Hypersthene	3.2	2.0	0.8	0.6
Enstatite	2.5		2.2	
total Pyroxenes	10.2	3.2	6.4	2.3
Epidote	1.3	1.0	2.6	1.5
Titanite	1.0		0.4	
Zircon	0.7		0.9	
Tourmaline	0.4		0.1	
Stauro., Sillin., Kyan.	0.7		0.8	
others	2.4		2.5	
opaques	18.8	4.8	16.8	2.5
alterites	10.5		11.1	

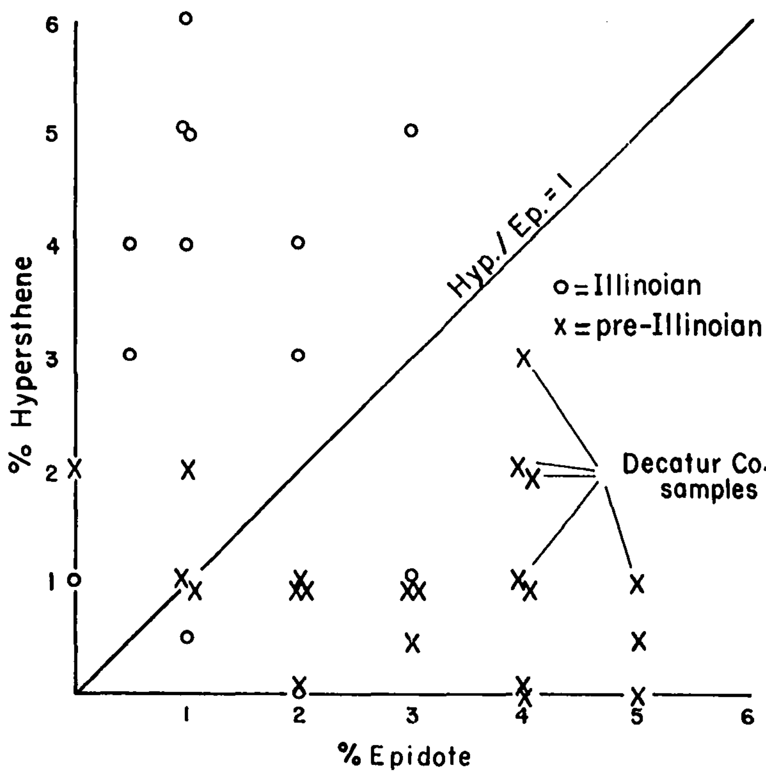

Figure 9 - Hypersthene-epidote percentages in Illinoian and pre-Illinoian tills (0.5% used for "trace").

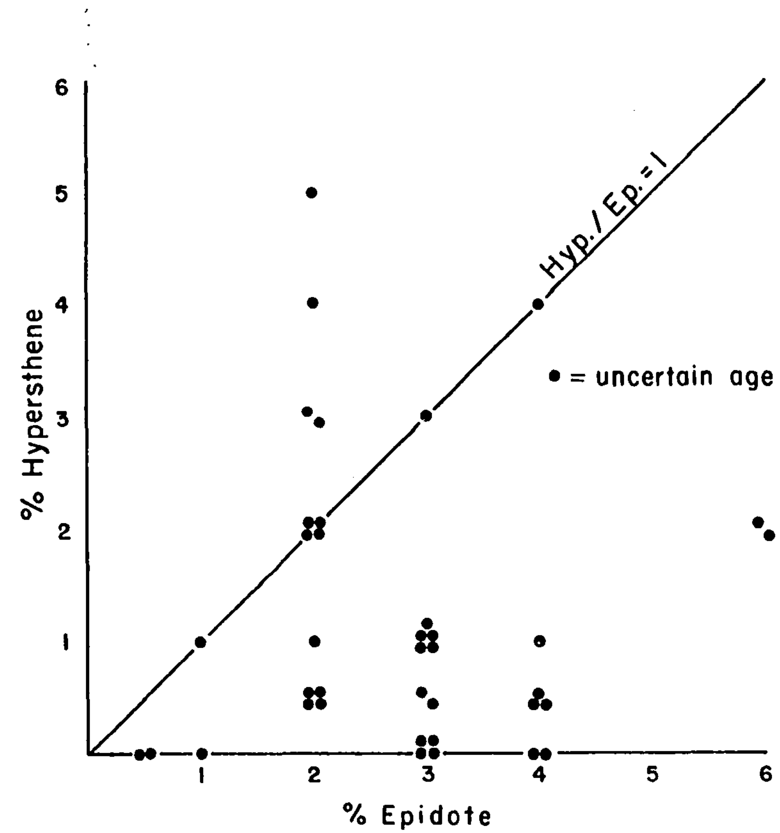

Figure 10 - Hypersthene-epidote percentages in uncertain-age till (0.5% used for "trace").

shown graphically in Figure 9. The hypersthene and epidote percentages of the uncertain samples are plotted in Figure 10. Nearly all of these samples have a hypersthene/epidote ratio of less than 1.0 and therefore fall into the pre-Illinoian group. On this basis, the uncertain samples of southeastern Indiana, southwestern Ohio, and northern Kentucky appear to be related to the same ice advance that deposited the pre-Illinoian till. However, because both the pre-Illinoian and the uncertain samples are within the area invaded by ice moving from the northwest (Fig. 4) - probably across similar source rocks - this correlation is not, by itself, considered significant.

Light Mineralogy

Analysis of the light mineral fraction has helped to distinguish till sheets in Illinois (Johnson, 1964; Willman, Glass, and Frye, 1963) and in northeastern Ohio and Pennsylvania (White, 1969; White, Totten, and Gross, 1969). In general, however, light mineral studies have shown the relative abundances of these minerals to be very uniform; only in northeastern Ohio and Pennsylvania is the light mineralogy known to be significantly different between till sheets.

Detailed line counts of the light minerals were made on only ten samples which were considered representative of each age group and geographic area. In all cases, the quartz-plagioclase-potassium feldspar abundances were nearly the same. The quartz content ranges between 78 and 90 percent, the plagioclase between 0 and 3 percent, and the potassium feldspar between 7 and 20 percent. Therefore, the light mineral content of the tills in this area was of no help in distinguishing the tills.

Miscellaneous Mineralogical Properties

Two additional properties of the tills were measured, (1) weight percent of heavy minerals in the fine and very fine sand fraction, and (2) weight percent of the fine and very fine sand fraction soluble in hydrochloric acid (Table 9 in Appendix). The arithmetic means in the Illinoian (Clermont Lobe) and pre-Illinoian samples were the same for the total heavy mineral content (2.6%; standard deviation 0.4%) and for the soluble content (32%; standard deviation 3.1% for Illinoian and 9.2% for pre-Illinoian). The only significant difference from these means is a 5 to 15 percent decrease in the carbonate (soluble) content of the "uncertain" samples in southeastern Indiana. This decrease is greatest along the western edge of the study area and probably reflects the increasing influence of less calcareous bedrock in that area.

Pebble Lithology

The relative percentages of pebble-sized material in till has been used to distinguish till sheets that were deposited by ice that traversed areas of different bedrock types. The advantage of pebble counts over microscopic or other laboratory tests is that it is simple and rapid. These studies have been profitably used in the central U. S. from Iowa to Ohio (Anderson, 1957; Norris, Gross, and Goldthwait, 1950). In Ohio, the standard procedure has been to collect at least 100 pebbles, one to three inches in maximum length, from a specific portion of the outcrop that has been marked off in advance (Goldthwait, oral communication, 1963). These pebbles are identified either in the field or later in the laboratory. Although the rock categories used in a pebble count depend upon the particular nature of the suite of rocks, most workers have relied on the basic sedimentary, igneous, and metamorphic groups.

The results of the 22 pebble counts made for this study are shown in Table 10 in the Appendix. In all but one sample (R-4), limestone was the major rock constituent, ranging from 46 to 100 percent of the total. Dolomite was, in most cases, the second most abundant lithology, varying from 0 to 45 percent. The percent of chert pebbles varies between 0 and 5 in all samples except two (R-4 and R-5) where the percent rises to 84 and 29, respectively. All other rock components - sandstone-siltstone, shale (gray and black), acid igneous and metamorphic, basic igneous and metamorphic, and quartzite - are found in quantities of 7 percent of less and in only a few samples does the percent exceed 2 for any of these rock types.

In this study, as in most others, the limestone/dolomite ratio appears to be of greatest value in subdividing the samples on a stratigraphic or geographic basis. With only one exception (K-3), all samples which were collected within the area where leaching depths exceed 12 feet (pre-Illinoian) have limestone/dolomite ratios greater than 15/1. The ratios of all samples collected within the area where leaching depths are between 6 and 8 feet (Illinoian) are less than 6/1 and greater than 1/1. Samples which were collected outside of these areas, the "uncertain" samples, can be placed into two categories on the basis of their limestone/dolomite ratios. The uncertain samples whose ratio exceeds 15/1 are considered pre-Illinoian in age and are located adjacent to the other pre-Illinoian samples on the uplands of Boone and Gallatin County, Kentucky. The uncertain samples whose ratio is less than 15/1 are located in southeastern Indiana, extreme western and northern Hamilton County, and the low elevation sites along the Ohio River in Kentucky. These samples are interpreted as being Illinoian in age. Figure 15 presents a summary of these interpretations.

The anomalously high percentage of chert from two samples along the western edge of the study area (location R-4 and R-5, Fig. 1) is thought to be the result of ice erosion of a local concentration of residual chert which had been weathered out of the Silurian limestones of that area, probably from the Laurel Limestone. Although pebble counts were not made at other locations near the edge of the Silurian outcrops in the western study area, nearly all exposures of till from north-central Trimble County, Kentucky, to central Ripley County, Indiana, contain unusually high percentages of chert pebbles. North of central Ripley County, the chert components are not noticeably high except in the basal, Nebraskan, till at location DK-1 in southeastern

Decatur County, Indiana. Similar chert concentrations have been reported by Gooding (1966) from buried "Kansan" tills in this area and to the north. Because large quantities of chert would probably be produced only after a long period of weathering of the bedrock surface, Gooding feels that those tills which contain high percentages of chert represent deposits of the first ice sheet to invade that area. This does not necessarily mean, as Gooding suggests, that all tills with a high chert content were deposited by the same Kansan or pre-Illinoian ice sheet. It simply means that wherever the chert-rich tills are found, no earlier ice advance is likely to have invaded that particular area.

INTERPRETATION OF EARLY DRAINAGE IN THE REGION

Introduction

A study of the early glacial and pre-glacial drainage in the area was necessary in order to more clearly understand the glacial relationships. Primarily the study was topographic but, in several places, the stratigraphy was studied in detail. The following section reviews the most widely accepted ideas on the early drainage of the region and proposes several major changes in the interpretation.

Teays Drainage

The major pre-glacial river in the region was the Teays, studied in detail first by Tight (1903) and named for now-abandoned valleys in West Virginia. This ancient drainage system headed in the Appalachians and the trunk stream flowed westward across central Ohio, Indiana, and Illinois to the Mississippi Embayment (Fig. 11). The name Teays is used in this report, as Wayne (1956, p. 36) suggested, to refer only to the pre-glacial streams of the Teays River drainage basin.

Much of the old Teays drainage system has been buried beneath glacial drift. Commonly the ancient valley bottoms are about 200 feet above the present major drainageways and 100-200 feet below the uplands. In southwestern Ohio, southeastern Indiana, and northern Kentucky, the Teays-age streams have an intrenched meandering pattern (Plate 1).

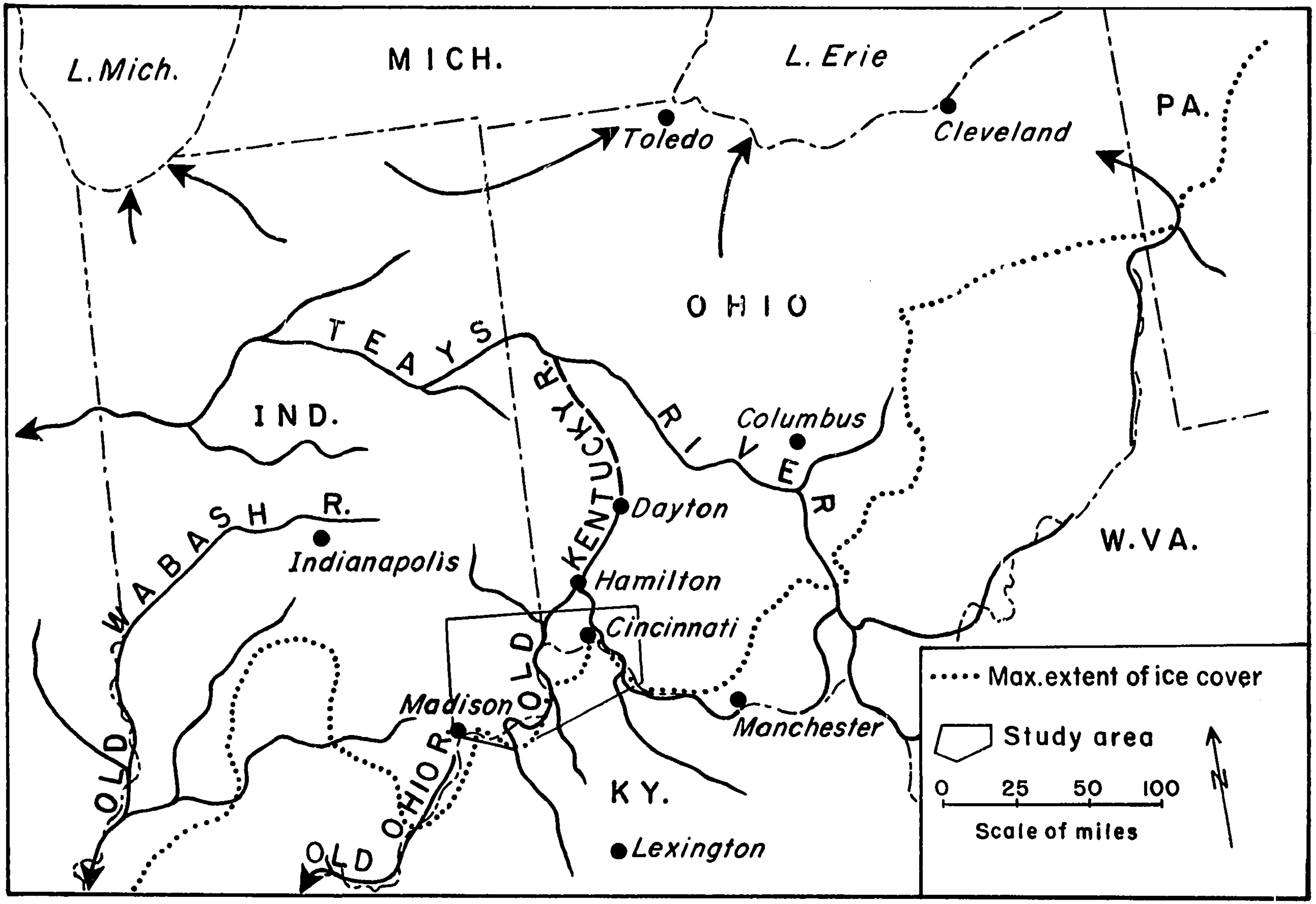

Figure 11 - Pre-glacial (Teays-age) drainage in Ohio, Indiana, and northern Kentucky (after Wayne, 1956, Fig. 9).

Several writers (Coffey, 1958, 1961; Durrell, 1961, p. 51) have suggested that the pre-glacial drainage was across northern Ohio and Indiana into the Great Lakes' basins rather than westward across the central parts of these states. According to Coffey and Durrell, the west-flowing Teays system was not developed until after the invasion of Nebraskan ice. No evidence is available to confirm this hypothesis and the buried bedrock surface maps of Ohio (Cummins, 1959, Pl. 2) and Indiana (Wayne, 1956, Fig. 5, Pl. 1) do not show any valleys connecting the central parts of these states with the Great Lakes' basins.

In southwestern Ohio, southeastern Indiana, and northern Kentucky, much of the intrenced and meandering Teays-age valley system - which lies about 100-200 feet below the upland level at 650-700 feet in elevation - is now abandoned. The present drainage pattern follows these abandoned routes closely (Plate 1). Although there has been considerable debate about the direction of the Teays-age streams south and west of Hamilton, Ohio, most recent authors have concluded that they flowed northward through the Cincinnati area to Hamilton and eventually joined the main westward-flowing Teays River in central Ohio (Fig. 11).

Several authors have proposed names for the main pre-glacial streams in this area and, in some cases, more than one name was applied to the same river. Fowke (1898) was the first to recognize that the pre-glacial drainage in the area was northward through Hamilton and into the main Teays valley. He also named most of these pre-glacial

Table 5 - Summary of names used for pre-glacial (Teays-age) rivers in southwestern Ohio, southeastern Indiana, and northern Kentucky. The names that should be retained are underlined and shown in Plate 1.

