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DIVISION OF GEOLOGICAL SURVEY
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Report of Investigations No. 92

GLACIAL GEOLOGY OF HIGHLAND COUNTY, OHIO

by

Theodore E. Rosengreen

Columbus
1974

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GEOLOGY SERVES OHIO

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ABSTRACT

Glacial drift deposits of two stages cover nearly all of Highland County. Late Wisconsinan drift mantles the northern third of the county and Illinoian drift covers the remainder, except for the southeasternmost corner. During the two glaciations ice deposited at least four till units in the county: Rainsboro (Illinoian), and Boston, Caesar, and Darby I (Late Wisconsinan), oldest to youngest. The significant end moraines, Mt. Olive, Cuba, and Reesville, were built at the maximum advance or readvance positions of the ice which deposited the Boston, Caesar, and Darby I tills, respectively.

At one locality, pre-Rainsboro drift overlies a well-developed paleosol in stratified drift of gravel and sand. Analyses of the till show that it is unlike the Rainsboro drift which overlies it; it may be either early Illinoian or Kansan drift.

Results of analyses show that the Rainsboro, Caesar, and Darby I tills are very similar in clay mineral, calcite-dolomite, and pebble composition, and in particle-size distribution. Relative to the Boston till, all are characterized by a clay mineral composition that is high in illite (about 78 percent) and low in vermiculite and chlorite (about 13 percent), a low limestone/dolomite pebble ratio (about 0.32) and a high total calcareous pebble content (about 86 percent), and a high total $CaCO_3$ equivalent for the <2 mm size fraction (about 30 percent). The Boston till is characterized by a composition that is low in illite (55 percent), high in vermiculite and chlorite (34 percent), high in limestone/dolomite (almost 1.0), and low in total calcareous rocks (75 percent) and total $CaCO_3$ equivalent (20 percent).

Previously, on the basis of soil development (primarily depth of carbonate leaching) there has been thought to be an Early Wisconsinan drift in Highland County. The soil is unusually deep, developed in loess on Boston till, but in accordance with its low carbonate content. The parent material has been exposed to weathering about 21,000 years, as revealed by two radiocarbon age determinations (ISGS-42, ISGS-44). These dates definitely identify the Boston till as Late Wisconsinan in age. In addition, they give supporting evidence that the Scioto Lobe reached its maximum southern position about 21,350 years B.P. (average of OWU-159, OWU-160, ISGS-42, ISGS-44), about 850 years before the Miami Lobe maximum.

Significant differences (99 percent confidence level) exist in the Darby I, Caesar, Boston, and Rainsboro tills for mean values of loess-cover thickness and depths of leaching. These criteria can be used for distinguishing between the major till—soil associations and hence the identity of the till parent material for this area.

INTRODUCTION

Regional setting

Highland County is located in southwestern Ohio (fig. 1) and has an area of 558 square miles. The climate of the county is humid-temperate continental and the annual precipitation of about 43 inches is well distributed throughout the year. Short periods of heat and cold are common; the highest temperature recorded is 105° and the lowest is -30°F. The average temperature for January is about 31° and for July about 74°F. The county lies predominantly in the physiographic province of the glaciated Central Lowland, but about 15 percent of the land area is in the low Appalachian Plateaus province. Most of the latter is unglaciated.

Geologically, Highland County is one of the most diversified areas in Ohio. The stratigraphic range of exposed bedrock, from Upper Ordovician to Lower Mississippian, is greater than that of any other county except Adams. One of Ohio's largest limestone cave developments (in the Late Silurian Peebles formation) is located at the eastern border of the county on the south wall of Rocky Fork gorge. Drift from two glaciations covers nearly all the county; about a tenth of its area is unglaciated (pl. 1). Late Wisconsinan drift mantles the northern third of the county. Illinoian drift covers the remainder of the lowland province and abuts the hills east at the foot of the plateau area.

The highest elevation within the county is Washburn Hill on the plateau east of Marshall, 1,343 feet above sea level. The lowest elevation, just under 700 feet, is 5 miles to the south along Baker Fork at the southern county line. In contrast to this relief of about 650 feet, there is an extensive flat plain of about 1,000 feet elevation in the western part of Highland County.

FIGURE 1.—Location of Highland County.

In the southern part of the county between these two extremes is an upland area which is thoroughly dissected by streams and in which topography is controlled by bedrock. The northern third of the county has rolling topography which is controlled chiefly by glacial drift.

Previous investigations

Early geologic investigations of the county dealt mainly with bedrock. Edward Orton in 1871 contributed the earliest significant report. One of the greatest contributions to our knowledge of the stratigraphy and paleontology of Highland County was made by August Foerste in 1917 when he revised the nomenclature of the Niagaran Series. A major contribution to the bedrock geology was made by Richard Bowman in his Ph.D. work in 1956.

The earliest significant report available on the glacial geology of this area is that by Frank Leverett in 1902. He wrote a monograph dealing with the glacial formations and drainage features of the Erie and Ohio basins. By today's standards, which stress interpretation of glacial stratigraphy and quantitative data, Leverett's work has to be considered reconnaissance. In 1936 the Geological Survey of Ohio published James Rogers' investigations during the summers of 1929 and 1930 into the geology of Highland County. However, his study contributed little more than the descriptive work of Leverett. Jane Forsyth in 1961 described unique soils in a narrow belt across Highland County between Late Wisconsinan and Illinoian drift as evidence for an Early ("early") Wisconsinan drift. James Teller in 1964 (see also 1967) mapped the glacial geology of Clinton County to the west, and Richard Goldthwait has unpublished studies made in Ross County, just east of Highland County, for the Ohio Division of Water.

Procedures

Most of the field work was conducted during the summers of 1968 and 1969. Material was investigated chiefly by digging, but abundant use was made of the soil auger. Depth of leaching was measured by application of dilute hydrochloric acid to drift material. Only well-drained sites of slight relief were measured. Most pH determinations were made in the B1 horizon because it yields the lowest values most consistently. A Hellige-Truog kit was used to measure pH. Pebble counts were taken at all significant sections and at many single till exposures. The procedure involves collecting 100 pebbles, from 1 to 3 inches in diameter, as they are uncovered during the course of digging below the weathered soil zone. Each sample was collected from a selected exposure covering a few square yards at most. Till fabric was recorded at the time the pebbles were collected by measuring the preferred orientation of the long axis of pebbles not less than 1 inch long. Only pebbles with a length-to-breadth ratio greater than 3:2 were measured; the direction of plunge of the long axis was taken, not the amount.

Mapping was done on 7.5-minute topographic maps (U.S. Geological Survey, 1960, 1961): Bainbridge, Belfast, Byington, Good Hope, Greenfield, Hillsboro, Leesburg, Lynchburg, Martinsville, Memphis, New Market, New Martinsburg, New Vienna, Rainsboro, Sardinia, Sinking Spring, South Salem, Sugar Tree Ridge. Unpublished data collected by Williams and others (1970) were used to assist in mapping of bedrock and of terrace and alluvial deposits.

Particle-size distributions for samples of till were determined using the procedure described by the American Society for Testing and Materials (1964). Heavy minerals were identified using a petrographic microscope; 200 grains were identified on each slide. Semiquantitative estimations of the clay minerals were determined by a modified Johns, Grim, and Bradley (1954) x-ray diffraction method developed by L. P. Wilding and L. R. Drees of The Ohio State University's Agronomy Department. Calcite-dolomite percentages of the <2-mm size fraction for tills were determined using the Chittick gasometric determination technique described by Dreimanis (1962). For a detailed description of the laboratory procedures used, the interested reader is referred to Rosengreen (1970).

Acknowledgments

This research was part of a Ph.D. dissertation submitted to The Ohio State University (Rosengreen, 1970), where it was read by R. P. Goldthwait, A. LaRocque, and G. Faure (Department of Geology). The dissertation was read also by L. P. Wilding (Department of Agronomy), who gave constructive criticism and suggestions on that portion of the manuscript concerned with soils. Analyses of till for clay-mineral composition and calcite-dolomite content were done in the Department of Agronomy; thanks go to L. R. Drees of that department for his assistance during the analyses.

I wish to express my gratitude to the Ohio Division of Geological Survey for financial support of the field investigations and for help given in the final preparation and critical reading of this report. Appreciation is extended to Niles McLoda of the Soil Conservation Service, U.S. Department of Agriculture, for discussing characteristics of the recently mapped soils of Highland County. Identification of wood collected in the county was made by G. W. Burns of the Department of Botany at Ohio Wesleyan University. Carbon-14 dates were provided by the U.S. Geological Survey, Washington, D. C., and the Illinois State Geological Survey.

PREGLACIAL SETTING

The oldest rocks exposed in Highland County are of Late Ordovician age, and the youngest is the Lower Mississippian Berea Sandstone (table 1). Figure 2 is a generalized geologic map showing the distribution of the time-rock system. Rocks belonging to the Niagaran Series (Middle Silurian) have a greater areal distribution than all others combined. Structurally these Paleozoic rocks form part of the east limb of the Cincinnati arch. The general strike of these rocks is north-northwest, and they dip east-northeast at 20 to 30 feet per mile (Bowman, 1956, p. 1). The oldest formation is exposed only in the northwestern corner of the county along the creek bottom of Flat Run. Eastward across the county successively younger rock is exposed. The youngest bedrock forms the flat-topped mountains of the Appalachian Plateaus province along

TABLE 1.—*Generalized stratigraphic section for Highland County*[1]

SYSTEM	Formation	Lithology	Thickness (ft)
MISSISSIPPIAN	Berea	Sandstone, buff to gray, fine-grained; interbedded thin shales	0-200
DEVONIAN	Ohio	Shale, dark-brown or gray, fissile; calcareous concretions; pyrite and marcasite	0-300
	Olentangy	Shale, blue, fissile; black partings	0-60
	Hillsboro	Sandstone, white or yellowish, fine-grained, friable	0-20
SILURIAN	Tymochtee	Dolomite, gray to blue-gray, very fine-grained; argillaceous partings	0-80
	Greenfield	Dolomite, tan to blue-gray, fine-grained, distinctly bedded	
	Peebles	Dolomite, light-gray to bluish-gray, very fine-grained, massive; vugs and cavities common	0-100
	Lilley	Dolomite, gray to bluish-gray, finely crystalline; argillaceous locally; crinoidal carbonate lithofacies	0-55
	Bisher	Dolomite, reddish-brown or buff, fine-grained, silty; locally with blue-gray limestone	0-84
	Rochester	Clay shale, bluish-green; weathering to light yellow	0-95
	Dayton	Limestone, gray to greenish-gray, fine-grained, very dense and hard	0-7
	Brassfield	Limestone, bluish-gray to pink, massive to thin-bedded; shale partings	0-50
ORDOVICIAN	Undifferentiated	Shale, greenish, calcareous; with thin-bedded limestone	12
		Shale, calcareous; with thin-bedded limestone	65
		Shale, calcareous; with thin-bedded limestone	30
		Clay shale, calcareous; with thin-bedded limestone	50
		Shale, calcareous; with thin-bedded limestone	5

[1]In part from Rogers (1936), Bowman (1956).

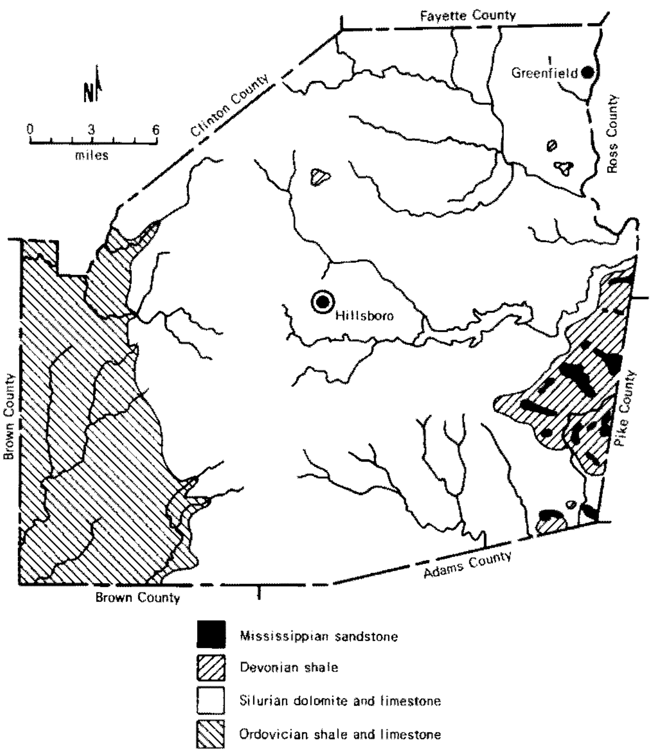

FIGURE 2.—Generalized geologic map of Highland County.

the eastern border of Highland County south of Rocky Fork.

The preglacial surface of the county may be divided into four areas on the basis of topography and well-log data. These divisions agree in part with the distribution of the various rock series. One of these areas, a narrow strip along the southeastern border of the county, is the edge of the Appalachian Plateaus province. Its western boundary is here capped by the resistant Berea Sandstone and forms the Mississippian Escarpment. A dissected upland area with accordant levels extends west of the Mississippian Escarpment for about two-thirds the distance across the county. The western edge of this area is formed by the north-south-trending Niagaran Escarpment, which consists of the Bisher and Lilley Dolomites. The escarpment rises about a hundred feet above an extensive flat and poorly drained area to the west. Although the topography of this till plain is almost entirely drift controlled, data from well records show that the rock surface below is also very flat. The bedrock surface probably represents an erosion surface at the base of weak Ordovician shale and limestone. In the northern part of the county a large area, roughly trapezoidal in shape, has moderate bedrock relief. One corner extends south a short distance, bisecting the dissected uplands and Mississippian Escarpment. Silurian bedrock is the chief material underlying the glacial drift of this area, but Mississippian Ohio Shale caps some of the prominent hills (see fig. 2).

The work of streams during that general period of erosion before glaciation (Stout and others, 1943, p. 51) is ascribed to the Teays and all streams contemporaneous with it. Before glaciation, Highland County was indeed a "highland" drainage divide. A major divide extends north-south through the western part of the county along the Niagaran Escarpment. Drainage east of the divide flowed east and joined the master Teays. Drainage west of the divide flowed southwest and was part of the headwaters of the Norwood River, a major tributary to the Teays. During the Teays Stage major valleys were developed east of the drainage divide. Today Rocky Fork, Clear Creek, Rattlesnake Creek, and Paint Creek occupy parts of these valleys. Areas of greatest relief are located along the courses of these four valleys. However, much of the erosion done by the preglacial streams is now obscured by later streams and by drift deposited during the Illinoian and Wisconsinan glaciations.

METHODS AND RESULTS OF STRATIGRAPHIC CORRELATION

Identification and correlation of glacial strata is accomplished through several empirical methods; however, each is of questionable value if used alone. The factors considered during this study are stratigraphy, surface soils, paleosols, clay-mineral composition, particle-size distribution, pebble lithology, calcite-dolomite content, till fabric, and radiocarbon dates. Results and conclusions drawn from each of these follow.

Stratigraphy

The most important aspect of stratigraphy is the establishment of local stratigraphic sections, each contributing a segment of the glacial history. These are then correlated with other sections by equating strata on the basis of quantitative or semiquantitative analyses of lithologic units. Seldom does a problem arise as to the relative age of units at a single section. However, without the presence of a lithologically distinct marker bed, correlation based solely on similar sequences of beds in several exposures and/or intervening well logs is of very questionable value; glacial deposits are characterized by repeatable sequences (*i.e.*, till-gravel-till), and two similar sequences in close proximity may belong to different glaciations.

In Highland County glacial drift deposits of two stages comprise four till units, Rainsboro (Illinoian), and Boston, Caesar, and Darby I (Late Wisconsinan), which together cover nearly all the county. At one locality well-exposed pre-Rainsboro drift may be either early Illinoian or Kansan in age. Characteristic exposures of these drifts are described in the following paragraphs.

Two tills, separated by 10 feet of gravel with a paleosol 5 feet thick at the top, are exposed in a cut bank along Blinco Branch. Analyses of clay-mineral composition, mechanical composition, pebble lithology, and carbonate content identify the upper till as belonging to the Late Wisconsinan ice advance. The name Boston, for the village of Boston in Highland County, has been proposed for this till (Rosengreen, 1970, p. 21), which underlies the surface, or loess cap, in a belt of drift 1 to 4 miles wide along the southern margin of the Wisconsinan drift (pl. 1). The type section (fig. 3; locality C58 in appendix) is exposed along Blinco Branch 2.1 miles east of Boston and about 700 feet south of U.S. 50.

The Boston till is primarily calcareous till and consists of fairly sparse pebbles (about 6 percent by weight) and cobbles in a compact but uncemented silt loam matrix. Details of the composition of the till are given under appropriate sections. The upper surface of the Boston till is constructional, and its southern extent is marked by the Mt. Olive Moraine (pl. 1).

The lower till at the type locality for the Boston till is identified as belonging to the Illinoian drift that directly underlies the surface, or loess cap, over the southern two-thirds of the county. The name Danville has been given informally (Goldthwait, 1955, p. 45) to Illinoian till of western Ohio. The till was named for the village of Danville, where about 18 feet of the till was exposed overlying Silurian limestone in a quarry. However, for several years this name has been used also for a Wisconsinan till unit in Illinois and Indiana. Therefore the name Rainsboro, for the village of Rainsboro, is here proposed for the Illinoian till unit in Highland County, Ohio.

The Rainsboro till is primarily calcareous, very compact, locally cemented, with abundant pebbles (about 15 percent by weight) and cobbles in a loam matrix. The till is significantly different from the Boston till in composition and can be readily identified in sections containing both units. Thick exposures of Illinoian till are few; the depth of oxidation at 12 sites ranges from 9 to 15 feet and averages 13 feet. Both the oxidized yellowish-brown and the unoxidized dark-gray portions of the till are very compact, noticeably more so than for Wisconsinan till. In addition, Illinoian till is characterized more by vertical joints than is Wisconsinan till. The joints extend down from the oxidized till into the dark-gray till for 3 to 10 feet and are filled with illuvial clay films ranging in color from yellowish red to strong brown to yellowish brown.

A sequence of three tills is exposed in a cut bank in Fall Creek (locality D36). The lowest till, identified as Rainsboro, is separated from the middle till, which is Boston, by 6 feet of paleosol developed in sandy silt (fluvial). A 1-foot layer of rubble and gravel separates the Boston till from the uppermost till, which is identified as Caesar till on the basis of its composi-

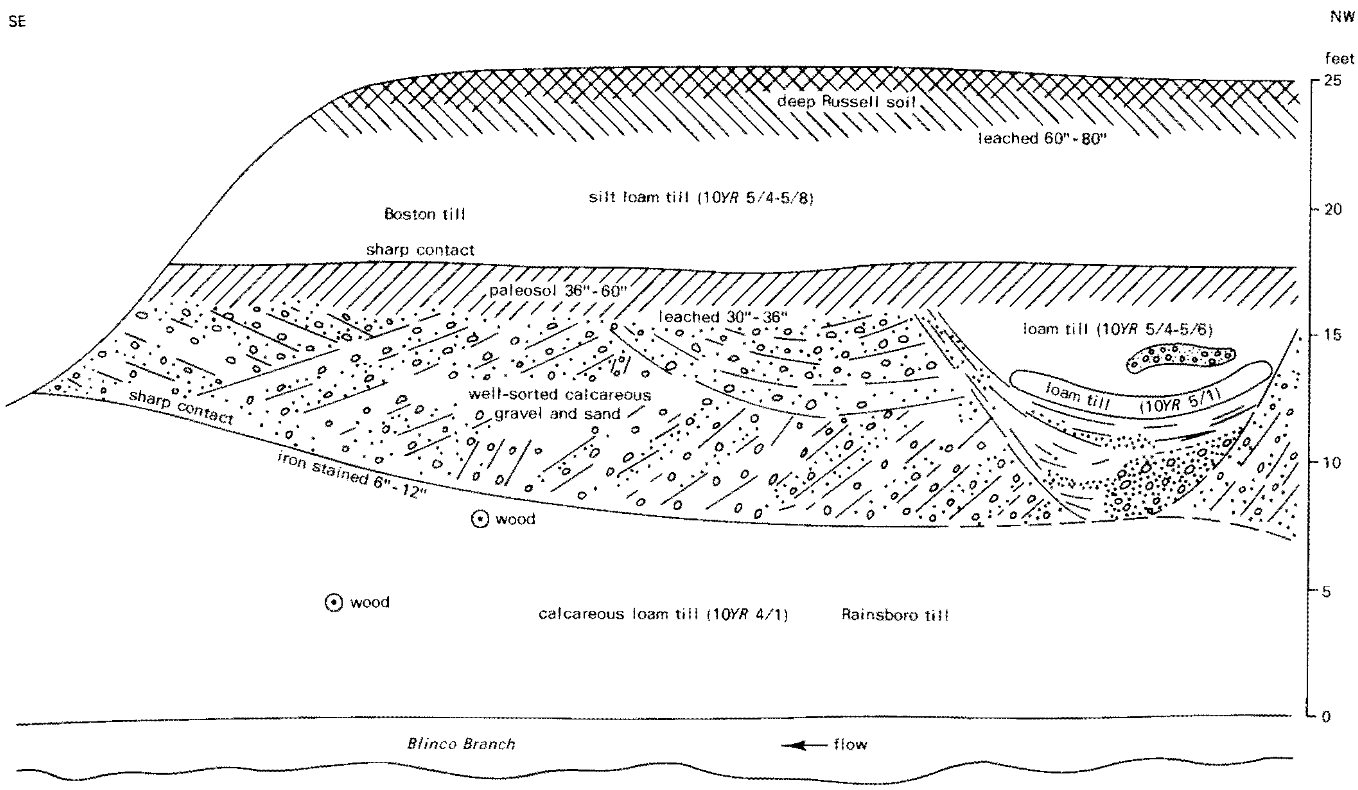

FIGURE 3.—Type section of the Boston till.

tion, stratigraphic position, and radiocarbon age determination. Caesar till directly underlies the surface, or thin loess cap, south of the Reesville Moraine and extends to the distal edge of the Cuba Moraine. The till is calcareous and compact, with a loam matrix, and is very similar in composition to the Rainsboro till.

