THE LATE GLACIAL AND LACUSTRINE DEPOSITS OF ERIE AND HURON COUNTIES, OHIO

DISSERTATION

Presented in Partial Fulfillment of the Requirements
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University

By

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PREFACE

PURPOSE AND SCOPE OF THIS STUDY

This study of the late glacial ice and lacustrine deposits of Erie and Huron counties, Ohio, was undertaken for the purpose of getting more information relative to the retreat of the last ice sheet from this area.

In the past there has been some question as to the continuity of the Defiance moraine across Huron County, so that it was particularly desirable to study this moraine and its relationships to other morainic belts. Attention was also given to the character of the till deposits, especially in regard to textural and weathering variations, in order to see if the various till sheets recognized by Dr. George White in northeastern Ohio could be distinguished in north central Ohio. In connection with this last named problem, mechanical analyses of till samples were made in the laboratory in order to arrive at roughly quantitative definitions of the textural variations observed in the field.

In the lacustrine plain section of the region studied an effort was made to delineate the areas of the various lake bottom sediments and to relate their deposition to the events which occurred in the Erie basin as the ice retreated northward.

ACKNOWLEDGMENTS

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The field work on which this study was based was supported by the Division of the Geological Survey, Department of Natural Resources, of the State of Ohio and to it and, most particularly, to Mr. John R. Melvin, Chief, go my thanks. Further financial aid came from the Division of Shore Erosion of the same department and I wish to thank it, and Dr. Howard Pincus of its Lake Erie Geological Research Program and the Department of Geology, The Ohio State University, for his kindness in making the arrangements and giving me access to the laboratory facilities in Sandusky, Ohio.

I also wish to acknowledge the financial support of the Department of Geology of The Ohio State University throughout the greater part of the period of my graduate studies as well as the help and advice received from various members of the staff of the department.

I am indebted to Dr. Claude Hibbard, Department of Geology, the University of Michigan; Dr. George W. Burns, Department of Botany, Ohio Wesleyan University; and Dr. H. B. Tordoff of the Museum of Natural Histroy, University of Kansas for identification of vertebrate and plant remains.

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INTRODUCTION

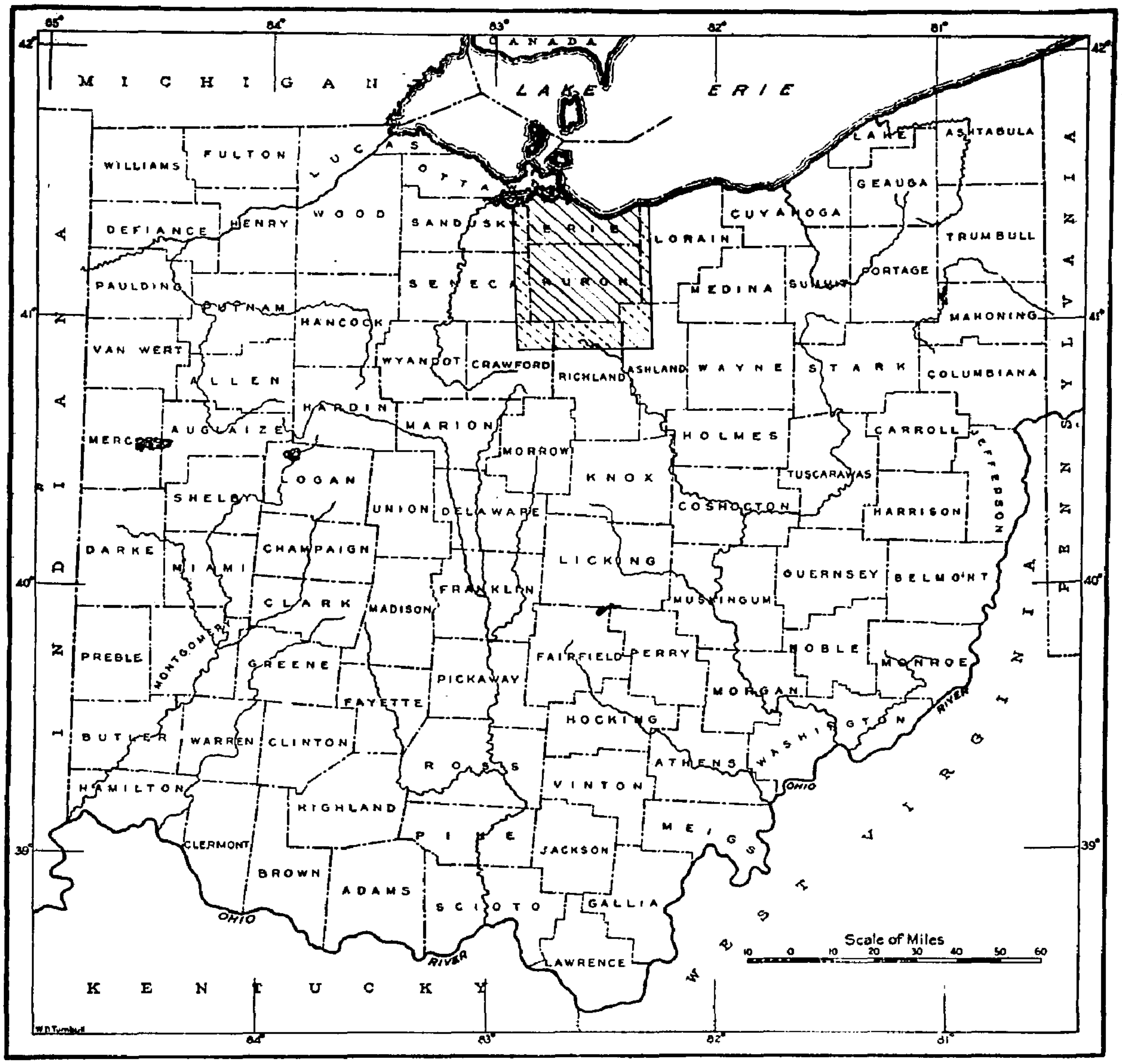
LOCATION OF AREA OF STUDY

The area studied was Erie and Huron counties, Ohio. (See Plate II.) As is always the case, however, geological problems do not limit themselves to civil boundaries and, therefore, as much time as possible was given to a survey of the surficial geology of adjacent parts of Sandusky, Seneca, Richland, Ashland and Lorain counties in effort to clarify some of the relationships observed within the two counties of the study.

GENERAL GEOLOGIC AND PHYSIOGRAPHIC RELATIONSHIPS

The area of the investigation lies on the eastern flank of the Findlay Arch and between 35 and 50 miles from its axis. The strike of the bedrock formations is roughly north-south in southern Huron County, but swings to a more northeasterly direction in the northern portion of the same county, and continues thus across Erie County. The regional dip to the east and southeast is gentle.

Both counties lie entirely north of the divide between the Erie and Ohio drainage basins and within the Central Interior Lowland. Two sections of this physiographic province have generally been recognized in Ohio: the Till Plains and the Eastern Lakes section. George White, however, in a study of the Pleistocene geology of the two counties immediately to the south (White, 1933) recognized a third physiographic unit which he called the "Low Plateau". This unit is also recognized in Huron and Erie counties. (See Plate IV.)



Location of area of study.

PREVIOUS WORK

The first systematic investigations of the geology of Erie and Huron counties were those of the Second Geological Survey of Ohio. These were but reconnaissance surveys and the reports of the surficial aspects of the geology are very brief. (Newberry, 1874, and Read, 1878)

Prior to this, Charles Whittlesey, a member of the First Ohio Survey, had called attention to the long sandy ridges which festoon the lake plain and had advanced the hypothesis that they represented subaqueous bars, developed when the lake waters within the Erie basin stood at higher levels (Mather, 1838, p. 55 and Whittlesey, 1850, p. 32).

A major contribution to the knowledge of this portion of the state was made by Frank Leverett in his study of the glacial formations of Ohio (Leverett, 1902). Although this report is written from a broader regional standpoint it contains the first delineation of the Defiance moraine in Huron County as well as descriptions of two eskers and the three major beaches as they occur in Erie and Huron counties. Some further studies of the lake plain were made by Leverett and Frank B. Taylor after the topographic mapping of Ohio. These were included with the publication of the summary of glacial and post-glacial events in all of the Great Lake basins (Leverett and Taylor, 1915). This latter work is a synthesis of all information known at the time concerning the post-glacial lakes and is still extremely valuable, although subsequent investigations by such workers as Stanley (1938), Bretz (1951 and 1951a), Chapman and Putnam (1951) and Hough (1952, 1952a and 1953) have altered and added to the details of the chronology. None of these last named investigators has been directly concerned with the southern shore of the Erie basin, but their work throws light upon events here.