NAMES OF PRE-GLACIAL RIVER	GEOGRAPHIC EXTENT OF NAME	DIRECTION OF FLOW	INITIAL REFERENCE
Old Limestone	In and adjacent to present Ohio River valley from Maysville to eastern Cincinnati, then north and west through Norwood Trough to present Mill Creek valley; original reference did not extend river north of Cincinnati.	northwest	Fowke (1898)
Manchester	Same as Old Limestone except headwaters extended to Manchester.	northwest	Fowke (1924, p. 86)
Old Licking	South from junction with Manchester River near New Richmond to present Licking River valley at Butler and then up present Licking; original reference extended river entire length of Licking River and north through Mill Creek valley to Hamilton.	north	Fowke (1898)
Old Laughery	In and adjacent to Great Miami River valley from Hamilton to mouth of Laughery Creek and then up Laughery Creek valley.	northeast	Fowke (1898)
Old Kentucky	Same as Old Laughery from Hamilton to Laughery Creek but from there it continues south and west along present Ohio River valley to Carrollton and then up Kentucky River valley.	northeast	Fowke (1900)
Cincinnati	Roughly same as Old Kentucky.	northeast	Tight (1903, Pl. 1)
Hamilton	Southwestward from Hamilton but then, before reaching the Ohio River valley, westward into Indiana.	southwest	Stout, Ver Steeg, and Lamb (1943)
Eagle*	Same as Old Kentucky from Hamilton to near Patriot where it then leaves present Ohio River valley through now-abandoned channels into the headwaters of the present Eagle Creek.	north	Durrell (1961)

* The name Eagle River should only be retained for that portion south of the junction with the Old Kentucky River near Patriot.

rivers for the first time. Table 5 summarizes the various names used; those retained by the author are underlined and also shown on Plate 1. Evidence to support the interpretation that the abandoned Teays-age valleys in this region were north-flowing is:

(1) Reconstruction of the ancient meandering valley pattern (Plate 1) shows that the entrance angle of many of the tributaries to the Old Kentucky River would have been barbed if the river had flowed south instead of north.

(2) Bedload deposits in these channels are composed primarily of pebbles of "Pottsville-like" quartz and Mississippian chert that were probably derived from the southeast and southwest. In addition, the ancient streams flowing from the <u>southwest</u> toward Hamilton (Plate 1) contain Mississippian geodes (but no coal pebbles) while those flowing from the southeast contain coal pebbles but no Mississippian geodes (Miller, 1895; Cressman, 1968; Jillson, 1946, p. 20-30; Swadley, 1969a, b; Durrell, 1961; Hester, 1965). It seems, therefore, that these two ancient valleys did not contain the same river - since their loads were different - but were separate north-flowing tributaries in the same system that drained the area south of Hamilton (Plate 1).

Early Post-Teays Drainage

Major changes in the Teays river system probably occurred when the first (pre-Illinoian) ice sheet pushed south across the main Teays River valley in central Indiana and/or Ohio and dammed its westward outlet (Fowke, 1898; Ver Steeg, 1936, p. 927, 936; Wayne 1956, p. 35; Durrell, 1961, p. 52). The main changes brought about by this glaciation were: (1) to sever the southwestern Ohio, southeastern Indiana, northern Kentucky drainage basin from that of the main Teays system; (2) to cause the abandonment of many of the meandering Teays-age valleys for nearby but more direct routes; (3) to integrate the old Teays waterways of the area into a southwest-flowing Ohio River system; and (4) to intrench the new drainage routes 200 or more feet below the old Teays valley floors, often to a depth below that of today's valley bottoms, this deep-valley stage is referred to as Deep Stage drainage (Ver Steeg, 1936).

The integration of the old Teays waterways into the Ohio River system necessitated that several major Teays-age divides across the present Ohio River valley be breached. Within the area of this study was the divide at Madison, Indiana, which separated the north-flowing Old Kentucky River from that of the southwest=flowing Old Ohio River (Fig. 11). Damming of the downstream (northern) portions of the Teays system north or west of Hamilton, Ohio, produced ponding in the Old Kentucky, Manchester, and Old Licking River valleys. Eventually as these waters spilled westward across the divide at Madison into the Old Ohio River basin, a new outlet was established and the direction of water flow from Hamilton to Madison was reversed. Probably at about the same time, the waters of the Old Licking and Manchester Rivers were added to the headwaters of the new southwestward-flowing Ohio River.

Time of Teays Abandonment

The events leading to the abandonment of the meandering Teays valleys and the establishment of the present Ohio River drainage in this area have never been well-documented by field evidence. It is possible that the change came about in a more complex way than has been previously postulated and may involve multiple early glaciations.

It is suggested here that part of the Old Kentucky River, that part south of Carrollton, Kentucky, may have been captured by the westward-flowing Old Ohio River system prior to glaciation as it cut headward through the col at Madison, Indiana. Leverett (1929, p. 8) has reported another such capture of the Old Ohio River drainage basin on a portion of the Old Kentucky River about 50 miles upstream from Carrollton near Lawrenceburg, Kentucky. The fact that the meandering Old Kentucky, Manchester, and Old Licking Rivers were intrenced suggests that uplift was going on during Teays time.

Since the shorter route to the Mississippi Embayment was westward through the Old Ohio River, intrenchment and headward growth probably were more rapid in the Old Ohio River system than in the Teays system. If such a piracy did take place, it would certainly be less difficult to reverse the flow of the remaining north-flowing portion of the Old Kentucky River when ice first invaded the drainage basin of that river.

Most have suggested that it was not until Kansan time that the Teays drainage in this area was severed from the main Teays system and the north-flowing Old Kentucky River was reversed and integrated with the Manchester-Old Licking Rivers. There are, however, several strong lines of evidence to challenge these conclusions and postulate that the Teays waterways of this area were not only incorporated into a west-flowing Ohio River system before Kansan glaciation but were also cut well below the old Teays valley bottoms by that time. The evidence for this is presented below.

(1) Near Batavia, in Clermont County, Ohio, beneath more than 30 feet of calcareous Illinoian till and outwash is a 10- to 13-foot unit of weathered clayey silt and sand - believed to be alluvium - which overlies a partially leached coarse gravel (Fig. 12). The gravel, which may be pre-Illinoian outwash, is at an elevation of 580 feet, about 70 feet below the valley bottoms of the main Teays valleys in this area. Holowaychuck and Wilding of The Ohio State University (written and oral communication, 1970) interpret the weathering in the alluvium as "a well-developed paleosol, comparable in development to soils that have been forming since 'late' or possibly 'early' Wisconsinan deposition". This paleosol is interpreted to be Yarmouthian in age. Preliminary pollen studies in the alluvium (Warren, University of Cincinnati, 1970) show an upward decrease in gymnosperm (primarily pine and spruce) pollen and an increase in angiosperm (primarily hardwood) pollen. The upper two feet of the alluvial unit is barren of gymnosperm pollen. The author interprets this change as an indication of a warming climate, probably following Kansan glaciation. Therefore, if deposition of the alluvium was initiated at the end of the Kansan, the cutting of

9 ft. till, calcareous

1 ft. silty clay, calcareous, laminated

9 ft. sand, calcareous, bedded, silty & v. fine grained at top, coarse grained at base

2 ft. clayey silt, upper portion laminated, non-calcareous

8-11 ft. silty clay, increasingly sandy & pebbly toward base (=alluvium), non-calcareous, poorly bedded, fine to coarse angular blocky soil structure with clay coatings on ped surfaces

1-3 ft. coarse gravel, lgly ls cobbles, finer and non-calcareous in upper 1 ft.

0-2 ft. silty clay, pebbles & ls slabs incr. toward base, lower half weakly calcareous with mollusks & wood (=landslide debris?)

Creek level
580 ft.

Figure 12 - Stratigraphic section exposing Yarmouthian paleosol in Aftonian Deep Stage valley; 0.6 miles north of Batavia in Clermont County, Ohio where SR 222 crosses Backbone Creek. More detailed description in Appendix.

this Teays tributary valley - to a depth well below the main Teays valleys of the area - must have been initiated even before Kansan glaciation.

(2) In western Boone County, till is found 150 feet below the Teays valley bottoms in an area where it is difficult to extend a tongue of Illinoian ice to deposit it (locations B-8 and B-11, Fig. 1). Although the laboratory data on the till is inconclusive, the presence of pre-Illinoian till (leached 16 feet) on the uplands a short distance to the north suggests that the till may also be pre-Illinoian in age. The deep valley in which the till is found would, therefore, have to have been cut by Kansan time.

(3) Within the Mill Creek valley in Hamilton County (location H-17, Fig. 1), well below the level of the Teays-age valley bottoms at an elevation of 520 feet, Durrell (1961, p. 57; Durrell _in_ Durrell, Forsyth, and Goldthwait, 1961, p. 80) has described a 13-foot leached sand unit between two calcareous tills. He interprets this leached sand zone as being either a decapitated Yarmouthian soil profile or the results of a long period of interstadial weathering. If the soil is Yarmouthian, then the deep valley cutting would have to be pre-Kansan in age.

(4) The first strong evidence for Nebraskan glaciation east of Illinois is now known in Decatur County in southeastern Indiana (Fig. 3). With Nebraskan ice advancing this far south in Indiana, the north flowing Teays sytem would have been ponded. This ponding would have caused the waters in the Old Kentucky River to spill westward across the divide which separated it from the Old Ohio River drainage basin. The new west-flowing Ohio River would thus have been established and pre-Kansan

intrenchment could easily have taken place.

In summary, the author feels that the north-flowing pre-glacial Teays system was abandoned and a new Ohio River established and cut well below the Teays valley bottoms (to the so-called Deep Stage level) prior to Kansan glaciation. The course of the new, Aftonian, Ohio River was about the same as that of the present Ohio River except from the eastern edge of Cincinnati to Lawrenceburg where it had a more northerly route via Hamilton (Fig. 13). Since Nebraskan ice came at least as close as Decatur County in southeastern Indiana, it probably was largely responsible for producing these changes. It is possible, however, that part of the Teays sytem, the headwaters of the Old Kentucky River south of Carrollton, was captured by the westward-flowing Old Ohio River even before the first ice entered the area.

Drainage Changes Resulting from Kansan Glaciation.

The drainage changes resulting from Kansan glaciation are presented with the assumption that the new Ohio River system had already been established and cut several hundred feet below the old Teays valley bottoms. These valleys are referred to as Aftonian Deep Stage valleys (Fig. 13).

With the invasion of Kansan ice, the route of the Ohio River from Cincinnati to Hamilton to Lawrenceburg was blocked and the water had to seek a new route around the ice. It is suggested here that the Cincinnati-Hamilton-Lawrenceburg segment of the Ohio River (Fig. 13) may have been abandoned at this time and a shorter more southerly route

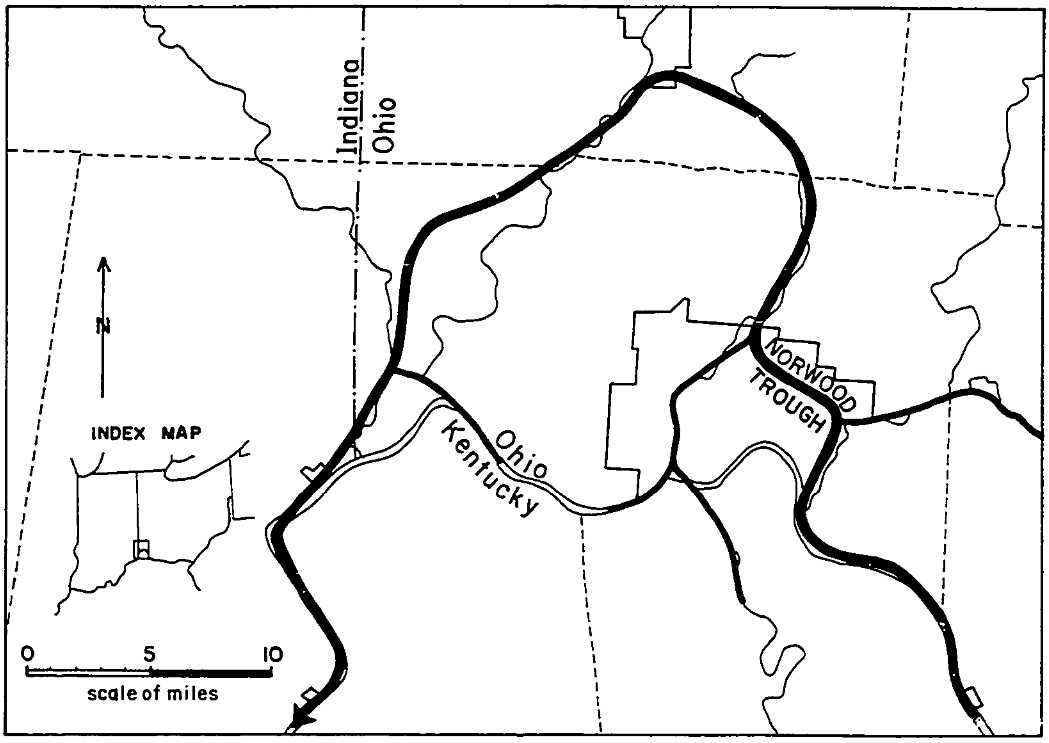

Figure 13 - Aftonian Deep Stage drainage in the Cincinnati area.

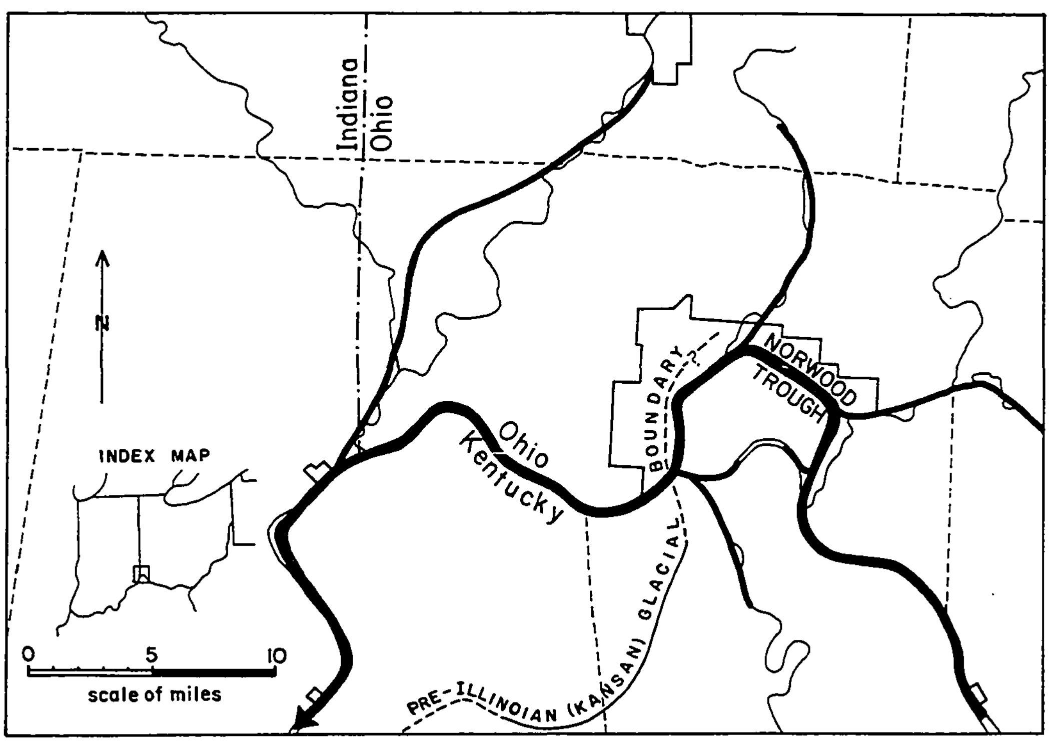

Figure 14 - Yarmouthian Deep Stage drainage in the Cincinnati area.

established. The proposed new river course is shown in Figure 14. Deepening of these valleys would again produce a Deep Stage period - Yarmouthian Deep Stage.

The position of the Kansan ice front along the western edge of the Mill Creek valley in Cincinnati (Fig. 14) would seem to support the above interpretation. Elsewhere in this area, there probably was little change in the main drainage patterns which were established prior to Kansan glaciation.

Previous interpretations have shown that the Cincinnati-Hamilton-Lawrenceburg route of the Ohio River was not abandoned until Illinoian time (Leverett, 1902, p. 116-117; Fenneman, 1916; Durrell, 1961). Because there is no more evidence for this interpretation than for the present one, both should be considered as possibilities.

Drainage Changes Resulting from Illinoian Glaciation

The present major drainage lines in southwestern Ohio, southeastern Indiana, and northern Kentucky were definitely established by the end of Illinoian time. The remaining portion of the Ohio River that had flowed north around Cincinnati in the Little Miami River valley, Norwood Trough, and Mill Creek valley (Fig. 14) - or, the Cincinnati-Hamilton-Lawrenceburg route (Fig. 13) - was diverted southward into its present valley by Illinoian ice.

The Yarmouthian course of the Great Miami River from south of Hamilton to near Lawrenceburg (Fig. 14) was also pushed southeastward out of its valley by advancing Illinoian ice (Durrell, 1961, p. 57). Its present course was established as an ice marginal channel in a relatively narrow valley, one to three miles southeast of the old valley, along a 10-mile distance between the northern edge of Hamilton County and Cleves, Ohio.

Just south of this area a temporary river change took place near Lawrenceburg when Illinoian ice crossed the Ohio River valley and forced the river to cut a new channel parallel to the old one. The ice barely invaded Kentucky and the now-abandoned, three-mile-long Illinoian valley was cut less than a mile east of the present valley. The well-known Split Rock conglomerate is found at the downstream end of this valley and probably was deposited in alluvial fan fashion as this valley was cut (Fowke, 1898, p. 8-9; Durrell, 1961, p. 56-57).

Another drainage change took place near Carrollton, Kentucky. Here, either Illinoian or Kansan ice pushed south into the mouth of the Kentucky River valley and, along a short distance, forced the river to cut a new valley about two miles to the west.

Numerous other temporary drainage channels were cut as the Illinoian ice invaded the valleys of the area. Since these are of little significance in interpreting the glacial history of the area, they will not be discussed.