A section with two tills is exposed in a cut bank of a tributary to Walnut Creek, 2.2 miles east of East Monroe (locality A60). The lower unit, identified as Caesar till, is separated from the upper till by a calcareous unoxidized silt bed, 2 feet thick. The upper 2 feet of the Caesar till is oxidized also to a dark brown (10*YR* 4/3). The upper till, here located on the distal edge of the Reesville Moraine, is Late Wisconsinan. This unit is called the Darby I (Goldthwait and others, 1965). It forms the drift directly underlying the surface, and was deposited during the readvance of the Scioto Lobe to the Reesville Moraine. The paleosol (oxidized till) at the top of the Caesar till was developed during the time interval between retreat of the glacier from the Cuba Moraine to its subsequent readvance to the Reesville Moraine.

A sequence of three tills separated by gravels is exposed 3 miles north of Hillsboro (locality C51) in a cut bank along Clear Creek. The uppermost two tills are identified as Rainsboro on the basis of composition and their location south of the Wisconsinan boundary. The lowest till differs in composition from the Rainsboro till and overlies a paleosol which is 4 feet thick. This till represents a pre-Rainsboro advance, whose age may be early Illinoian or possibly pre-Illinoian. No other pre-Rainsboro till of similar composition was found in the county. The paleosol is developed in a gravel which contains pebbles of foreign lithology, namely, granitic and metamorphic rock, suggesting that the gravel is an earlier drift deposit, possibly Kansan in age. Drift of Kansan age has been identified in the Cincinnati area (Teller, 1970).

Exposures with stratigraphy of several units are found in a number of localities in Highland County. All sections with significant stratigraphy are described in the appendix.

Surface soils

Till–soil associations.—Five different Late Wisconsinan tills, associated with five major soils, are recognized in western Ohio (Forsyth, 1965). Three of these are found in Highland County, along with the Illinoian Rainsboro till–Cincinnati soil association. The Wisconsinan soils, found in irregular east-west belts generally parallel to end moraines, are distinguished from each other on the basis of (1) the presence or absence and thickness of a silt (loess) cap and (2) the depth of soil development. The characteristics of these soils and of the Illinoian soil are summarized in table 2; those which are diagnostic for a particular soil are italicized. Figure 4 shows the general distribution of the soils in Highland County.

On the basis of a soil whose intensity and depth of weathering are intermediate between those of Illinoian and Late Wisconsinan ages, it has been postulated that an older Wisconsinan drift exists. This soil, called deep Russell, is restricted in occurrence, being recognized only in a very narrow belt along the Wisconsinan boundary in Highland and western Ross Counties. Russell soils are characterized specifically by a silt (loess) cap greater than 18 inches thick. The deep

TABLE 2.—*Significant characteristics of major till–soil associations in Highland County*[1]

Till unit	Soil	Thickness of silt cap (in)[2]	Depth of leaching at well-drained site (in)[2]	Boundary to south	Boundary to north
Darby I	Miami 6A	*generally absent*	14-47	Reesville Moraine	Powell Moraine
Caesar	Miami 60	*<18*	17-58	Cuba Moraine	Reesville Moraine
Boston	shallow Russell 67s[3]	*>18*	*35-60*	Mt. Olive Moraine	Reesville Moraine
Boston	deep Russell 67	*>18*	*60-80*	Mt. Olive Moraine	Cuba Moraine
Rainsboro	Cincinnati 75	*12-55*	*69-149*	Illinoian boundary	Wisconsinan boundary

[1]Modified from Forsyth (1965, p. 223).
[2]Italicized where diagnostic.
[3]Developed in Caesar till in a few places.

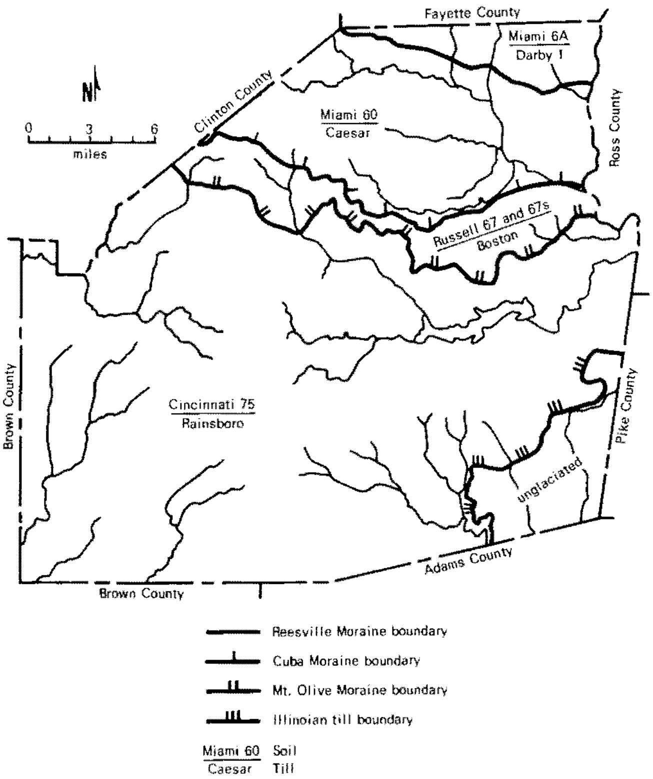

FIGURE 4.—Distribution of major till—soil associations in Highland County.

Russell soil differs from the shallow Russell soil mainly in depth of weathering, being leached to depths greater than 60 inches.

The boundary separating the Miami 6A and Miami 60 soil associations is generally the distal edge of the Farmersville Moraine (Miami Lobe) or the Reesville Moraine (Scioto Lobe). Recent work by soil scientists, however, has shown that there is no significant difference between these two soils in west-central Ohio (Wilding, Jones, and Schafer, 1965), and these workers do not recognize Miami 6A and 60 areas anymore, using instead Miamian (for the well-drained sites). This study indicates also that no significant difference exists in the composition of the parent material of the 6A soils (Darby I till) and that of the 60 soils (Caesar till).

Although no significant difference may exist between Miami 6A and 60 soil areas elsewhere in Ohio, in Highland County there is a significant difference in the thickness of the loess cover. On this basis the two areas can be readily separated. For this reason, the former terminology of Miami 6A and Miami 60 will be used in this report. It should be remembered, however, that all other soil characteristics are similar in the two areas.

In the Miami Lobe area of western Ohio the areas to the south dominated by shallow Russell soils are generally separated by a silt line (Forsyth, 1961) from areas to the north characterized by Miami 60 soils. South of the line the silt cap is more than 18 inches thick; north of the line it is thinner or absent. To the east, in the Scioto Lobe, these soils tend to occur together as a complex. In Highland County, although both Miami 60 soils and shallow Russell soils occur on both sides of the silt line, the former are dominant to the north and the latter to the south. Shallow Russell soils, present in a complex association with deep Russell soils, appear to be more weathered than the Miamian soils, having somewhat brighter colors for sites of similar drainage. The silt line generally is the distal edge of the Cuba Moraine, suggesting a significantly greater amount of loess deposition on the Boston till than on the Caesar till. In the complex of Russell soils south of the silt line, it is believed that the significant differences between the deep and shallow soils are quite clearly related to the combined effects of loess thickness and local compositional variations in the Boston till.

North of the area dominated by Miami 60 soils is an area of dominantly 6A soils, generally without a noticeable loess cover. In this case the distal edge of the Reesville Moraine marks the boundary between the two areas.

Depth of leaching.—The present work in Highland County has resulted in delineation of four areas which differ from each other in average depth of leaching (fig. 5)

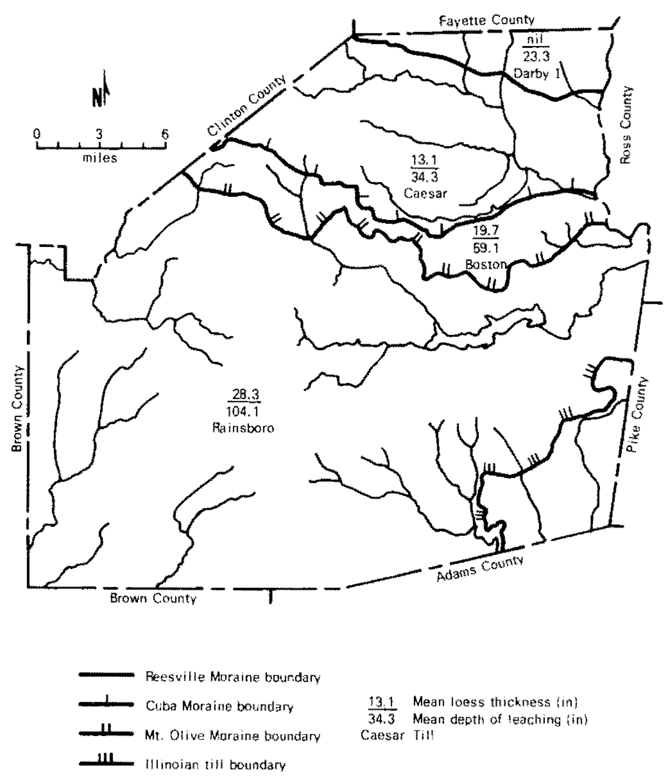

FIGURE 5.—Areas in Highland County of distinctly different thicknesses of loess cover and depths of carbonate leaching.

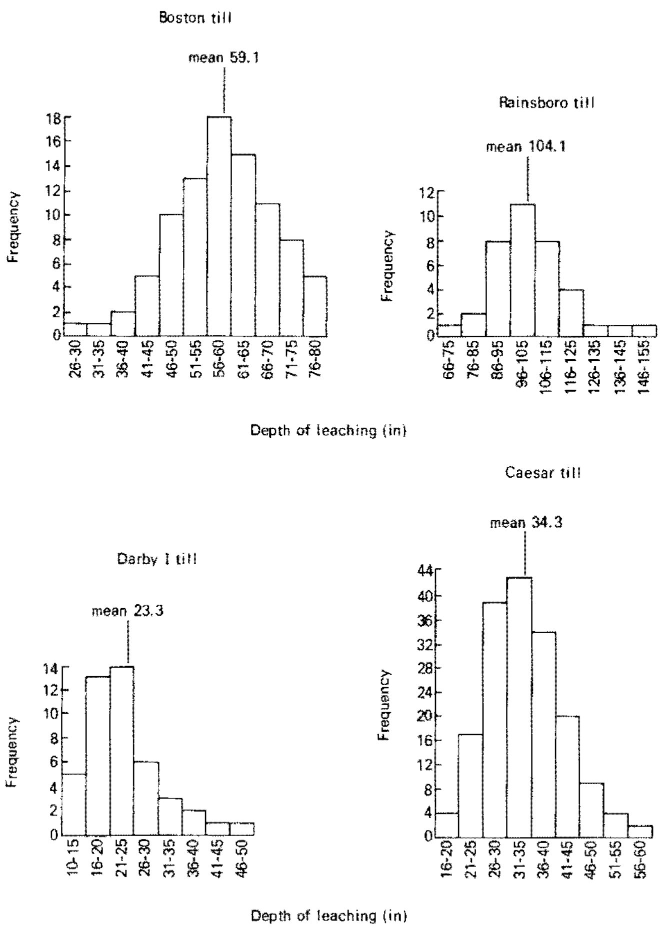

FIGURE 6.—Distribution of depth of carbonate leaching in relation to frequency for till units in Highland County.

and coincide with the areas of the major soil associations (fig. 4).

A series of histograms (fig. 6), one for each till unit, shows the distribution of depth of leaching in relation to frequency of occurrence for sites examined in Highland County. The arithmetic mean and standard deviation for the depth of leaching associated with each till unit are listed in table 3. The value for the depth of leaching includes the thickness of the leached loess cover. Confidence levels (Dixon and Massey, 1957) for the significance of mean differences between till units were computed as: Darby I and Caesar tills, 99 percent; Caesar and Boston tills, 95 percent; Boston and Rainsboro tills, 99 percent. Clearly, the significant differences of the means for the depths of leaching may be used as criteria for differentiating these till units.

Depth of leaching is directly related to time: the greater the time interval of leaching, the greater the depth of carbonate removal. However, time is not the only controlling factor; texture, permeability of parent material and of the resulting soil, carbonate content and type, clay content and type, topography, rainfall, temperature, depth to ground water, biotic environment, and rate of surface erosion or deposition may also affect carbonate leaching. According to Merritt and Muller (1959) carbonate content seems to be the most important factor.

Carbonate content has an inverse relationship to the depth of leaching: the smaller the content of carbonate, the greater the depth of leaching (other factors remaining constant). If we let L represent the depth of leaching, T time, and C the carbonate content, then the proportionality $L \propto T/C$ may be written. By careful selection of sites to be examined, the numerous other factors that affect leaching can be kept fairly constant. If we let k be the proportionality constant, then the proportionality becomes an equation: $L=T/C(k)$. Although the equation is a general expression relating the depth of leaching to time and carbonate content, its use is not widely applicable because k is a variable constant; its value changes with time and carbonate content.

Probably the most significant factor causing k to change with time is the very important effect, which is seldom recognized, that removal of carbonate has on depth of leaching: the remaining material is concentrated proportionally to the amount of carbonate removed. For example, 25 percent carbonate content will affect the rate of leaching much less than half that of 50 percent content. On carbonate removal, a material with an original 25 percent clay content will be concentrated into three-quarters of its original thickness and will consist of one-third clay material. In a 50 percent carbonate example, the clay content will increase by 100 percent in the leached zone. In the 25 percent carbonate examples, it increased by only $33\frac{1}{3}$ percent. One can therefore expect a till of lower carbonate content to be leached to a greater depth than a till of higher carbonate content; this depth should be somewhat greater than a direct proportionality (other factors being equal). This relationship suggests an answer to the apparent anomaly of greater depths of leaching for the Boston till relative to the Darby I, Caesar, and Rainsboro tills.

Figure 5 shows that the Boston till (postulated as Early Wisconsinan by some earlier workers) is leached to a mean depth of 59.1 inches. It has a mean loess cover of 19.7 inches which, subtracted from the mean depth of leaching, gives a leaching depth of 39.4 inches for the till. This is about 16 and 18 inches more, respectively, than the depths of leaching associated with the soils of the Darby I and Caesar till areas and has been assumed by some geologists to be the result of time.

To determine if the greater depth of leaching characteristic of soils developed in the Boston till was due to the time factor rather than to variation in composition, carbonate content analyses were done on the till units in Highland County (see p. 15). Caesar till averaged 35 percent more total $CaCO_3$ equivalent than Boston till. Under similar conditions of weathering,

TABLE 3.—*Soil characteristics associated with till units in Highland County*

Till unit[1]	pH	Depth of leaching (in)	Loess (in)	$CaCO_3$ equivalent content (%)
Darby I				
mean	6.4	23.3	generally	32.6
σ	0.5	7.5	absent	2.4
cv	7.8	32.1		7.4
n	26	45	45	3
range	5.5-7.8	14-47		30.4-35.2
Caesar				
mean	6.2	34.3	13.1	26.6
σ	0.9	8.0	4.2	4.6
cv	14.5	23.3	32.1	17.3
n	63	172	172	12
range	4.7-7.8	17-58	6-27	21.0-34.0
Boston				
mean	5.3	59.1	19.7	19.7
σ	0.5	10.6	6.3	2.9
cv	9.4	17.9	32.0	14.7
n	47	89	89	9
range	4.5-6.5	27-80	10-36	14.3-22.9
Rainsboro				
mean	4.6	104.1	28.3 *34.4*[2]	30.5
σ	0.2	16.0	7.8 *9.3*	4.6
cv	4.3	15.4	27.6	15.1
n	37	37	37 *104*	12
range	4.2-4.9	69-149	12-49	21.1-35.7

[1]Mean, arithmetic mean; σ, standard deviation; cv, coefficent of variation; n, number of sites examined.
[2]Loess values for 104 sites on the Illinoian till plain.

if a till with a $CaCO_3$ content of 26.6 percent can be leached to a depth of 21.2 inches (mean of Caesar till minus mean of loess thickness, table 3) in a unit of time, then a till with 19.7 percent carbonate content (mean of Boston till) should be leached 28.6 inches in the same amount of time. According to C^{14} dating, about 18,000 years (W-91, W-331, Y-448) is the average time that the Caesar till has been exposed to weathering since deglaciation. Thus 1.18 inches (on the average) of Caesar till was leached each thousand years. In the same unit of time the Boston till would be leached at an average rate of 1.59 inches per thousand years.

Two radiocarbon determinations (ISGS-42, ISGS-44) date the Boston till at about 21,000 years B.P. (clearly not Early Wisconsinan). At the average rate of 1.59 inches of leaching per thousand years, this amounts to an additional 4.8 inches, or a total of 33.4 inches, of carbonate removal. This compares fairly closely to the average 39.4 inches measured for depth of leaching in the Boston till, excluding the loess cap.

When the important effect of the lower carbonate content of the Boston till is considered (depth of leaching is not a direct proportionality as calculated above, but an exponential function as mentioned earlier), the difference of 6 inches between the calculated and observed depth of leaching is resolved; the Boston till would be leached of carbonates to even greater depths than figured by a direct proportionality calculation.

Values for $CaCO_3$ content and corresponding depth of leaching are plotted on the graph in figure 7 for the Caesar, Boston, and Rainsboro tills. The Darby I was not plotted because only three carbonate analyses are available. Just those carbonate values were used that had depths of leaching values taken at or in close proximity to the site sampled.

The distinct grouping of the points for each till exemplifies the effect of carbonate content on depth of leaching. It is recognized that many more points should be plotted for each till before any sound conclusions can be derived from such a diagram. Nevertheless, the distribution of points and the resulting best-fit regression lines suggest that variability in depth of leaching within the same till parent material is a result of carbonate content. In actuality a regession curve would probably be more representative of the relationship: this is suggested by the slope of the Boston till regression line, about -0.7, relative to the slope, -0.4, for the Caesar till. The greater portion of this increase is probably due to the lower carbonate content and not to the additional 3,000 years of weathering.