Several detailed studies of the physical aspects of the abandoned shorelines of northern Ohio were made by Frank Carney including those portions on the Vermilion (1911), Bellevue (1913) and Sandusky (unpublished) quadrangles.

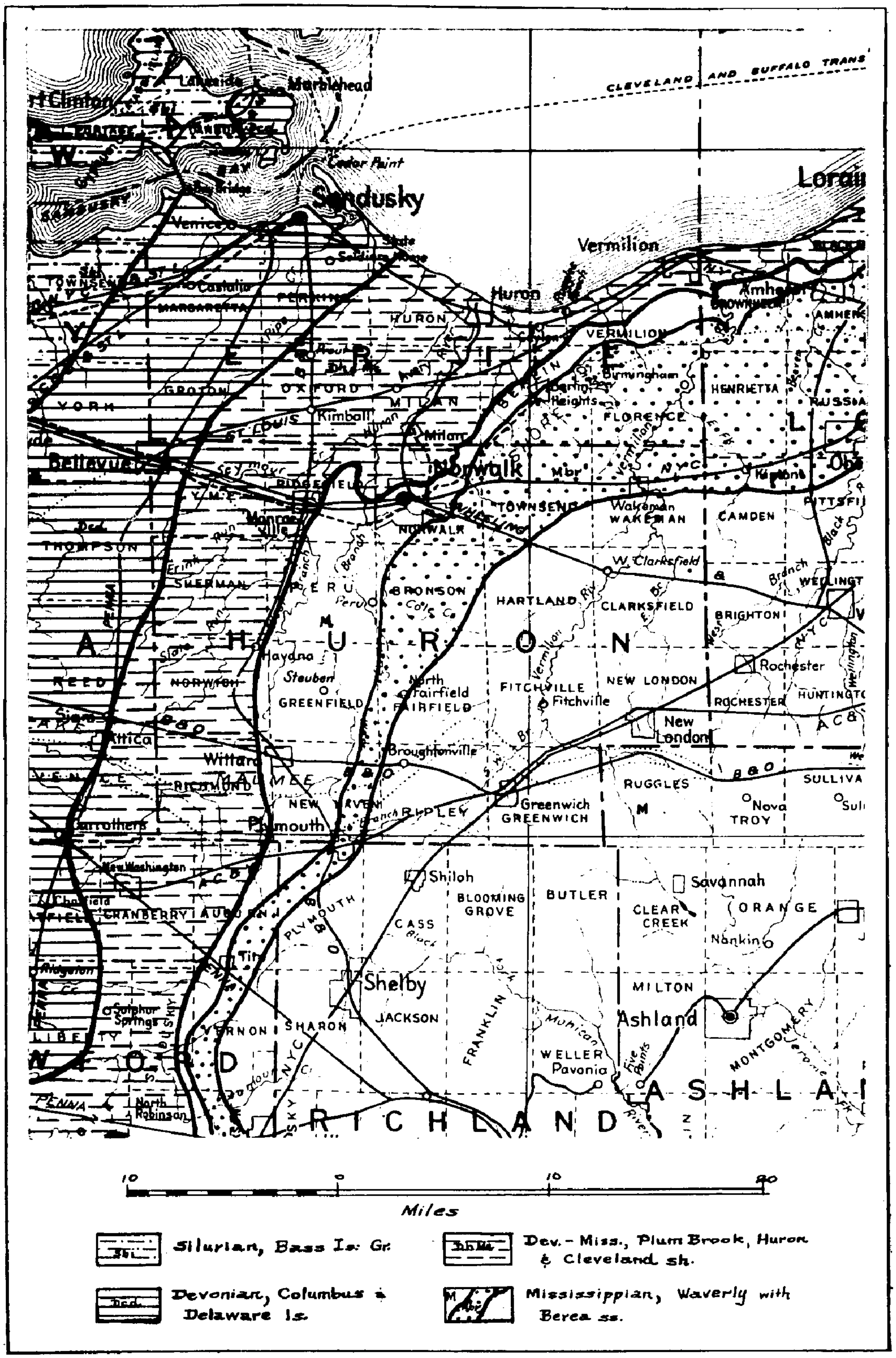
George W. White has mapped the moraines of north central Ohio, by constructing projected profiles from topographic maps (White, 1939).

George D. Hubbard, in collaboration with some of his students, has conducted several investigations of physiographic features in this part of Ohio (Hubbard and Champion, 1925 and Hubbard and Rockwood, 1940).

In 1905 E. L. Moseley published the results of his investigations of the Sandusky Bay-Cedar Point area and advanced several hypotheses regarding the glacial and post-glacial history of that area.

The drainage changes of north central Ohio during the Pleistocene have received some study by Ver Steeg (1934 and 1936) and White (1934). In the latter instance the major concern is with the region to the south and east of Huron County, but some information relative to the Huron and Vermilion basins is also included.

Within the past several years the Department of Natural Resources of the State of Ohio has supported the Lake Erie Research Program. Paul Shaffer (1951) made a study of erosion processes along the shores of Sandusky Bay and some of the results of the investigations have been presented in theses for the Master of Science degree in the Department of Geology of The Ohio State University and that by Raymond Metter (1952) is concerned with Cedar Point and the shore east to Huron in Erie County.



Generalized geologic map of Erie and Huron counties, Ohio.

BEDROCK GEOLOGY

REGIONAL STRUCTURE

As has been stated, Erie and Huron counties are located on the eastern limb of the Findlay Arch. The pattern of outcrop is a banded one with the rocks having a general north-south strike in southern Huron County which changes to an east-northeast to west-southwest direction in the northern part of the area (Pl. III). The regional dip to the south and southeast is approximately 35 feet per mile.

SEQUENCE OF FORMATIONS

The oldest bedrock exposed is in the extreme northwestern part of Erie County where the Put-in-bay dolomite of Late Silurian age forms Crystal Rock Hill (Carman, 1927, p. 491). The Put-in-bay dolomite is underlain by the Tymochtee shaly dolomite which is not naturally exposed in Erie County.

In going from this northwest corner of Erie County to the southeast corner of Huron County, i.e., downdip, the underlying bedrock is successively of upper Silurian, middle and upper Devonian and Mississippian age. Table I, on the following page, gives the complete sequence of formations recognized in the area of study.

It should be stated in regard to this table that there are several controversial points: The Devonian-Mississippian boundary is variously placed between the Berea and Bedford, where there is a strong unconformity; at the top of the Cleveland shale; and as here shown, at the base of the Cleveland shale. The relationship between the Huron shale and the Chagrin shale is not clear. Some stratigraphers interpret them as different facies; others believe that the Chagrin wedges out between the Huron and Cleveland shales.

SEQUENCE OF BEDROCK FORMATIONS IN ERIE AND HURON COUNTIES

TABLE I

SYSTEM	SERIES	GROUP	FORMATION	DESCRIPTION	THICK-NESS
MISSISSIPPIAN	Lower	Cuyahoga	Orangeville sh.	dove colored sh. and thin-bedded, fine grained, blue ss., weathering to a rusty brown; "turtlebacks" common.	100'
			Sunbury sh.	black fissile sh.	8-15'
			Berea ss.	medium to fine grained, generally massive ss.; gray on unweathered surface, yellow on weathered	70' avg. 0-200'
			Bedford sh.	3. soft brown or chocolate brown argillaceous sh. 2. ss., similar to Berea in appearance; thickness highly variable. 1. soft, blue gray, argillaceous sh. with a few gray ls. layers	50'avg. 0-75'
			Cleveland sh.	black carbonaceous sh.; cone-in-cone layers common.	60'+
DEVONIAN	Upper		Chagrin sh.	green and blue arenaceous sh.	0-32'
			Huron sh.	black carbonaceous sh.; carbonate concretions common, particularly near base.	300'
	Middle		Prout ls.	hard siliceous ls.	0-9'
			Plum Brook sh.	soft gray sh. with thin layers of argillaceous ls.	40-60'
			Delaware ls.	bluish gray, finely crystalline ls., becomes a sooty brown when weathered; nodular chert frequently localized along bedding planes.	70'
			Columbus ls.	3. thin to medium-bedded blue ls. 2. massively bedded blue to brown ls. with some chert. 1. light brown crystalline dolomitic ls.	65'
		Detroit River	Lucas dol.	light gray to brown fine textured limy dol.; weathers to a bluish gray.	30'
			Amherstburg dol.	bluish gray to brown limy dol.; finely crystalline; massive	45'
SILURIAN	Upper	Bass Island	Raisin River dol.	bluish gray to brownish gray dol. in massive beds	55'
			Put-in-bay dol.	gray, brecciated, coarse textured dol. in massive beds.	35'
			Tymochtee shaly dol.	thin to massive beds of brown dol. with thin shaly layers.	