INTERPRETATION OF GLACIAL DEPOSITS

Pre-Kansan Glaciation

The first glacial event recorded in southwestern Ohio, southeastern Indiana, and northern Kentucky is the invasion of Nebraskan ice. Evidence at a single cut in Decatur County, Indiana (Fig. 3), appears to be substantial enough to make this conclusion. In this cut the basal or Nebraskan till is overlain by three Kansan tills, the upper one with a Yarmouthian soil developed in it, and this is overlain by an Illinoian till. Oxidation in the basal till is thought to represent the vestiges of an Aftonian weathering zone and the till is, therefore, Nebraskan in age. The Nebraskan till is named, in this paper, the St. Maurice till.

Schaber (1962) has interpreted two mineralogically distinct glaciofluvial deposits in northern Kenton County, Kentucky, as resulting from two separate (major) Kansan ice advances. Because of the substantial difference in depth of leaching between these two deposits - 44 feet and 34 feet - the present writer is inclined to consider one Nebraskan and the other Kansan - a possibility noted by Schaber (1962).

Till of Nebraskan age has been identified by Leighton and Ray (1965) in a cut 10 miles southwest of Cincinnati (location B-10, Fig. 1). Here, they have interpreted a leached, manganese-rich, clayey gravel unit ("gumbotil", "black soil remnants", and "leached till") between two tills as a truncated soil profile in the lower till. Since the surface (upper) till in the area is thought to be Kansan in age (Durrell, 1961), the lower till is considered Nebraskan by Leighton and Ray. Re-investigation of the cut by the author produced a completely different interpretation - that is, the leached and porous clayey gravel is a gravelly zone within the Kansan till which is an extension of the surface soil (stratigraphic section B-10 in Appendix). This is a concept recognized by Gooding, Thorp, and Gamble (1959). Others who have studied the cut (R. P. Goldthwait, A. M. Gooding, and R. H. Durrell, oral communication, 1969) have also expressed serious doubt as to the Nebraskan-age interpretation put forth by Leighton and Ray (1965).

Nebraskan ice deposits, then, are clearly recorded only as far south and east as Decatur County, Indiana. Since it was apparently this ice advance that was responsible for the abandonment of the north-flowing pre-glacial (Teays) drainageways and the establishment of a westward-flowing Ohio River, the position of the new Ohio River west of Cincinnati <u>may</u> reflect the approximate line to which this ice advanced. With this interpretation the Aftonian course of the Ohio River from Madison to, perhaps, Hamilton was established as an ice-marginal channel and was soon cut below the old Teays valleys so that when the ice melted the pre-glacial channel was not reoccupied. The deeply leached (44 feet) glacio-fluvial deposits in Kenton County may be the result of overflow from the Nebraskan-ponded Teays streams or possibly from deposition by Nebraskan meltwater.

Kansan and Illinoian Glaciation

Kansan till was first recognized as the surface deposit in southwestern Ohio and northern Kentucky by Durrell (1956). Rich (1956) proposed that much of the surface till in southeastern Indiana is also Kansan in age. Based on depth of leaching, which is generally greater than 12 feet, the author concludes that all upland till in Kenton and Boone Counties (Kentucky) and in much of southwestern Hamilton County (Ohio) is pre-Illinoian, probably Kansan, in age (Fig. 15). This till is herein informally named the Cincinnati till for its common occurrence in the western suburbs of Cincinnati. Depth to carbonates in eastern Hamilton County and Clermont County (Ohio) are consistently in the 6- to 8-foot range and are, therefore, considered Illinoian. The till in southeastern Indiana, westernmost Hamilton County, Ohio, and Gallatin and Carroll Counties, Kentucky, (the "uncertain"-age till of the study) is leached from 6 to 12 feet and no age assignment was initially made on the basis of the depth of leaching.

Figure 15 is a summary of all age interpretations made in the study. The Illinoian till of Clermont and eastern Hamilton Counties and the pre-Illinoian till of Boone, Kenton, southwestern Hamilton Counties are clearly distinguishable in this figure. Except for the three samples on the uplands of Gallatin County, which are distinctly pre-Illinoian-like, few of the uncertain samples are clearly pre-Illinoian or clearly Illinoian. Even when considered as a group, the uncertain samples do not give any clear indication as to their age. To further complicate the

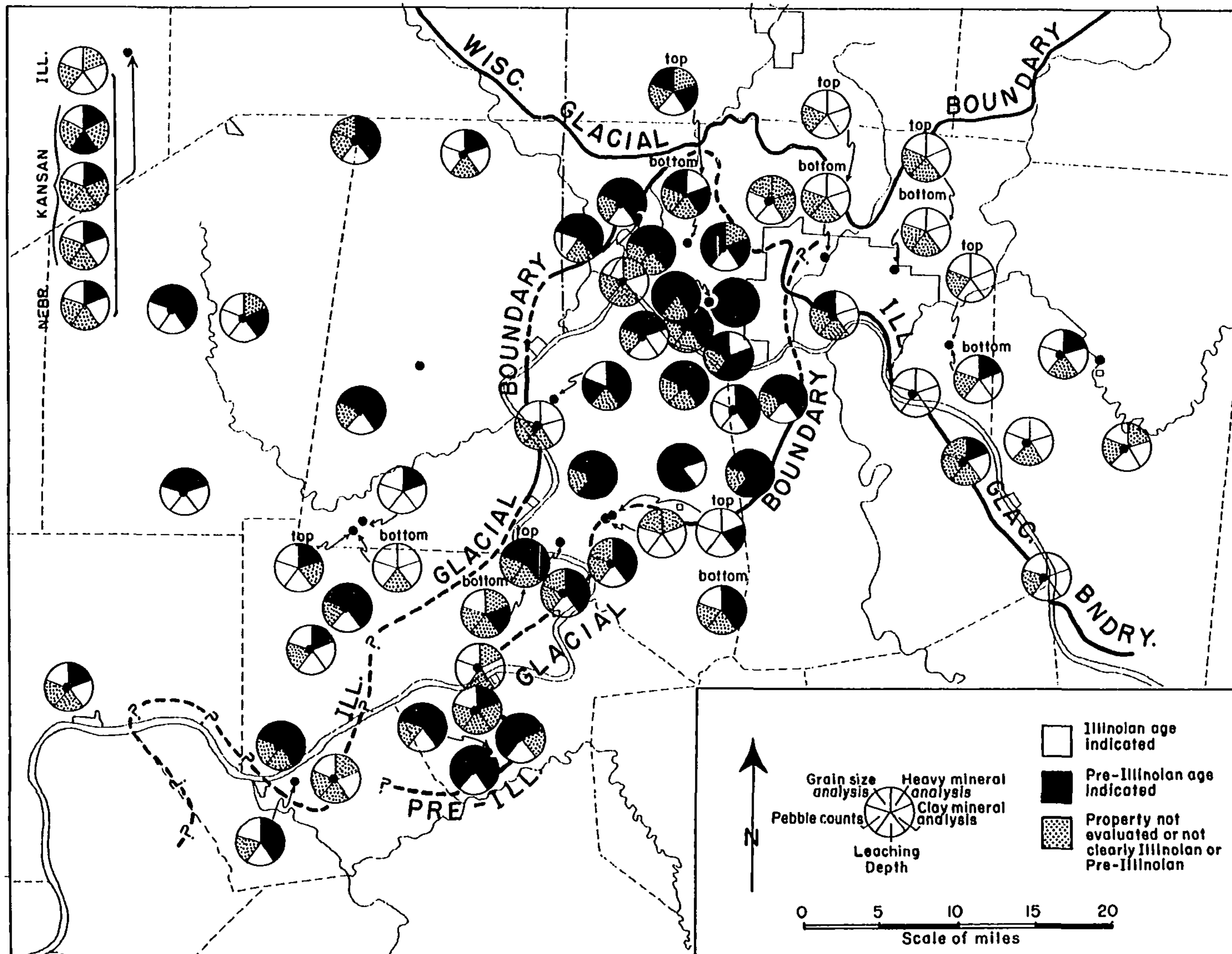

Figure 15 - Map showing summary interpretations of laboratory and field data.

matter, the properties of the Kansan and Nebraskan tills of Decatur County, Indiana (location DK-1), are more like those of the Illinoian tills of the Clermont Lobe than they are like the Kansan tills of northern Kentucky and southwestern Ohio.

Several possible explanations exist for the inconclusive age relations between the uncertain tills and the Illinoian and pre-Illinoian tills. These are, (1) the uncertain samples may actually be both Kansan and Illinoian in age, (2) the uncertain tills may not have been deposited contemporaneously with either of the till sheets with which they have been compared, and (3) the apparent "averages" of the till properties may not, because of the small number used, be truly representative of the widely varying properties of the till sheet. In the latter case, some of the uncertain samples would be expected to fall into one "average" while others would not.

On the basis of the laboratory data, the author does feel that the following conclusion is valid: since till fabric studies (Fig. 4) indicate that both the pre-Illinoian and the uncertain-age samples were deposited by ice flowing from the northwest, the numerous empirical differences between the two groups could be interpreted as the result of deposition by two different ice sheets. Combined with the consistently shallow (less than 12 feet) depth to carbonates within the area of uncertain-age samples, it is concluded that the surface till throughout most of southeastern Indiana and in a few adjacent parts of Kentucky and Ohio, post-dates the surficial till of northern Kentucky and southwestern Hamilton County, Ohio (Fig. 15). Although this post-Kansan till is probably equivalent to the Illinoian till of the Clermont Lobe, evidence to establish this is lacking.

The boundary between the Illinoian till in southeastern Indiana and the older drift on the uplands of Kentucky to the east lies near the Ohio River valley but is difficult to precisely delineate. Because of the repeated meltwater floods in the Ohio River valley, all till exposed within the valley has a shallow depth to carbonates; for this reason, leaching depths are of no value in defining the glacial boundary in this area. By combining the meager topographic, stratigraphic, and empirical evidence, the author has drawn the terminal boundary of the Illinoian (Harrison Lobe) ice along the western and northern edge of the Ohio River valley throughout most of the area (Fig. 15). Although future investigation may refine this boundary, the author feels that it is inaccurate by no more than a few miles. Table 6 presents a summary of averages of the "diagnostic" empirical data after the uncertain samples were divided into two groups - Illinoian and pre-Illinoian.

Table 6 - Averages of the four major "diagnostic" properties in the tills.

	Age of till (no. of samples)	grain size (% clay)	clay minerals (% kaol. & chlor.)	heavy minerals (hyp./ep.)	pebble counts ls/dol
Illinoian (13)		30	24	2.3/1	2.8/1
uncertain	Illinoian (23)	33	11	1/2.5	7.3/1
uncertain	pre-Illinoian (14)	34	8	1/2.4	16/1
pre-Illinoian (16)		39	6	1/3.2	53/1

In summary it does not seem that laboratory analyses offer a method of consistently differentiating the till sheets in this area. Empirical differences do exist but are only consistent between the northeastern-derived Illinoian till of the Clermont Lobe and the northwestern-derived pre-Illinoian till of northern Kentucky and southwestern Ohio.

The ice which invaded southeastern Indiana during the Illinoian (Harrison Lobe) was probably a very feeble advance, stagnating shortly after it reached its maximum southward extent. The bases for this conclusion are: (1) the thickness of till throughout most of this area is less than ten feet, (2) the upper few feet of the till is very silty and grades into the overlying silt (loess) cap which suggests that the ice stagnated, was covered by loess, and then melted producing a mixing of the wind-blown material and ice-carried debris, and (3) the absence of any constructional surface features which would have been produced if the ice had stood in equilibrium for even a short period of time.

At least two stadial advances of Kansan ice - the Alpine and the Columbia Stades - invaded southeastern Indiana as far south as Decatur County. This is indicated by Gooding's (1966) work and the cut in southeastern Decatur County (Fig. 3). A third fluctuation in the Kansan ice sheet is also indicated at the Decatur County cut, but this may only have been a minor fluctuation rather than a retreat of stadial magnitude. There is no indication that more than one Kansan ice advance ever reached into Kentucky or Ohio.

West of Cincinnati, as far south as central Ripley County, Indiana, there is evidence for two Illinoian stades - the Centerville and the Richmond Stades (Gooding, 1966). East of Cincinnati, two pulses of Illinoian ice - probably of stadial rank as suggested by the thin non-calcareous zone between the tills at H-13 (Fig. 1) - are indicated to have pushed as far south as about the Ohio River valley. These tills are correlated with the Centerville and Richmond Stades of southeastern Indiana and may be equivalent to the two Illinoian tills northeast of the study area in Highland County, Ohio, described by Goldthwait (1969, p. 11).

SUMMARY OF CONCLUSIONS

The first ice sheet to invade the area was the Nebraskan. The St. Maurice till clearly records its advance as far south as Decatur County, Indiana. Abandonment of the north-flowing pre-glacial (Teays) rivers in the area (Plate 1) and the establishment of a new southwest flowing Ohio River (Fig. 13) probably came about largely as a result of the Nebraskan invasion of ice. The location of the new Ohio River west of Cincinnati with which the present Ohio River coincides between the towns of Lawrenceburg and Madison (Indiana) may have been largely determined by the position of the edge of the ice sheet.

During the Aftonian Interglacial, the valleys of the new drainage routes were eroded several hundred feet below the abandoned Teays valley level to a depth at least as great as that of the present Ohio River valley bottom (±450 feet in elevation). This stage of valley development is referred to as Aftonian Deep Stage drainage.

Pre-Illinoian, probably Kansan, ice pushed across Indiana from the northwest advancing into Kentucky as far south and east as northern Kenton, Boone, Gallatin and Carroll Counties. In Ohio, this ice reached into western Hamilton County as far east as the present Mill Creek valley (Fig. 15). No pre-Illinoian ice deposits are known east of the Mill Creek valley. Till of Kansan age, the Cincinnati till, is found on the surface in northern Kentucky and extreme southwestern Ohio but in southeastern Indiana is buried nearly everywhere by younger drift. There were at least two, and possibly three, pulses (stades) of Kansan ice as far south as Decatur and Ripley Counties, Indiana. Two of these ice advances are correlated with Gooding's (1966) Alpine Stade (oldest) and Columbia Stade (youngest); the third may only represent a minor fluctuation within the Columbia Stade.

It is proposed that the course of the Aftonian Deep Stage Ohio River - around Cincinnati via Hamilton to Lawrenceburg (Fig. 13) - was permanently abandoned during Kansan glaciation. A new route was established which coincided almost exactly with the present course of the Ohio River except from the Little Miami River to the Mill Creek valley where it still flowed north through the Norwood Trough (Fig. 14). No other major drainage disruptions are known to have taken place at this time. Yarmouthian rivers flowed in valleys that were cut at least as deep as the Aftonian ones. This period of drainage is referred to as the Yarmouthian Deep Stage.

Illinoian ice invaded the area both from the northwest and the northeast. The northwestern ice, the Harrison Lobe, pushed south across Indiana to about the Ohio River, invading the Ohio River valley only near Carrollton (Kentucky) and just south of Lawrenceburg (Indiana), (Fig. 15). In westernmost Hamilton County the Harrison Lobe invaded the Yarmouthian valley of the Great Miami River and forced it to abandon its course for the one in which it now flows several miles to the southeast. Two stadial advances of Illinoian ice are known in the Harrison Lobe as far south as Ripley County, Indiana. Gooding (1963) has named these the Centerville Stade (oldest) and the Richmond Stade (youngest). Soon after the Harrison Lobe reached its maximum the ice stagnated.

The invasion of Illinoian ice from the northeast, the Clermont Lobe, crossed the Ohio River for a short distance into eastern Campbell County, Kentucky, and pushed into the eastern and northern portions of Hamilton County, Ohio (Fig. 15). Two Illinoian ice advances (stades) are recognized throughout most of the Clermont Lobe. These are correlated with the Centerville and Richmond Stades in southeastern Indiana.

The final changes in the course of the Ohio River in this area took place during Illinoian glaciation. The Yarmouthian route of the river around the northern edge of Cincinnati - in the Little Miami River valley, Norwood Trough, and Mill Creek valley (Fig. 14) - was abandoned as ice of the Clermont Lobe advanced south to about the present course of the river between Cincinnati and Covington (Kentucky).

Wisconsinan ice invaded only the northern edge of the study area. Outwash, probably from both Altonian and Woodfordian glaciers, was deposited in the major valleys south of the ice. Altonian and Woodfordian loess was deposited on the older drift surface throughout the area.

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APPENDIX

Table 7 - Grain-size analyses, weight percent in millimeter fractions of entire sample.