The marked slope, -1.8, of the regression line for the Rainsboro till relative to that for the Caesar till further demonstrates the exponential relationship of

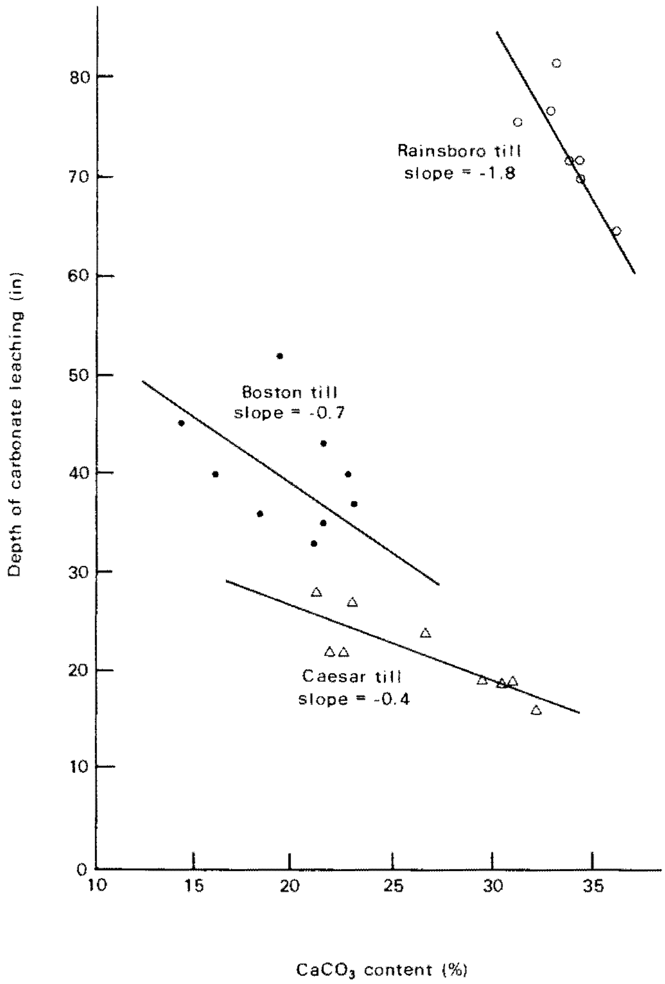

FIGURE 7.—Depth of carbonate leaching (minus thickness of loess cover) in relation to carbonate content.

depth of leaching to carbonate content over a period of time.

I believe that the significant differences between the depths of leaching developed in Illinoian Rainsboro till and those in Late Wisconsinan Darby I and Caesar tills are quite clearly related to age and not to parent material. Illinoian till at the surface in Highland County is associated with characteristic soils which are consistently thicker and more deeply weathered than those in Wisconsinan till. Analyses reveal that till parent materials of the 6A and 60 soils are very similar to those of the Illinoian till.

Depths of leaching in Illinoian till soils averaged about 104 inches for 37 well-drained sites examined. The mean loess thickness was 28.3 inches, giving a mean depth of 75.8 inches for leaching of the Illinoian till. This is about 54 inches more than the mean depth of leaching of the Darby I and Caesar tills. Also, it is clearly seen that the rate of leaching must decrease considerably with time. Since the end of the Illinoian glaciation (about 128,000 years ago according to Fairbridge, 1968, p. 923) the average rate of leaching for the Rainsboro till has been 0.59 inches per thousand years, while Wisconsinan 6A and 60 till soils have an average rate of leaching of 1.24 inches per thousand years. Figure 8 shows the depth of leaching plotted against time for average values obtained for Illinoian and Late Wisconsinan till soils of similar parent material. The important point shown by the curve is that the rate of leaching does decrease with time; the rate of leaching is given by the slope of a line tangent to the curve at a given time.

The depth of leaching is a significant means of differentiating the till units in Highland County. The method should prove useful wherever calcareous tills of contrasting carbonate content and/or age occur.

Loess cover.—Detailed petrographic and x-ray analysis of the loess cover of Ohio indicates that the loess was deposited in two stages, during Early and Late Wisconsinan time (Goldthwait, 1969). The thickest loess cover in the area is on Illinoian drift. Loess at 104 sites averaged 34.4 inches (table 3), becoming thinner from west to east. The clay minerals in the soil underlying the loess clearly indicate a weathering period longer than postglacial time, and it is clear from regional tracing that the soil was formed during Sangamonian time by weathering or by colluvial accumulation of weathered fine-grained material.

Loess covering the Boston drift of Late Wisconsinan age was found to have an average thickness of 19.7 inches at 89 sites. This suggests that about the lowest 15 inches of the loess cover in the Illinoian area was deposited prior to Late Wisconsinan time, probably during Early Wisconsinan time. However, a significant amount may have been deposited during advance of the Late Wisconsinan glacier to its southernmost position. Only by observation of the midloess break in the field or by laboratory analysis can the amount of loess belonging to the Early Wisconsinan be determined. Deposition of the second loess probably began at least 21,000 and perhaps as much as 28,000 years ago (Goldthwait, 1969).

Loess covering the Caesar drift averaged 13.1 inches at the 172 sites which were examined. Thus about 6 inches of loess was deposited during the time interval between retreat of the ice margin from its stand at the Mt. Olive Moraine to the beginning of the retreat from the Cuba Moraine. Loess deposition continued after retreat from the Cuba Moraine, but tapered off significantly after the readvance of the glacier to deposit the Reesville Moraine about 17,300 years ago (OWU-256, Moos, 1970). Loess is generally absent, or patchy at best, northward from the Reesville Moraine. Perhaps this was caused by a change in the regimen of the meltwater streams whose deposits provided a source for the loess, or perhaps vegetation rapidly stabilized the source deposits upon deglaciation.

There are significant differences (99 percent confidence level) in the mean values of the loess thick-

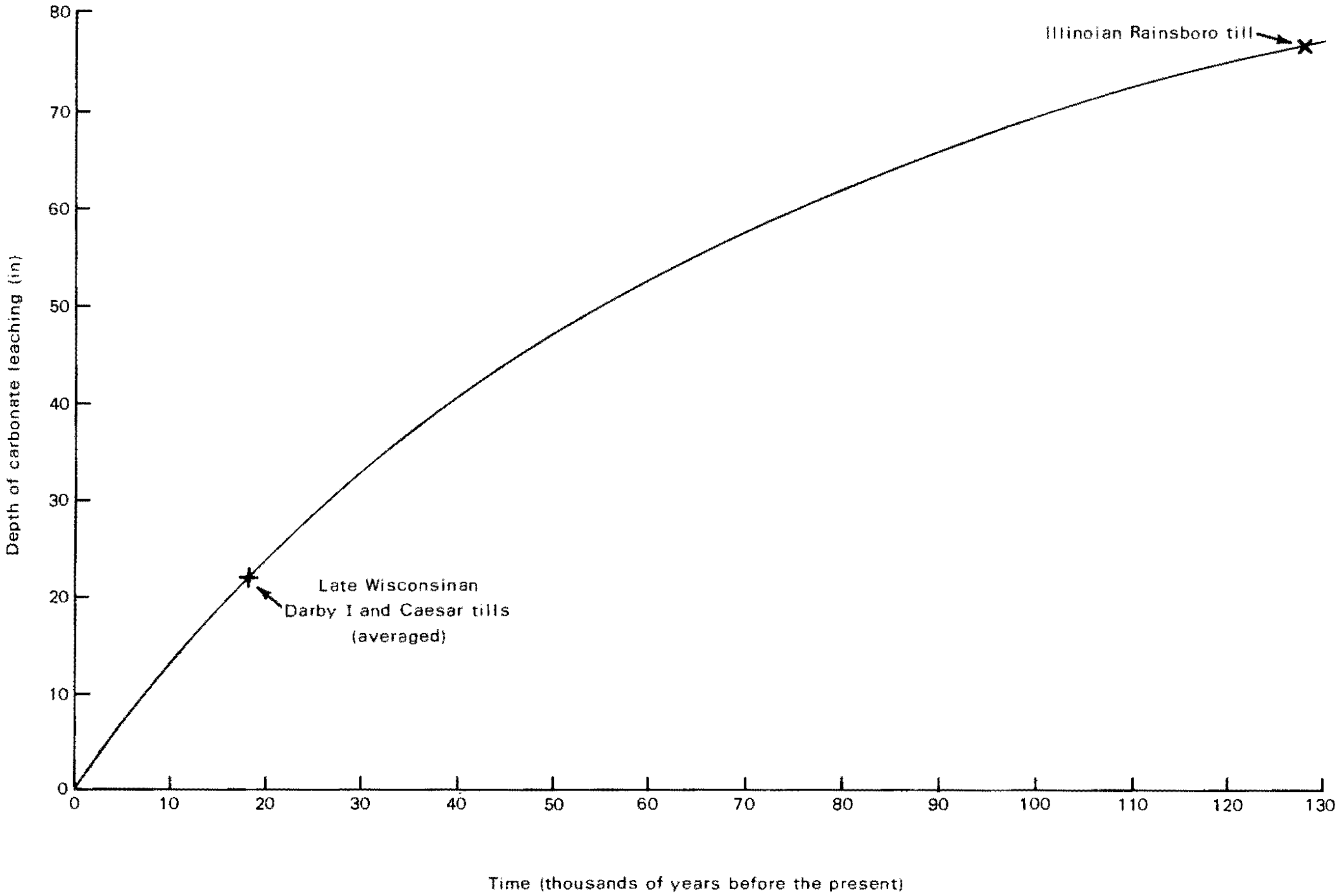

FIGURE 8.—Changing rate of leaching with time. The slope of a line tangent to the curve represents the rate of leaching in inches per thousand years at that time.

nesses associated with the till units in Highland County, and these values appear to be useful in distinguishing the till parent material for this area. Elsewhere this criterion should be used with caution owing to the variability in loess deposition over short distances.

Soil pH.—Generally, pH reflects the base status of the soil and is a measure of the intensity of acidity or alkalinity (not the capacity or total amount). Differences in pH values are generally attributed to degree of weathering or to time, providing the other soil-forming factors are the same. However, pH values may reflect differences in parent material which are not determinable in the field.

The pH determinations made during this study did not show any significant difference between the till—soil associations developed in Darby I and in Caesar drifts (table 3). This is not surprising because their parent materials are very similar and both are Late Wisconsinan in age. Russell soils developed in the Boston drift had an average pH value of 5.3, significantly lower (99 percent confidence level) than the 6.4 and 6.2 values for soils developed in the Darby I and Caesar drifts, respectively. Since the time factors for all three major soil associations are nearly the same (Late Wisconsinan age), one might conclude that the lower pH values in the Boston till are related to its significantly lower $CaCO_3$-equivalent content. However, owing to the thicker loess cover on the Boston drift, the pH measurements were made in the loess zone and not in the till parent material, as was the case for the Darby I and Caesar tills. Therefore, the lower pH values in the Russell soil association are probably related to texture and composition differences in the loess cover.

The lowest pH values in the Illinoian drift area generally are measured near the base of the loess cover or in the upper few inches of the underlying till parent material. Because the material in both these zones is older than the parent material of the 6A, 60, and 67 soil associations, the significantly lower (99 percent confidence level) mean pH value of 4.6 is the result of a longer span of weathering.

The use of pH values appears a useful criterion for distinguishing the major soil associations (with the exception of differentiating the Miami 6A from the 60), hence the identity of the till parent material. This method has extra value in that it can be used in the field.

Paleosols

A paleosol, especially one developed during an interglacial period and covered by deposits of a later glaciation, is one of the more reliable marker beds used in glacial stratigraphic correlations. Such a buried soil records weathering of sufficient duration for formation of the soil. Where found within a glacial sequence, therefore, it can be used as evidence for retreat and subsequent advance of ice and enables identification of at least two stratigraphic units.

The duration or time interval represented by a paleosol is not so readily deduced. If the entire soil profile is preserved, a general estimate can be made as to the amount of time necessary for its formation. From this estimate it may be possible to determine to which time interval the paleosol belongs. However, in most cases the paleosol is only partially preserved; the upper horizons are removed during subsequent ice advance, leaving generally the C horizon and perhaps part of the B horizon. In these cases, interpretation of the significance involves the use of the additional criteria discussed in the preceding sections.

A buried soil layer reported by Orton (1871, p. 266) is found at Marshall, where 11 out of 20 wells

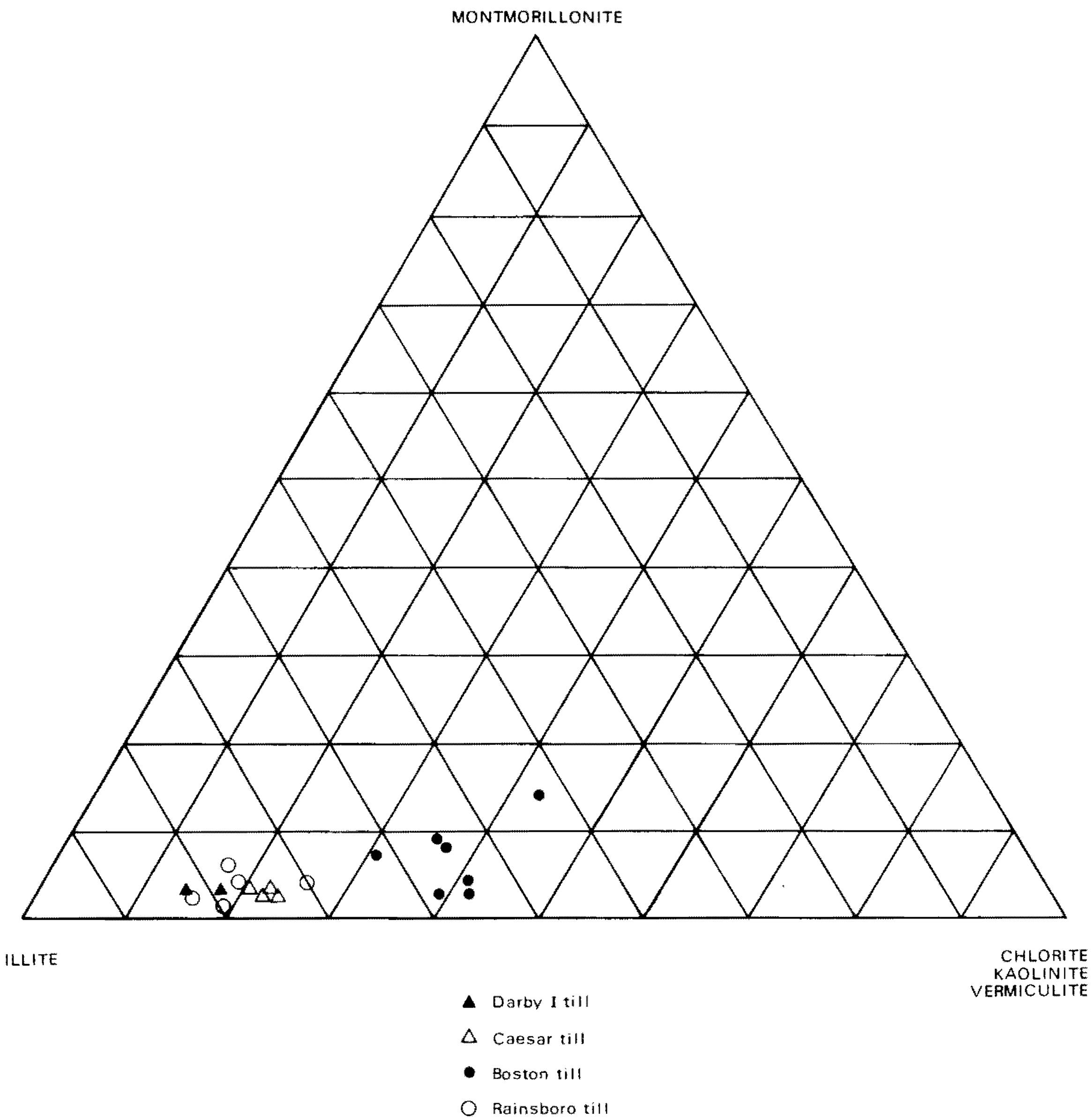

FIGURE 9.—Clay mineral compositions of till units in Highland County.

struck vegetal material at depths of 20 to 30 feet. Glacial drift is found beneath the paleosol, which is overlain by Illinoian drift; this buried soil, therefore, may represent either the time interval between two Illinoian advances or a pre-Illinoian (Yarmouthian?) interval. In the following paragraphs the principal paleosols found during this study are described (see appendix for detailed descriptions).

Paleosols believed to have been formed during Sangamonian interglacial time are exposed at several localities in the county. One is at locality C58, 2¾ miles west of Rainsboro, where the paleosol is 5 feet thick and is developed in gravel and till. This paleosol is overlain by the Boston till, identified on the basis of its composition. Another Sangamon paleosol is found 3 miles southeast of Samantha (locality D36). This buried soil consists of 5 to 6 feet of leached sandy silt overlying Illinoian till. Boston till, dated at 20,910±240 years B.P. (ISGS-44), overlies the paleosol and in turn is overlain by Caesar till. Another Sangamon paleosol is exposed beneath Boston till in a cut bank of a tributary to Little Rock Creek (locality C47); wood from the till was dated at 21,080±200 years B.P. (ISGS-42). A thin paleosol, leached from 6 inches to 2 feet, separates Rainsboro till from Caesar till in a road cut (State Route 138) about 4 miles southwest of Greenfield (locality B89). This paleosol appears to consist of the lower B and C horizons. A paleosol developed in Caesar till is overlain by Darby I drift 2.2 miles east of East Monroe (locality A60). A pre-Rainsboro paleosol, possibly formed during the Yarmouthian, is found in Clear Creek valley 3 miles north of Hillsboro (locality C51). This soil is developed in stratified drift overlain by three till beds (see p. 6).

Clay mineral analyses

The clay mineral assemblages in till reflect the composition of bedrock and soils that were incorporated into the ice during glaciation. The source is generally within a few hundred miles of the point of till deposition. The clay mineral content of tills in Ohio has been discussed mainly in the soils literature (Andrew, 1960; Bidwell, 1949; Holowaychuk, 1950; Wilding and others, 1965), with only a limited discussion by geologists (Droste, 1956; Teller, 1970).

The clay mineral compositions (fig. 9) of the Illinoian Rainsboro till and the Wisconsinan Darby I and Caesar tills are very similar and quite uniform within the county. They are characterized by high illite and low vermiculite content relative to the Boston till, which is uniform and characterized by low illite and high vermiculite content (table 4). All the tills have very low montmorillonite content, but that of the Boston

TABLE 4.—*Clay minerals in the* <2μ *size fraction of till units in Highland County*

Till unit[1]	No. of samples	Clay mineral content (relative %)				Peak height ratio[2]	
		Illite	Montmorillonite	Vermiculite + chlorite	Kaolinite	14Å AD / 10Å AD	14Å EG / 10Å EG
Darby I	2						
mean		80.5	3.0	13.5	3.0	.61	.37
σ		2.1	0.0	3.5	1.4	.01	.03
cv		2.6	0.0	25.9	46.6	1.6	8.1
cl (%)		99	99	99		99	99
range		79-82	3-3	11-16	2-4	.61-.62	.35-.39
Caesar	4						
mean		75.0	2.3	12.5	10.2	.35	.31
σ		1.4	0.5	4.0	2.4	0.5	.08
cv		1.9	21.7	32.0	23.5	142.8	25.8
cl (%)		99	99	99	99	99	99
range		74-77	2-3	7-16	8-13	.31-.42	.20-.42
Boston	7						
mean		54.9	6.9	33.5	4.7	1.18	.82
σ		5.8	4.0	6.3	5.0	.21	.17
cv		10.6	57.9	18.8	106.3	17.8	20.7
range		43-62	2-14	21-39	1-15	.90-1.52	.55-1.03
Rainsboro	5						
mean		77.0	3.6	14.0	5.4	.55	.38
σ		4.4	2.0	4.3	3.9	.12	.12
cv		5.7	55.5	30.7	72.2	21.8	31.5
cl (%)		99	99	99		99	80
range		70-82	2-6	8-19	2-11	.30-.79	.14-.51

[1]Mean, arithmetic mean; σ, standard deviation; cv, coefficent of variation; cl, confidence level of mean differences relative to Boston till value.
[2]AD, air-dry samples; EG, ethylene-glycol-treated clays.

TABLE 5.—*Particle-size distribution of till units in Highland County*

Till unit[1]	No. of samples	Particle-size distribution (% by weight: pebbles on total sample; sand-silt-clay on <2 mm size fraction) — Pebbles-granules 25.4-2.0 mm	Sand 2.00-1.00 mm	Sand 1.00-0.50 mm	Sand 0.50-0.25 mm	Sand 0.25-0.125 mm	Sand 0.125-0.062 mm	Total sand	Silt 0.062-0.002 mm	Clay <.002 mm
Darby I	4									
mean		15.0	5.7	5.8	6.8	8.1	7.7	34.1	51.0	14.9
σ		5.2	.3	.4	1.0	.53	.5	2.0	2.8	2.7
cv		34.7	5.3	6.8	14.8	6.2	6.5	5.8	5.5	18.1
range		11-21	5.5-6.1	5.4-6.4	5.5-7.7	7.5-8.5	7.2-8.3	32-35	47-54	11-17
Caesar	17									
mean		11.5	4.9	5.2	7.1	8.9	8.2	34.5	48.1	17.4
σ		3.4	1.5	1.4	1.7	1.7	1.3	6.7	3.7	4.1
cv		29.6	30.6	26.9	23.9	19.1	15.9	19.4	7.7	23.6
range		5-19	2.1-8.4	2.7-8.5	3.7-11.1	5.1-12.1	5.0-9.9	19-47	42-54	10-27
Boston	9									
mean		6.2	3.2	3.7	5.8	8.1	8.1	28.9	51.2	19.9
σ		1.1	.7	.6	.9	1.1	1.1	4.9	3.6	1.8
cv		17.7	21.9	16.2	15.5	13.6	13.6	17.1	7.0	9.1
range		5-8	2.3-4.7	2.9-4.9	4.8-7.6	7.1-10.6	7.2-10.6	25-39	43-55	17-22
Rainsboro	21									
mean		14.9	5.6	6.0	8.2	9.7	8.3	37.8	48.8	14.4
σ		5.1	1.4	1.5	2.1	2.2	1.4	8.0	5.1	3.7
cv		34.2	25.0	25.0	25.6	22.8	16.9	21.2	10.5	25.7
range		7-23	2.6-7.6	3.0-8.1	4.1-13.0	5.2-15.0	5.3-10.6	21-53	40-59	7-22

[1]Mean, arithmetic mean; σ, standard deviation; cv, coefficent of variation.

till is apparently about twice that of the others.