INFLUENCE OF BEDROCK ON TOPOGRAPHY

The major types of sedimentary rocks: sandstones, shales and carbonate rocks, are all represented in the bedrock of Huron and Erie counties, and since over much of the area, particularly the lacustrine plain, the covering of till, lake sediments and soil is relatively thin each type has topographic expression. Special mention will be made of these areas in the discussion of the physiographic units (pp. 18-20). Moreover, a consideration of the bedrock types on a broader scale shows them to have been important factors controlling glacial and lacustrine processes.

The pre-glacial lowland of the Erie basin was the result of stream erosion across the belt of easily eroded Devonian and Mississippian shales. As the ice sheets moved southward this lowland formed the natural avenue of their advance and the ice front developed a lobation because movement was more rapid along the axis of the basin. When the ice attempted to spread out southward in this region of Erie and Huron counties, it encountered the more resistant lower Mississippian sandstones, and the basin-facing Berea-Bedford sandstone escarpment in southwestern Erie County (Pl. 5, Fig. 1) was enough of an obstacle, that although the Wisconsin ice did rise above it and move on southward, it was thinner and less active than contemporaneous ice to the westward. The secondary lobation of the Erie lobe into a Scioto and Killbuck lobe as recognized south of Huron County reflects this interference.

PHYSIOGRAPHY

PHYSIOGRAPHIC UNITS

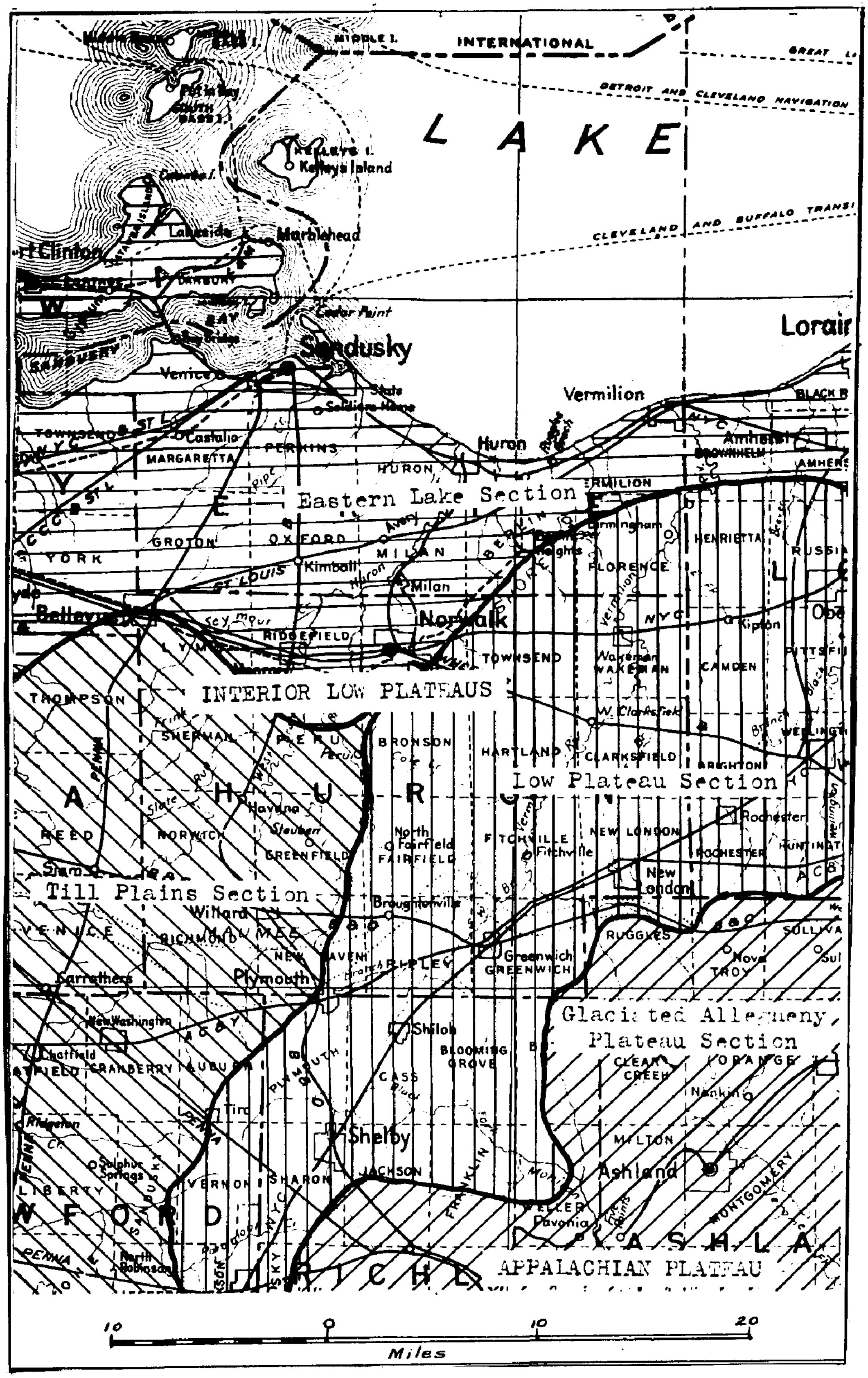
The accepted physiographic classification of the United States recognizes three provinces as being represented within the borders of Ohio: the Appalachian Plateaus, the Central Lowlands and the Interior Low Plateaus, the latter covering only a small area in the south central portion of the state (Fenneman, 1916, pp. 30-33 and map). The provinces are subdivided into sections, so that according to the classification a Till Plains section and an Eastern Lake section of the Central Lowlands are distinguished in northern Ohio, and the section of the Appalachian Plateaus province which is represented is the Glaciated Allegheny Plateau. The line separating this portion of the Appalachian Plateaus province from the sections of the Central Lowlands was originally delineated by Leverett (1902, p. 67) and lies east and southeast of the area of this investigation, so that Erie and Huron counties are entirely within the Central Lowlands.

Recognition of the Low Plateau Section

George White, working in an area just south of Huron County, found it of value to recognize a Low Plateau section, transitional between the Till Plains and the Glaciated Allegheny Plateau (White, 1934, p. 367-368). White's description of this physiographic unit is as follows:

> "... an area (in Richland, Crawford, Morrow, Knox and Delaware counties) having an elevation of 1100-1200 feet and lying between the Allegheny Plateau on the east and the Till Plain on the west. It is entirely covered by Wisconsin drift. In elevation, in relief and in prominence of glacial features this region is intermediate between its bordering regions. [It]... forms a gently curving belt, 5-16 miles in width..."

Pl. IV



Physiographic units in north central Ohio.

"Its eastern boundary is marked by the generally abrupt rise of the Allegheny Plateau. Its western boundary is along a scarp that follows the outcrop of the resistant Berea sandstone.... It appears to continue to southern Ohio where it becomes a part of the Lexington Plain section of the Interior Low Plateau province. The Low Plateau is part of an erosion surface cut in late Tertiary time on the weak Cuyahoga shale and shaly sandstone of Mississippian age and is correlated with the Lexington (Worthington) peneplain. The relief of the Low Plateau varies from only a few feet to as much as 100 feet, but averages less than 50 feet. It is covered by a thick blanket of drift so that its topography is glacially controlled."

On the basis of physiographic characteristics it is difficult to decide whether this Low Plateau should be considered part of the Appalachian Plateaus or the Central Lowlands. Farther south, beyond the glacial boundary, the Appalachian Plateau boundary is extended westward to include the area of Berea outcrop (Fenneman, 1916, p. 56) but within this glaciated region it seems more properly to belong to the Central Interior Lowlands province. The control of the topography rests with the glacial deposits to a much greater extent than within the glaciated Allegheny Plateau section of the Appalachian province.

The Low Plateau in Erie and Huron Counties

The concept of the Low Plateau physiographic unit is equally as valid in Huron and Erie counties as in the region to the south where it was recognized by White. It has already been pointed out (p. 8) that the Berea escarpment is a prominent feature in southeastern Erie County (Pl. V, Fig. 1), and it will be shown (pp. 92-93) that this escarpment affected the character of the glacial deposits across what is herein called the Low Plateau.