Sample number	>4.0	4.0-2.0	2.0-1.0	1.0-0.50	0.50-.250	.250-.125	.125-.062	sand & granules*	.062-.031	.031-.016	.016-.008	.008-.004	silt*	clay*
Illinoian till (Clermont Lobe)														
C-3	5.92	4.40	4.58	4.25	4.62	4.93	4.57	29.0	8.45	9.50	8.87	10.35	39.5	31.5
CL-1	5.15	4.50	5.13	5.00	6.23	6.91	7.39	37.2	9.29	7.74	13.26	0.66	32.6	30.2
CL-2a	7.75	4.10	4.39	4.82	6.43	7.44	7.39	37.5	10.67	7.52	7.76	4.85	33.4	29.1
CL-2b	3.46	4.54	5.26	5.43	6.94	7.92	7.76	39.2	10.38	7.45	7.90	5.65	32.5	28.3
CL-3	11.70	6.76	6.39	5.10	5.85	5.89	4.80	39.3	8.10	7.89	7.67	4.48	32.0	28.7
H-13a	5.13	3.09	3.81	3.72	4.66	5.28	4.77	25.7	6.40	11.90	5.95	12.35	39.1	35.2
H-13b	9.41	4.67	5.00	4.97	6.18	7.22	7.54	39.3	9.82	10.26	6.77	4.58	34.8	25.9
H-14	9.31	4.74	5.74	5.42	6.22	6.82	6.97	39.7	10.46	10.46	6.57	4.51	36.2	25.1
H-15a	2.88	3.48	4.20	4.30	7.73	8.00	6.28	35.0	9.85	10.56	8.21	6.10	35.7	29.3
H-15b	4.60	6.70	6.70	5.65	7.31	7.89	7.69	43.9	10.28	10.05	6.85	3.43	32.1	24.0
H-16	4.96	1.99	2.48	2.39	3.06	3.96	4.94	19.8	9.29	9.71	11.62	8.86	41.6	38.6
H-17a	2.97	2.91	3.33	3.87	7.34	6.85	6.33	27.5	10.74	13.31	9.57	6.30	41.2	31.3
H-17b	3.75	4.25	4.30	4.48	6.33	6.50	5.58	32.6	9.86	8.74	9.20	6.28	35.4	32.0

* Percent of <4.0 mm fraction

Sample number	>4.0	4.0-2.0	2.0-1.0	1.0-0.50	0.50-.250	.250-.125	.125-.062	Sd. & gran.*	.062-.031	.031-.016	.016-.008	.008-.004	silt*	clay*
pre-Illinoian till														
B-1	5.19	3.01	3.46	3.70	5.69	6.10	4.73	28.2	7.35	10.29	9.80	6.61	35.8	36.0
B-6	3.60	1.89	2.35	3.19	6.28	8.30	6.89	30.0	8.38	9.74	7.92	4.53	31.8	38.2
B-7	0.79	1.22	1.49	1.82	4.24	6.66	8.29	23.9	13.50	10.30	10.75	6.40	41.3	34.8
D-10	4.92	2.92	3.60	3.50	4.52	4.65	4.85	25.0	6.09	6.09	7.89	6.76	28.3	46.7
H-1	4.78	2.80	2.62	2.72	3.92	4.70	4.00	20.8	7.10	8.96	15.45	7.42	41.8	37.4
H-3	4.19	1.89	2.52	2.68	5.92	6.37	5.59	26.0	9.76	10.90	9.99	4.31	36.5	37.5
H-4	5.04	2.27	2.05	2.70	4.48	5.45	4.43	22.5	8.52	10.65	9.23	5.45	36.0	41.5
H-5	3.98	3.00	3.30	3.25	4.52	4.98	4.15	24.2	5.03	8.38	11.26	5.99	32.1	43.7
H-7a	1.31	1.47	1.90	2.09	4.20	6.38	6.39	22.7	8.71	10.12	10.12	4.71	34.02	43.1
H-7b	3.02	1.18	1.60	2.30	4.64	7.35	7.27	25.0	10.14	9.91	10.14	5.19	36.5	38.5
H-8	3.49	4.37	3.35	3.40	5.02	5.81	4.40	27.2	4.64	8.80	9.29	7.09	31.1	41.7
H-10a	3.88	4.61	3.08	3.20	5.88	5.61	4.40	26.9	7.74	8.46	9.19	6.53	33.1	40.0
H-10b	4.20	3.94	3.09	3.25	5.11	5.88	4.91	27.3	8.82	10.67	9.05	6.50	36.6	36.1
K-1	1.67	2.81	3.68	3.71	6.46	7.05	5.23	29.4	8.47	10.99	9.39	5.50	34.9	35.7
K-3	7.21	4.91	4.48	4.39	8.35	9.82	6.75	41.7	8.63	7.58	6.73	2.95	27.8	30.5
K-4	4.94	2.48	2.77	3.09	5.23	6.05	4.77	25.6	8.89	8.46	10.66	7.78	37.7	36.7

Sample number	>4.0	4.0-2.0	2.0-1.0	1.0-0.50	0.50-2.50	.250-.125	.125-.062	sd. & gran.*	.062-.031	.031-.016	.016-.008	.008-.004	silt*	clay*
uncertain-age till														
B-2	2.95	1.10	1.49	1.70	2.80	3.48	2.93	13.9	12.23	20.77	13.62	8.08	56.4	29.7
B-3a	6.29	6.40	6.72	9.70	8.53	6.64	4.08	45.0	4.90	6.22	6.41	5.31	24.4	30.6
B-3b	5.56	1.41	1.53	2.10	4.50	5.89	4.90	24.7	8.52	10.93	9.62	6.56	36.1	39.2
B-8	0.71	1.36	1.30	1.46	2.58	3.79	5.03	15.6	11.70	18.82	13.31	6.66	51.9	33.5
B-9	1.04	1.67	1.78	2.58	4.66	6.42	8.75	25.1	14.35	14.58	10.76	6.05	46.5	27.4
B-11a	0.53	2.73	3.04	4.03	7.63	9.80	9.57	39.0	11.96	11.07	7.97	5.53	36.7	24.3
B-11b	2.27	3.03	4.62	5.20	9.51	12.39	10.43	46.2	12.25	8.46	7.13	3.12	31.7	22.1
B-12	8.09	2.82	3.42	4.00	6.60	7.90	6.53	34.0	8.79	9.24	9.02	4.96	34.8	31.2
C-1	8.60	2.68	3.89	3.32	3.91	4.70	5.26	26.0	8.73	10.42	8.25	6.79	37.4	36.6
CR-1	1.13	2.61	3.58	4.10	7.16	8.71	7.50	34.2	12.06	10.27	9.61	5.14	37.4	28.4
CR-2	4.36	3.17	3.83	4.61	7.53	8.64	7.06	36.4	10.96	7.95	7.52	5.16	33.1	30.5
D-1	6.20	5.05	4.75	4.90	7.08	7.74	6.31	38.2	8.47	8.25	7.38	4.78	30.8	31.0
D-2	2.72	1.35	2.00	2.59	6.02	7.05	5.02	24.7	4.24	9.60	7.60	7.15	29.3	46.0
G-1	2.05	2.49	3.17	4.08	7.37	8.53	6.90	33.3	8.96	9.41	8.51	6.72	34.3	32.4
G-2	0.91	2.07	2.37	2.62	4.04	4.64	3.52	19.6	6.04	9.61	13.20	8.49	37.5	42.9
G-3	1.07	2.11	2.60	2.93	4.88	5.46	4.22	22.5	6.05	10.00	9.53	8.37	34.3	43.2

Sample number	>4.0	4.0-2.0	2.0-1.0	1.0-0.50	0.50-.250	.250-.125	.125-.062	sd. & gran.*	.062-.021	.031-.016	.016-.008	.008-.004	silt*	clay*
G-4a	1.59	1.90	2.17	2.43	3.84	5.52	4.18	20.4	7.59	9.10	11.38	8.60	37.2	42.4
G-4b	4.18	1.97	2.02	2.35	4.03	6.42	4.98	22.8	5.89	9.97	10.19	7.47	35.0	42.2
H-9	6.10	1.96	2.24	3.91	5.72	5.89	4.41	25.1	7.80	7.57	9.80	6.23	34.2	40.7
H-11	2.25	1.80	2.60	3.50	7.19	9.27	7.50	32.6	10.79	5.40	10.32	5.63	32.8	34.6
H-12	6.28	2.96	3.91	3.50	4.55	5.49	5.59	27.7	8.99	6.74	10.25	7.25	35.5	36.6
H-18	0.90	2.00	2.59	3.22	5.62	6.63	4.40	24.6	8.95	9.18	10.33	6.43	35.2	40.2
J-1	4.35	3.88	3.79	4.65	11.10	12.45	8.10	45.8	8.75	7.32	6.71	4.07	28.1	26.1
O-1a	5.93	1.31	2.12	2.93	6.39	7.93	7.01	29.4	11.77	9.53	8.66	7.10	39.4	31.2
O-1c	4.55	2.14	2.10	2.46	4.92	5.66	5.15	23.5	9.60	12.28	12.51	7.59	44.0	32.5
O-1d	1.87	2.22	3.10	3.80	7.10	8.06	6.23	31.0	10.39	11.54	11.54	7.38	41.7	27.3
O-1e	2.33	3.03	3.45	4.05	7.87	11.29	8.53	39.2	8.92	10.75	10.29	5.03	35.8	25.0
O-2	2.79	2.31	3.45	4.45	8.38	8.61	6.30	34.5	10.87	5.43	10.87	8.05	36.1	29.4
R-1	1.08	1.79	2.51	4.10	8.88	10.02	7.32	35.1	8.23	6.67	7.56	5.12	27.9	37.0
R-3	1.05	1.58	2.25	3.41	6.78	8.95	8.46	31.8	12.48	12.07	12.89	7.16	45.0	23.2
R-4	0.10	1.49	1.68	2.63	4.92	6.28	5.69	22.7	6.32	7.67	9.26	9.48	32.8	44.5
R-5	4.17	3.15	2.94	3.98	7.68	8.51	6.20	33.9	7.32	9.84	9.61	5.49	33.6	32.5
S-1	0.80	1.28	1.90	2.62	5.10	6.03	4.57	21.6	7.71	6.16	10.12	4.41	28.6	49.8

Sample number	>4.0	4.0-2.0	2.0-1.0	1.0-0.50	0.50-.250	.250-.125	.125-.062	sd. & gran.*	.062-.031	.031-.016	.016-.008	.008-.004	silt*	clay*
S-2	1.68	2.50	3.60	4.29	8.08	9.40	7.50	36.0	9.63	8.51	7.17	5.16	30.9	33.1
S-3	0.80	0.70	0.80	1.58	4.66	5.42	3.61	16.8	6.31	9.69	9.91	7.20	33.6	49.6
S-4	0.93	1.84	2.50	2.60	5.29	7.80	8.76	29.0	12.53	14.10	5.82	5.37	38.2	32.8
S-6	2.25	1.96	2.31	3.08	6.62	8.73	7.56	31.0	8.31	9.98	9.27	5.47	33.7	35.3
DK-1a	15.09	3.44	3.55	3.54	5.70	7.35	6.40	35.3	6.84	7.82	6.26	9.97	36.4	28.3
DK-1b	0.80	1.65	3.89	5.60	8.29	9.66	8.04	37.4	11.04	8.96	11.73	7.13	39.2	23.4
DK-1c	2.75	2.07	3.34	4.55	10.48	11.73	8.29	41.4	9.61	8.52	8.73	5.46	33.3	25.3
DK-1d	2.00	1.35	3.29	4.79	11.19	12.90	9.33	43.8	11.21	6.37	8.81	3.51	30.4	25.8
DK-1e	2.34	1.39	2.58	4.92	13.64	14.59	9.11	47.4	8.50	7.83	8.05	3.35	28.3	24.3
DK-1f	0.48	1.69	2.72	3.99	8.62	9.75	7.14	34.1	8.82	13.23	6.48	3.37	32.1	33.8
PCM-1a**	5.61	3.32	3.91	4.03	7.36	9.30	8.48	38.6	12.00	9.56	7.53	5.90	37.1	24.3
PCM-1b**	1.98	3.50	3.95	4.57	8.67	10.12	8.72	40.3	11.04	9.71	8.17	4.42	34.1	25.6

**Samples from Cagles Mill cut in western Indiana (1a is Kansan, 1b is Illinoian - Wayne, 1958, p. 10).

Table 8 - X-ray diffraction analyses of clay minerals

Sample number	Percent in <2µ fraction: Expandable minerals	Kaolinite & Chlorite*	Illite	Chlorite present	Kaolinite present
Illinoian till (Clermont Lobe)					
C-3	42	12	47	o	+
CL-1	32	15	53	o	+
CL-2a	44	19	37	+	++
CL-2b	38	12	50	+	++
CL-3	27	24	49	+	++
H-13a	32	27	41	+	++
H-13b	39	23	38	+	++
H-14	27	27	46	+	++
H-15a	23	28	48	+	++
H-15b	26	29	45	+	++
H-16	22	33	43	+	++
H-17a	17	30	52	+	++
H-17b	28	27	46	+	++

* Includes non-expandable vermiculite

\+ Present in small to large quantities

++ Present in small to large quantities but more abundant than +

o Absent or present in very small quantities

Sample number	Exp.	Kaol. & Chlor.*	Illite	Chlor. pr.	Kaol. pr.
pre-Illinoian till					
B-1	56	5	39	?	?
B-6	71	6	22	o	+
B-7	57	8	35	o	+
B-10	28	15	57	o	+
H-1	60	4	36	o	o
H-3	57	5	37	o	+
H-4	69	4	27	?	?
H-5	60	4	36	o	+
H-7a	55	7	38	o	+
H-7b	51	6	43	+	+
H-8	50	3	47	o	?
H-10a	46	5	48	o	+
H-10b	48	5	47	o	+
K-1	63	5	32	o	+
K-3	57	7	36	?	?
K-4	51	6	43	o	+

Sample number	Exp.	Kaol. & Chlor.	Illite	Chlor. pr.	Kaol. pr.
uncertain-age till					
B-2	56	7	37	o	+
B-3a	58	11	32	o	+
B-3b	67	8	25	?	?
B-8	35	13	52	o	+
B-9	46	5	49	o	+
B-11a	56	6	39	o	+
B-11b	48	7	45	o	+
B-12	39	20	41	?	?
C-1	40	8	52	o	+
CR-1	41	16	43	+	++
CR-2	51	7	42	o	+
D-1	43	7	50	+	?
D-2	68	8	25	o	+
G-1	43	7	50	o	+
G-2	37	4	59	o	+
G-3	49	5	46	o	+
G-4a	44	6	50	o	+
G-4b	52	6	42	o	+
H-9	54	3	43	o	+
H-11	41	27	31	?	?
H-12	47	11	42	o	+

Sample number	Exp.	Kaol. & Chlor.	Illite	Chlor. pr.	Kaol. pr.
H-18	48	9	42	o	+
J-1	31	13	56	o	+
O-1a	40	23	38	+	++
O-1c	33	27	40	+	?
O-1d	42	8	50	o	+
O-1e	45	9	45	o	+
O-2	32	9	58	o	+
R-1	55	9	36	?	?
R-3	58	10	32	?	?
R-4	22	14	65	o	+
R-5	48	8	44	o	+
S-1	67	7	26	o	+
S-2	37	9	54	o	+
S-3	64	8	28	o	+
S-4	44	11	44	+	?
S-6	53	6	41	o	+
Dk-1a	32	35	32	o	+
DK-1b	41	21	38	o	+
DK-1c	31	27	43	+	++
DK-1d	28	28	44	+	++
DK-1e	59	7	35	o	+
DK-1f	43	21	36	o	+

Sample number	Exp.	Kaol. & Chlor.	Illite	Chlor. pr.	Kaol. pr.
PCM-1a**	30	37	33	+	++
PCM-1b**	35	36	29	+	++

** Samples from Cagles Mill cut in western Indiana (1a is Kansan, 1b is Illinoian - Wayne, 1958, p. 10).

Table 9 - Heavy mineral and carbonate analyses (in percent) of .062-.250 mm fraction

Sample number	Weight % of heavies	Garnet, colorless	Garnet, pink, etc.	total Garnet	Hornblende	Tremolite-Actino.	total Amphiboles	Augite-Diopside	Hypersthene	Enstatite	total Pyroxenes	Epidote	Titanite	Zircon	Tourmaline	Stauro.,Sillim.,Kyan.	others	opaques	alterites	Wt. % sol. in HCl
Illinoian till (Clermont Lobe)																				
C-3	2.1	8	11	19	37	6	43	4	5	tr	9	1	0	2	0	1	2	12	12	35.5
CL-1	2.3	8	4	12	42	4	46	3	0	2	5	2	1	2	2	1	1	16	13	29.5
CL-2a	2.8	6	8	14	35	2	37	4	3	3	10	2	1	1	tr	tr	tr	23	11	28.2
CL-2b	2.1	8	11	19	32	1	33	3	1	3	7	3	1	2	2	tr	2	24	8	27.6
CL-3	3.1	8	10	18	39	tr	39	6	6	4	16	1	1	tr	0	3	2	13	7	36.1
H-13a	3.1	6	9	15	36	3	39	4	4	1	9	tr	tr	tr	0	1	6	16	13	35.0
H-13b	2.4	6	8	14	30	6	36	5	5	2	12	3	0	0	0	1	3	20	11	28.7
H-14	2.6	5	5	10	30	4	34	4	3	2	9	tr	5	0	0	0	5	24	12	31.2
H-15a	2.5	6	6	12	36	tr	36	4	tr	2	6	1	0	1	0	tr	2	28	13	32.6
H-15b	3.0	9	9	18	33	2	35	5	1	4	10	0	2	tr	0	0	2	20	13	28.3
H-16	2.1	8	8	16	41	2	43	6	4	4	14	1	0	tr	tr	1	2	16	6	30.0
H-17a	2.5	7	6	13	36	5	41	4	5	4	13	1	1	1	1	0	3	17	10	31.4