The very close similarity in clay mineral composition of the Darby I, Caesar, and Rainsboro tills probably reflects similar origins in the Erie Lobe. Glaciers that advanced from the north contained a high proportion of illite, derived from middle to upper Paleozoic rocks in Ohio. The contrasting clay mineral composition of the Boston till may in part reflect the fact that an intensely weathered soil (Sangamon) of a former landscape was incorporated into it.

Particle-size distribution

The distribution of particle sizes has been used as a criterion for correlation of tills in Ohio. It has proven very satisfactory and internally consistent in some studies (Shepps, 1953; Steiger, 1967) and inconclusive in others (Forsyth, 1956), but in this area the data show that it is a useful and corroborating criterion for correlation. Particle-size distributions reveal that the Darby I, Caesar, and Rainsboro tills have very similar mechanical compositions: the corresponding arithmetic means for the sand, silt, clay, and pebble size grades are all within 4 percent of each other (table 5). The data show also that the Boston till is overall finer in texture than the Darby I, Caesar, and Rainsboro tills. This textural difference is readily observable in sections containing some combination of these units (localities C58 and D36). Confidence levels for the significance of mean differences between the Boston till and the Darby I, Caesar, and Rainsboro tills are given in table 6.

Pebble counts

Pebble lithology has proven to be very useful in distinguishing drifts in central Ohio, and proved to be equally useful in Highland County. Pebble counts made from 51 till exposures and 13 gravel deposits showed that the Darby I, Caesar, and Rainsboro tills have very similar pebble lithologies that contrast sharply with those of the Boston till (table 7). The Boston till is significantly different (99 percent confidence level) from the other three till units for all lithology groupings, except the "igneous + metamorphic." The

TABLE 6.—*Confidence levels for significance of mean differences for particle-size distributions between the Boston till unit and the Darby I, Caesar, and Rainsboro till units*

Till unit	Percent confidence — Boston till: Pebbles	2.0-1.0 mm	1.0-0.5 mm	0.5-0.25 mm	Total sand	Silt	Clay
Darby I	99	99	99	-	90	-	99
Caesar	99	99	99	95	95	-	-
Rainsboro	99	99	99	99	99	-	99

most significant contrast in lithologies is in the limestone/dolomite ratio; the value is nearly 1.0 for Boston till, 0.24 for Darby I, 0.35 for Caesar, and 0.35 for Rainsboro. Locally, however, the Rainsboro ratio is influenced strongly by the relative increase in limestone and decrease of dolomite in the Upper Ordovician and Lower Silurian strata; in western Highland County the average limestone/dolomite ratio for five pebble counts was 0.80. Figure 10 is a three-component diagram which gives the distribution of the significant rock groups for each unit. Distinction and correlation of till by pebble content has the added advantage of being applicable in the field.

Calcite-dolomite analyses

The composition and quantity of calcite and dolomite present in tills is determined by the composition and quantity of bedrock and derived soil incorporated by the ice during glaciation. Using the Chittick gasometric method (Dreimanis, 1962), 72 calcite-dolomite analyses were made on the <2-mm size fraction of 36 till samples from Highland County (each sample was run twice, the results averaged). Analyses involved determination of the weight percentages of calcite, dolomite, and total $CaCO_3$ equivalent (% $CaCO_3$ = % dolomite × 1.083 + % calcite). The mean values for each till unit are shown in table 8, along with the confidence levels of mean differences from comparable values for the Boston till. For a discussion of the role which carbonate content plays in relation to depth of leaching, see page 8. The analyses show that there are significant differences in the percentages of limestone and dolomite and in the total $CaCO_3$ equivalent between the Boston till and the other till units. The average percentages of limestone and dolomite in Darby I, Caesar, and Rainsboro tills are very similar; that of the Boston till is quite different.

Calcite-dolomite content can be used for stratigraphic correlation of the Boston till and for distinguishing it from the Darby I, Caesar, and Rainsboro tills in Highland County. The Darby I and Rainsboro tills are most similar. Values for some samples of the Caesar till show large individual deviations from the average values, in some cases approaching values for the Boston till; however, differences between the two tills are great enough to allow a distinction. In contrast to these definitive differences, the ratio of calcite to dolomite is fairly similar among all the till units. Considered in relation to values of calcite/dolomite ratios for the pebble lithologies, this is an anomalous relationship for which there is no readily apparent explanation.

Heavy mineral analyses

The usefulness of heavy minerals in establishing stratigraphic correlations in glacial deposits has been

TABLE 7.—*Pebble lithologies of till units and Illinoian gravel in Highland County*

Till unit[1]	No. of samples	Pebble lithology (%)					
		Igneous + metamorphic	Shale + sandstone	Limestone + chert	Dolomite	Limestone + chert / Dolomite	Total calcareous
Darby I	5						
mean		4.2	7.6	17.6	70.6	0.25	88.2
σ		2.8	3.8	1.3	3.6	.03	3.1
cv		66.6	50.0	7.4	5.1	12.0	3.5
range		0-7	5-14	16-19	66-75	.21-.29	85-91
Caesar	15						
mean		7.5	8.9	21.1	62.5	0.34	83.6
σ		3.3	5.5	5.9	9.5	.15	6.6
cv		44.0	61.8	27.9	15.2	44.1	7.9
range		3-14	3-24	12-31	44-78	.15-.49	68-94
Boston	7						
mean		7.1	17.5	37.3	38.1	0.98	75.4
σ		3.6	6.1	8.6	8.6	.15	6.2
cv		50.7	34.9	23.1	22.6	15.3	8.2
range		2-12	13-26	32-51	30-51	.57-1.70	63-81
Rainsboro	23						
mean		7.0	7.0	22.5	63.5	0.35	86.0
σ		2.5	4.6	9.3	9.6	.24	5.0
cv		35.7	65.7	41.3	15.1	68.6	5.7
range		2-12	2-20	12-46	40-80	.15-1.15	74-93
Illinoian gravel	10						
mean		5.2	4.7	23.2	66.9	0.34	90.1
σ		2.1	2.8	8.2	7.7	.16	3.0

[1]Mean, arithmetic mean; σ, standard deviation; cv, coefficent of variation.

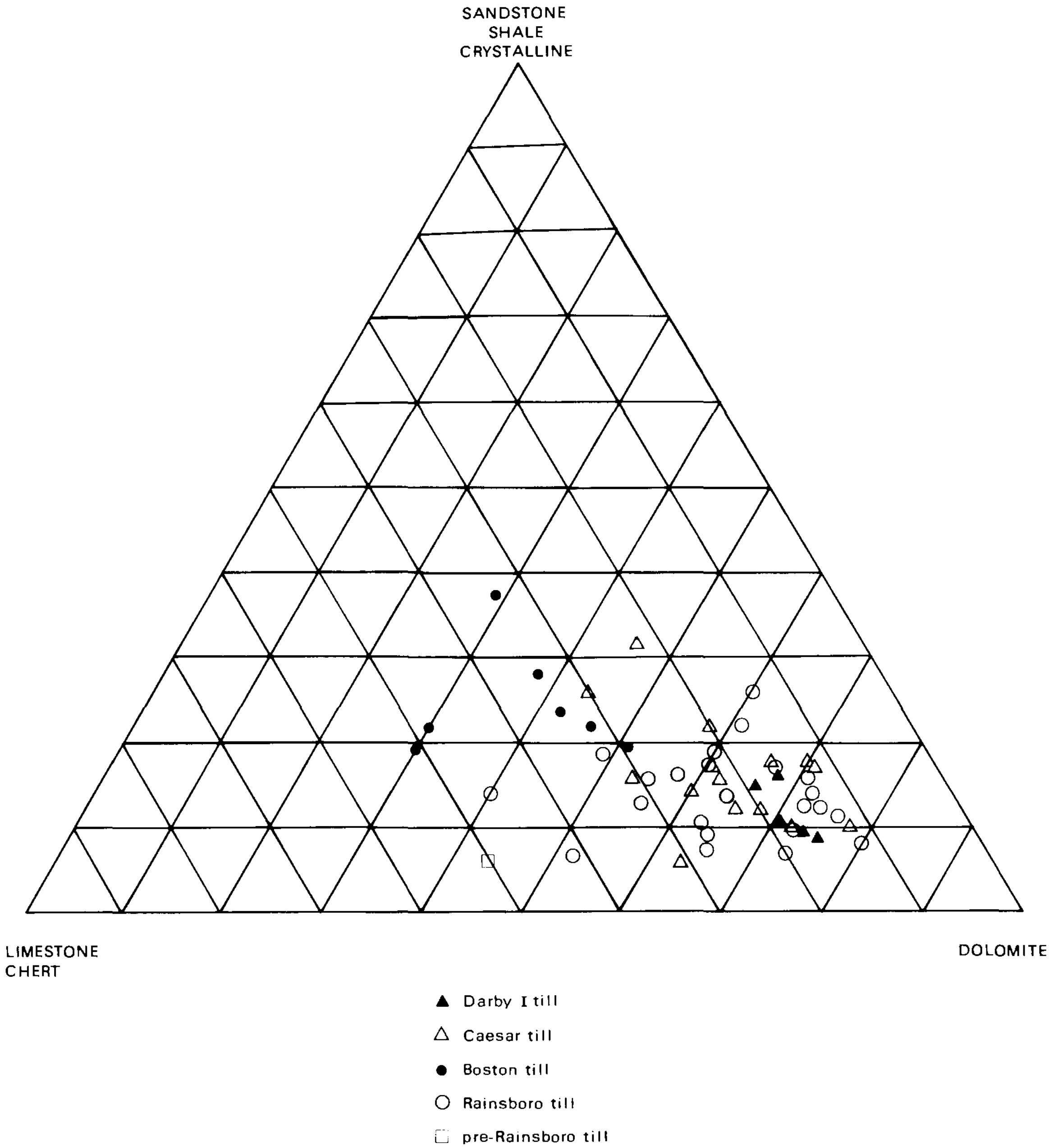

FIGURE 10.—Pebble lithologies of till units in Highland County.

demonstrated in Ontario (Dreimanis and others, 1957) and in Illinois (Willman and others, 1963): certain heavy minerals effectively differentiate tills from different source areas. In Highland County the primary source of heavy minerals in tills is the Precambrian metamorphic and igneous rock of the Canadian Shield.

Heavy mineral analyses were made on the very fine sand fractions (0.062-0.125 mm) of 32 calcareous tills in Highland County. The mean values in table 9 show that for the most part there is similar distribution of mineral suites among the till units. Most differences in comparable means are not significant when standard deviation is considered. Teller (1970, p. 38) came to the same conclusion for the heavy mineral suites in the Illinoian and pre-Illinoian tills of southwestern Ohio, southwestern Indiana, and northern Kentucky. The general similarity shown by the analyses is expected because all the tills in Highland County were deposited by ice of the Erie Lobe. However, there are a few significant differences in the mean values for the total opaque minerals and the total transparent-translucent minerals. In both groups the Boston till has values significantly different (95 percent confidence level) from those of the Caesar till and (99 per-

TABLE 8.—*Calcite and dolomite content in the <2-mm size fraction for till units in Highland County*

Till unit[1]	No. of samples	Calcite and dolomite content (% by weight)			
		Calcite	Dolomite	$CaCO_3$ equivalent	Calcite / Dolomite
Darby I	3				
mean		8.8	22.0	32.6	.40
σ		0.7	2.8	2.4	.08
cv		7.9	12.7	7.4	20.0
cl (%)		99	99	99	
range		8.4-9.6	19-25	30-35	.34-.50
Caesar	12				
mean		8.3	16.8	26.5	.49
σ		2.7	2.0	4.6	.13
cv		32.5	11.9	17.4	26.5
cl (%)		95	99	99	
range		4.8-13	14-20	21-34	.31-.75
Boston	9				
mean		6.0	12.5	19.5	.48
σ		1.7	1.4	2.9	.11
cv		28.3	11.2	14.9	22.9
range		3.0-8.7	10-14	14-23	.29-.66
Rainsboro	12				
mean		10.7	19.0	31.3	.56
σ		2.6	1.6	4.6	.12
cv		24.3	8.4	14.7	21.4
cl (%)		99	99	99	
range		4.1-13	16-21	21-36	.26-.72

[1]Mean, arithmetic mean; σ, standard deviation; cv, coefficent of variation; cl, confidence level of mean differences relative to Boston till value.

cent confidence level) from those of the Rainsboro till and may be distinguished from them on this basis.

Differences in the percentages of specific opaque heavy minerals may allow distinction of separate till units in exposures where there are several tills. For instance, the pyrite-marcasite content in tills is altered significantly by contributions from local Paleozoic shales: a slight difference in source direction may result in definitive differences in pyrite-marcasite content for sections (localities C51 and C58) with more than one till unit. Similarly, differences in black heavy mineral content readily show more than a single till unit at localities A60, B89, and D8.

Fabric analyses

The basic premise in making fabric analyses is that the preferred alignment of the long axes of the pebbles is imparted either during transportation of the pebbles within the ice or at the time of emplacement of the pebbles and corresponds to the direction of movement of the ice. It is found also that the pebbles tend to plunge upstream toward the source of the moving ice (Holmes, 1941). A recent study (Young, 1969, p. 2351) questions whether till fabric can represent the direction of ice motion during active glacial erosion, considering that till is certainly the product of a depositional phase of glaciation. Nevertheless, till fabric is used in this study as an indicator of direction of ice motion because, as mentioned by Goldthwait

TABLE 9.—*Heavy mineral content of the very fine sand fraction (0.062-0.125 mm) for till units in Highland County*

Till unit[1]	No. of samples	Heavy mineral content (%)															
		Opaque		Transparent and translucent													
						Garnet											
		Black	Total	Rutile	Monazite	Pink	Clear	Total	Hornblende	Actinolite and tremolite	Augite and diopside	Hypersthene	Enstatite	Epidote	Sphene	Others	Total
Darby I	3																
mean		19.0	21.3	2.3	1.7	8.0	10.6	18.7	37.3	5.7	5.0	2.7	3.7	1.0	0.0	1.0	79.1
σ		6.9	9.1			2.6	3.1	4.0	6.5								9.1
cv		36.3	42.7			32.5	29.2	21.4	17.4			2.73					11.5
Caesar	10																
mean		27.5	36.5	1.7	0.9	7.6	12.1	19.7	27.2	2.7	2.7	2.9	2.0	1.6	0.6	1.5	63.5
σ		6.6	9.8			2.0	3.7	4.6	6.9								9.8
cv		24.0	26.8			26.3	30.6	23.3	25.4			2.69					15.5
Boston	8																
mean		24.6	27.8	1.1	2.2	6.0	14.5	20.5	30.8	3.4	4.3	1.8	1.3	2.4	1.1	3.7	72.6
σ		4.5	4.6			1.8	2.8	2.7	3.7								4.4
cv		18.3	16.5			30.0	19.3	13.2	12.0			2.86					6.1
Rainsboro	10																
mean		29.4	37.3	1.8	1.2	6.0	13.5	19.5	27.1	3.0	2.4	2.3	1.6	1.5	0.2	2.0	62.6
σ		7.1	6.4			2.2	4.4	5.3	6.0								6.4
cv		24.1	17.1			34.0	32.6	27.2	22.1			3.27					10.2

[1]Mean, arithmetic mean; σ, standard deviation; cv, coefficent of variation.

(1971), ". . . so many strong fabrics elsewhere do nearly parallel known striae and indicator paths, that the relation can hardly be fortuitous."

Thirty-one till fabrics were measured in Highland County and the results plotted in the form of rose diagrams. Till fabrics of the Caesar till indicate that ice movement was from the north-northeast between Samantha and Rattlesnake Creek to the east (fig. 11, nos. 8-12) and from the north-northwest near Leesburg (nos. 1-3). The three fabrics measured in the Darby I till near Greenfield (nos. 4-6) indicate that ice movement in that area was from the north-northeast.

Of the four fabrics measured in the Boston till, three show strong movement of depositing ice from the north-northwest (fig. 12, nos. 1-3). Till fabric (fig. 12, no. 4) measured in the distal edge of the Mt. Olive Moraine is anomalous relative to the others, possibly due to the mode of emplacement of the till or to subsequent slumping.

Fifteen till fabrics were determined in Illinoian Rainsboro till (fig. 13). Nearly all show strong indications of ice movement from the north-northwest.

In sections containing multiple till sheets, till fabrics can be used as a supplementary criterion to distinguish between units. This is clearly seen at locality D36, where three tills are present. Values for the upper till (fig. 10, no. 12) indicate a predominantly eastern source, as do those for the lower till (fig. 12, no. 4); values for the middle till (fig. 11, no. 2) show a north-northwest direction of ice advance.

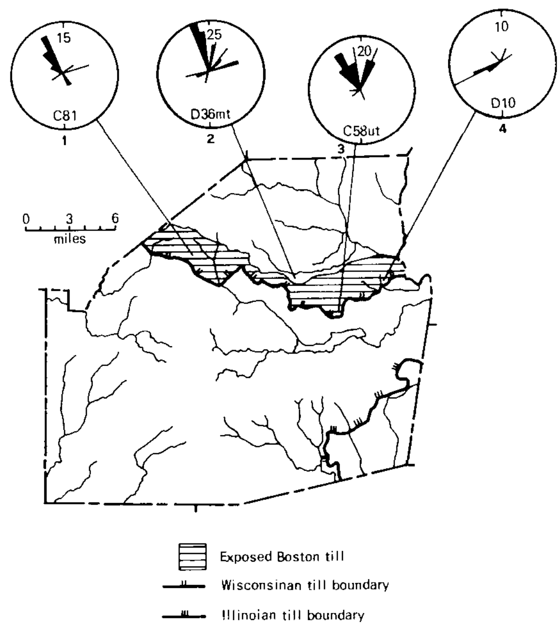

FIGURE 12.—Till fabrics of the Boston till in Highland County. Number of pebbles used shown at top of diagram and site number at bottom; *ut*, upper till; *mt*, middle till.

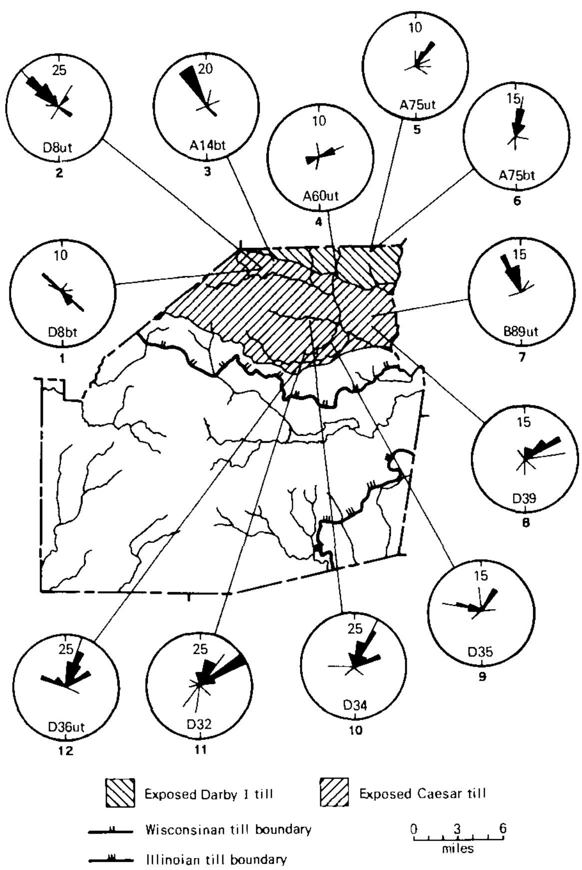

FIGURE 11.—Till fabrics of the Darby I and Caesar tills in Highland County. Number of pebbles used shown at top of diagram and site number at bottom; *ut*, upper till; *bt*, bottom till.