At the latitude of the southern boundary of Huron County the Low Plateau is about ten miles wide. In northeastern Huron and southeastern

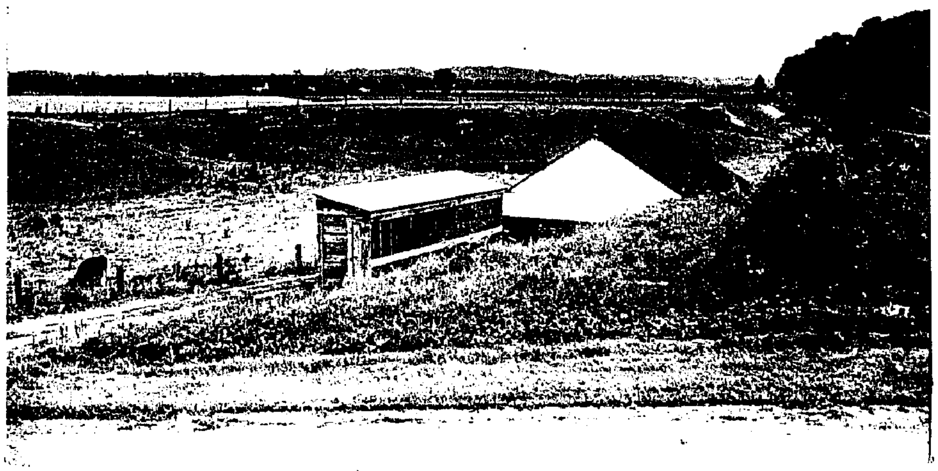


Fig. 1 - View southward toward Berea escarpment east of Berlin Heights.

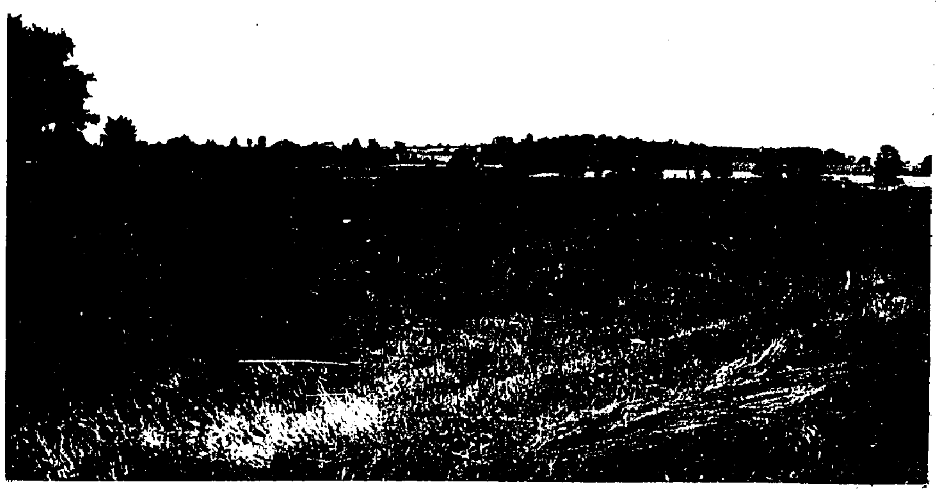


Fig. 2 - Bedrock hills within area of ground moraine in southeastern Erie County

Erie counties where the strike of the controlling bedrock has shifted to an easterly direction the width increases to between 20 and 25 miles. The elevation in the northern part of the area is somewhat lower than the 1100-to 1200-foot figure given by White, for the Berea crops out at elevations of 750-800 feet. Back of the escarpment the topography of the Low Plateau is glacially controlled except for a number of Berea hills capped with only thin till in southeastern Erie County (Pl. V, Fig. 2).

Till Plains Section

The Till Plains section, as the name is here used (Low Plateau excluded), is not represented in Erie County. In Huron County its boundaries are the line of the Berea-Bedford contact on the east and the shoreline of Lake Maumee III on the north (Pl. IV). The major elements of the surface are ground moraine and belts of end moraine. The bedrock underlying the glacial deposits of most of this section in Huron County is shale and limestone. In Lyme Township, where the drift is thin, the low relief of the ground moraine reflects, to a large extent, the surface of the limestone beneath and sink holes are common. The topography of the Till Plains is generally that of a glaciated area in an early stage of dissection. There is, however, an area of sub-mature dissection in Peru and northern Greenfield townships the genesis of which is discussed below (p. 115).

Eastern Lake Section

In north central Ohio the Eastern Lake section is coincident with the area of the lacustrine plain developed by various lake levels within the Erie basin (Pl. IV). Its southern boundary is the shoreline of Lake Maumee III. Except for eastern Erie County where the Maumee shoreline lies on top of the Berea escarpment the bedrock underlying the lake plain is the same as that beneath the till plain in Huron County: shale and limestone.

In northern Ohio in general, the lacustrine processes have operated to smooth out irregularities of an already glaciated surface so that the aspect of the lake plain is typically that of an almost level plain sloping imperceptibly to the north. The monotony of its aspect is broken only by long low ridges of sand and gravel. These ridges represent the beaches of former lake levels and are frequently augmented by dune accumulations on top. Except on these ridges both the natural surface and interior drainage of the lacustrine plain are poor; the former because the drainage systems have not yet developed and the latter because the lacustrine sediments, clay and silty clay, are for the most part impermeable.

The Lacustrine Plain of Erie County

Much of the lake plain of Erie County is atypical in respect to the characteristics mentioned above. Bedrock lies within 30 feet of the surface except in the vicinity of the Huron River valley, north of Milan, and so often makes its influence felt in the surface forms.

In the vicinity of Bellevue there is only a thin covering of till and lake sediments over the Silurian and Devonian carbonate rocks and a surface pitted with sink holes has developed. Lines of surface drainage are short and discontinuous, but the underground drainage is good. The downward movement of the waters continues through the Columbus limestone and the Lucas dolomite into the Amherstburg dolomite. The extremely porous nature of the Amherstburg lends itself to continuous lateral movement, so the waters are channeled along it to come to the surface in lovely springs at its up dip extremity in and around Castalia, Erie County.

Also near Castalia there are a number of bedrock hills which give the area a relief in excess of 50 feet. These hills, capped by the more resistant Columbus limestone, existed as shoals, islands and peninsulas during the various lake stages and the hill slopes have been modified by wave action. Wave-cut cliffs on the hill flanks mark lake levels, and beaches, frequently of coarse cobble, are present in the more sheltered locations.

Cliffs cut in the Prout limestone form a strong sector in the Maumee II shoreline at Strongs Ridge, east of Bellevue on State Route 113 (Lyme Township, Huron County)[1]. Northeastward from Strongs Ridge

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1. Huron and Erie counties are the westernmost counties in the old Connecticut Western Reserve. They were surveyed, shortly after title was acquired from the Indians in 1805, on the plan of five mile square townships with the ranges numbered westward from the Pennsylvania boundary, and townships, northward from the southern boundary of the Reserve (intended to be the 41st parallel). Erie and Huron counties lie in ranges 20 to 24.

The civil townships coincide with the originally surveyed townships and reference to townships in these counties is made, in this paper, by civil township name, e.g., Norwalk, Oxford etc.

Division of the townships within Erie and Huron counties is on a regular rectangular plan but there are only four sections to a township. Such large sections do not offer a very convenient method of describing locations, therefore, locations within the townships are given here with reference to roads. Roads thus mentioned in the text have been labeled on Plate I.

to its type locality near the freight station of Prout, the position of this limestone is discernible in a low ridge on the lake plain.

The belt of upper Devonian and lower Mississippian black shales underlies what may be considered more typical lacustrine plain topography. In several places the shale has a very thin covering and along the abandoned shorelines there are remnants of low cliffs cut into the shale. Due to the ease with which the shale weathers, however, they are scarcely distinguishable from the beaches.

In one such area in the vicinity of North Monroeville in Oxford Township, Erie County and Ridgefield Township, Huron County, very shallow shale in front of the Whittlesely beach presents a problem in the agricultural management of the soil. Abundant pyrite within the shale oxidizes so rapidly that suggested lime tonnages based on pH determinations fall far short of meeting the lime requirements.