Sample number	Weight % of heavies	Garn., clss.	Garn., pink	total Garn.	Hbl.	Trem.-Act.	total Amph.	Aug.-Diop.	Hyp.	Enst.	total Pyr.	Epidote	Titanite	Zircon	Tourm.	St.,Sill.,Ky.	others	opaques	alt.	Wt. % sol. in HCl
H-17b	2.8	10	7	17	39	3	42	6	4	2	12	2	1	tr	0	1	1	15	8	34.8
pre-Illinoian till																				
B-1	2.5	10	5	15	34	4	38	5	1	2	8	4	tr	1	tr	tr	2	20	12	34.4
B-6	3.0	7	13	20	36	5	41	4	tr	1	5	3	tr	2	1	2	tr	14	13	13.0
B-7	2.3	4	10	14	36	5	41	4	0	4	8	5	tr	3	tr	1	tr	17	10	20.3
B-10	1.9	9	9	18	35	3	38	1	0	2	3	4	tr	tr	0	2	0	21	14	34.2
H-1	2.1	13	8	21	33	3	36	5	1	4	10	1	1	1	tr	0	2	21	8	49.3
H-3	3.4	10	6	16	41	tr	41	6	2	3	11	1	0	1	0	0	4	17	7	25.6
H-4	2.7	13	10	23	30	1	31	1	1	3	5	2	tr	1	0	1	6	16	13	32.7
H-5	2.2	11	9	20	37	3	40	3	tr	3	6	5	1	tr	0	tr	3	14	10	40.9
H-7a	2.7	13	11	24	35	1	36	3	2	2	7	0	2	tr	0	tr	5	16	11	28.6
H-7b	2.8	9	13	22	38	2	40	1	1	3	5	1	1	1	0	1	4	16	9	24.8
H-8	2.2	9	11	20	40	4	44	2	0	tr	2	2	0	0	0	tr	2	17	12	43.8
H-10a	2.4	7	11	18	38	4	42	3	0	2	5	4	0	tr	tr	2	2	18	9	38.0
H-10b	3.1	10	11	21	35	2	37	4	1	1	6	2	tr	tr	0	2	4	13	12	32.1

Sample number	Weight % of heavies	Garn., clss.	Garn., pink	total Garn.	Hbl.	Trem.-Act.	total Amph.	Aug.-Diop.	Hyp.	Enst.	total pyr.	Epidote	Titanite	Zircon	Tourm.	St.,Sill.,Ky.	others	opaques	alt.	Wt.% sol. in HCl
Pre-Illinoian till (cont.)																				
K-1	2.5	6	8	14	36	3	39	5	1	2	8	2	tr	1	0	tr	2	19	15	31.0
K-3	2.9	4	7	11	36	5	41	5	1	1	7	3	1	1	tr	2	2	14	15	22.6
K-4	2.9	6	9	15	43	4	47	3	1	2	6	3	0	3	tr	0	2	16	8	35.1
Uncertain-age till																				
B-2	3.0	10	7	17	37	4	41	6	tr	3	9	4	tr	1	0	0	2	19	8	34.3
B-3a	2.8	9	11	20	33	4	37	3	2	3	8	2	2	1	0	tr	1	16	13	20.2
B-3b	2.6	7	8	15	38	5	43	5	2	3	10	6	2	2	0	tr	1	13	9	19.6
B-8	2.5	6	9	15	39	6	45	5	1	3	9	1	tr	2	1	0	1	16	8	31.6
B-9	2.4	2	11	13	42	5	47	5	tr	1	6	2	1	2	0	tr	2	19	9	34.3
B-11a	3.0	5	12	17	38	4	42	7	0	2	9	3	0	1	tr	tr	2	15	11	24.8
B-11b	3.7	4	9	13	37	4	41	8	3	1	12	2	1	2	2	0	1	12	15	23.8
B-12	4.0	5	12	17	36	3	39	6	4	3	13	2	1	2	2	0	3	16	7	24.0
C-1	1.7	6	10	16	32	8	40	4	tr	2	6	2	1	tr	3	0	1	24	6	28.6
CR-1	3.6	8	11	19	40	5	45	7	2	2	11	2	1	0	0	tr	2	11	10	25.7

Sample number	Weight % of heavies	Garn., clss.	Garn., pink	total Garn.	Hbl.	Trem.-Act.	total Amph.	Aug.-Diop.	Hyp.	Enst.	total pyr.	Epidote	Titanite	Zircon	Tourm.	St., Sill., Ky.	others	opaques	alt.	Wt. % sol. in HCl
Uncertain-age till (cont.)																				
CR-2	3.3	5	15	20	38	3	41	3	1	3	7	4	0	2	0	0	1	15	11	26.8
D-1	2.4	8	15	23	33	4	37	3	tr	1	4	4	tr	2	1	0	1	18	10	34.7
D-2	2.2	4	12	16	40	5	45	1	0	2	3	3	0	3	tr	1	2	17	11	16.2
DK-1a	1.8	9	10	19	33	1	34	3	1	4	8	4	tr	1	2	1	4	19	11	24.7
Dk-1b	2.6	6	7	13	36	2	38	3	2	3	8	4	0	4	tr	tr	4	16	13	21.4
DK-1c	2.8	5	9	14	36	3	38	5	3	2	10	4	0	3	tr	tr	3	19	8	15.3
DK-1d	2.9	6	5	11	39	3	42	8	2	2	12	4	0	2	tr	0	3	19	7	14.9
DK-1e	2.1	7	8	15	41	3	44	3	1	1	5	5	0	1	0	1	2	21	6	14.8
DK-1f	2.8	5	11	16	36	1	37	4	2	2	8	2	tr	1	1	2	2	21	10	12.3
G-1	3.3	8	11	19	39	2	41	2	1	2	5	3	0	2	tr	2	1	21	6	21.7
G-2	2.4	9	10	19	34	3	37	0	0	3	3	4	1	2	tr	1	3	18	13	30.3
G-3	2.3	8	11	19	36	5	41	2	0	3	5	3	0	2	tr	0	2	18	10	30.6
G-4a	2.1	4	10	14	33	7	40	tr	1	2	3	3	0	3	tr	tr	4	23	9	25.8
G-4b	1.8	8	12	20	28	6	34	3	2	2	7	6	tr	2	tr	1	4	16	11	22.0
H-9	2.7	8	12	20	35	4	39	4	tr	2	6	2	tr	3	0	1	1	14	13	35.4

Sample number	Weight % of heavies	Garn., clss.	Garn., pink	total Garn.	Hbl.	Trem.-Act.	total Amph.	Aut.-Diop.	Hyp.	Ernst.	total Pyr.	Epidote	Titanite	Zircon	Tourm.	St.,Sill.,Ky.	others	opaques	alt.	Wt. % sol. in HCl
uncertain-age till (cont.)																				
H-11	3.3	8	9	17	36	3	39	5	4	4	13	4	0	tr	tr	tr	1	18	8	16.6
H-12	1.5	9	11	20	38	4	42	3	0	2	5	tr	1	4	0	2	tr	20	7	42.0
H-18	2.8	10	12	22	38	4	42	2	1	2	5	3	2	tr	1	2	tr	13	9	22.8
J-1	2.4	5	9	14	45	3	48	7	tr	2	9	4	1	tr	1	1	1	12	9	15.0
O-1a	3.1	5	6	11	39	4	43	3	3	4	10	2	2	0	tr	2	2	14	14	19.8
O-1c	2.5	7	12	19	34	tr	34	6	5	2	13	2	tr	tr	tr	tr	2	15	12	25.3
O-1d	2.4	6	5	11	42	4	46	8	2	7	17	2	2	1	0	tr	2	9	10	21.8
O-1e	2.3	4	7	11	42	2	44	7	1	3	11	3	tr	tr	tr	tr	3	18	9	24.6
O-2	2.3	10	11	21	40	4	44	2	tr	2	4	3	0	1	tr	2	2	15	9	20.8
R-1	2.3	9	9	18	39	2	41	3	1	1	5	3	tr	1	0	2	2	14	15	18.7
R-3	2.9	9	7	16	31	5	36	4	0	4	8	tr	3	3	tr	1	3	18	12	19.6
R-4	1.8	6	11	17	35	3	38	1	tr	4	5	2	tr	3	0	1	2	21	11	21.6
R-5	2.2	7	10	17	30	3	33	3	0	1	4	3	1	2	0	tr	4	27	9	18.6
S-1	2.8	9	13	22	33	5	38	3	0	3	6	1	0	1	0	1	2	17	11	19.7

Sample number	Weight % of heavies	Garn., clss.	Garn., pink	total Garn.	Hbl.	Trem.-Act.	total Amph.	Aug.-Diop.	Hyp.	Enst.	total Pyr.	Epidote	Titanite	Zircon	Tourm.	St.,Sill.,Ky.	others	opaques	alt.	Wt. % sol. in HCl
uncertain-age till (con.t)																				
S-2	3.3	6	13	19	41	3	44	3	1	3	7	2	2	0	0	0	1	17	9	20.3
S-3	1.2	10	10	20	24	3	27	1	0	4	5	4	tr	3	1	1	2	24	12	5.3
S-4	2.8	9	3	12	44	3	47	6	3	3	12	3	1	3	0	0	2	13	7	32.2
S-6	3.0	10	9	19	38	4	42	4	tr	1	5	3	0	2	0	tr	1	20	7	18.1
PCM-1a*	2.6	6	8	14	32	4	36	6	6	2	14	3	0	2	0	1	2	17	10	23.6
PCM-1b*	2.2	5	10	15	33	3	36	6	3	3	12	1	tr	3	0	0	tr	22	11	21.7

*Samples from Cegles Mill cut in western Indiana (1a is Kansan, 1b is Illinoian-Wayne, 1958, p. 10).

Table 10 - Percent of individual rock types in pebble fraction

Sample number	coarse xtln ls	fg & silty ls	total ls	dolomite	chert	ss & sltst	shale: b=black g=gray	acid ign & meta	basic ign & meta	quartzite	total ls/dol
Illinoian till (Clermont Lobe)											
CL-1	35	11	46	45	4	1	1b	0	3	0	1.0
CL-3	64	15	79	15	2	0	1b	1	2	0	5.2
H-14	54	14	69	31	0	0	1g	0	0	0	2.2
pre-Illinoian till											
B-10	80	12	92	6	0	1	0	0	1	1	15.4
H-1	96	4	100	0	0	0	0	0	0	0	∞
H-8	90	8	98	0	1	0	0	1	1	0	∞
H-10	76	19	95	2	1	0	0	2	0	1	47.5
K-3	61	8	69	22	1	1	1b	2	4	2	3.1
uncertain-age till											
B-8	70	15	85	11	0	0	2b	0	0	2	7.8
B-9*	70	7	77	4	4	4	4b	7	0	0	19.2
B-11	58	23	81	11	2	2	1g 2b	1	0	2	7.4
CR-2	82	7	89	6	3	0	1g	1	0	0	15.0
D-1	51	20	71	23	1	0	0	2	2	1	3.1
G-2	83	7	90	4	0	3	2g	0	0	2	22.5
G-4	81	12	93	3	1	0	0	1	0	2	31.0

* Based on only 27 pebbles

Sample number	coarse xtln ls	fg & silty ls	total ls	dolomite	chert	ss & sltst	shale: b= black g=gray	acid ig & meta	basic ign & meta	quartzite	total ls/dol
uncertain-age till (cont.)											
H-9	69	12	81	12	1	0	1g	2	0	1	6.8
H-12	67	7	74	20	1	1	0	1	2	0	3.8
O-1 (top)	69	9	78	10	2	0	2b	5	2	1	7.8
O-1 (bottom)	65	12	77	9	5	0	1b	3	2	3	8.5
R-4	4	4	8	3	84	0	0	3	0	1	2.7
R-5	18	39	57	5	29	1	2b	4	1	1	11.1
S-4	71	12	83	10	1	0	1g	1	0	1	8.3

Locations of Samples and Stratigraphic Sections

The locations for all samples and stratigraphic sections discussed in the text and described in the Appendix are presented below. They are arranged alphabetically by state and then by county. They are located in reference to points shown on the most recent 7 1/2-minute topographic quadrangle maps (abbreviated Q). Distances are measured in straight lines from the city halls or main road crossings of towns. Elevations are given for the base of the glacial section and were determined from the 7 1/2-minute topographic maps.

INDIANA

Dearborn Co.

D-1 1.3 mi. SE of Saint Leon, in road cut along I-74, 0.7 mi. ESE of SR 1 interchange (NE 1/4 NE 1/4 sec. 14, T. 7 N., R. 2 W.) (Cedar Grove Q); elev. 970 ft.

D-2 1.0 mi. N of Dillsboro, in roadcut along road between Dillsboro and Cold Springs, 0.1 mi. S of its junction with Love Hollow (NE 1/4 NE 1/4 sec. 11, T. 7 N., R. 3 W) (Dillsboro Q); elev. 860 ft.

D-3 2.6 mi. WNW of Wilmington, in road cut along SR 350 (NW 1/4 NE 1/4 sec. 28, T. 5 N., R. 2 W) (Aurora Q); elev. 830 ft.; section.

Decatur Co.

DK-1 0.7 mi. W of St. Maurice, in stream cut 0.05 mi. N of where 200 North Road crosses creek (SW 1/4 SW 1/4 sec. 30, T. 11N., R. 11 E.) (New Point Q); elev. 990 ft.; section.

Ohio Co.

O-1 0.5 mi. N of Bear Branch, in roadcut along road between Bear Branch and Milton (SE 1/4 SW 1/4 sec. 14, T. 4 N., R. 3 W.) (Bear Branch Q); elev. 820 ft.; section.

O-2 1.4 mi. NE of Bear Branch, in pipeline ditch, 0.1 SW of road between St. Peters Church and Downey Corner (NW 1/4 NW 1/4 sec. 13, T 4 N., R. 3 W.) (Bear Branch Q); elev. 840 ft.

Jefferson Co.

J-1 3.0 mi. NW of Madison, in creek bank 0.2 mi. E of junction of SR 107 and SR 7 (NW 1/4 SE 1/4 sec. 21, T. 4 N., R. 10 E.) (Clifty Falls Q); elev. 830 ft.

Putnam Co. (western Indiana; Cagles Mill cut, Wayne, 1963, p. 71)

PCM-1 3.2 mi NE of Poland, in spillway from Cagles Mill Reservoir, 0.8 mi. SE of town of Cagles Mill (SE 1/4 NW 1/4 sec. 13, T. 12 N., R. 5 W.); (Poland Q); elev. 750 ft.

Ripley Co.

R-1 3.4 mi. NE of Spades, in borrow pit 0.1 mi. N of I-74 along new road, 0.3 mi. W of Ripley Co. line (SW 1/4 sec. 27, T. 10 N., R. 3 W.) (Spades Q); elev. 980 ft.

R-3 4.2 mi. W. of Milan, in roadcut along 300 North Rd., 0.3 mi. E of Delaware Rd. (SE 1/4 SE 1/4 sec. 20, T. 8 N., R. 12 E.) (Milan Q); elev. 970 ft.

R-4 3.2 mi. E. of Rexville, in roadcut 0.3 mi. W. of Kentuck Creek along east-west road through Rexville (SW 1/4 SW 1/4 sec. 14, T. 6 N., R. 11 E.) (Rexville Q); elev. 940 ft.

R-5 0.9 mi. S of B & O Railroad crossing at U. S. 421 in Osgood, along northern edge of new quarry 0.2 mi. E of 200 West Road and 0.05 mi. S of 300 North Rd. (NW 1/4 NW 1/4 sec. 27, T. 8 N., R. 11 E.) (Versailles Q); elev. 980 ft.

Switzerland Co.

S-1 0.9 mi. S. of Braytown, in roadcut along north-south road between Braytown and SR 56, 0.1 N of McKay Cemetery (SE 1/4 SE 1/4 sec. 25, T. 2 N., R. 4 W.) (Carrollton Q); elev. 870 ft.

S-2 2.7 mi. WNW of Mt. Sterling, in roadcut along road on Smith Ridge, 0.2 mi. N of Tumblebug Creek (NE 1/4 SW 1/4 sec. 29, T. 3 N., R. 3 W.) (Vevay North Q); elev. 760 ft.

S-3 1.8 mi. S. of Fairview, in roadcut along road between Fairview and Mt. Sterling (NW 1/4 SW 1/4 sec. 11, T. 3 N., R. 3 W.) (Vevay North Q); elev. 850 ft.

S-4 0.6 mi. NE of Florence, in roadcut along Little Hominy Ridge Rd., 0.1 mi. N of Turtle Creek (NW 1/4 SW 1/4 sec. 31, T. 2 N., R. 1 W.) (Florence Q); elev. 520 ft.

S-6 1.8 mi. NNE of Patriot, in roadcut along east-west road across Mexico Bottom, 1.3 mi. W of SR 156 (NW 1/4 SW 1/4 sec. 6, T. 1 N., R. 1 E.) (Patriot Q); elev. 540 ft.

KENTUCKY

Boone Co.

B-1 1.6 mi. ESE of Hebron, in roadcut along new SR 1334, 0.5 mi. W of SR 1334 and SR 236 junction (Burlington Q); elev. 850 ft.

B-2 0.7 mi. WNW of Big Bone in roadcut along SR 338, 0.8 mi. WNW of SR 338 and Big Bone-Union Rd. (Rising Sun Q); elev. 580 ft.

B-3 2.4 mi. SE of Rabbit Hash, in roadcut 1.6 mi. W of SR 338 and Gunpowder Creek junction (Rising Sun Q); elev. 500 ft.

B-6 2.8 mi. NW of Hebron at Francisville, in roadcut along small road 0.05 mi. NE of SR 237 (Burlington Q); elev. 790 ft.

B-7 at Waterloo, in house foundation 0.1 mi. NE of junction of East Bend Rd. and road between McVille and Waterloo (Rising Sun Q); elev. 830 ft.

B-8 2.7 mi. SE of Waterloo, in roadcut along SR 536, 0.8 mi. E of SR 536 and Gunpowder Creek junction (Rising Sun Q); elev. 520 ft.

B-9 2.4 mi SE of Petersburg, in roadcut 0.1 mi. SW on small road off Commissary Rd. (Lawrenceburg Q); elev. 670 ft.

B-10 2.7 mi. N of Union, in roadcut along Pleasant Valley Rd., 1.7 mi. NW of U. S. 42 (Union Q); elev. 810 ft.; section.

B-11 2.7 mi. SE of Waterloo, in roadcut 0.15 mi. N along small road off SR 536 (Rising Sun Q); elev. 640 ft.; section.