Radiocarbon dating

Six radiocarbon age determinations (table 10) have been made on wood found in Highland County during this study. Two of the samples were from till of Illinoian age and the others from Wisconsinan tills.

A cut bank along Blinco Branch (locality C58) yielded two separate pieces of wood from till which is identified by stratigraphy, clay mineralogy, pebble lithology, texture, and carbonate content as Rainsboro till of Illinoian age. The wood was dated in hopes of obtaining a finite date of >60,000 years B.P. However, the date on the log, which was taken out of the uppermost foot of the till unit, was 25,300±600 years B.P. (I-4797, Coleman, 1972). This part of the till was soft and saturated with ground water, and the log was probably contaminated either *in situ* or during handling. The second piece of wood was obtained a year later from the compact portion of the Rainsboro till; this sample, however, is believed to have been contaminated in the laboratory, and a minumum age of >37,770 years B.P. (ISGS-59, Coleman, 1972) has been assigned.

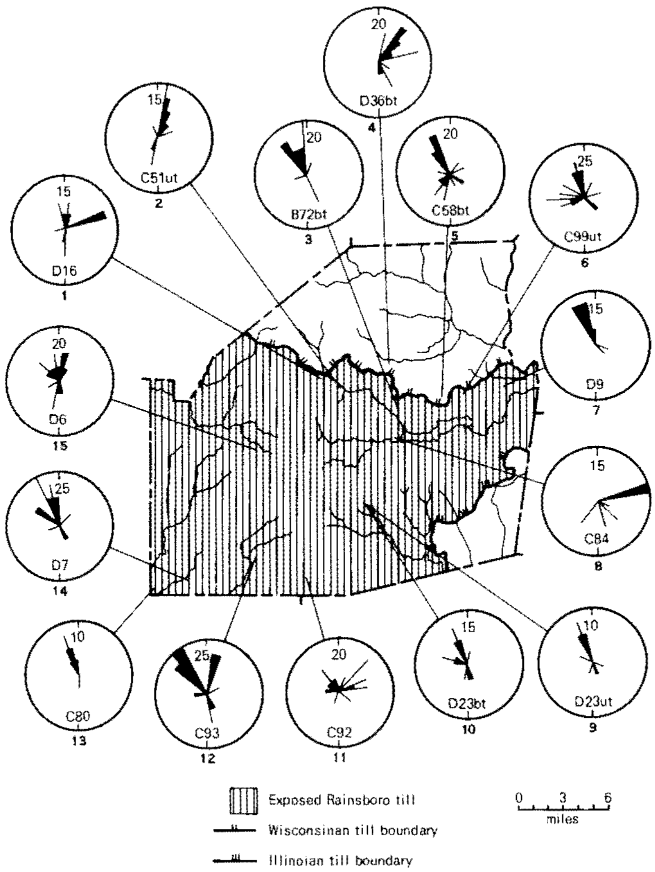

FIGURE 13.—Till fabrics of the Rainsboro till in Highland County. Number of pebbles used shown at top of diagram and site number at bottom; *ut*, upper till; *bt*, bottom till.

Previous radiocarbon dating indicated that the Late Wisconsinan ice front advanced into Ohio 24,600±800 years B.P. (W-71) and reached its maximum southern position 20,500±800 years B.P. (W-304) in the Miami Lobe and 18,500±420 years B.P. (Y-448) in the Scioto Lobe (Goldthwait, 1958). On the basis of an average of several age determinations, it has been believed that the Miami Lobe reached its maximum position about 1,400 years before the Scioto Lobe (Goldthwait, 1958). Two of the new radiocarbon dates give evidence that the 1,400-year spread is not valid. A log found 2 miles south of Samantha (locality C47) near the base of the Boston till in the Mt. Olive Moraine yielded a date of 21,080±200 years B.P. (ISGS-42), identifying the till as Late Wisconsinan. The till overlies a paleosol (Sangamon?) developed in gravel. Another exposure, a cut bank along Fall Creek (locality D36), reveals three tills, the lowest two separated from each other by a paleosol consisting of 6 feet of leached sandy silt. The till overlying the paleosol is identified by clay mineral data, texture, pebble lithologies, and carbonate content as Boston till; a small branch found at its base was dated at 20,910±240 years B.P. (ISGS-44). This till is overlain by a 1-foot-thick layer of rubble and gravel, which in turn is overlain by 12 feet of Caesar till.

These dates from the Boston till are important in two ways: (1) they definitely identify the drift as Late Wisconsinan in age and not Early Wisconsinan, as has been postulated, and (2) they support two previous radiocarbon dates (21,140±1,435 years B.P., OWU-159; 22,255±1,650 years B.P., OWU-160; Ogden and Hay, 1967) on buried wood from pre-Cuba Moraine till in the Todd Fork valley west of Sligo in Clinton County. An average of the four dates (OWU-159, OWU-160, ISGS-42, and ISGS-44) indicates that the Scioto Lobe reached its maximum southern position about 21,350 years B.P., about 850 years before the Miami Lobe maximum. The two age determinations from Todd Fork valley probably date the stand at the Vandervort Moraine (Teller, 1967), which trends southeast in eastern Warren and western Clinton Counties. In Warren County, the Vandervort is overlapped at right angles by the Hartwell Moraine of the Miami Lobe (fig. 14) and eastward is overlapped diagonally by the Cuba Moraine; the Cuba in turn overlaps the Mt. Olive Moraine at right angles farther east

TABLE 10.—*Radiocarbon age determinations on wood from Highland County*

Till unit	Locality	Dated by	Material	Age (years B.P.)	Lab. no.
Caesar	D35	U.S. Geol. Survey, Washington, D.C.	*Picea* sp. (log)	20,460 ± 700	W-2459
Caesar	D39	U.S. Geol. Survey, Washington, D.C.	*Picea* sp. (log)	20,820 ± 600	W-2465
Boston	C47	Ill. State Geol. Survey	*Picea* sp. (log)	21,080 ± 200	ISGS-42
Boston	D36	Ill. State Geol. Survey	*Larix* sp. (branch)	20,910 ± 200	ISGS-44
Rainsboro	C58	Ill. State Geol. Survey	*Picea* sp. (branch)	>37,770	ISGS-59
Rainsboro	C58	Isotopes	*Picea* sp. (log)	25,300 ± 600	I-4797

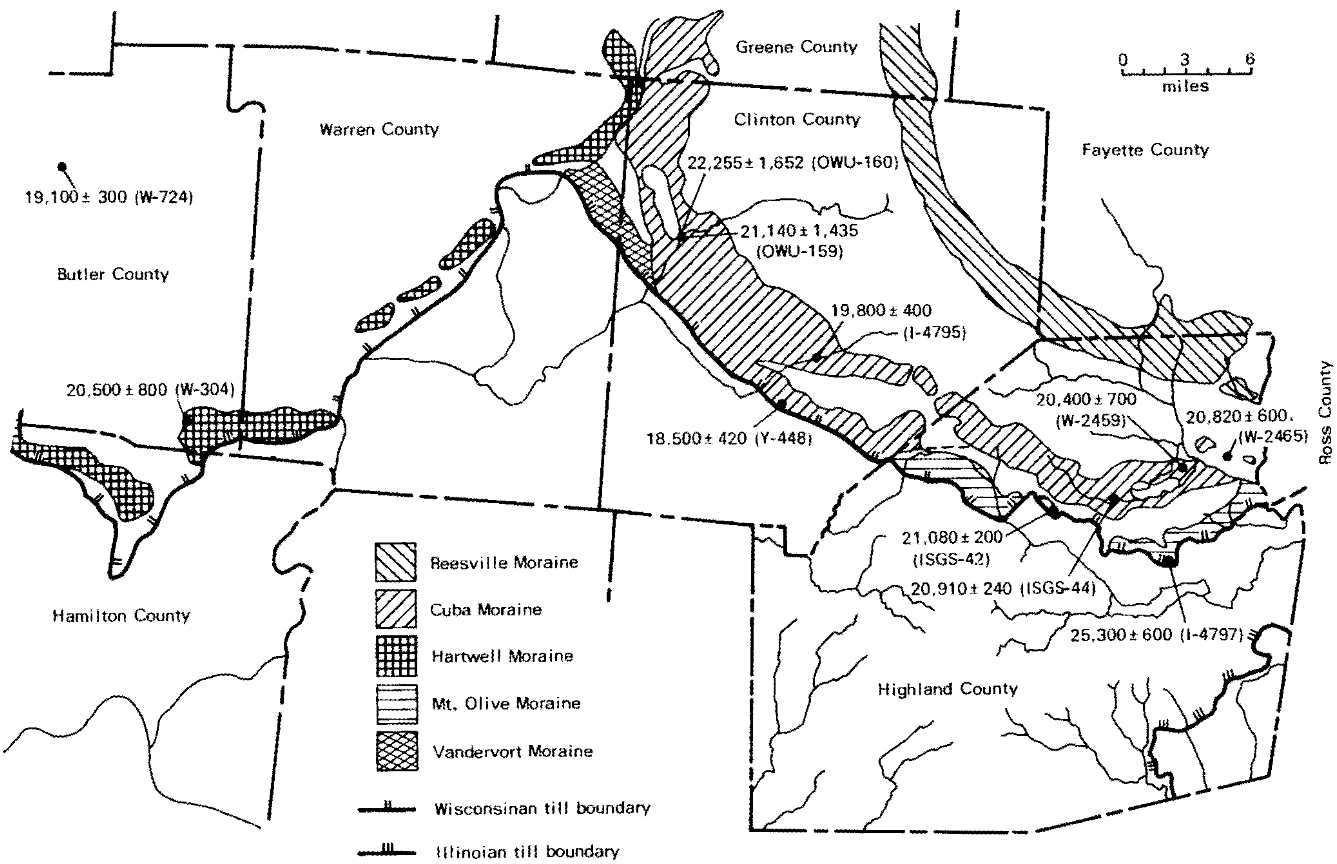

FIGURE 14.—Locations of moraines and sites of radiocarbon dates in Highland, Clinton, Warren, and parts of Hamilton, Butler, Greene, and Fayette Counties.

at the Highland-Clinton County line. The drifts of the Vandervort and Mt. Olive Moraines may well be the same stratigraphic unit.

A date of 20,400±700 years B.P. (W-2459) on a log found in the Caesar till of the Cuba Moraine (locality D35) identifies the moraine as Late Wisconsinan. Another log from the Caesar till was found in a cut bank along Cedar Run (locality D39) and gave a date of 20,820±600 years B.P. (W-2465). In Clinton County, a relatively recent radiocarbon determination (Teller, 1964, p. 70, location 4X) dates a log from Caesar till at 19,800±400 years B.P. (I-4795). This till underlies a sand-gravel-till-sand (top to bottom) section that is about 23 feet thick and is located in the area of the inner Cuba Moraine; however, the till appears to be related to the drift deposited during advance of the glacier to the position of the outer Cuba Moraine. Several previously determined radiocarbon dates (Y-448, W-91, W-331, OWU-52) on logs from the Cuba Moraine in Clinton and Ross Counties, west and east, respectively, of Highland County, give a younger age: an average of 18,108 years B.P.

Two hypotheses may explain these apparently anomalous dates; I believe the first one seems the most plausible. In the first hypothesis, dates I-4795, I-2459, and I-2465 may have been determined on wood incorporated by the glacier during its southward advance and therefore may represent the time the trees were uprooted rather than the times they were deposited with the drift of the Cuba Moraine. The youngest material in the moraine probably more accurately represents the time of the Cuba stand; in this case about 18,100 years ago. In the second hypothesis, the group of more recently determined dates may represent the glacier's stand at the position of the Cuba Moraine in Highland and Clinton Counties only. This average date (I-4795, W-2459, W-2465) is about 20,340 years ago. Dates of this magnitude have not been obtained from the Cuba Moraine in adjoining counties, suggesting that the outermost push of the Scioto Lobe in these counties would have come at a later time, about 18,100 years B.P.

GLACIAL FEATURES

In Highland County there is no well-developed marginal ridge at the border of the Illinoian drift. At its maximum advance, the Illinoian glacier either did not make a stand long enough to build a moraine, or erosion has since obscured any moraine that was formed. Instead there is a zone of transition from a driftless area to one in which the drift is a well-defined deposit. This occurs in a distance of less than half a mile and in many places in a space of a few hundred yards. The border of the Illinoian till conforms more or less to features of major relief, abutting hills and extending short distances down valleys (pl. 1).

Illinoian ground moraine

An area of about 150 square miles of Illinoian till plain makes up the western one-fourth of Highland County. This surface is generally very flat and is somewhat poorly to poorly drained (surface slope ranging from less than 5 to about 15 feet per mile). In this area west of the Niagaran Escarpment the average thickness of drift is 53 feet (based on data from 60 well logs), with a range from 6 to 147 feet. Controlling the topography is the nearly flat southwestward-sloping bedrock surface below the drift cover (pl. 1).

From the Niagaran Escarpment eastward, the preglacial bedrock surface predominantly determines topography; only in the east-central part of the county, in the vicinity of Carmel, Marshall, and Rainsboro, is ground moraine constructional, with a hummocky undulating surface. Just south of Hillsboro kames and related ice-contact drift are chiefly responsible for the topography (pl. 1).

In the hilly region around Hillsboro and to the south and southeast, thickness of till is variable. In the northern portion of this hilly region, 15 to 20 feet of Illinoian till mantles all the upland. Till accumulation is much thicker in valleys, with depths of 40 feet common. However, on the valley slopes till is generally absent and bedrock is the predominant surface material. Southward the till gradually becomes thinner on the upland (flat-topped ridges for the most part), and bedrock exposures become more common. Finally, in the region of Fairfax and Belfast and southward, ridges and slopes are almost devoid of till.

Apparently Illinoian ground moraine was deposited over much of Highland County with very little erosion of the preglacial surface. This is typical in the terminal area of a far-travelled glacier. At several sites, including rock quarries, residual soils and/or oxidized weathered rock extend 10 to 20 feet beneath the base of unoxidized till.

Late Wisconsinan moraines

Late Wisconsinan or Woodfordian drift covers the northern third of Highland County. The drift was deposited in a system of four end moraines and associated ground moraine. Three of the moraines are more or less continuous across the county.

Mt. Olive Moraine.—Drift deposited during the first advance of the Late Wisconsinan glacier forms a belt 1 to 4 miles wide across Highland County. An end moraine forms the southern 1- to 2-mile portion of this drift. The name Mt. Olive has been proposed for this moraine from the church on the moraine crest 3 miles south of New Vienna (Rosengreen, 1970, p. 88). The Mt. Olive Moraine is readily traced across most of the county (pl. 1). At its western boundary, just south of New Vienna, the moraine emerges as a low ridge from beneath the Cuba Moraine (next northward), which overlaps the former at about right angles. A well-developed loop moraine is found along the sides of Hussey Run valley for about half a mile, curving in toward the center of the small valley where Hussey Run has cut a gap through the moraine. Similar but less distinctive loops are located a mile west in Clear Creek valley and 2 miles east in Little Rock Creek valley.

From Hussey Run valley eastward to Boston the boundary between the moraine and Illinoian drift to the south is inconspicuous as a result of strong bedrock control of topography and accompanying thinning of the Wisconsinan drift. For the most part the Wisconsinan drift extends southward to just beyond the bedrock crest which forms the northern drainage divide of Clear Creek. Between Boston and Rainsboro the Wisconsinan glacier was strongly influenced by topography. A tongue of ice extended southward down Blinco Branch, coming within a mile of the site of Rocky Fork Lake and depositing moraine in a broad loop. From here the Mt. Olive Moraine can be traced eastward, crossing the road three-quarters of a mile north of Rainsboro. The moraine trends northeastward toward Paint Creek and continues into Ross County just south of the mouth of Rattlesnake Creek.

Cuba Moraine.—Leverett (1902, p. 341) named the Cuba Moraine after a town that stands on the moraine crest in south-central Clinton County. He (1902, p. 341-342) incorrectly traced this moraine across Highland County to just south of Hillsboro and then east to Beech Flats in Pike County. Also, he ascribed it to Early Wisconsinan based on its topography, on its general freedom from silt in relation to the Illinoian till plain to the south, and on the fact that it is situated beyond the terminus of the Late Wisconsinan deposits as mapped by Chamberlin (1883, p. 339-341). However, radiocarbon dating has since placed the Cuba Moraine as Late Wisconsinan in age.

Rogers (1936, p. 44) correctly cast doubt on the age of this Early Wisconsinan drift border. He believed it to be "probably" Illinoian. Rogers believed, incorrectly however, that Early Wisconsinan drift was present at the surface in the county. He assigned this age to a belt of drift chiefly on the basis of depth of leaching and loess cover. He believed that the Mt. Olive Moraine, which he called the Cuba, formed the southern boundary and that Rattlesnake Creek and Lees Creek formed the northern boundary for this Early Wisconsinan drift.

In this study the Cuba has been traced from Clinton County eastward into Highland County; it forms the end moraine north of the Mt. Olive Moraine.

Most of the Cuba Moraine in Clinton County consists of two elements, an outer and inner, separated by narrow stretches of ground moraine. In Highland County the inner Cuba generally abuts the outer Cuba Moraine; patches of ground moraine occur between them in only a few places. Field relationships suggest that the inner Cuba Moraine represents a stand of the Late Wisconsinan ice after a short retreat from the outer Cuba position. No stratigraphic evidence was found to suggest that the inner Cuba represents a stand after a significant readvance of the glacier.

The outer Cuba Moraine enters Highland County from Clinton County just south of New Vienna, where it overlaps the Mt. Olive Moraine. The inner Cuba Moraine enters the county north of New Vienna and fades out northeast of Samantha, but is prominent 2 miles east of Samantha on the north side of State Route 138. Northwest of New Petersburg, Fall Creek flows along the distal edge of the outer Cuba Moraine, and Big Branch separates it from the inner Cuba Moraine. The Cuba Moraine of this area is very hummocky, with numerous knolls and short ridges, and does not possess the long continuous crests and gently undulating surface characteristic of the moraine to the west. East of Rattlesnake Creek the Cuba Moraine is hard to recognize because of the influence of bedrock on its topography. The moraine patches trend eastward into Ross County; here the course of the Cuba Moraine is not obvious because of numerous bedrock hills. It is at this position, near the Ross County line, that the Late Wisconsinan drift seems to overlap the northwest-trending Mt. Olive Moraine.

Wilmington Moraine.—The Wilmington Moraine was named by Teller (1964, p. 25) for a subdued ridge which in Clinton County lies parallel to the Cuba Moraine and 2 miles north of it. Rogers (1936, p. 47) noted the moraine, but did not give it a name. In Highland County, this moraine rises less than 20 feet above the till plain to the south and about 30 feet above that to the north. It enters the county 3 miles west of the village of Highland. Here the South Fork of Lees Creek flows eastward along its distal edge for about a mile, then turns northward through the moraine and flows north of it for a mile. The moraine becomes indistinguishable from ground moraine just south of Highland. Eastward, scattered hummocks just north of and paralleling Bridgewater Creek suggest the position of the Late Wisconsinan ice edge at the time of Wilmington Moraine deposition. The faintness and lack of stratigraphy of the Wilmington elements suggest that this was not the important readvance postulated by Teller (1964, p. 67).

Reesville Moraine.—The Reesville Moraine was named by Leverett for the village that stands on the moraine crest in Clinton County. The moraine is double crested throughout much of its course in that county, but in Highland County the crests are discontinuous, and hummocky topography is characteristic. The moraine forms a slightly arcuate belt across the northern portion of Highland County, nowhere extending far enough south to be completely inside the county. The distal edge of the Reesville Moraine is scarcely noticeable; the rise onto the moraine is generally not abrupt. The most noticeable height is due north of Leesburg; eastward from East Monroe the rise is less pronounced. The moraine rises 30 to 80 feet above the ground moraine to the south.

Stratified ice-contact deposits

Kames are small mounds and larger hills consisting of poorly sorted to well-sorted sand and gravel deposited from running water in close association with glacial ice or stagnant ice. Such features are common in Highland County and are most plentiful in the drift of Illinoian age; only a few kames are located in the Wisconsinan deposits.

The largest area of kame accumulation and related ice-contact stratified drift is found from 2 to 4 miles south of Hillsboro from the junction of Rocky Fork and South Fork westward for 6 miles to Shackleton. Within this area there are at least 24 large kames or kame groups and numerous gravel mounds and low knolls. Probably one of the more picturesque groups of kames is just northwest of U.S. 62 and a mile southwest of Hillsboro. Another very striking group, located just north of State Route 138, between Shackleton and Rocky Fork, consists of several connected hills forming kame and kettle morainic topography in which the highest kames have an elevation exceeding 1,200 feet.