The Berea-Bedford Escarpment

In the discussion of the Low Plateau as a physiographic unit (p.11) one boundary was described as being along the Berea-Bedford contact. Reference has also been made to the importance of the northward facing escarpment at this stratigraphic position in determining the character of the glacial deposits on the Low Plateau (p. 8). Yet it still seems preferable to place this escarpment as it occurs in southeastern Erie County in the Eastern Lakes section and to continue to use the well-developed and continuous Maumee shoreline, which here lies on top and south of the escarpment, as the southern boundary of the Lake section. This avoids the embarrassment of having major shorelines outside the section with which they are genetically associated.

Furthermore, in Erie County, drawing the section boundary at the Berea-Bedford contact would result in an unnatural division,for the height of the escarpment at Berlin Heights is due in good part to a strong local development of the middle sandstone member of the Bedford. At Berlin Heights this member is 20 feet thick, but it thins rapidly in both directions (Read, 1878, p. 289). The three best developed shorelines in this area, Maumee III, Whittlesey and Warren, are all clearly represented within the rise of the escarpment.

DRAINAGE

Trunk Streams

Roughly three quarters of the total area of these counties is drained by two river systems, the Huron and Vermilion. Both rivers have their sources 30 to 35 miles south of Lake Erie in the Fort Wayne-Wabash moraine complex. In the Till Plains and Low Plateau these major streams with their tributaries display a well developed dendritic drainage pattern. As the lake water receded from the highest shoreline to the present water level, the courses of these rivers were extended across the lake plain, and in these lower reaches neither is joined by a significant tributary, for the typical pattern of the youthful lacustrine plain is still that of small parallel streams which flow directly into the lake.

The total area of the Huron River basin is 403 square miles and that of the Vermilion is 272 square miles. In both cases only a small part of the basin lies outside the borders of Erie and Huron counties. Ver Steeg (1936 and 1934), by plotting bedrock elevations, has shown that there were pre-glacial or interglacial predecessors of these two rivers. Both of these ancestral streams had their sources south of the present divide.

Valleys of the Major Streams

The valleys of these two major streams can be characterized as being in the stages of youth and early maturity. The exact stage of development attained varies, of course, from one reach to another depending upon the material in which the valleys are being cut and the position relative to local base level (Lake Erie).

Mature Lower Courses: Both rivers have well developed flood plains in their lower reaches, that of the Huron extending as far south as Milan, or a straight line distance of about seven miles. The mature portion of the Vermilion River is shorter due to the more resistant Mississippian sandstones and shales which extend to within three miles of the lake in eastern Erie County. In common with all streams entering Lake Erie from the south and west, the mouths of the Vermilion and Huron rivers are drowned.

Gorges: Above these mature portions of the Huron and Vermilion the valleys display the gorges and rapids of late youth. The gorge of the Vermilion River extends from Rugby south to Wakeman (about 15 miles); that of the Huron River is shorter, extending only from Milan to Monroeville (about 10 miles). The Huron River gorge is cut in the Cleveland

Tributary of Huron River intrenched in black shale north of Monroeville.

and Huron black shales (Pl. VI), while the Vermilion has exposed a bedrock succession from the shales and sandstones of the Cuyahoga group at Wakeman to the black shales at its downstream end. The upper, or red, Bedford shale which occurs in the valley walls several miles south of Birmingham, Erie County, was the inspiration for the name "Vermilion".

Vermilion River Valley South of Wakeman: South from the fork of the East and West branches of the Vermilion to the southward facing edge of the Defiance moraine the Vermilion valley is slightly more advanced in development than where bedrock controls it.

At Fitchville the river changes its direction of flow to almost due east as it crosses the bed of a small post-glacial lake (see p. 63). The valley itself is youthful and quite shallow. From the northern edge of Ashland County to the river's source in the Savannah Lakes the youthful character of the Vermilion valley is somewhat obscured by the still distinct outline of the wide partially filled interglacial valley (Ver Steeg, 1934, p. 617) in which the river flows.

Huron River Valley South of Monroeville: South of its gorge section the West Branch of the Huron River follows a rather straight course in a shallow V-shaped valley across the lacustrine plain of the Norwalk embayment. From the vicinity of Pontiac south to about Steuben the valley takes on more mature outlines, meandering rather widely and having a well developed flood plain. Upstream from Steuben it again displays the characteristics of a youthful stream.

Other Drainage Systems

Areas of parallel drainage on the lake plain are found between the lower portions of the Huron and Vermilion rivers and in western Erie County, excluding the region of underground drainage from Bellevue to Castalia. Plum Brook and Pipe Creek are the largest of these parallel streams.

In addition there is a small part of southwestern Huron County which is drained by Honey Creek, a tributary of the Sandusky River, and a narrow strip in the southeastern part of the same county which lies within the Black River basin.

RELIEF OF PRESENT SURFACE

The highest elevation to be found in the two counties is in the extreme southeastern corner of Greenwich Township, Huron County, along the Base Line Road, one half mile east of State Route 13. Here the elevation at the edge of the Allegheny Plateau is 1193 feet. In Erie County, within the Low Plateau, a high elevation of 902 feet is reached by a hill just southwest of Florence. Since the entire area of the two counties lies north of the Ohio-Erie drainage divide, Lake Erie at 573 feet is the base level for the trunk streams.

The lake plain is characteristically an area of low relief. Bedrock features, however, give locally a relief much above the average, as for example, in the vicinity of Castalia where it is slightly in excess of 50 feet, and along the edge of the escarpment in southeastern Erie County. At Berlin Heights a maximum relief of 180 to 190 feet is reached.

The relief of the ground moraine surface averages from five to ten feet, the only prominent exceptions being at the northern end of the Low Plateau section where hills of Berea sandstones rise as much as 90 to 100 feet above the surrounding plain (Pl. V, Fig. 1), and where isolated glacio-fluvial ridges and hills rise as much as 30 feet above the ground moraine.

Within the belts of end moraine, both in the Till Plain and Low Plateau sections, the relief is generally less than 50 feet.

Maximum drainage relief is found along the Vermilion River gorge in the Low Plateau.

PRE-GLACIAL RELIEF

The buried topography of this portion of Ohio seems to be that of a border region lying between the Appalachian Plateau of eastern Ohio and the more gently rolling surface cut on the limestone and shales of the western part of the state. Ver Steeg (1936, pp. 921-922) characterized the shale and limestone surface as consisting of gently rising valley slopes, broad low divides and wide valleys. His mapping of this surface indicated a gradient of about six feet per mile for the ancestral Huron and Sandusky rivers.

The buried surface in the eastern part of the two counties is apparently somewhat more rugged than the present glaciated surface. Drainage relief along the old Vermilion valley is reported as about 300 feet (ibid, p. 921).

GLACIAL FEATURES OF THE LOW PLATEAU AND TILL PLAIN

The area of Huron and Erie counties has already been discussed from the point of view of physiographic units and three such units were recognized (p. 13). When it comes to the primary purpose of this study, however, it is in many regards more convenient to make a twofold division of (1) lacustrine plain, and (2) glaciated plain and plateau. The surface features in both the Low Plateau and the Till Plain are primarily the result of glacial processes and, while the area of the lacustrine plain was also glaciated, the surface has been modified by lacustrine processes. The boundary between these two divisions is that which marks the southern limits of the Eastern Lake section: the highest abandoned shoreline.

GLACIAL PROCESSES

Four general categories of processes dependent upon glaciers may be recognized: (1) glacial erosion, (2) direct deposition by glaciers, (3) melt-water deposition and (4) erosion by melt-waters. There had undoubtedly been considerable glacial erosion by the various ice sheets over the area of Huron and Erie counties. This is reflected in the large amount of locally derived material in the till and glacio-fluvial deposits and in the striae on bedrock surfaces. For the most part, however, the surface in the plain and plateau is the product of deposition by the glaciers and glacial melt waters.

GLACIAL SURFACE FORMS

The features of the glaciated plain and plateau in Huron and Erie counties will be described under three headings; 1) those which consist largely of glacial till and are the result of direct deposition from the ice (ground moraine and belts of end moraine); 2) those built of sorted and stratified material and which are the product of deposition from glacial meltwaters (eskers, kames and outwash); and 3) those which reflect the lacustrine processes of pro-moraine lakes.

Method of Mapping

Glacial surface forms were mapped by driving over the countryside and noting the topography on U. S. G. S. topographic maps[2]. Of the maps used the Vermilion, Sandusky, Bellevue, Siam and Bucyrus maps are contoured with a 10-foot contour interval; all others, a 20-foot interval. Neither interval was found satisfactory for delineating the glacial surface forms and, therefore, an additional system of map notation was used in order to arrive at a more precise definition of the topography.