B-12 3.2 mi. S of Petersburg, along Ohio River at junction with Woolper Creek (below "Light") (Lawrenceburg Q); elev. 460 ft.; section.

Campbell Co.

C-1 1.4 mi. ESE of Camp Springs in roadcut 0.1 mi. W of where road crosses Tenmile Creek (New Richmond Q); elev. 620 ft.

C-3 in Mentor along SR 8 in roadcut (Laurel Q); elev. 530 ft.

Carroll Co.

CR-1 1.1 mi. NW of Easterday on bulldozed hillslope along NE side of Fourmile Creek valley, 1.9 mi. SE of its junction with U. S. 42 (Vevay South Q); elev. 640 ft.

CR-2 3.6 mi. WNW of Easterday in borrow pit along new road between U. S. 42 and SR 36, 0.4 mi. SE of U. S. 42 (Carrollton Q); elev. 520 ft.

Gallatin Co.

G-1 2.3 mi. SW of Warsaw, in gully in valley side, 0.2 mi. WNW of bridge across Craigs Creek (Florence Q); elev. 480 ft.

G-2 2.8 mi. WNW of Glencoe, in roadcut, 0.15 mi. W on new road off SR 465 at Indian Camp Creek (Glencoe Q); elev. 750 ft.

G-3 2.4 mi. N of Sparta, in roadcut along SR 35, 0.6 mi. N of I-71 interchange (Sanders Q); elev. 730 ft.

G-4 1.9 mi. NW of Sparta, in roadcut along N side of I-71, 1.0 mi. WSW of SR 35 interchange (Sanders Q); elev. 700 ft.

Kenton Co.

K-1 1.1 mi. NE of Devon, in roadcut for new road between SR 1303 and end of "proposed" road at Kenton Co.-Boone Co. line, 0.3 mi. W of SR 1303 (Independence Q); elev. 860 ft.

K-3 1.7 mi. NW of Erlanger, cut for new road 0.1 mi. W of Erlanger Rd., 0.8 mi. N of I-75 interchange for Erlanger (Covington Q); elev. 830 ft.; section.

K-4 3.4 mi. NE of Erlanger, roadcut on S side of I-75, 0.2 mi. W of U. S. 25 interchange (Covington Q); elev. 810 ft.

OHIO

Clermont Co.

CL-1 2.5 mi. WNW of Batavia, in roadcut along SR 32, 0.1 mi. W of Shayler Run (Batavia Q); elev. 820 ft.

CL-2 0.4 mi. NW of Bantam, in roadcut along SR 125, at junction with new SR 222 (Batavia Q); elev. 820 ft.

CL-3 2.5 mi. E of New Palestine, in stream cut along Pond Run Rd., 0.1 mi. from SR 749 (Withamsville Q); elev. 570 ft.

CL-4 0.6 mi. N of Batavia, in stream cut about where Backbone Creek crosses SR 222 (Batavia Q); elev. 580 ft.; section.

Hamilton Co.

H-1 2.5 mi. NW of Cheviot, in house foundation cut on west side of Race Rd. between I-74 and West Fork Rd. (Addyston Q); elev. 810 ft.

H-3 0.5 mi. N of Anderson Ferry dock and 0.3 mi. W of Anderson Ferry Rd. in new road cut (Covington Q); elev. 870 ft.

H-4 3.2 mi. NW of Anderson Ferry dock, in pipeline ditch, 0.1 mi. S of Rapid Run Rd. on west side of Pontius Rd., (Burlington Q); elev. 815 ft.

H-5 3 mi. S of Miamitown, 0.6 mi. W of junction of SR 264 and Zion Rd. along pipeline (Addyston Q); elev. 785 ft.

H-7 2.5 mi. SE of Miamitown on S side of Rybolt Rd. exit ramp of I-74 (Addyston Q) elev. 650 ft.; section.

H-8 1.2 mi. SW of Cheviot, 0.2 mi. SSW of junction of SR 264 and C & O RR on east side of new road (Addyston Q); elev. 820 ft.; section.

H-9 1.2 mi. W of Miamitown in road cut on S side of I-74 (Addyston Q); elev. 730 ft.

H-10 2.3 mi. SW of Cheviot, in house foundation cut, 0.2 mi. E of Ebenezer Rd. and 0.3 mi. S of Werk Rd. (Addyston Q); elev. 850 ft.; section.

H-11 on south edge of Cleves in deep cut for U. S. 50 on E edge of Harrison State Park (Hooven Q); elev. 530 ft.

H-12 1.1 mi. NE of Groesbeck, in house foundation cut along Pipin Rd., 0.4 mi. SE of junction of Compton and Pipin Rds. (Cincinnati West Q); elev. 810 ft.

H-13 1.8 mi. S of Newtown in roadcut at corner of Hunley and Copperglow Rds., 0.4 mi. E of Clough Pike (Withamsville Q); elev. 650 ft.; section.

H-14 across from River Downs racetrack in gravel pit along U. S. 52 (Newport Q); elev. 500 ft.; section.

H-15 2.6 mi. NW of Redbank, 0.1 mi. N of proposed I-71 route in access road cut between Ridge and Kennedy Avenues (Cincinnati East Q); elev. 560 ft.; section.

H-16 in Cincinnati 2.2 mi. S of St. Bernard, in pipeline trench along I-71 near where Melish Ave. crosses Pennsylvania RR (Cincinnati East Q); elev. 740 ft.; section.

H-17 in Cincinnati 1.4 mi. NNW of St. Bernard, in Rack Sand and Gravel Co. "sandpit" on Este Ave. (Cincinnati West Q); elev. 500 ft.: stratigraphy described by Durrell (1961, p. 78-80).

H-18 3.5 mi. N of Hooven, in cut along I-74 at Morgan Rd. overpass (Hooven Q); elev. 660 ft.; stratigraphy described by Durrell (1961, p. 129-130).

DESCRIPTION OF STRATIGRAPHIC SECTIONS

B-10: Boone Co., Kentucky, 2.7 mi. N of Union

3' silt, leached, dark yellowish brown (10 YR 4/4), lower boundary indistinct.

11' till, leached, upper 2-5' silty grading downward into a manganese-rich, clayey, fine gravel zone (these upper zones are comparable to Leighton and Ray's (1965) units 4, 5, and 6 of Section 2), the gravel zone grades downward into strongly oxidized (strong brown, 7.5 YR 5/6) silty and sandy till that is mottled with black (7.5 YR 2/0) and pale brown (10 YR 6/3); the gravel zone is interpreted as a water-worked portion of the till (possibly beneath or within the ice sheet) and the manganese accumulation as the result of ground water moving through the more permeable zone; lower boundary indistinct.

4' till (clay loam till), upper 2' leached, $CaCO_3$ nodules in places just below leached zone, brown (10 YR 4/3).

Base of cut 810 feet

Several shallow cuts to the east expose a 1- to 4-foot leached till below a 1- to 3-foot calcareous till which contains $CaCO_3$ nodules just above the leached zone. Because of these nodules and because there is no visible break within the till (both the leached and calcareous portions are texturally similar except for the absence of limestone pebbles in the leached portion), the leaching is interpreted as having resulted from an upward movement of (vadose?) groundwater from a deeper permeable zone (such as the gravel zone described in the above section).

B-11: Boone Co., Kentucky, 2.7 mi. S of Waterloo

14-17' sand, fine grained, increasing clay content toward top, leached 15', no bedding visible, large $CaCO_3$ cemented slabs of sand at base of zone of leaching, some convolutions of till up into the basal part of the sand (1-6 inches), lower boundary distinct but irregular.

6-8' till, leached 0-2', large well-cemented $CaCO_3$ nodules at base of leaching zone in till, yellowish brown (10 YR 5/4), lower boundary distinct; sample B-11b 6' from top of unit.

3-6+' sand, fine grained, no bedding visible, calcareous, large $CaCO_3$ cemented slabs of sand at top of unit, lower boundary distinct but irregular.

2+' till, silty and sandy, calcareous, light yellowish brown (10 YR 6/4) with thin horizontal bands of iron staining; sample B-11a.

Base of cut 640 feet

B-12: Boone Co., Kentucky, 3.2 mi. S of Petersburg ("Split Rock Conglomerate" area)

30' covered

60' gravel and sand, particle size ranges from boulders to coarse grained sand, poorly sorted, poorly bedded, calcareous and tightly cemented by $CaCO_3$ in many places (forms vertical cliff), lower boundary distinct but with up to 20' of relief.

10' till, calcareous, grayish brown (2.5 Y 5/2) with yellowish brown (10 YR 5/4) along joints; sample 8' from top.

12' covered

Base of section at 460 feet

CL-4: Clermont Co., Ohio, 0.6 mi. N. of Batavia (overall description)

25' till, lower portion calcareous and unoxidized, upper part inaccessible, dark grayish brown (2.5 Y 4/2), lower boundary indistinct.

1' silty clay, laminated, calcareous, dark grayish brown (2.5 Y 4/2), grades into underlying unit.

9' sand, bedded, calcareous, grades from silty v. fine grained sand at top to coarse grained sand at base, a few pebbles scattered throughout, brown (10 YR 5/3) to yellowish brown (10 YR 5/6), lower 0.5 dark brown (7.5 YR 4/4), lower boundary distinct.

0.5' clayey silt, laminated, non-calcareous, dark yellowish brown (10 YR 4/4) grading downward into dark reddish brown (5 YR 3/3), lower boundary indistinct.

1.5' clayey silt, no bedding visible, non-calcareous, poorly developed coarse angular blocky structure with no coatings on ped surfaces, v. dark gray (10 YR 3/1), lower boundary indistinct.*

8-11' silty clay, increasingly sandy and pebbly toward base (includes igneous types), non-calcareous, no bedding visible in upper half, poor bedding and one cut and fill structure observed in lower half (=alluvium), olive gray (5 Y 4/2); distinguished from overlying unit primarily by dark reddish brown (5 YR 3/3) mottling and clay coatings on poor fine to coarse angular blocky ped surfaces; lower half contains irregular shaped masses of sandy clay up to 2' in length and 0.5' wide that are surrounded by a thin clay skin, these masses cross bedding planes and are interpreted as filled animal burrows, lower boundary gradational.*

1-3+' coarse gravel, composed primarily of cobbles but with boulders up to 2.5' in length, finest gravel near top, calcareous except in finer upper foot, most rocks are angular to subrounded limestones and have weathering rinds, 94% limestone, 3% shale, 2% siltstone, 1% chert, several quartzites and xtlns observed.*

0-2+' silty clay, increasing sand and pebble content toward base, weakly calcareous in lower 1', scattered limestone slabs up to 1.5' in length, dark gray (5 Y 4/1), large pelecypod and small gastropod shells common in lower half, wood and bone fragments and part of a turtle shell incorporation (=landslide debris?); not observed below thickest part of gravel unit.

Creek level 580 feet; bedrock at this elevation near west end of cut.

* Detailed description of paleosol morphology in these units follows on next-page.

CL-4: Clermont Co., Ohio, 0.6 mi. N of Batavia (detailed soils description of non-calcareous alluvial and gravel units of preceeding CL-4 section by L. Wilding and N. Holowaychuck of The Ohio State University Agronomy Department, April 1970)

Ab 0-24" Yellowish brown (10 YR 5/4) silty clay loam with many (40%) faint yellowish brown (10 YR 5/6) mottles; weak medium and coarse prismatic parting to weak fine, medium, and coarse angular blocky; light brownish gray (10 YR 6/2) calcareous coatings on prism faces up to 2 mm thick, some cemented; gradual boundary.

Micromorphology: A few very thin (<.05 mm), very patchy yellowish brown (10 YR 5/4) ferri-argillans on ped surfaces. Most surfaces, however, are bleached and show evidence of degradation and skeletans. Sand grains are mostly uncertain. No evidence of clay films in the unoxidized portion of the matrix.

B1tb 24-42" Grayish brown (10 YR 5/2) fine silty clay loam with common yellowish brown (10 YR 5/4) mottles and some (3%) strong brown (7.5 YR 5/8) streaks and fibers up to ½ mm thick; dark reddish brown (5 YR 3/3) coatings up to 2 mm thick on prism surfaces; weak very coarse prismatic with massive interiors; very firm; few (2%) fine (<7 mm) rounded quartz pebbles; few black Fe-Mn bodies up to 5 mm across-resemble charcoal; pH 7.6; clear boundary.

Micromorphology: Nearly continuous, thin (.05-.1 mm) very dark brown (10 YR 3/2) argillans around relic ped surfaces. Peds in place are weakly expressed, medium sized, and angular and subangular blocky. The structure appears weak because apparently this zone has been compressed sufficiently that the relic structure is not apparent until the soil is dried. A number of medium to thick (.1-.5 mm) dark clay films lining channel walls. Some bleached areas present along some structural surfaces. A crystalline lithic was noted.

B21irb 42-45" Very dark brown and black (10 YR 2/2 and 2/1) Fe-Mn material, part in weakly nodular concretionary form with common yellowish brown (10 YR 5/6) mottling in interiors; some concretions up to 2 cm across and cannot be cut with a knife; massive; thickness range 2 to 4 inches; pH 7.7; clear boundary.

Micromorphology: A few thin (<0.1 mm) ferri-argillans along major structural surfaces. Manilliated infillings of Fe-Mn compounds in matrix are sesquans or mangans. This zone has the appearance of strong accumulation of Fe-Mn concretions, stains and infillings.

B22tb 45-68" Gray to dark gray (5Y 5/1-4/1) silty clay with common (5%) olive gray (5Y 4/2) mottles or fine bodies and common (5-10%) strong brown (7.5 YR 5/6 and 5/8) streaks and very coarse mottles up to 5 mm thick; few (about 2%) black and very dark brown (10 YR 2/1 and 2/2) fine Fe-Mn bodies; common dark reddish brown (5 YR 3/3) coatings on vertical and oblique surfaces; very weak very coarse prismatic with massive interiors, lower part crushes to weak very fine angular blocky; few fine (<7 mm) quartz pebbles; pH 6.7; diffuse boundary.

Micromorphology: A few patchy, thin (.05-.1 mm very dark brown (10 YR 2/2) argillans around ped surfaces. Relic peds are weakly expressed, large in size and angular blocky. Most pores are either clay-filled or have thick (1-2 mm) linings along channel walls. A few thin strong brown (7.5 YR 5/6) ferri-argillans along some root channels and ped surfaces.

B23tb 68-91" Light olive brown (2.5 Y 5/6) fine silty clay loam with common (20%) fine greenish gray (5 GY 3/3) thin (<1 mm) coatings on some of the more distinct vertical and oblique surfaces; very weak very coarse prismatic parting to weak fine angular blocky structure; moderately firm; pH 5.4; clear or abrupt wavy and irregular boundary.

Micromorphology: Nearly continuous, Medium to thick, (0.25-0.5 mm) reddish brown (5 YR 4/3, 4/4) ferri-argillans along old root channels and structural surfaces. Also patchy, thin to thick (0.1-.5 mm) gray (5Y 6/1) clay films in the gray matrix. This horizon exhibits significant impregnation with translocated clay. A number of the pores are filled with clay.

IIB24tb 91-109" Dark grayish brown (10 YR 4/2) sandy loam or sandy clay loam with appreciable medium sand; massive; sticky; pH 7.9.

Micromorphology: Patchy, thin to medium (0.1-0.2 mm) ferri-argillans along major structural surfaces. Also a number of sand grains are bridged and coated with thin clay films.

IIIB25tb 109-121" Dark brown (10 YR 3/4) loamy coarse sand or sandy loam with (about 30%) coarse faint very dark grayish brown (10 YR 3/2) mottles; massive; cemented - need spade or pick for separation; about 10% rounded and subrounded pebbles up to 1 1/2 cm across, quartz and some chert; few extensive oblique surfaces, some with grayish brown calcans; pH 8.0.

Micromorphology: Nearly all of the same grains are bridged and coated with thick ferri-argillans and ferri-mangans. This has resulted in semi-induration of this horizon such that it can barely be broken with the hand when air dry.

IIIB3tb 121-152" Yellowish red (5 YR 5/6-4/6) sand with many large (up to 25 cm long) oblongate distinct bodies of yellowish brown (10 YR 5/6) sand and common (5%) thin bands, streaks and coatings of dark reddish brown (5 YR 3/3-4/3); massive; very firm in place, partially cemented but can be crumbled by hand. Intermingled with the sandy material are common irregular massive bodies up to 30 cm across, some with distinct boundaries, of olive gray (5 Y 5/2) clay loam with common (5-10%) coarse prominent bluish gray (5 B 5/1) mottles that change to greenish gray (5 GY 5/1) on exposure, and reddish yellow (5 YR 5/6) periphery. Few (2%) rounded and subrounded pebbles up to 2 1/2 cm across, crystallines common; pH 7.8; abrupt boundary.

Micromorphology: sand portion- Similar to horizon above in that most of the sand grains are bridged and coated with ferri-argillans. However the ferri-argillans are much thinner for this zone.

152-164" Olive gray (5 Y 4/2) sandy loam or sandy clay loam with common (5%) bluish gray (5 B 5/1) mottles; calcareous.

164" to flood water level in stream. Very stony layer with calcareous gray and yellowish brown calcareous clay loam matrix with some bluish gray and greenish gray mottling. Stones are angular, subangular and subrounded calcareous rock fragments up to 30 cm across, weathering rinds up to 1 1/2 cm thick; stones appear to be horizontally oriented.

<u>D-3</u>: <u>Dearborn Co., Indiana, 4.9 mi. W of Aurora</u>

3' silt, leached, yellowish brown (10 YR 5/4) mottled with grayish brown (10 YR 5/2) and brown (7.5 YR 4/4).