Several scattered kames are found along the northward-facing slope south of Rocky Fork Lake. The small village of Marshall is situated atop a broad kame. Another kame, 3 miles west of Marshall, trends east-west for nearly a mile. Numerous kames are found among the Mississippian outliers near the eastern border of the county; two large kames are located just west and north of Spargur Hill near Carmel and several small kames are situated north of Irons Mountain. A large kame complex extends from The Point at the mouth of Rocky Fork northwestward for about 3 miles.

The majority of Illinoian kames in Highland County exhibit the fresh topography that is generally associated with kames of Wisconsinan age. This is the main reason Leverett (1902) believed the kames belonged to deposits of Early Wisconsinan age. However, the deposits are several miles from the Wisconsinan boundary in most places (pl. 1) and are surrounded by drift assigned an Illinoian age on the basis of its weathered profile.

Several of the large kames south and west of Hillsboro show significant erosion; they have radial drainage patterns with long spurs extending outward up to half a mile from the summits; ravines are cut as much as 30 feet deep between the spurs. Calcareous gravel is within 2 feet of the surface on the slopes of the kames.

Soils which have been developing since Illinoian time are dark brown to reddish brown, with hues of 7.5*YR* when formed in topographic positions with good soil aeration and internal drainage. These brighter hues are characteristic of soils developed in kames in the Illinoian area of Highland County; those in the Wisconsinan area have hues of 10*YR*. The color of soil has been related to time in that soils become redder with time.

There are only a few kames of Wisconsinan age in Highland County. A group of kames forms the eastern edge of the Mt. Olive Moraine near the mouth of Rattlesnake Creek. The gravel hills are striking when viewed from the ground moraine near New Petersburg. Numerous erratic boulders up to 2 feet in diameter are scattered around the bottom and between the knolls of this kame group, suggesting ice-contact origin. Depth of leaching ranges from 2 to 5 feet. A moulin kame is located just south of the Cuba Moraine a mile west of New Petersburg. Blocks of conglomerate, formed by cementation of the kame gravel, are scattered along its base.

A large gravel and sand deposit exposed along the west wall of Rattlesnake Creek 2 miles north of New Petersburg is being actively exploited. This deposit appears to be an extensive kame terrace and not a remnant of a valley train: no matching terrace deposits at similar heights could be found across the valley or downstream.

Two eskers are found within the area of Illinoian drift. They are sinuous ridges composed of moderately well-sorted sand and gravel deposited so high that ice must have flanked running water. The largest esker is just east of Rocky Fork Lake and has a length of over 2 miles. The other esker, which has been extensively exploited, is just west of State Route 73 2½ miles southeast of Hillsboro.

Outwash deposits

Illinoian outwash.—Streams fed by glacial meltwater laid down outwash deposits adjacent to and beyond the margins of the glaciers which invaded Highland County. Illinoian outwash deposits are by far the most widespread.

Extensive outwash terraces are present along the upper parts of the valleys of Rocky Fork and its main tributary, Clear Creek. The terrace tops are from 40 to 60 feet above present stream level and are highest at the valley edge. In many places the terrace tops merge with the valley edge and there is no abrupt change in slope. These extensive terraces are remnants of Illinoian valley train deposits which filled the valley from a mile northwest of Carmel to a position just west of Hillsboro. Subsequent fluvial erosion has removed the outwash deposits along the valley axes, leaving terraces along the sides. The material of the valley train in the upper reaches of both valleys is gravel; downstream the deposits become finer textured. Along Rocky Fork Lake, sand and pea gravel are the dominant components. Depth of leaching ranges from about 7 feet in gravel to 18 feet in sand and silt.

Outwash was deposited in several smaller stream valleys in the county, but in smaller and less significant amounts. In southwestern Highland County poorly preserved terraces are found along the lower reaches of the valley of North Fork White Oak Creek, in the area of Buford and south. Better preserved and more extensive terraces are located along the East Fork White Oak Creek in the area of Mowrystown. Deposits are thin in both valleys, generally less than 20 feet thick, and sand is the chief material of the terraces. Depth of leaching is over 10 feet on the few remaining flat areas. In the valleys of Brush Creek and its tributaries in southeastern Highland County, Illinoian outwash terraces are 20 to 40 feet above present stream level. For the most part the terraces are narrow and poorly preserved, with few flat tops.

A large plain of thin outwash was deposited in the area from west of Rainsboro to Paint Creek during retreat of the Illinoian glacier. The outwash has a more or less smooth southeastward slope, and is overlapped on the north by the Mt. Olive Moraine. Sand and pea gravel cover most of the outwash plain surface.

During retreat of Illinoian ice from its terminal position in Baker Fork, meltwater flowed southward through the cols between Irons Mountain, McCoppin Hill, and Long Lick Hill, depositing an outwash fan up to 2 miles long. From the apex of the fan to its distal edge the surface drops 80 feet; a gradient of 40 feet per mile. Outwash was deposited in a similar manner in the valley tributary to Baker Fork between Long Lick Hill and Washburn Hill, but erosion has deeply dissected the deposit, exposing underlying till in most of the area.

Wisconsinan outwash.—Numerous terraces are found along the valleys of major streams whose headwaters drain the area covered by Late Wisconsinan drift. There are several Late Wisconsinan terrace systems within the major stream valleys of Rattlesnake and Paint Creeks. The terraces are at various heights above the present stream levels and consist mainly of gravel and sand. For the most part, outwash of individual terrace systems was deposited while the ice front was at a moraine stand (pl. 1). Depth of leaching ranges from 28 to 75 inches. Commonly a silty surface layer 10 to 36 inches thick covers the lower and more level terraces.

Lacustrine sediments

Laminated silty clay and silt were deposited as shown in two deep exposures, localities B76 and C84, in Rocky Fork valley. At the west end of Rocky Fork Lake (locality C84) is a sequence of strata indicating progradation of a delta into a glacial lake: laminated sediments at the bottom, crossbedded sands in the middle, and channel gravel within sands in the uppermost layers. At both exposures the laminated sediments extend to an altitude of 920 feet. During the early stages of deglaciation of Rocky Fork valley, a proglacial lake existed upvalley from the site of Beaver Mill and was larger than the present manmade Rocky Fork Lake. The surface of the lake was as high, at 920 feet above sea level, as the bedrock surface at Beaver Mill. The proglacial lake was apparently filled while valley trains were being built in the valleys of Rocky Fork and Clear Creek.

Nearly all the material at the surface at Beech Flats just east of the county line consists of silt. Well-log data reveal that the silt is generally 20 to 40 feet thick and overlies sand, gravel, and till. Several road cuts east and southeast of Cynthiana expose bedded silt, some coarsely laminated. In Highland County these silts are found between McNary Hill and Jones Hill, 3 miles north of Cynthiana. For the most part they form a smooth surface at an altitude of about 960 feet. Locally, subdued kames rise above the surface level of the flats. The silts were deposited in a proglacial lake which formed in the area as a result of Illinoian ice blocking northward drainage to Paint Creek.

Boulder concentrations

The surface distribution of boulders greater than 10 inches in diameter is shown in figure 15. Although a study of the lithologies of the boulders was not made, it is estimated that over 75 percent are foreign crystalline erratics from Canada. The remainder consists of local bedrock, largely dolomite and limestone. Greater concentration of boulders on end moraines relative to surrounding ground moraine suggests that the boulders accumulated as ice marginal load, largely superglacial (Goldthwait, 1969).

The boulder distribution shows a definite increase in density on the Reesville, Cuba (both inner and outer), and Mt. Olive Moraines. Boulder density is somewhat greater along the eastern portion of each of these moraines. This eastward concentration coincides with roughness of the surface and may in part reflect local removal of surficial fines which had partially covered some of the boulders. However, the increase may reflect an actual greater number of boulders deposited in this part of the county. Concentrations of boulders on the thick loess covering the Illinoian till plain are similar to concentrations found on the relatively thinner loess covering the Wisconsinan ground moraine. Apparently the boulders were not buried by subsequent loess deposition. Frost heaving and related movements (Bryan, 1946) probably kept the boulders on the surface.

GLACIAL HISTORY

Pre-Illinoian time

Pre-Illinoian drift is recognized at the surface in Ohio only in the southwestern corner of the state near Cincinnati (Durrell, 1961; Teller, 1970). In Highland County possible pre-Illinoian drift is found at the base of an exposure about 3 miles north of Hillsboro (locality C51). The drift in question consists of a till unit overlying a paleosol 4 feet thick that is developed in sand and gravel containing foreign crystalline pebbles. Analyses of the till show that it is unlike the Illinoian Rainsboro drift which overlies it. The lower till, underlain by stratified material, may be either Early Illinoian or Kansan drift.

Illinoian Stage

During the Illinoian Stage ice advanced into Highland County from the north-northwest. At its maximum advance the ice margin formed an arcuate boundary, covering all but the southeastern corner of the county and trending northward from a mile west of Louden (Adams County) to North Uniontown, then northeastward to the valley of Baker Fork and into Pike County (pl. 1). The positions of the ice front during later phases of the Illinoian Stage are not known conclusively. This is because of a general absence of morainic features, a result of erosion and possibly in part of nondeposition. Retreatal positions of ice fronts described below are based on erosional and constructional features and on the assumption that such positions are grossly similar to that of the maximum advance.

During maximum advance of the Illinoian glacier a major drainage change took place in the area of Beech Flats, a large lowland area now largely drained by Baker Fork. This drainage change was noted by Fowke (1895) and described by Tight (1895) in some detail. Prior to the ice advance, drainage from Beech Flats was northeastward into preglacial Paint Creek. During the maximum advance, ice invading Beech Flats from the north blocked its drainage and a proglacial lake was formed (fig. 16A). An outlet for the lake was established over a low col, at an altitude of about 960 feet, between Fort Hill and Reeds Hill at the headwaters of the preglacial valley. Drainage from the lake followed the present course of Baker Fork southward to Ohio Brush Creek and ice-contact drift was deposited in the area just east of Cynthiana in Beech Flats. This maximum stand was probably of short duration: morainic deposits are limited in size and extent.

Following the maximum advance, the ice front retreated a short distance and made a stand of substantial duration. The ice front extended approximately east-west across the northern edge of the Beech Flats area, still blocking the preglacial drainage route. West of Cynthiana the ice front blocked the small valleys of Heads Branch and Factory Branch (fig. 16B). Abundant outwash and ice-contact drift were deposited at this time. Meltwater deposited extensive amounts of sediment in the proglacial lake which occupied the area, filling it to an altitude of about 960 feet and forming a large flat plain. In places the preglacial valley floor was aggraded as much as 240 feet. Local kame deposition resulted in morainic topography with heights up to 40 feet above the plain. Drift deposits in the Beech Flats area were so extensive that the reversal of drainage became permanent. At this time the valley of Ohio Brush Creek was the major drainage outlet for meltwater issuing from the ice front in southeastern Highland County.

Following this stand, the Illinoian glacier retreated a short distance and made another stand (fig. 17A). The ice margin extended from The Point in Paint

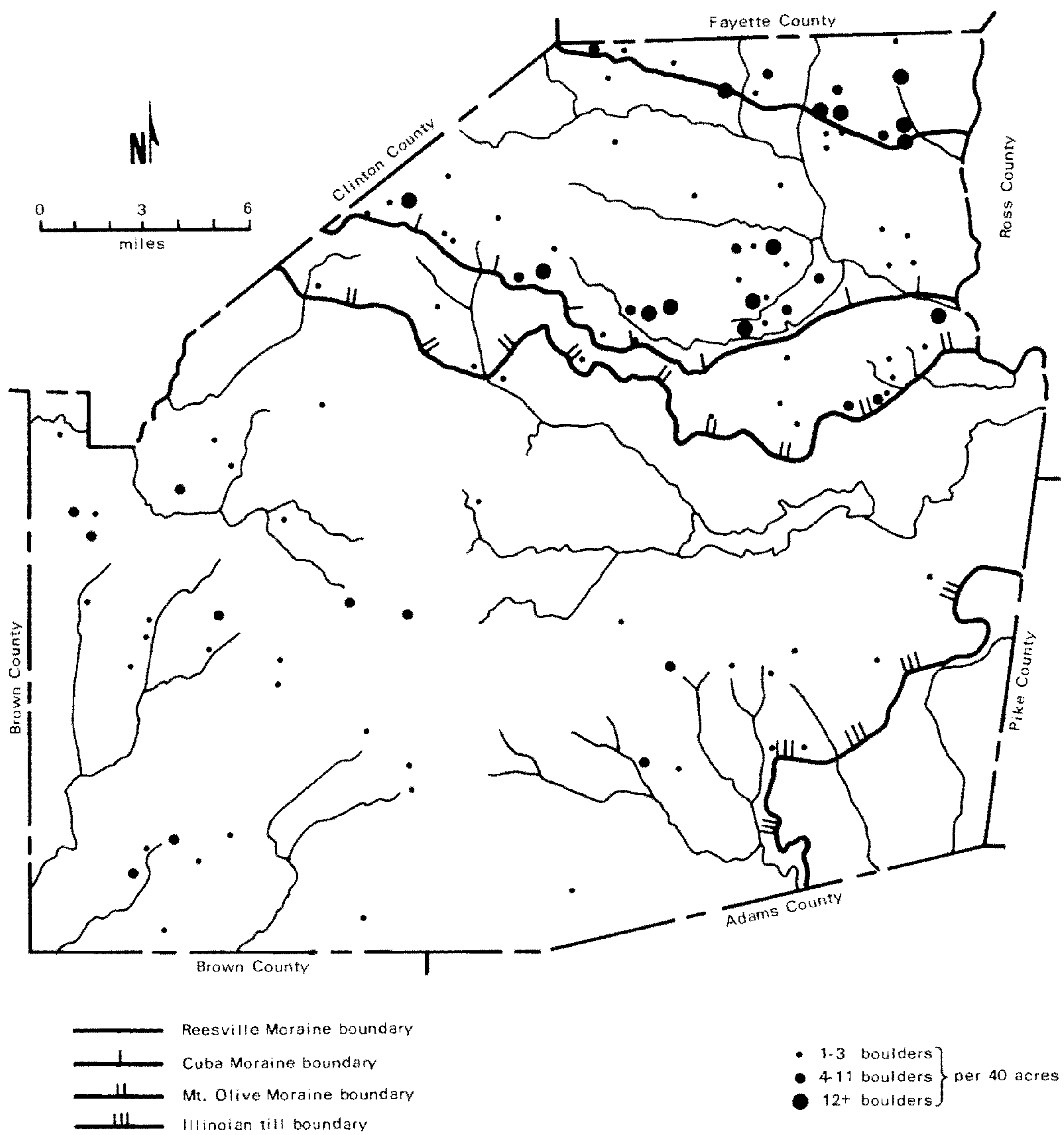

FIGURE 15.—Distribution and density of boulders in Highland County.

Creek valley westward along the Mississippian outliers to Carmel and then to Marshall. Abundant ice-contact drift was deposited along this margin, largely as kames. The north-south trending esker just north of Carmel was probably deposited at this time. Southwestward from Marshall the ice margin cannot be determined with confidence: only isolated morainic deposits are present and topography is largely bedrock controlled. Probably the margin extended across the headwaters of Elm Run and then southward toward Fairfax. Outwash which forms the terraces along Elm Run and much of Ohio Brush Creek was deposited during this stand. The kame 2 miles south of Berrysville was probably deposited as an ice-marginal feature at this time. The ice front had retreated sufficiently during this stage to open another drainage outlet, this one to the east along the distal edge of the Mississippian outliers to Paint Creek.

As the Illinoian ice withdrew from this stand, a proglacial lake formed in the depression of Rocky Fork valley. The lake stood at an altitude of about 920 feet. The preglacial valley of Rocky Fork in large part had been filled by drift, and the large esker which crossed the valley north of Carmel formed the eastern boundary of the lake. The outlet for the lake was across Silurian bedrock at the south end of the esker at Beaver Mill. The ice front retreated to a position north of Rainsboro (fig. 17B) and made a stand there. Meltwater deposited extensive amounts of sediments east of the lake, forming an outwash plain. Outwash deposits rapidly filled the proglacial lake and began building a valley train.

Several isolated patches of morainic drift along the northward-sloping surface south of Rocky Fork show that during this retreatal phase the ice front trended from northeast to southwest east of this area and from east to west in the rest of the county. Extensive ice-contact sediments were deposited at this time in the preglacial lowland area of Rocky Fork valley just south of Hillsboro. Large portions of ice were probably detached from the glacier during downwasting over the

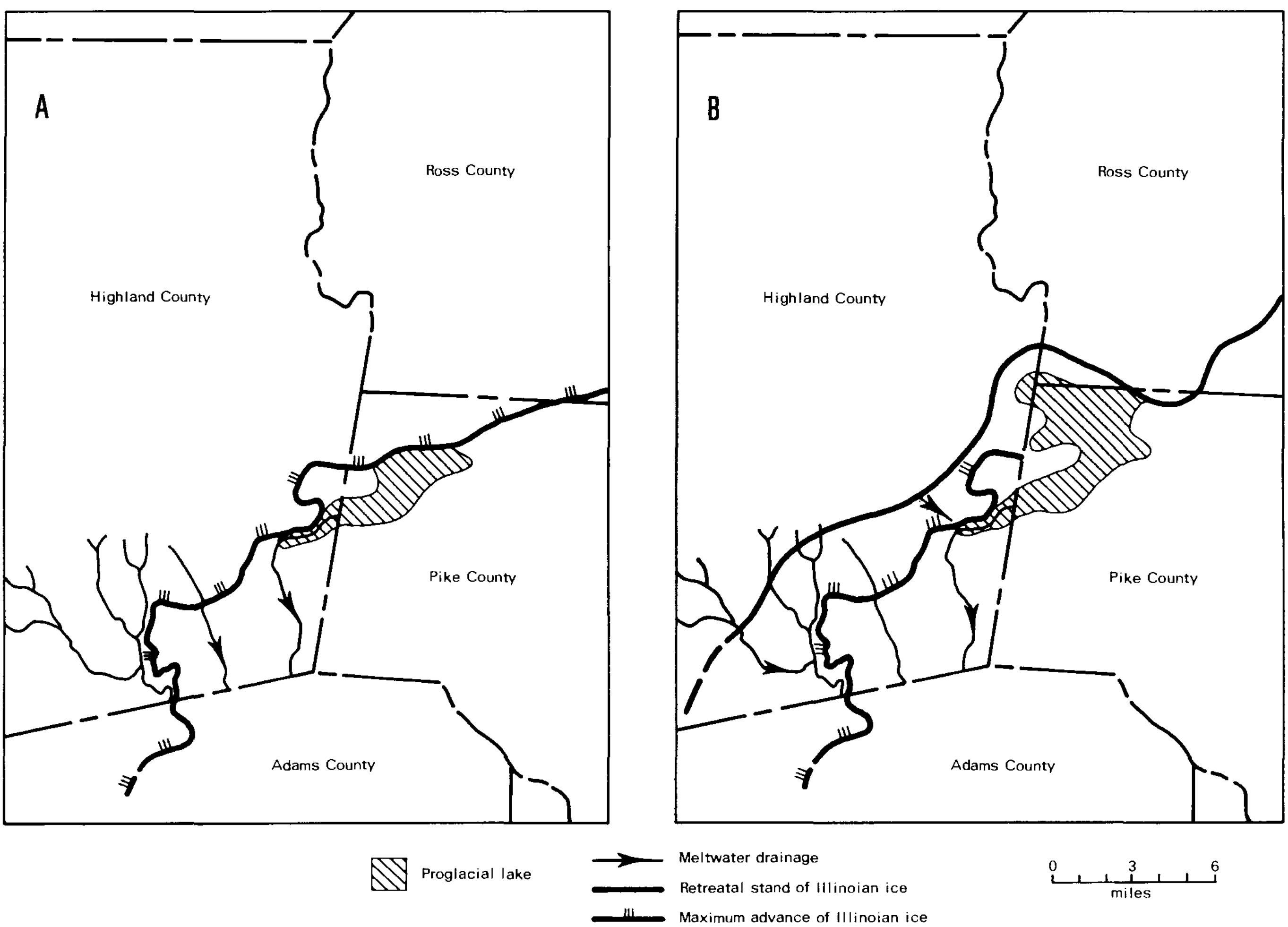

FIGURE 16.—Proglacial lake in the Beech Flats area; *A*, at time of maximum advance of Illinoian ice, *B*, during a retreatal stand.

bedrock highs. The large kame terrace built along the west slope of Clear Creek valley just northwest of its mouth marks the ice edge in this locality.

Major changes in meltwater drainage occurred during this stage of ice recession. The ice had retreated west and north of the drainage basin of Ohio Brush Creek, and that stream no longer received meltwater from the glacier. West of the Niagaran Escarpment the drainage system of White Oak Creek received the meltwater. The sand and gravel of the terraces along its valley were deposited at this time.