Ground moraine was mapped where the till surface was gently undulating, i.e. where there were only shallow swales and broad gently sloping hills. Eskers and occasional isolated kames or bedrock hills were considered acceptable within the limits of ground moraine. Good end moraine topography was defined as strongly rolling, i.e. with knobs

2. In reference to this method of topographic surveying it may be said that although roads in the two counties are not laid out along section lines spaced a mile apart (See footnote 1, p. 15), for the most part they are closely enough spaced to allow a general view, in this region of relatively low relief, of the nature of the topography between roads. In some cases it was necessary to walk to a better vantage point, and, of course, some features require closer investigation.

and kettles. (See Pls. IX and X) A third topographic type was also recognized, in many cases intermediate in position as well as relief. It may be characterized as gently rolling with small depressions and low but sometimes sharp hills.

Moraine Boundaries

The most difficult boundary to draw was that between the backslope[3] of end moraines and the ground moraine. The topography on either side of the line may be gently rolling or even gently undulating, for an attempt was made to place the moraine boundary where a consistent rise toward moraine crests began in the constructional topography.

The southern limits of the end moraines were, in most cases, easily discernible, due to the abandoned lake beds or moraine controlled stream valleys which frequently lie immediately in front.

Moraine Crests

Within the end moraines an attempt was made to find continuous crest lines, a "crest line" or "moraine crest" being defined as a string of morainic knobs or hills possessing continuity for at least several miles and with summits above the general level of the constructional topography on either side. A moraine belt itself may actually represent several short term readvances, or even be the result of constructive processes associated with two or more major readvances. A con-

3. Throughout this paper "moraine front" and backslope" will be used to designate the southward and northward facing moraine slopes respectively. This terminology is similar to that of Leverett (1902, etc.) who referred to "inner" and "outer" moraine borders. "Stoss" and "lee" have also been used in a somewhat similar manner but I object to this usage because it seems to imply a mechanism of end moraine formation which while it may be valid for a particular moraine is not necessarily so.

tinuous crest line on the other hand presumably marks the position of the ice front at one period of time. It was hoped that crests could be traced across such areas as the Shiloh moraine knot where several moraines merged and would aid in correlating the various maraine sectors. Actually the hope was not born out because where the general trends become questionable continuous crests could not be found. The experience of this study suggests that in moraine areas where no crests are discernible there may have been either an excess of glacio-fluvial drainage or thin ice was unable to leave a clear record of its advance to a previously built moraine.

Meltwater Deposits

The surface forms of such meltwater deposits as kames and eskers are generally quite distinctive, but before positive identification can be made it is, of course, necessary to see the character of the material of which these features are built. Here in Ohio, sand and gravel pits have frequently been opened in these deposits of sorted glacial debris; in other cases cuts or excavations revealed the nature of the material; and where no exposures were available auger borings usually provided the necessary information.

The presence of outwash channels and pro-moraine lake beds was also suggested by the topography, but again the character of the underlying material had to be investigated.

Till Deposits

End Moraines

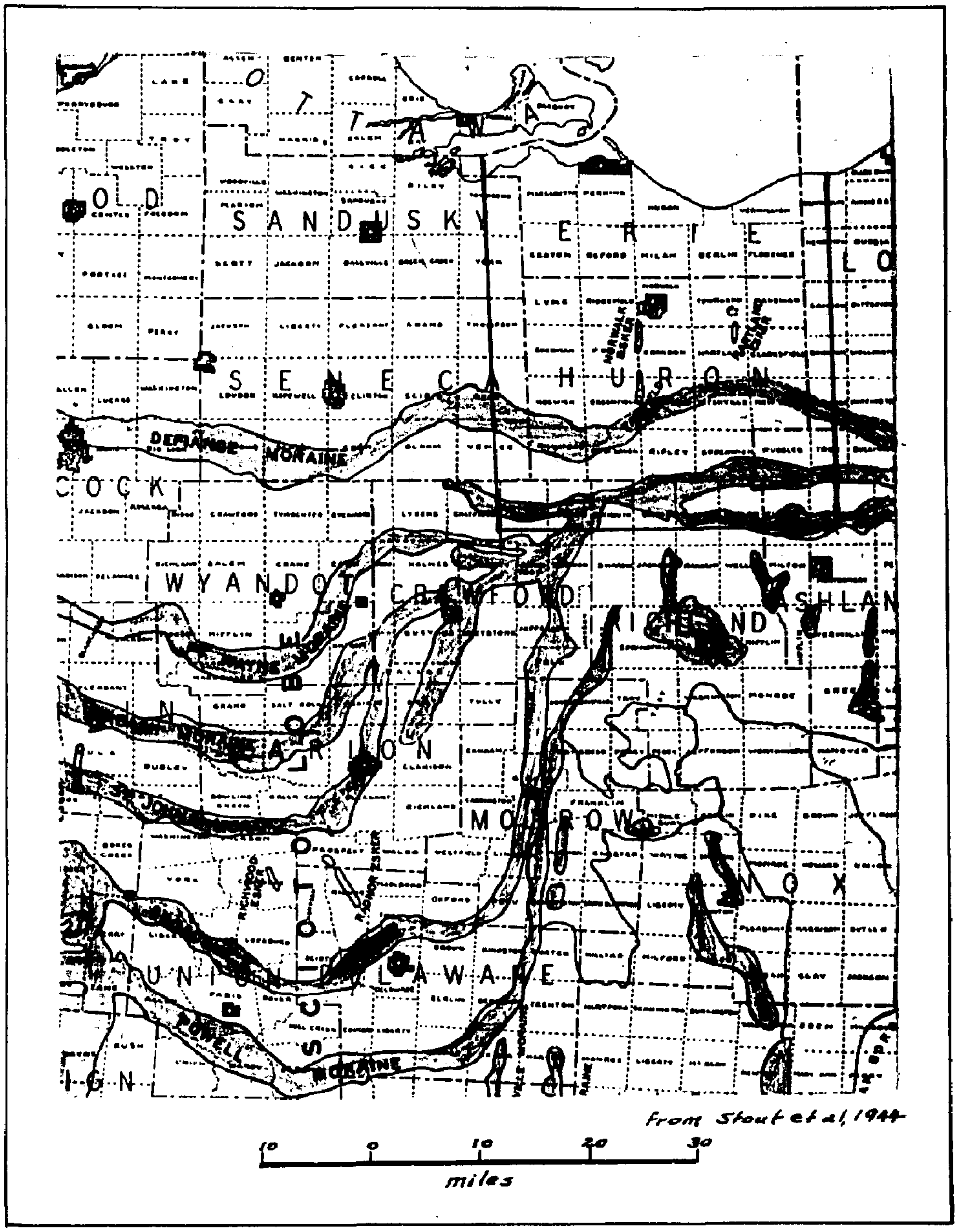
Within Huron County and the region just to the south there are three major end moraines: the Wabash, Fort Wayne and Defiance (Pl. I).

These are all recessional moraines of the Wisconsin glacier and were grouped by Leverett (1902, pp. 545-619) under the heading of "Moraines of the Maumee Lobe". As White (1935, p. 43) pointed out, however, they might well be called "Moraines of the Erie Lobe" for although slight loops in the morainic belts do indicate that some lobation of the ice front still remained at the time of their formation, all three moraines can be traced directly across the "roots" of the Miami, Scioto and Killbuck[4] lobes.

The entire width of the Defiance moraine belt lies within the limits of Huron County. South of the Defiance, and separated from it by ground moraine and abandoned lake beds, is another morainic belt. Only the northern or backslope of this belt enters Huron County. That portion of the belt in northern Richland County, just south of Ripley and New Haven townships, Huron County, will be referred to as the Shiloh moraine knot for several bands of moraines are here merged. The morainic belts which come together have been variously mapped and correlated in the past. Because the areas in which the answers to the questions of continuity and correlation lie are too far removed from the area of this study to have permitted even a brief reconnaissance, a brief summary of past interpretations will be given, and the one which I favor will then be used as a basis for further discussion.

Moraine Correlations: In Crawford County Leverett (1902, Pl. XIII and p. 571) mapped everything south from the Willard Marsh to Broken Sword Creek as Fort Wayne moraine (See Pl. VII), apparently not re-

4. White (1934a, p. 455) gave the name "Killbuck lobe" to that portion of glaciated Ohio which Leverett (1902, p. 403) referred to as the "shoulder of the Scioto lobe".