8' till, leached 6', calcareous portion high in limestone (cobble sizes), yellowish brown (10 YR 5/4) mottled with light gray (10 YR 7/1), lower boundary not distinct.

2.5' till, calcareous (less so than overlying unit), 3-inch wide leached (strong brown, 7.5 YR 5/6) band 4 inches below top of unit, pale brown (10 YR 6/3) mottled with strong brown (7.5 YR 5/6), lower boundary is a distinct color boundary.

5' till, leached 4', strong brown (7.5 YR 5/6) grading downward into yellowish brown (10 YR 5/4) with pale brown (10 YR 6/3) and very dark gray (10 YR 3/1) mottling and staining on ped surfaces.

Base of cut 830 feet.

DK-1: Decatur Co., Indiana, 0.7 mi. W of St. Maurice

Illinoian drift

9' till, leached 7', brown (10 YR 4/3) with yellowish brown (10 YR 5/6) staining along joints; sample DK-1f, lower boundary distinct.

Kansan drift

1' clayey sand and gravel, leached.

0.5-1' silt, leached, light brownish gray (10 YR 6/2) mottled with strong brown (7.5 YR 5/8), lower boundary distinct and sli. undulating.

7' humic gley soil in till, grain size grad. increases from silty and sli. sandy clay at top to clay loam till in lower portion, very small angular block structure at top grading downward into small angular blocky structure, upper portion mottled dark gray (10 YR 4/1) to reddish brown (5 YR 4/3), iron-cemented till nodules (up to 1' in length) and limonite concentration in basal 1' of unit, lower boundary is leached/calcareous line.

9' till, calcareous, upper 4' oxidized (yellowish brown, 10 YR 5/4) with dusky red (2.5 YR 3/2 iron coatings along joints, $CaCO_3$ crusts in upper 2 inches, lower portion is dark gray (10 YR 4/1), basal 0.5' very silty; samples DK-1e (upper half) and DK-1d (lower half), lower boundary distinct.

1' sand and gravel, bedded, calcareous, lower boundary distinct.

1.5' till, calcareous, oxidized brown (7.5 YR 4/3) to reddish brown (5 YR 4/4) in upper and lower 0.5'; sample DK-1c, lower boundary distinct.

0-0.1' pebbly silt, poorly bedded, calcareous, gray, lower boundary indistinct

0-0.1' silt, calcareous, light gray, lower boundary indistinct.

0-0.3' clayey and silty sand, non-calcareous, buff, lower boundary distinct.

1.5' till, calcareous, few pebbles except in upper 4" where concentration is high (may be washed zone), upper 1' unoxidized (grayish brown, 2.5 Y 5/2), lower 0.5' oxidized (reddish brown, 5 YR 4/4); sample DK-1b, lower boundary distinct.

Nebraskan drift

7' till, calcareous, very high content of chert pebbles with largest sizes and greatest amount in upper 3', upper 5' oxidized brown (10 YR 4/3) with dark reddish brown (2.5 YR 3/4) coatings on fine network of joint surfaces, lower 2' dark grayish brown (10 YR 4/2), contains wood frags.; sample DK-1a, lower boundary distinct.

2' chert gravel, pebble and cobble sizes with smaller sizes and calcareous clayey matrix near top, all frags. are angular chert.

Creek level 990 feet.

H-7: Hamilton Co., Ohio, 2.5 mi. SE of Miamitown

34' till, clayey, leached 8', fills bedrock channel and till thins rapidly to west, mottled yellowish brown (10 YR 5/6) and grayish brown (2.5 Y 5/2) with strong brown (7.5 YR 5/6) along joints in upper half; sample H-7a (3' from base) and H-7b (15' from base), lower boundary not distinct.

3' clay and silty clay, bedded, calcareous, overlies bedrock along west edge of channel and gravelly clay east of this sloping edge, lower boundary distinct.

0-3' silty and gravelly clay, no bedding visible, weakly calcareous, iron stained, a local aquifer.

Base of cut 650 feet

H-8: Hamilton Co., Ohio, 1.2 mi. SW of Cheviot

3' clayey silt, leached, lower boundary indistinct.

12-16' till, leached 6-16', leached portion very clayey except in upper 2' which is silty, leached zone yellowish brown (10 YR 5/4) mottled with black and yellowish brown (10 YR 5/6); calcareous portion light yellowish brown (2.5 Y 6/4) with yellowish brown (10 YR 5/4) staining 1/2 inch to either side of joints, large limestone slabs (up to 2' in length) at base of unit; sample 3' from base, lower boundary distinct.

12-16' silt, clay, and fine grained sand, bedded, calcareous, some contorted bedding, light yellowish brown (2.5 Y 6/4) to dark gray (10 YR 4/1); limestone crops out at this elevation a few hundred feet to the north.

Base of cut 820 feet

H-10: Hamilton Co., Ohio, 2.3 mi. SW of Cheviot

Composite section from several cuts

9' till, clayey, leached 0-4' (surface bulldozed), yellowish brown (10 YR 5/4) to black (5 Y 2/2); sample H-10a (from lower third) and H-10b (from upper third), lower boundary distinct.

16' clay, bedded with thin silt beds, non-calcareous except for $CaCO_3$ concretions which occur along bedding planes, joints, and possible root penetration tubes, color bands of brown (7.5 YR 5/4) and light gray (5 Y 7/2).

2' silty clay (probably alluvium), non-calcareous; overlies bedrock.

Base of cut 820 feet

H-13: Hamilton Co., Ohio, 1.8 mi. S of Newtown

15' till, leached 4', yellowish brown (10 YR 5/4) in upper half, dark gray (10 YR 4/1), strong brown (7.5 YR 5/6) on joint surfaces and as mottling, abundant wood fragments near base; lower boundary distinct; sample H-13b 6' from base.

0.1' silt, calcareous, grayish brown (2.5 Y 5/2), lower boundary distinct.

0.2' silt, non-calcareous, very dark gray (10 YR 3/1) at top to dark grayish brown (2.5 Y 4/2) at base, contains woody fragments, lower boundary indistinct.

0.2' pebbly silt, upper 1 inch non-calcareous, lower portion weakly calcareous, a few ghost pebbles, lower boundary indistinct.

6' silt, sand, and gravel, calcareous, bedded, (largely covered).

16' till, calcareous, two separate 2-3' silt, sand, and gravel beds or lenses (lateral extent uncertain) in lower half (largely covered), dark gray (5 Y 4/1) to grayish brown (2.5 Y 5/2); sample H-13a 8' from top of unit.

Base of cut 650 feet

H-14: Hamilton Co., Ohio, across from River Downs racetrack

12' silt, leached, unbedded except in lower portion which is poorly bedded with v. fine grained sand and a few pebbles, yellowish brown (10 YR 5/6) mottled with strong brown (7.5 YR 5/8) and olive yellow (2.5 Y 6/6) in upper half.

2' covered

15' till, calcareous, dark gray (5 Y 4/1) with brownish yellow (10 YR 6/6) staining out from joints in upper 3', wood fragments abundant (2 pieces Pinus spp. identified by G. Burns, Ohio Wesleyan Univ.); sample 7' from top.

35' sand and gravel, cobble sizes common, poorly bedded, poorly sorted, calcareous.

Base of cut 500 feet

H-15: Hamilton Co., Ohio in northeastern Cincinnati in the Norwood Trough

5-7' silt, clayey near base, leached, lower boundary indistinct.

6' sandy clay with small pebbles (till?), leached, olive gray (5 Y 5/2), strong brown (7.5 YR 5/6), and black (5 Y 2/2) mottled, lower boundary indistinct.

5-7' clayey silt grading downward into sand and silty gravel, leached 4-5', poorly bedded, color variable and mottled yellowish brown (10 YR 5/8) to light yellowish gray (10 YR 6/2), lower boundary not distinct and uneven.

5' till, silty, calcareous, compact, gray (5 Y 5/1) with yellowish brown (10 YR 5/4) oxidation in upper half and basal 6 inches, lower boundary distinct; sample H-15b from lower half.

2-6' sand, gravel, silt, and clay, bedded, calcareous, lower boundary distinct with up to 5' of relief.

2-5' till, silty, calcareous, compact, dark gray (5 Y 4/1) with brown (10 YR 4/3) oxidation in upper 6 inches; sample H-15a.

Base of cut at 560 feet

<u>H-16</u>: <u>Hamilton Co., Ohio, in eastern Cincinnati</u>

20' till, calcareous (surface bulldozed), lower portion clayey, upper third brown (10 YR 5/3), lower portion gray (2.5 Y 5/0) to dark greenish gray (5 GY 4/1), many pieces of wood (2 pieces <u>Picea</u> sp. identified by G. Burns, Ohio Wesleyan Univ.); two large inclusions found - one of non-calcareous clayey bedrock residuum and the other of peaty, gastropod-rich silt much like the underlying silt unit (land gastropods <u>Discus cronkhitei</u>, <u>Succinea avara</u>, <u>Retinella</u> sp., <u>Pupilla muscorum</u>, <u>Hawaiia minuscula</u>, <u>Euconulus fulvus</u>, and <u>Columella alticola</u> identified by A. La Rocque, Ohio State Univ.; <u>C. alticola</u> is suggestive of a cooler climate but all others are found in humid climates much like the present one in Cincinnati); sample 10' from base, lower boundary somewhat gradational.

0.5' clay, no visible bedding, calcareous, gray (2.5 Y 5/0), lower boundary distinct.

0.5-1' silt, bedded, upper 1-4 inches is silty peat, weakly calcareous in lower half, contains a few large pieces of wood and a clump of moss (<u>Thuidium abietinum</u> B.S.G., identified by H. Crum, Univ. Michigan; common today on well-drained sandy locations in the Great Lakes area), land gastropods <u>Gastrocopta</u> sp., cf. <u>G. contracta</u> (from peaty upper portion), <u>Gastrocopta</u> sp., <u>Succinea avara</u>, and <u>Discus cronkhitei</u> (from silty lower portion) (identified by A. La Rocque, Ohio State Univ.; all gastropods indicate climatic conditions like those in Cincinnati today); very dark grayish brown (10 YR 3/2) to brown (10 YR 4/3), lower boundary indistinct.

3' silty clay, grades downward into clay, non-calcareous, a few small ghost pebbles along upper boundary and several small pieces of siltstone scattered throughout, woody fragments found, dark greenish gray (5 BG 3/1), overlies and is somewhat gradational into limestone and shale bedrock.

Base of cut 740 feet

K-3: Kenton Co., Kentucky, 1.7 mi. NW of Erlanger

2' silt, leached, brownish yellow (10 YR 6/6, dry), lower boundary is defined only by color.

2' silt, leached, very pale brown (10 YR 7/4, dry), lower boundary distinct.

8-13' till, leached 7', strong brown (7.5 YR 5/6) grading downward into brown (10 YR 5/3); sample 2' from base, lower boundary distinct.

0.1' clay, calcareous.

3' silty clay, non-calcareous, light yellowish brown (10 YR 6/4).

1' clay, non-calcareous, olive to bluish green; overlies weathered bedrock.

Base of cut 830 feet

O-1: Ohio Co., Indiana, 0.5 mi. N of Bear Branch

20' till, silty leached 5-10', basal 1' is very silty, brown (10 YR 5/3), samples 3' (O-1d) and 10' (O-13) from base.

2' silt, bedded, calcareous, lower boundary distinct.

0.5' sand and gravel, limestone slabs up to 1 foot long, tightly cemented with $CaCO_3$ and limonite, lower boundary gradational.

2' sand, bedded, calcareous, lower boundary distinct.

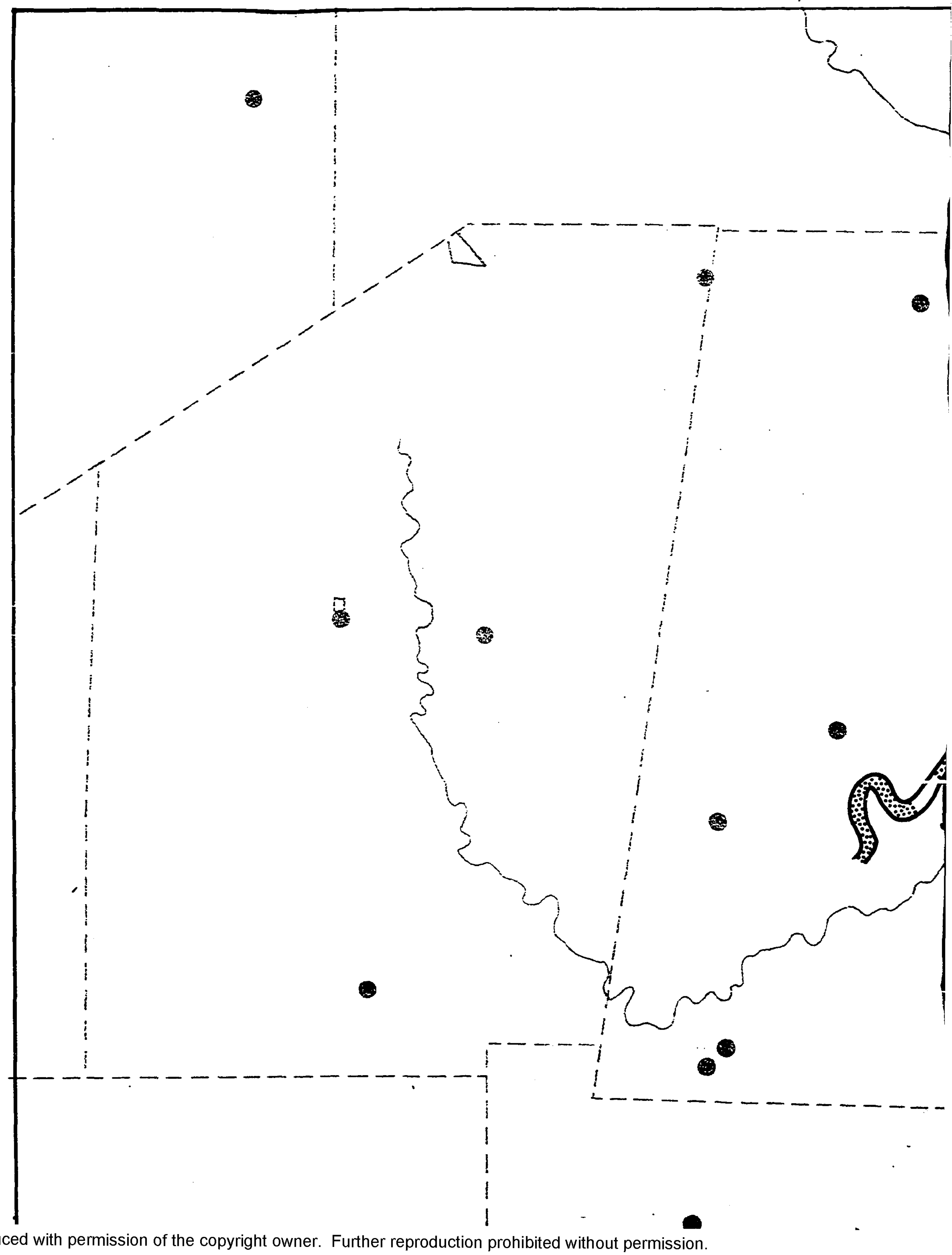
22' till, silty, calcareous, dark grayish brown (2.5 Y 4/2) with thin dark gray (5 Y 4/1) clay coatings on some ped surfaces, contains wood (1 piece Tsuga sp. identified by G. Burns, Ohio Wesleyan Univ.) and several masses of non-calcareous dark olive gray (5 Y 3/2) clay; samples 3' (O-1a) and 17' (O-1c) from base.

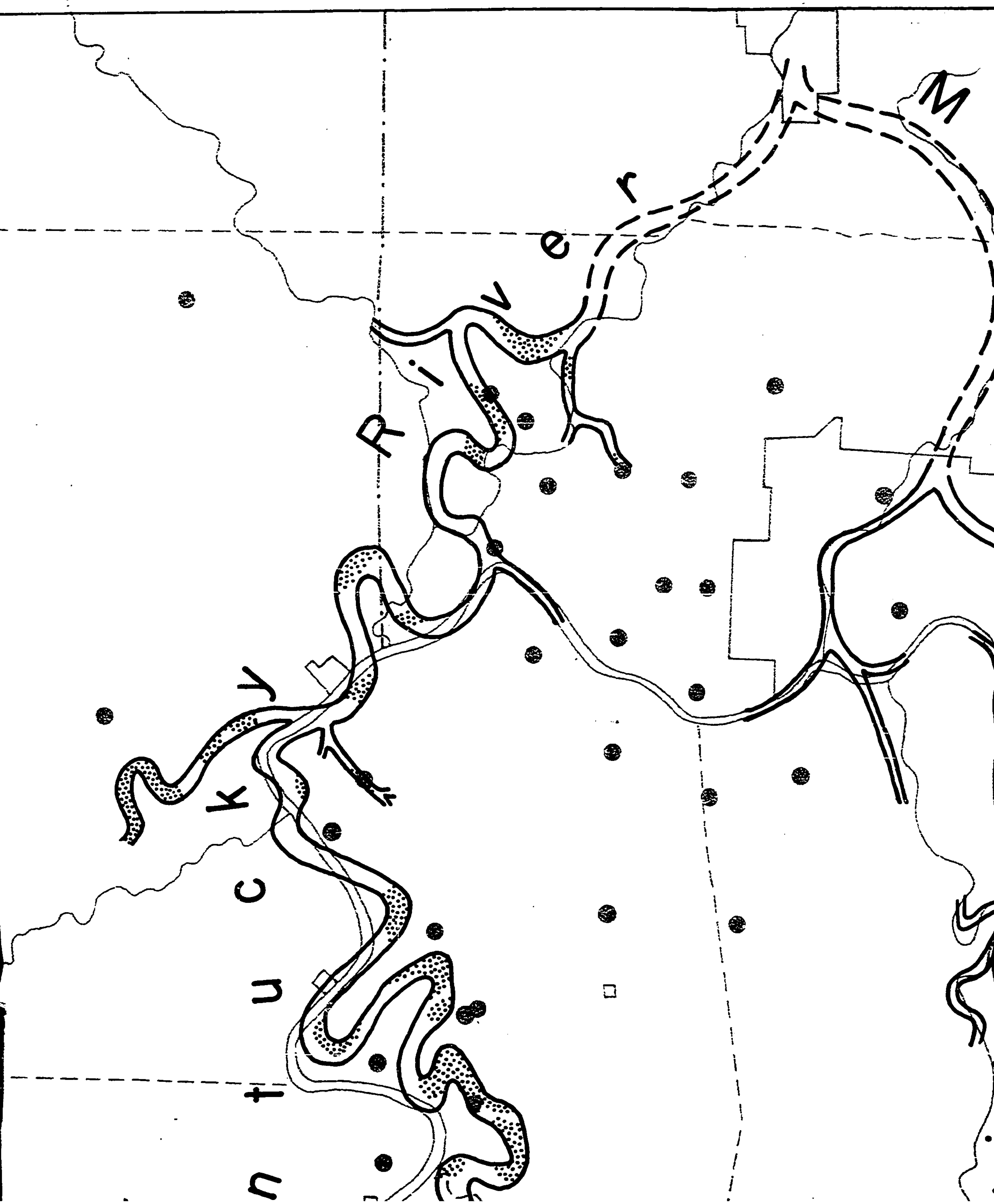
1' silt, bedded, calcareous.