According to Fowke (1895, p. 17), a preglacial stream followed the valley of the present Rattlesnake Creek to a point about a mile northwest of The Point; from there it continued southwest to join the valley of the present Paint Creek. Thus the old channel cut across the present prominent loop of Paint Creek north of The Point. Rogers (1936, p. 19) recognized that the diversion of meltwater around the loop was caused by Illinoian morainic material blocking the former channel. However, he believed that the channel was occupied for a time by Wisconsinan marginal drainage. According to Williams and others (1970), Illinoian soils are developed in the gravel material in the channel. Altitudes of Wisconsinan terraces mapped during the present study show that Wisconsinan meltwater flowed around

FIGURE 17.—Positions of the Illinoian ice margin during three retreatal stands in Highland County.

the loop.

The preglacial drainage of Paint Creek was suggested by Rogers (1936) to have been to the north. He states (p. 19):

> The fact that the valley widens to the north suggests that the preglacial drainage was in that direction . . . The widening of the valley to the north is even more pronounced, however, from Greenfield northward, and its headwaters converge, in going upstream, with those of North Fork of Paint Creek and other southeastward-flowing streams.

Fowke (1895, p. 22) demonstrated that the upper part of North Fork drained northwestward from a col near Frankfort in Ross County. However, during this stage of ice retreat drainage to the north was blocked by Illinoian ice, and meltwater escaped southward through the bedrock hills north of the juncture of Rattlesnake Creek with Paint Creek. Thus the present southward course was established at this time. Initially, meltwater flowed through the hills at an altitude of about 850 feet, but a gorge 70 feet deep has since been cut into Silurian dolomites of the Bisher, Lilley, and Peebles formations.

Continued retreat of the Illinoian glacier placed the ice front at a position just west of Hillsboro, across the headwaters of Clear Creek and Rocky Fork (fig. 17C). The morainic topography of numerous kames indicates that a stand of the ice front probably took place at this locality. Extensive outwash trains were built during this stand in the valleys of Rocky Fork and Clear Creek. The glacier retreated north of the White Oak Creek drainage basin, and meltwater west of the Niagaran Escarpment escaped westward by way of the valley of the East Fork of the Little Miami River. After this stand the Illinoian glacier retreated northward out of Highland County and the Sangamon Interglaciation followed.

Wisconsinan Stage

Early Wisconsinan substage.—The Altonian or Early Wisconsinan glacier did not advance south into Highland County as has been proposed on the basis of soils found in the county, although drift believed to represent this glaciation is found at several localities in Ohio (Forsyth, 1961, p. 61). In Highland County during this period, loess was deposited upon the Illinoian drift. The loess was derived from outwash along the Little Miami River to the west. The nearest dated drift (Gahanna till with Lockbourne outwash, Franklin County, Goldthwait and others, 1965) suggests that the loess is 46,000 to 52,000 years old. A detailed study (Goldthwait, 1969) of the loess deposits in southwestern Ohio showed that 45 percent of the loess cover was deposited prior to the Late Wisconsinan substage. Up to 55 inches of loess was deposited during Early and Late Wisconsinan on Illinoian drift in the area.

According to Teller (1964, p. 64), Early ("early") Wisconsinan ice extended as far south as the central part of Clinton County; till from this advance is not known to be present at the surface, but outwash deposits are found along several streams south of the Late Wisconsinan border. None of the drift assigned this age has been dated; however, the till may be Late Wisconsinan in age and equivalent to the Boston till in Highland County.

Late Wisconsinan substage.—The Late Wisconsinan glacier advanced into Highland County about 21,000 years ago and at its terminal position covered the northern third of the county. The ice front extended across the county from just north of Rainsboro on the east to a position 3 miles south of New Vienna on the west (fig. 18A). While the glacier stood at this position, the Mt. Olive Moraine was built, and outwash was deposited in the valleys of Clear Creek, Paint Creek, Turtle Creek, and their tributaries. Paint Creek valley has deposits extending well into Ross County. During this stand meltwater escaped across the outwash plain near Rainsboro and eroded the Illinoian deposits to form the narrow valleys of Puncheon Run and Plum Run.

Following the stand at the position of the Mt. Olive Moraine, the ice front retreated northward an unknown distance before readvancing to a new position about 18,000 years ago. At its maximum readvance position (fig. 18B) the ice front made a stand during which two essentially parallel belts of end moraine were deposited, separated in places by narrow stretches of ground moraine. Collectively, the moraine is called the Cuba, and the belts are distinguished locally as the inner Cuba and outer Cuba. The inner Cuba probably represents a minor retreatal phase. During this retreat and readvance a thin blanket of loess, averaging about 6 inches, was deposited on the freshly exposed Boston drift as well as on the Illinoian drift to the south.

While the ice margin stood at the position of the Cuba Moraine, meltwater escaped southward by way of the East Fork of the Little Miami River, Clear Creek, Fall Creek, Rattlesnake Creek, and Paint Creek. Meltwater channels were cut along the margin of the outer Cuba Moraine a mile northeast of New Petersburg, through a segment of the outer Cuba south of Careytown, and through the inner Cuba Moraine 2 miles east of Samantha (pl. 1). Outwash was deposited along the valleys of the main drainage routes at this time.

Following this stand, the ice front retreated and made a stand a few miles north, building the Wilmington Moraine. This moraine is best developed in Clinton County; it can be distinguished for a distance of only 2 miles in Highland County. Scattered morainic topography that parallels the course of Bridgewater Creek probably records the position of the ice front east of the discernible moraine (fig. 18C). This retreatal position was probably of short duration. The major route by which meltwater escaped at this time was by way of Bridgewater Creek to Hardin Creek, then to Rattlesnake Creek and finally into Paint Creek.

The Scioto Lobe ice then made a significant retreat northward to a position at least midway into Fayette County, possibly much farther, and then readvanced to a position a few miles inside Highland County, building the Reesville Moraine at this stand (fig. 18D). Organic material obtained from a silt unit (Melvin loess?) beneath Darby I drift in Fayette County (Moos, 1970) dates this readvance at 17,340±390 years B.P. (OWU-256). Major drainage for meltwater at this stand was by way of Lees Creek, Rattlesnake Creek, and Paint Creek. Outwash forming many of the low-level terraces in these valleys and associated tributaries was deposited at this time. Drift had previously filled the preglacial valley of Lees Creek northeast of Leesburg and meltwater was diverted south of its former course, flowing over Silurian dolomite. Since then a gorge over a mile long and 80 feet deep has been eroded into bedrock. Following the stand at the

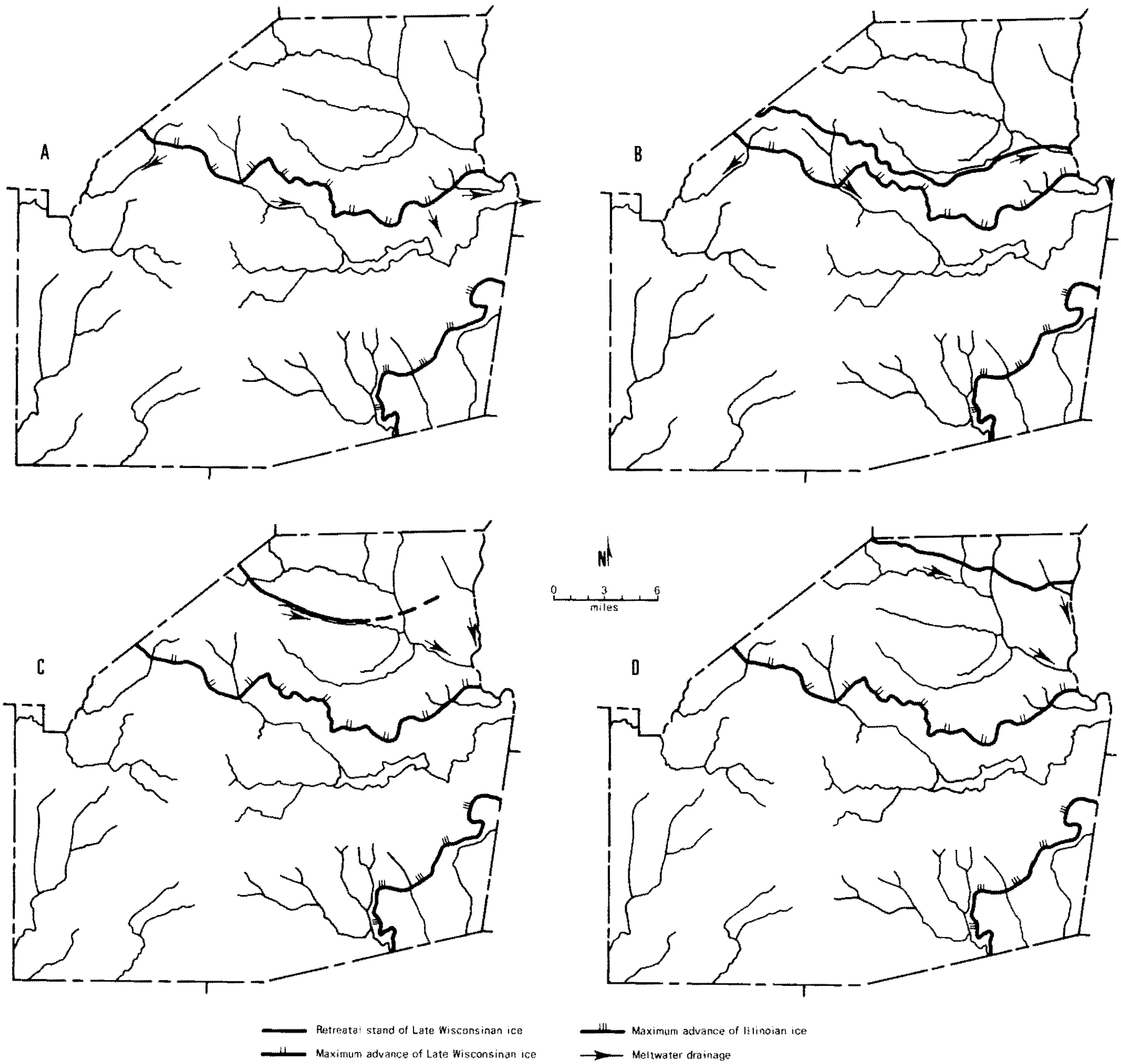

FIGURE 18.—Positions of the Late Wisconsinan ice margin in Highland County during *A*, maximum advance, the stand at the Mt. Olive Moraine, *B*, the retreatal stand at the Cuba Moraine, *C*, the retreatal stand at the Wilmington Moraine, and *D*, the retreatal stand at the Reesville Moraine.

Reesville Moraine, loess deposition essentially ended in this area.

The glacier receded into Fayette County. It made a stand of short duration about 3 miles north of the Reesville Moraine, building a low undulating moraine about 20 feet high. This moraine is unnamed; it trends northwest from western Fayette County into Clinton County, where the town of Sabina is located on the crest (fig. 19A). Meltwater escaped southward and cut channels through low cols in the Reesville Moraine just north of East Monroe and northwest of Leesburg. The present course of the Middle Fork of Lees Creek was thus established. Part of the low-level outwash in Lees Creek valley was deposited at this time.

Following this stand, the ice front again retreated a short distance and took up a new stand, during which the Glendon Moraine was built. Meltwater escaped southeast along the distal edge of the glacier and then flowed south into Highland County through the Reesville Moraine, following the meltwater channel that was already established (fig. 19B). Since then a gorge 70 feet deep and half a mile long has been cut into Silurian bedrock just southeast of East Monroe. Meltwater deposited low-level outwash along the upper stretches of Rattlesnake Creek, Walnut Creek, and Paint Creek at this time.

The Scioto Lobe then continued its northward retreat and made two additional stands in Fayette County, forming the Esboro and Bloomingburg Moraines. Meltwater from both these stands escaped south by way of Paint Creek; however, the outwash deposits are not distinguishable from each other in Highland County. Retreat of the Scioto Lobe ice north of the Bloomingburg Moraine allowed meltwater to escape eastward and westward around Highland County and down the major drainage valleys of the Scioto River and the Miami River, respectively.

Wisconsinan ice subsequently retreated out of Ohio about 12,500 years ago. By 8,500 years ago a warm climate had come to the state; bogs of that age preserved pollen of oak, elm, poplar, ash, and maple.

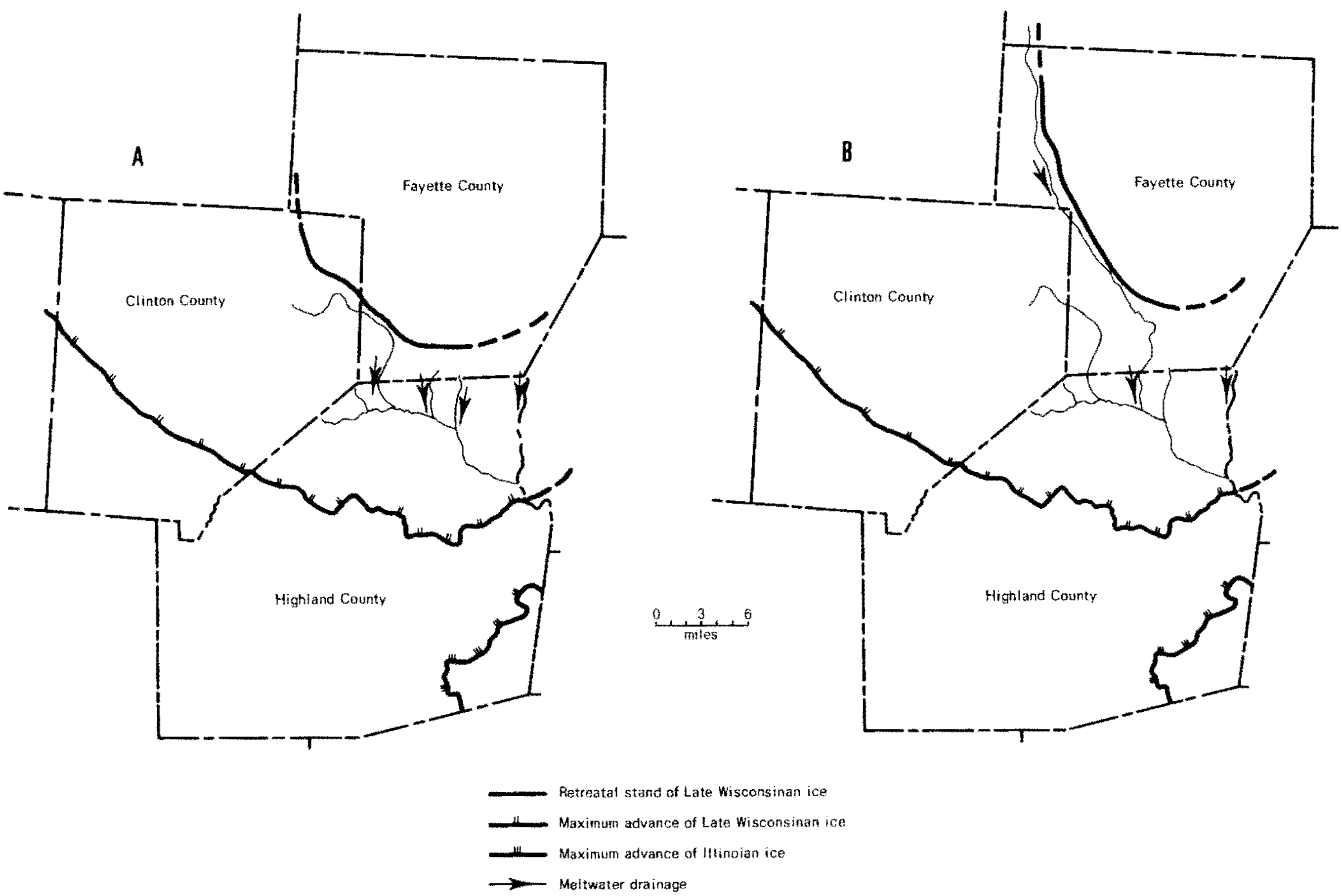

FIGURE 19.—Positions of the Late Wisconsinan ice margin during *A*, the retreatal stand at an unnamed moraine in Fayette and Clinton Counties, and *B*, the retreatal stand at the Glendon Moraine in Fayette County.

MINERAL RESOURCES

Limestone and dolomite

The most valuable resources in Highland County are limestone and dolomite. They find their greatest use presently in road aggregate and to a smaller extent for agricultural amendments. In the past the Brassfield Limestone, and Bisher, Lilley, and Peebles dolomites were all quarried, but in recent years the Brassfield and Lilley have been the only units exploited. An asphaltic phase in the Lilley formation has been quarried since the early 1930's for natural asphaltic aggregate, which is used for road construction. This phase is found in several places along the drainage divide between Willettsville and Hillsboro. At present the only active production of this stone is from a quarry 1.5 miles southeast of Willettsville. The interested reader is referred to the work of Bowman (1956) for a detailed report on the economic aspects of bedrock in Highland County.

Sand and gravel

The significant sand and gravel accumulations in Highland County are glacial in origin and were deposited as kames, eskers, and outwash. At present sand and gravel are of secondary importance as natural resources in the county because the local market demand is small, and neighboring counties have ample deposits. Only one gravel pit is presently being actively exploited. It is located 2 miles northwest of New Petersburg in Wisconsinan-age material of Paint Township (locality B47). Only two gravel deposits of Illinoian age are presently being used in the county and only on an infrequent basis (localities C94 and D41).

The size and volume of Illinoian sand and gravel deposits exceed by far the size and volume of those attributed to the Wisconsinan glaciation, but the cost of exploitation is likewise much greater. This expense is due to two factors: cementation and thick overburden. In nearly all large kame and esker deposits of Illinoian age, the deposits are locally cemented with calcium carbonate and form massive conglomerates 3 to 8 feet thick. Overlying the conglomerate is 3 to 7 feet of weathered gravel. Limestone pebbles have been leached out or, if present, have a soft chalky consistency. Where deposits of Illinoian age are poorly drained or fine grained, the overburden is 12 to 15 feet thick.

One of the largest accumulations of Illinoian sand and gravel is located south of Hillsboro from Rocky Fork westward to Shackleton. Within this area of about 12 square miles, there is a kame complex and related ice-contact stratified drift consisting of at least 24 large kames or kame groups and numerous gravel mounds and low knolls. Several of the kames in this area are as high or higher than the surrounding bedrock hills of the Niagaran Escarpment. Well-log data reveal that the bedrock surface is generally over 100 feet beneath the kame surface; two wells encountered bedrock more than 150 feet down. A gravel pit located about 2½ miles southwest of Hillsboro (locality C94), just south of Rocky Fork, has exposed the north side of a kame that rises to an elevation of over 1,130 feet. At this site about 100 feet of gravel and sand overlie 30 feet of exposed Danville till.

Kame material in this area is leached and oxidized to different depths. At site C94 the gravel is fresh: limestone pebbles are found within 2 or 3 feet of the surface and oxidation extends to about 5 feet. Large blocks of conglomerate, resulting from cementation of the gravels by calcite, are exposed in the gravel pit. In a few places these blocks, some of which exceed 10 feet in diameter, are found on slopes and at the bases of the kames within the area. Most of the steep-sided kames that are composed of gravel and minor amounts of sand have similar weathering characteristics. Kames consisting of finer materials are leached relatively deeper and generally are broad low knolls. One of this nature, located 2 miles south of Hillsboro on State Route 247, rises to just over 1,060 feet above sea level. A pit in the east side exposes 15 feet of leached silty sand overlying very well-sorted pea gravel and sand; oxidation extends to a depth of 20 feet. The kames at Marshall and to the west contain chiefly sand with minor amounts of fine gravel and are leached to at least 8 feet (limit of auger).

The kames among the Mississippian outliers have variable surface weathering effects: the knolls consist of gravels leached to about 4 feet, and the gentle slopes consist of sand leached to about 7 feet. Four to 6 feet of sand and gravel overlying till occurs along State Route 506 between Carmel and Cynthiana. Well logs in this area show that bedrock generally is 70 to 100 feet below the drift surface.

Although extensive Illinoian outwash terraces are found along the major stream valleys in Highland County, they are of little economic value due to their thinness, generally less than 35 feet. When removal of 15 to 20 feet of overburden is considered, the thickness of usable sand and gravel is only about 20 feet. Toward the valley sides the deposits thin considerably, and most of the outwash material consists of weathered overburden.

Several of the kames in the complex northwest of The Point contain very well-sorted gravel and sand. Most of the broad knolls have poorly sorted gravels. Depths of leaching ranged from 2 to 15 feet and oxidation from 3 to 15+ feet. Well-log data show that these stratified ice-contact deposits are generally 30 to 40 feet thick, much thinner than those south of Hillsboro. East of the Niagaran Escarpment isolated kames are found throughout the Illinoian drift area.