Moraines in north central Ohio (Scioto and Killbuck lobes).

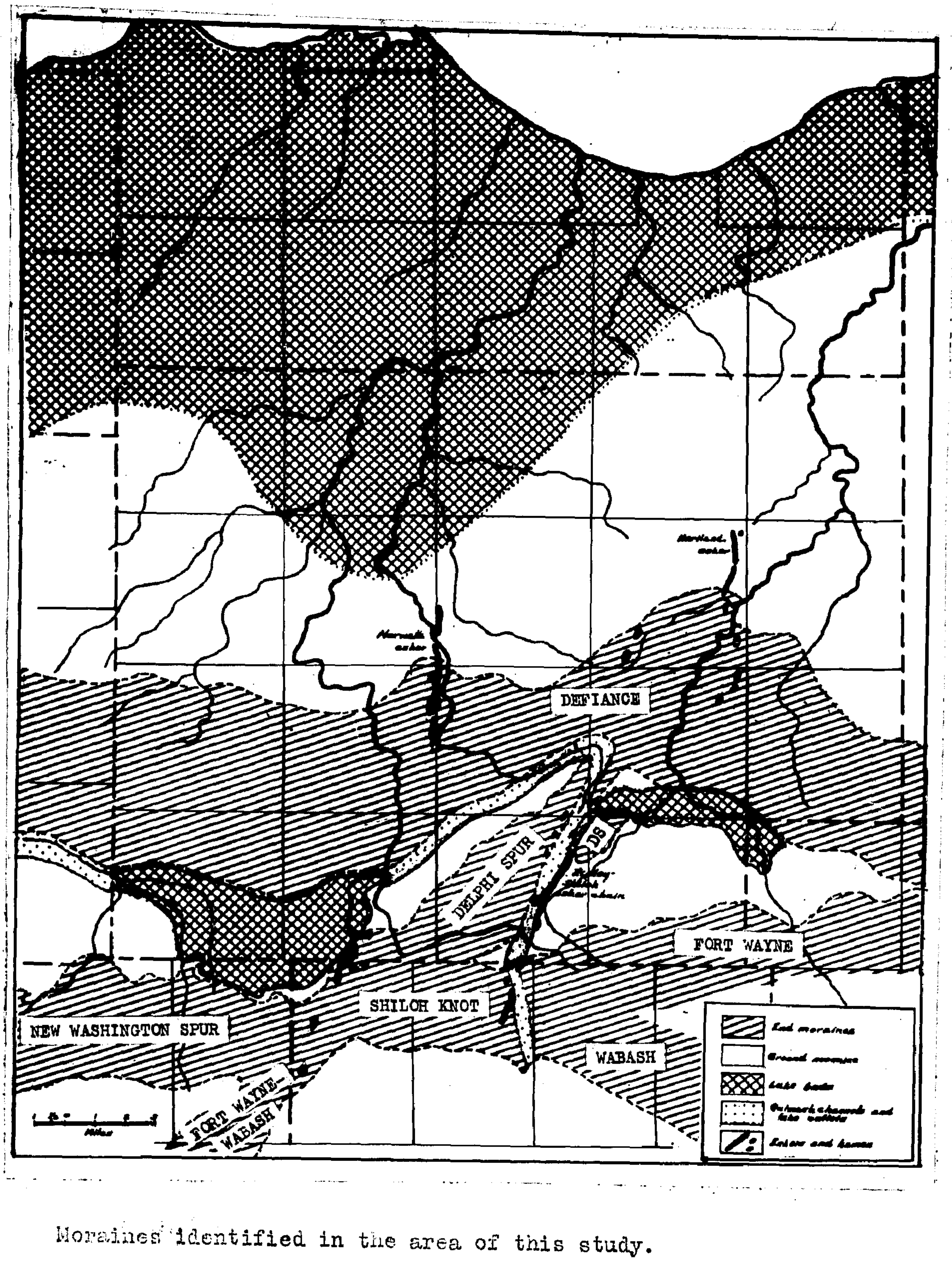
cognizing an old lake bed south of the morainic topography near New Washington.

White (1937, p. 36) constructed a map of some of the moraines of north central Ohio from projected profiles and called the New Washington belt the Fort Wayne moraine, including all the rest of the morainic topography south to the Sandusky River in the Wabash. In the paper which this map accompanied, however, he stated that since his profiles had been constructed primarily to show the north-south trending segments of the Broadway and Powell moraines they did not reveal the east-west trending Fort Wayne and Wabash too well. Later (1939, Fig. 2, p. 279 and p. 287), using north-south profiles, he changed his earlier correlation and showed the New Washington belt as a spur, extending westward from what in this paper is called the Shiloh knot and ending abruptly in Chatfield Township, Crawford County. The name Fort Wayne was then applied to the morainic belt just north of Broken Sword Creek and south of the previously mentioned lake bed.

Hubbard and Rockwood (1942, p. 243 and Fig. 11, p. 244) interpret the old lake bed (Tabor School area) as a large kettle within the Fort Wayne moraine.

Dr. White's 1939 correlation represents actual and detailed work on the problem and so is accepted here. It is the interpretation used on the map of the glacial deposits in Ohio which was published in conjunction with Bulletin 44 of the Ohio Geological Survey (Stout et al, 1943, map opp. p. 20). It would seem, however that detailed field mapping of crests within the Fort Wayne moraine from the region of Dunkirk, Hardin County, to central Crawford County might well be of value.

Pl. VIII



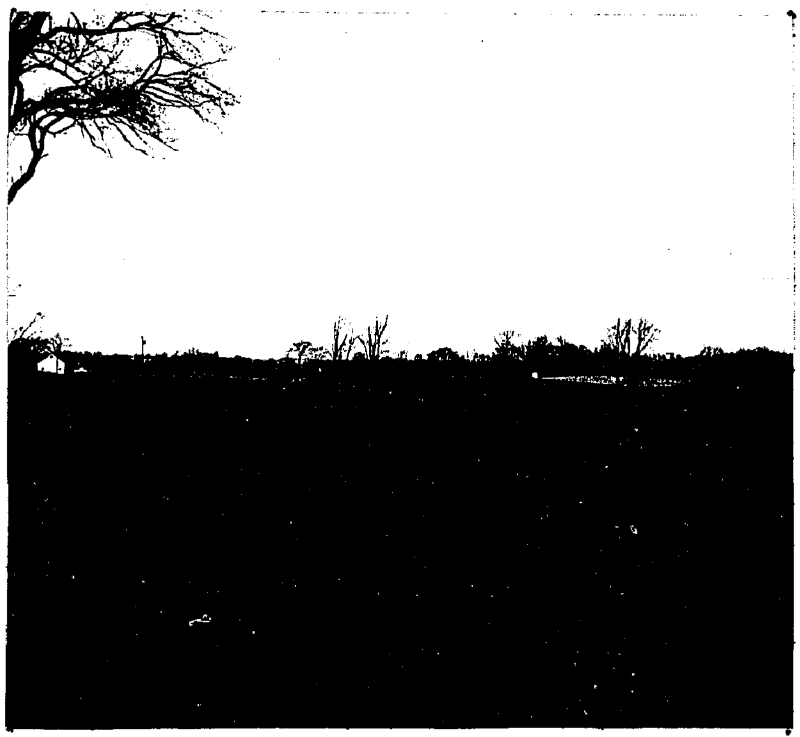
Moraines identified in the area of this study.

<u>Shiloh Moraine Knot</u>: "Shiloh moraine knot" is the name given in this paper to that area in northern Richland County, south of Plymouth, where the Wabash, Fort Wayne and several lesser morainic belts merge (Pl. VIII). The frontal crest of the Wabash does continue across the southern portion of the knot, but within the body of the complex jumbled drift knolls, kames and eskers are the rule (Pl. IX, Fig. 1 and Pl. XIV, Fig. 2). The till is somewhat sandy and underlying lenses and layers of sand and gravel are common (See p.92).

There are at least two ways of looking at the relationship of the knot to other larger features: 1) The area is interlobate in position between the Scioto and Killbuck lobes. This interlobate position, especially between lobes of such unequal development as the Killbuck and Scioto would mean the overlapping and piling up of moraines one on top of the other, so that the belt of morainic topography is not the result of one advance of the ice. 2) The bedrock of the Low Plateau and particularly its western boundary, the Berea escarpment, was enough of an obstacle during Cary time to allow only thin and sluggishly moving ice across this area. In this latter case moraine development would be irregular and stratified drift hills common.