0-1' sand and fine gravel, bedded, limonite cemented in places.

0-1' silty clay, non-calcareous, dark olive gray (5 Y 3/2) with black (5 Y 2/1) staining on medium angular blocky ped surfaces; overlies limestone bedrock with bluish green color.

Base of cut 820 feet




ntucky River
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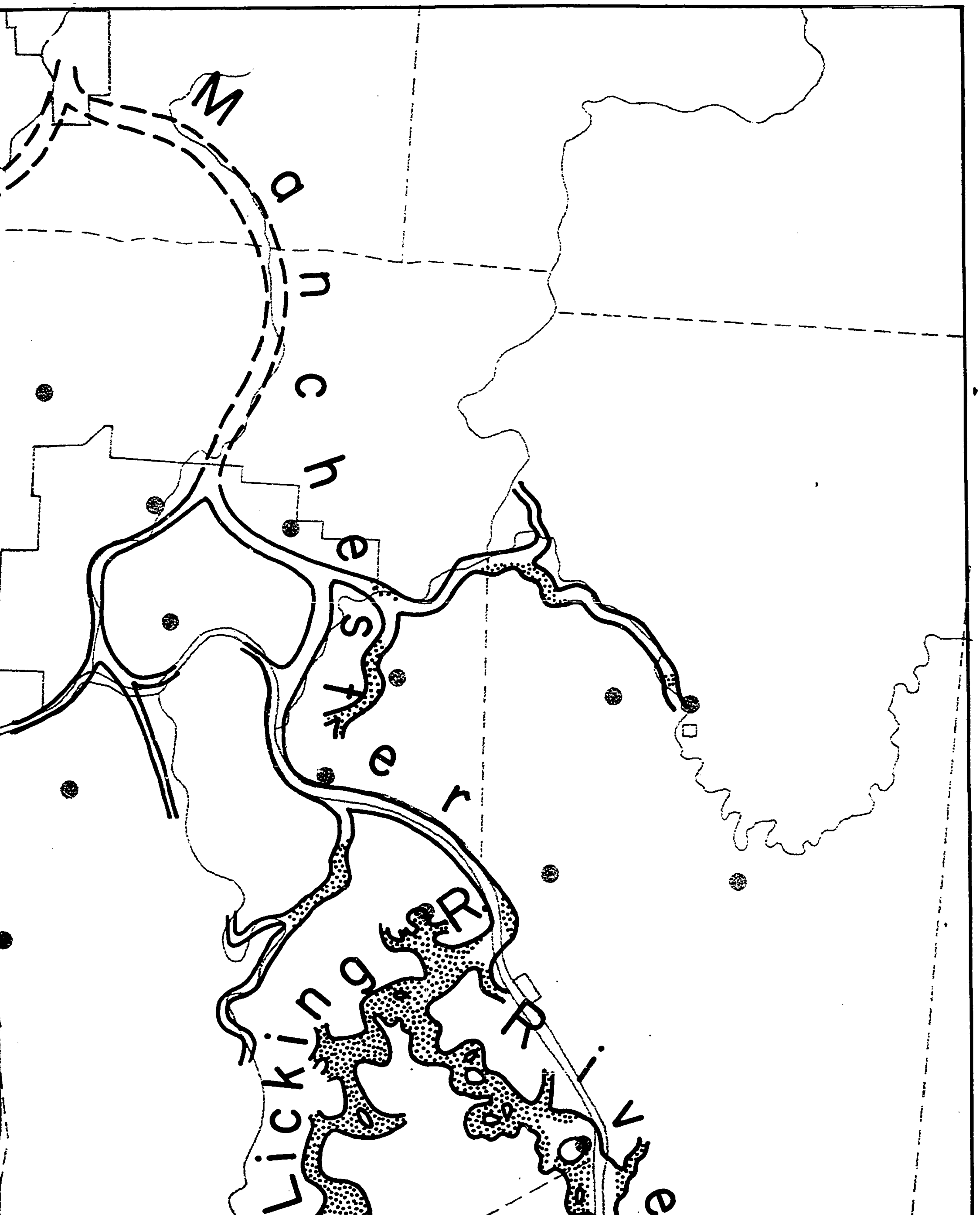
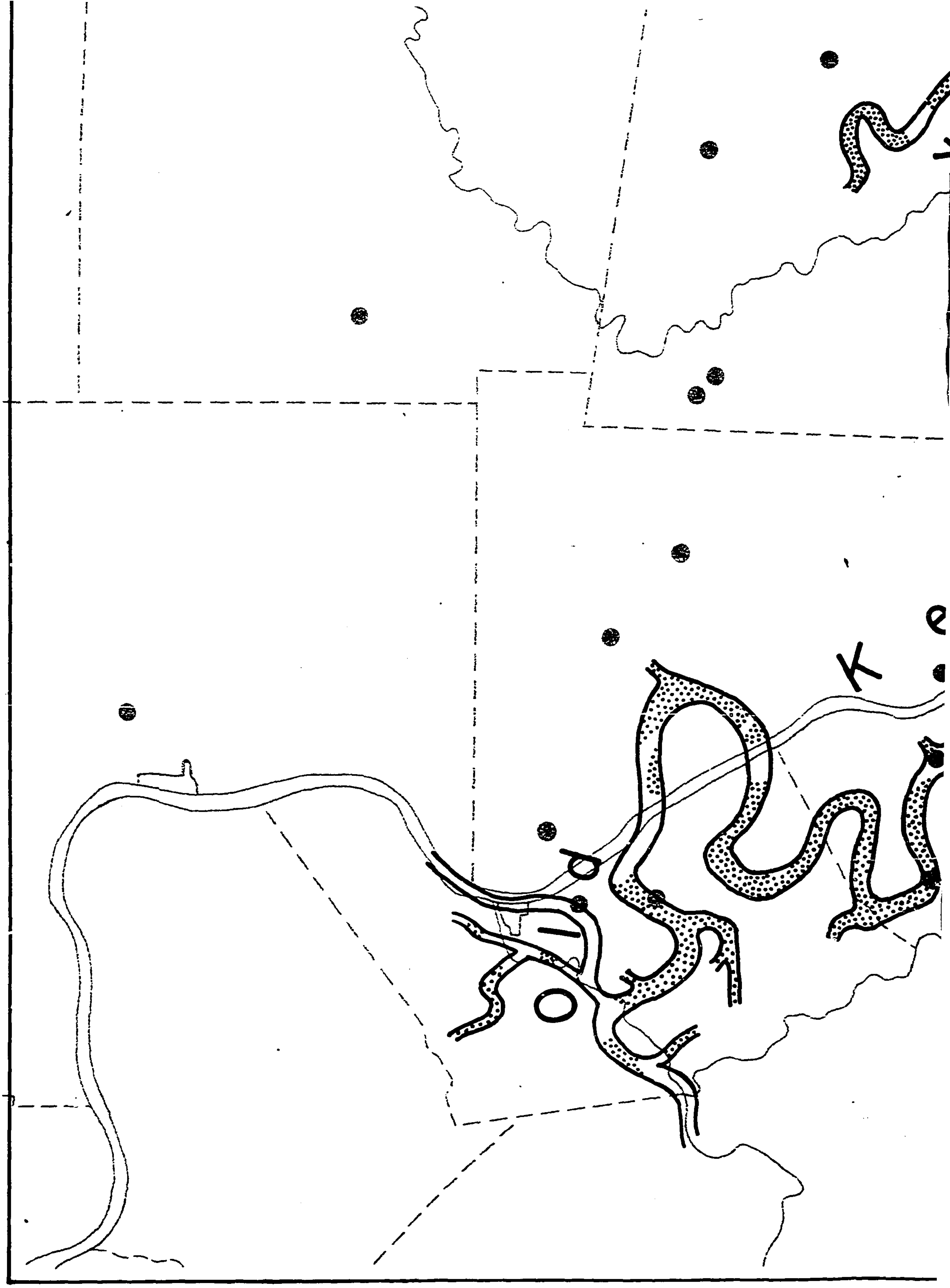

Manchester
Licking R.
R. River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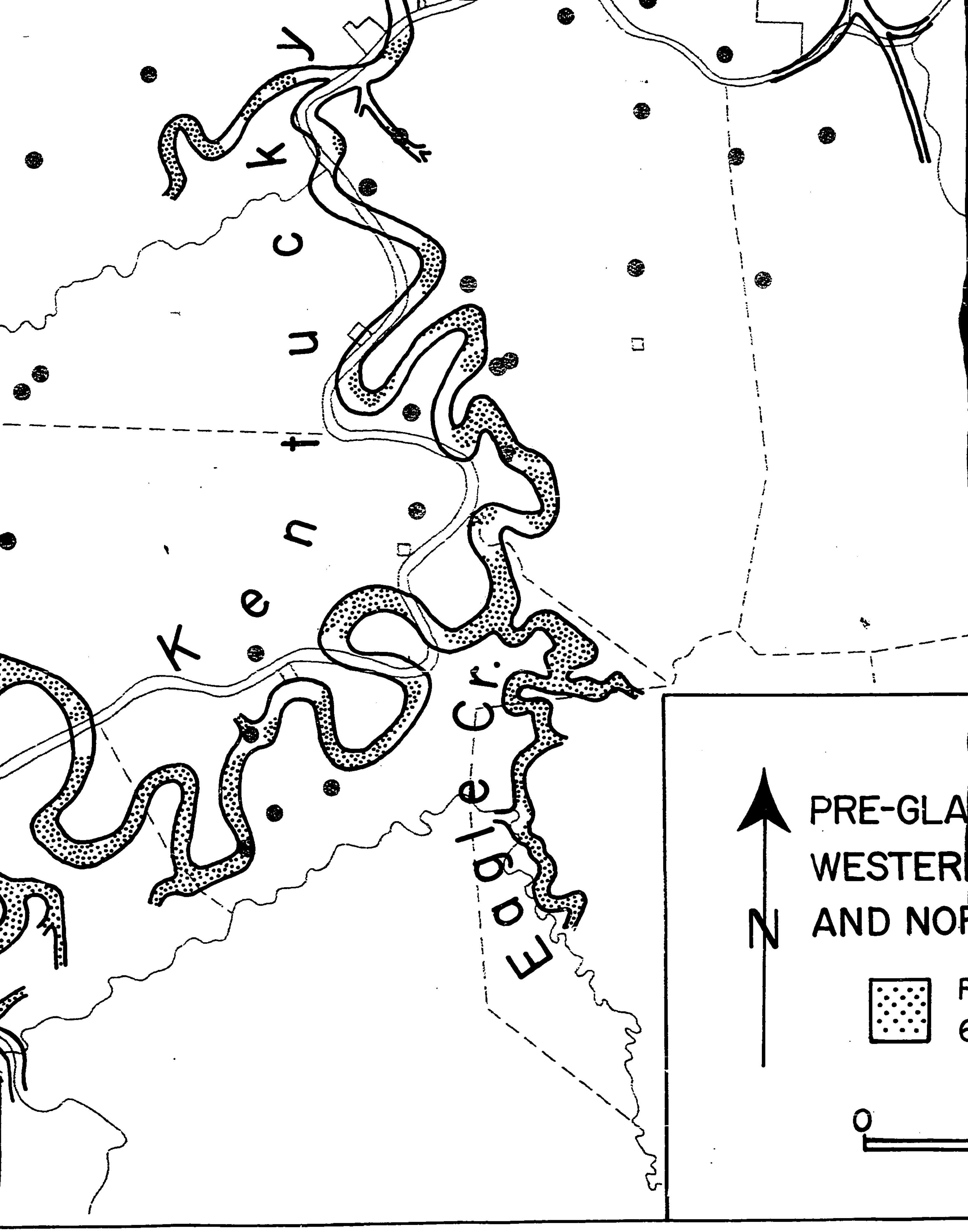
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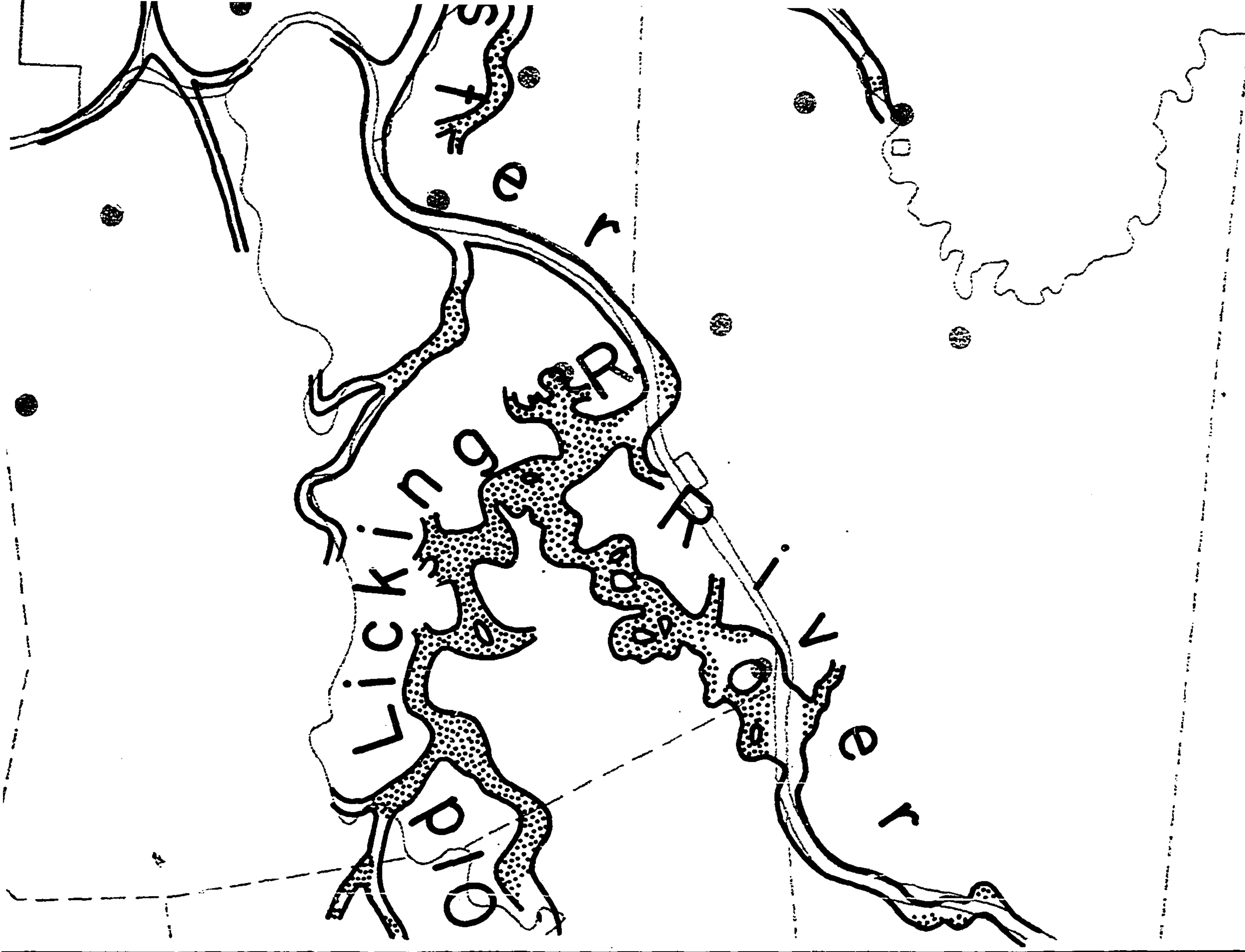

Plate 1

PRE-GLACIAL(TEAYS-AGE) DRAINAGE IN SOUTH-WESTERN OHIO, SOUTHEASTERN INDIANA, AND NORTHERN KENTUCKY.

N

Remaining segments of valley floor at 650–700 feet.

0 5 10 15 20

Scale of miles