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APPENDIX

Distances are straight line measurements from town centers used as reference points. Abbreviations used below for various analyses performed on samples are: CM, clay minerals; MA, mechanical analysis; PC, pebble count; C/D, calcite/dolomite ratio; HM, heavy minerals; F, fabric; ut, upper till; mt, middle till; bt, bottom till; Ox, oxidized.

Locality

A14 1.3 mi NNE of Leesburg on W bank of tributary to Lees Creek, Fairfield Twp.

Ft	*Description*
0.5	Silt, dark-grayish-brown (10*YR* 4/2)
2.3	Till, dark-yellowish-brown (10*YR* 4/4), leached
7	Till, yellowish-brown (10*YR* 5/4), oxidized. MA. Darby I till (A14ut)
22	Till, slump
3	Till, gray (7.5*YR* 5/1); uppermost 5 in. oxidized. MA, PC
	Creek (955 ft)

A60 2.2 mi ESE of East Monroe on N bank of tributary 50 ft N of railroad track and 25 ft W of Jury Rd., Madison Twp.

Ft	*Description*
14	Till, brown (10*YR* 5/3), oxidized; uppermost 12 in. leached
1	Till, dark-gray (10*YR* 4/1), unoxidized. CM, MA, PC, C/D, HM, F. Darby I till (A60ut)
1.5	Silt, dark-gray (7.5*YR* 4/0), massive, unoxidized. MA. (A60)
0.3-0.5	Silt, strong-brown (7.5*YR* 5/8), laminated, strongly oxidized; local cementation with limonite
0.5	Silt, dark-brown (10*YR* 4/3), massive, oxidized
0.5	Gravel and sand, dark-brown (10*YR* 4/3), oxidized
2	Till, dark-brown (10*YR* 4/3), oxidized. MA, PC, C/D. Caesar till (A60bt)
	Ditch (930 ft)

A75 2.1 mi NW of Greenfield on S bank of Holiday Run, 800 ft N of Greenfield Sabina Rd., Madison Twp.

Ft	*Description*
13	Till, yellowish-brown (10*YR* 5/4), oxidized; uppermost ⅔ ft leached. CM, MA, PC, C/D, F. Darby I till (A75ut)
0.5	Sand, silt, dark-yellowish-brown (10*YR* 4/4), partially leached
7	Till, yellowish-brown (10*YR* 5/4), oxidized. MA, PC, C/D. Caesar till (A75btOx)
6	Till, gray (10*YR* 5/1), unoxidized. MA, C/D, F. Caesar till (A75bt)
	Creek (932 ft)

Locality

B9 2.0 mi SW of Greenfield on W bank of Duncan Run, Madison Twp.

Ft	*Description*
5.5	Till, yellowish-brown (10*YR* 5/4), oxidized
1.5	Till, gray (10*YR* 5/1), unoxidized. PC. Darby I till (B9)
4-6	Gravel, well-sorted, calcareous. Till, dark-gray (10*YR* 4/1), unoxidized. Caesar(?) till
	Creek (900 ft)

B47 2.2 mi NNW of New Petersburg at gravel pit on W wall of Rattlesnake Creek, Paint Twp.

Ft	*Description*
0-4	Silt, dark-brown (7.5*YR* 4/4), leached, strongly oxidized
0-5	Till, brown (10*YR* 5/3), oxidized, weakly compact; uppermost 2.3 ft leached. Caesar till
50	Gravel, poorly sorted to sorted, calcareous; a few beds of stratified silt and/or sand 1-3 ft thick; uppermost 5 ft oxidized. PC. Boston gravel
	Bedrock (820 ft)

B72 0.9 mi SW of Boston on S bank of tributary to Clear Creek, 15 ft W of Carper Rd., Liberty Twp.

Ft	*Description*
12	Till, yellowish-brown (10*YR* 5/4), very compact, oxidized; leached 5-6 ft; common vertical joints with light-reddish-brown (5*YR* 4/6) clay films. MA, PC. Rainsboro till (B72ut)
6-10	Sand and gravel, oxidized; thinning southward. PC. (B72)
3-6	Till, dark-gray (7.5*YR* 4/0); lowest 3 ft unoxidized. MA, PC, F. Rainsboro(?) till (B72bt)
	Ditch (940 ft)

B76 2.0 mi SE of Boston on E slope of inlet to Rocky Fork Lake, 600 ft S of Rittenhouse Rd.; section taken during park site construction, Paint Twp.

Ft	*Description*
8	Sand, light-yellow-brown (10*YR* 6/4) and yellowish-brown (10*YR* 5/6-5/8), stratified, leached, highly oxidized; reduced, light-gray (10*YR* 7/1), upper

Locality	Ft	Description
		2 ft brownish-yellow (10*YR* 6/6) silt
	7	Silt and silty clay, strong-brown (7.5*YR* 5/8), stratified, leached; local cementation with limonite; abrupt change to underlying unit
	25	Till, gray (2.5*YR* 5/0); uppermost 5 ft oxidized, calcareous, remainder unoxidized. PC, MA. Rainsboro till
		Lake (880 ft)

B89 3.2 mi NNE of New Petersburg, 0.1 mi SW of Cedar Run at State Route 138 road cut, N side, Madison Twp.

Ft	*Description*
0-13	Till, yellowish-brown (10*YR* 5/4), oxidized; uppermost 2.5-3 ft leached, top 1.5 ft silt. MA, PC, C/D, HM, F. Caesar till (B89ut)
0.5-2	Silty clay (paleosol), yellowish-brown (10*YR* 5/6-5/8), leached, highly oxidized. Sangamon
5-8	Till, yellowish-brown (10*YR* 5/4), oxidized, calcareous; common fine and medium distinct brownish-yellow (10*YR* 6/8) and yellowish-brown (10*YR* 5/8) mottles. MA, PC, C/D, CM, HM, F. Rainsboro till (B89bt)
	Road (925 ft)

C47 2.2 mi SSE of Samantha on S bank of tributary to Little Rock Creek, Penn Twp.

Ft	*Description*
13	Till, yellowish-brown (10*YR* 5/4), oxidized; uppermost 4-5 ft leached; top 1.5 ft silt
5	Till, dark-gray (10*YR* 4/1), unoxidized; *Picea* sp. MA, PC, C/D. Boston till (C47)
2	Clayey gravel (paleosol), yellowish-red (5*YR* 6/8), leached, oxidized. Sangamon
	Creek (960 ft)

C51 2.9 mi N of Hillsboro, 0.8 mi W of U.S. 62 on bank of Clear Creek, Liberty Twp.

Ft	*Description*
0-10	Till, yellowish-brown (10*YR* 5/4), oxidized. MA, PC, C/D, HM, F. Rainsboro till (C51ut)
2-4	Sand and gravel, yellowish-red (5*YR* 4/8-5/8), highly oxidized
1-3	Till, yellowish-brown (10*YR* 5/4), oxidized. PC, C/D, HM. Rainsboro till (C51mt)
2-8	Gravel, oxidized; thinning eastward
6-13	Till, gray (10*YR* 5/0); lowest 3 ft unoxidized; abundant vertical fractures with dark-brown (7.5*YR* 4/4) clay coating. MA, PC, C/D, HM. pre-Rainsboro (C51bt)
4.5	Clayey gravel (paleosol), yellowish-red (5*YR* 4/8), leached; uppermost 1 ft mixed with till, partially calcareous. Yarmouthian(?)
3	Sand and silt, stratified, oxidized; brownish-yellow (10*YR* 6/6-6/8) strata; yellowish-brown (10*YR* 5/4) sand strata; calcareous 0.5 ft from top
3	Silt, light-yellowish-brown (10*YR* 6/4), massive, oxidized; changing to unoxidized light gray (10*YR* 6/0) in lowest 0.5 ft
	Creek (950 ft)

C58 2.1 mi E of Boston and 0.1 mi S of U.S. 50 on bank of Blinco Branch, Paint Twp.

Ft	*Description*
1-2	Silt, leached
6-10	Till, yellowish-brown (10*YR* 5/4), oxidized; leached 36-80 ft below surface; pH 4.9 at 2 in. below surface. MA, PC, C/D, HM, F. Boston till (C58ut)
3-5	Clay loam (paleosol), leached to 3 ft sandy loam, partially leached another 2 ft (Sangamon), gradually changing to lithology below
6-10	Gravel and sand, well-sorted, oxidized. PC. Rainsboro gravel (C58)
6-10	Till, dark-gray (10*YR* 4/1), unoxidized; uppermost 0.5-1 ft oxidized; thickening westward at expense of overlying gravel; *Picea* sp. HM, MA, PC, C/D, CM, F. Rainsboro till (C58bt)

C84 4.0 mi ESE of Hillsboro in road cut on E side of "airport" road, 0.1 mi N of State Route 124, Liberty Twp.

Ft	*Description*
0-18	Sand, yellowish-red (5*YR* 4/6-4/8), leached, well-sorted; crossbedding in lowest 6 ft highly oxidized; some channel gravel, 6 to 8 ft thick, in upper section
5-7	Silt and clayey silt, dark-brown (10*YR* 4/3), laminated; uppermost 2-3 ft oxidized, calcareous; lowest 3-4 ft dark gray (10*YR* 4/1), unoxidized. MA. (C84)
3-30	Till, dark-gray (10*YR* 4/1), unoxidized; thickening southward at expense of overlying material. MA, PC, C/D, HM, F. Rainsboro till (C84)

C95 4.2 mi E of Rainsboro to The Point, then 1.5 mi N to the S wall of Paint Creek valley at site of Paint Creek Reservoir dam excavation, Paint Twp.

Ft	*Description*
10-25	Gravel and sand, yellowish-red (5*YR* 5/8) and strong-brown (7.5*YR* 5/8), leached, highly oxidized
2-7	Till, dark-brown (7.5*YR* 4/4), leached
1	Clay, yellowish-red (5*YR* 5/8); residual soil
	Bedrock (800 ft)

C99 0.5 mi WSW of Rainsboro, 0.1 mi S of U.S. 50, on S bank of Puncheon Run, Paint Twp.

Locality

Ft	*Description*
5-7	Silt, dark-brown (7.5*YR* 4/4) to yellowish-brown (10*YR* 5/6), leached; locally lowest 1 ft laminated and calcareous
0.5	Sand, dark-brown (7.5*YR* 4/4), leached
1	Gravel, yellowish-brown (10*YR* 5/6), calcareous
4	Till, dark-gray (7.5*YR* 4/0-10*YR* 4/1), calcareous; uppermost and lowest 5 in. oxidized, yellowish-brown (10*YR* 5/4). MA, PC, C/D, F. Rainsboro(?) till (C99ut)
1	Sand, light-yellowish-brown (10*YR* 6/4), oxidized
1.3	Till, dark-brown (10*YR* 4/3), oxidized
7	Gravel, yellowish-brown (10*YR* 5/6-5/8), poorly sorted, oxidized. PC. Rainsboro gravel (C99)
2	Till, gray (10*YR* 5/1), very pebbly; center 1 ft unoxidized. PC. Rainsboro till (C99mt)
2	Gravel, unoxidized
1-2	Silt, dark-gray (10*YR* 4/1), laminated, unoxidized. MA. (C99)
	Creek (890 ft), till, dark-gray (10*YR* 4/1), unoxidized. MA, C/D. Rainsboro(?) till (C99bt)

Gravel terrace — 100-500 ft E of above location on S bank

Ft	*Description*
25	Gravel, dark-brown (7.5*YR* 4/4); leached 55-80 in.; oxidized below to yellowish brown (10*YR* 5/8). PC. Rainsboro gravel (C99tr)
	Creek (890 ft)

D8 — 0.2 mi N of intersection of U.S. 62 and State Route 138 (Leesburg) on W side of road cut, Fairfield Twp.

Ft	*Description*
25	Till, uppermost 10 ft oxidized and yellowish brown (10*YR* 5/4); changing abruptly to lithology below; MA, PC, C/D, HM, F. Caesar till (D8ut)
4	Till, yellowish-brown (10*YR* 5/4-5/8), oxidized, lowest 1 ft unoxidized. CM, MA, PC, C/D, HM, F. Caesar till (D8bt)
3	Sand, oxidized
	Ditch (1,000 ft), bedrock 2-3 ft below

D35 — 1.8 mi NW of New Petersburg, 500 ft NE of road on S bank of Big Branch, Paint Twp.

Ft	*Description*
3	Colluvium, oxidized
3	Gravel and sand, leached
6	Till, dark-gray (2.5*Y* 4/0), unoxidized; *Picea* sp.; MA, PC, C/D, HM, F. Caesar till (D35)
	Creek (855 ft)

D36 — 2.9 mi SE of Samantha, 900 ft E of State Route 138 on S bank of Fall Creek, Liberty Twp.

Ft	*Description*
0-12	Till, yellowish-brown (10*YR* 5/4), oxidized; leached 2.5 ft. CM, MA, PC, C/D, HM, F. Caesar till (D36ut)
0.5-1	Rubble and gravel, partially leached, clay accumulation in upper 3 in., abrupt change to lithology below
8-10	Till, yellowish-brown (10*YR* 5/4), calcareous; lowest 2-3 ft gray (10*YR* 5/1), unoxidized; small pieces of wood common, *Picea* sp. CM, MA, PC, C/D, HM, F. Boston till (D36mt)
5-6	Silt, (paleosol), leached; uppermost 6 in. dark yellowish brown (10*YR* 4/4-3/4), lowest silt grading to brown (7.5*YR* 5/4). MA. Sangamon (D36)
3-4	Till, calcareous; lowest 1 ft unoxidized. CM, MA, PC, C/D, HM, F. Rainsboro till (D36bt)
	Creek (1,020 ft)

D39 — 2.7 mi NNE of New Petersburg in cut bank on S side Cedar Run, 150 ft S of Rowe Rd., Madison Twp.

Ft	*Description*
0-14	Till, yellowish-brown (10*YR* 5/4), oxidized
14-22	Till, gray (10*YR* 5/1), unoxidized; *Picea* sp. MA, PC, F. Caesar till (D39)
	Creek (860 ft)

Sample locations not mentioned above:

C94 — 3.0 mi NW of New Market in gravel pit just S of juncture of Holladay Rd. with Ervin Rd., elev. 1,000 ft, New Market Twp.

D41 — 2.0 mi S of Rainsboro in gravel pit of esker along State Route 70, elev. 990 ft, Paint Twp.

STATE OF OHIO
John J. Gilligan, Governor
DEPARTMENT OF NATURAL RESOURCES
William B. Nye, Director
DIVISION OF GEOLOGICAL SURVEY
Horace R. Collins, Chief

GLACIAL GEOLOGY OF HIGHLAND COUNTY, OHIO

by Theodore E. Rosengreen

1974

EXPLANATION

QUATERNARY	Recent		al	Alluvium
	Pleistocene	Wisconsinan	Wtr	Terrace, erosional, cut in outwash or bedrock
			Wo (1 2 3 4 5 6)	Outwash, preserved as terraces
			Wk (1 2 3)	Kame
			Wg (1 2 3 4)	Ground moraine
			We (1 2 3 4)	End moraine
			Wt/br (1 2 3 4)	Till, less than five feet thick, or exposed bedrock
		Illinoian	Itr, Io	Outwash, preserved as terraces or outwash plain
			Il	Lacustrine deposit
			Iic	Ice-contact stratified drift, kame, kame complex, kame terrace, and esker
			Ig, Itp	Ground moraine and till plain
			It/br	Till, less than ten feet thick, or exposed bedrock

Drift or outwash related to specific moraines:

1 Mt. Olive
2 Cuba
3 Wilmington
4 Reesville
5 Unnamed moraine between the Reesville and Glendon Moraines in Clinton and Fayette Counties
6 Glendon

Boundary of a mapped deposit, *dashed where approximate*

Limit of a significant advance or readvance of the ice front, *dashed where approximate*

Limit of a major (stage) glacial advance, *dashed where approximate*

Sand and gravel pit

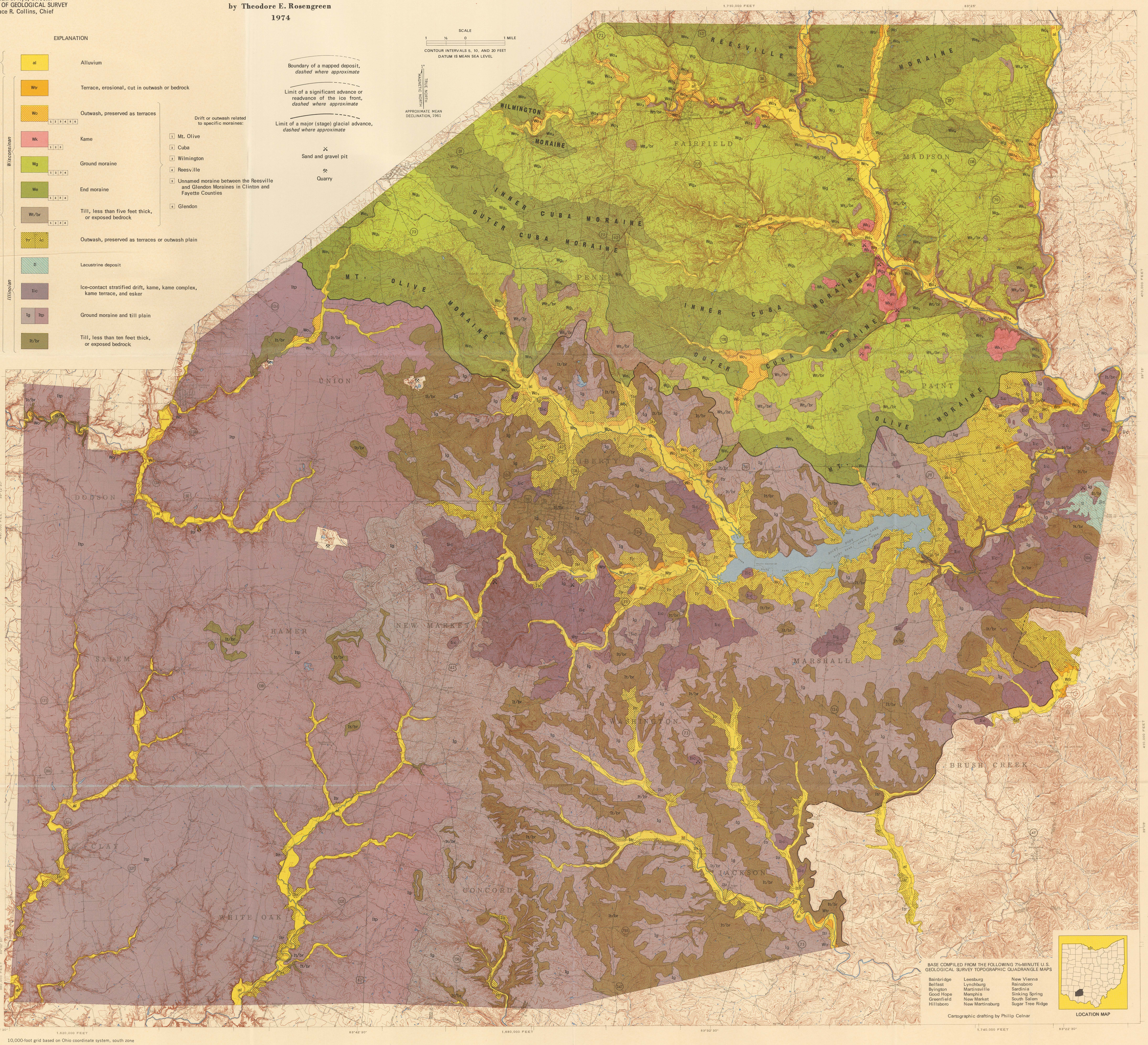
Quarry

SCALE

1 ½ 0 1 MILE

CONTOUR INTERVALS 5, 10, AND 20 FEET
DATUM IS MEAN SEA LEVEL

TRUE NORTH
MAGNETIC NORTH
1°
APPROXIMATE MEAN DECLINATION, 1961



10,000-foot grid based on Ohio coordinate system, south zone

BASE COMPILED FROM THE FOLLOWING 7½-MINUTE U.S. GEOLOGICAL SURVEY TOPOGRAPHIC QUADRANGLE MAPS

Bainbridge	Leesburg	New Vienna
Belfast	Lynchburg	Rainsboro
Byington	Martinsville	Sardinia
Good Hope	Memphis	Sinking Spring
Greenfield	New Market	South Salem
Hillsboro	New Martinsburg	Sugar Tree Ridge

Cartographic drafting by Philip Celnar

LOCATION MAP