The lobation itself, of course, merely reflects the presence of a bedrock obstacle, so that from either direction we ultimately approach the same answer: the Shiloh moraine knot is the result of the influence of bedrock on ice movement and deposition.

<u>Wabash Moraine</u>: The Wabash moraine lies entirely outside the two counties of this report, but it is mentioned here because it is an element within the Shiloh moraine knot.



Topography within Shiloh moraine knot southeast of Plymouth.

East of Shiloh, where two distinct belts of moraine are once again apparent, there is little doubt but that the southernmost is the Wabash for its crest can be traced from at least as far west as Bucyrus, Crawford County, to Rome, Richland County, i.e. along the southern edge of the knot. Several miles east of Rome some uncertainty as to crest lines arises because of the possible confusion with bedrock hills marking the edge of the Allegheny Plateau. Much more than a brief reconnaissance is needed to map this portion of the Wabash moraine with any accuracy. White (1933, p. 212), however, reports that the Wabash is quite distinct from Rome to the area of the Summit County Highland.

Fort Wayne Moraine: The Fort Wayne moraine merges with the Wabash in the vicinity of Tiro, Crawford County and a Fort Wayne crest is identifiable northwest of the Wabash crest for several miles. This crest is lost among a group of sand and gravel hills near the eastern edge of the Shiloh knot in Crawford County. Eastward from this point to Shiloh it was impossible to trace a continuous crest within the body of the moraine knot. At the northeastern limits of Shiloh, however, a sharp crest appears and it can be traced east and northeastward to the northern portion of Section 3, R. 18 W., T 23 N., Richland County. This crest and the northern morainic belt of which it is part is generally recognized as Fort Wayne.

From Section 3 to the Vermilion River valley no continuous crest was found, although the topography in southern Greenwich Township, Huron County, is distinctly morainic (Pl. IX, Fig. 2) with well-developed knobs and kettles. In northern Butler Township (Sections 1 and 2, R.18 W., T.23 N. and sections 5 and 6, R. 17 W., T 23 N.), Richland County, there are patches of good morainic knobs, but they are separated by areas of almost level ground moraine. This poor moraine development probably reflects the influence of the western edge of the Allegheny Plateau upon the ice.

East of the Vermilion River, on the uplands of the plateau, two crest lines occur within the Fort Wayne belt. One is near the front of the moraine and trends northeastward from Savannah; the other has a more easterly trend and lies within a half mile of the southern boundary of Ruggles Township, Ashland County. These two crests merge at the 1228 corner in the southeast corner of Troy Township, Ashland County, and from this point a single strong crest continues eastward at least as far as State Route 60, south of Sullivan, Ashland County.

New Washington Spur Moraine: As mentioned above (p. 29) the town of New Washington, Crawford County, is situated in an area of good morainic topography (Pl. X) which is part of a moraine belt mapped by White (1939) as extending from the northwestern corner of T.1 S., R16 E., Crawford County eastward into Richland County where it merges with the Fort Wayne and Wabash moraines in the Shiloh knot. I was able to trace a sharp crest in this moraine from just north of the village of Chatfield to Auburn Center near the Crawford-Richland county line, where it is lost among the jumble of till and gravel knolls at the western edge of the knot.

From Chatfield to Section 20, R.20 W., T 22 N., the southern limit of this belt is easily mapped for an old lake bed lies directly in front (south) of the moraine (Pl. X, Fig. 2). The northern limit is almost equally clear cut, being a boundary between the moraine and another abandoned lake bed now occupied, in part, by the Willard Marsh.

Fig. 1 - Topography within New Washington spur moraine east of New Washington.

Fig. 2 - View southward from New Washington spur moraine to Tabor Lake bed in the distance.

<u>Defiance Moraine</u>: G. K. Gilbert, in the course of his work in northwestern Ohio, was the first to recognize the Defiance moraine, or Blanchard as he called it (Gilbert, 1873, pp. 541-542). Approximately 30 years later Leverett (1902, pp. 586-589 and Pl. XIII) traced this moraine eastward across the area of Huron and adjacent counties. I am in general agreement with Leverett's mapping, although because of the criteria here used for drawing the line between the backslope and the ground moraine (p. 25) the width of the moraine as I have mapped it is sometimes greater. Then in one or two cases areas included within the moraine belt by Leverett have not been mapped as moraine in this study.

Moraine Front: From Attica in Seneca County to north of New Haven, Huron County, the front of the Defiance moraine is clearly marked for it rises abruptly above the flat land of an abandoned pro-glacial lake bed. Eastward from the New Haven vicinity to southwestern Fitchville Township the front is still easily discernible above the almost level ground moraine and an outwash channel.

In southwestern Fitchville Township there are two patches of morainic topography, within which are strong crests with a northeast-southwest trend. These patches are interpreted as being part of a northeast trending spur from the Shiloh knot. (See p. 40.) The crests are lost at the Vermilion River valley and the spur seems to be overlapped by the Defiance moraine (p. 41). West of the Vermilion River a strong moraine front is once again visible above the silty plain of another small proglacial lake bed (Pl. XI). Continuing eastward into Ruggles Township, Ashland County, the valley of Buck Creek marks the southern boundary of

View northward to front of Defiance moraine from New London Lake bed.

the moraine. From the eastern limits of Ruggles Township to the Medina County line, the Fort Wayne end Defiance moraines are separated only by the narrow valleys of Buck Creek and the West Fork of the Black River.

Moraine Crests: From Attica, Seneca County, to Celeryville in western Huron County, two good crests were traced within the Defiance moraine. At Celeryville the southernmost dies out, but the second continues to be well-developed as far eastward as the West Branch of the Huron River in southeastern Greenfield Township. North of New Haven and about three miles east of Celeryville a frontal crest is again present. It can be traced northeastward into the northwestern corner of Fitchville Township. Between this latter point and the Vermilion River there is no crest; instead there is a series of individual till and gravel knolls, often prominent in themselves, but which cannot be linked into a continuous crest. These knolls occur in a roughly north-south line along the west side of the Vermilion valley and a similar line is found on the east side of the river. (See p. 53.)

East of the Vermilion River near Fitchville a low frontal crest was mapped. As this is traced eastward, south of New London, it becomes stronger until it is quite prominent at Hereford, Ashland County. In the sector east of Hereford the Defiance moraine is at edge of the Allegheny Plateau section of the Appalachian Plateaus province.

Inner Border: The northern, or backslope, limit of the Defiance moraine in eastern Seneca County and across Norwich Township, Huron County, is relatively simple to map. Continuing eastward into Greenfield Township, however, the boundary becomes obscured in an area of more mature dissection. This area which occupies most of northern Greenfield Township and much of Peru Township, south of the Maumee III beach was included in the Defiance belt by Leverett (1902, p. 588). I believe, however, that the hills and rather deep swales represent destructional rather than constructional topography, for the tops of the divides show a gentle, continuous, northward slope to the level of the Maumee III beach. (See p. 115) Therefore, I have not included this area in the end moraine.

East of the Peru Center Road in northeast Greenfield Township there are till knobs which have a roughly north-south alignment along the western side of the Norwalk Esker. At its southern end this line appears to merge with the prominent crest which crosses State Route 61 in the southeast corner of Greenfield Township, although the hills themselves do not form a continuous ridge. Several auger holes in these hills showed till and no sand and gravel. The till, however, is somewhat sandier than normal for the Defiance moraine, and may be the result of some washing of the material. These knobs are included in the moraine so that there is a short northern extension between the two branches of the Huron River.

From the East Branch of the Huron River eastward to the Huron County limits the moraine lies across the Low Plateau. The exact placing of the northern boundary here may be open to some question, but it is felt that its location could be generally agreed upon within a mile or so.

A well-developed spur which includes the gravel hills on either side of the Vermilion River carries the northern limits of the Defiance north as far as central Hartland and Clarksfield townships. Beyond south-western Clarksfield Township the northern limits of the moraine are mapped as trending southeastward to the Lorain county line, just west of the village of Rochester in Lorain County.

An inner member of the Defiance moraine was traced westward by Leverett (1902, p. 581 and Pl. XIII) from Richfield, Summit County, through the city of Medina, to a point 5 miles north of Lodi and then into Huron County, north of the latitude of Rochester. I could find no evidence for such a morainic belt in Huron County, nor, for that matter, west of the Rochester-Huntington township line in Lorain County. Just north of the village of Huntington, in the latter township, however, the crest of this member is easily discernible. Leverett's method of mapping end moraines led him to show ground moraine between this inner belt and the main outer belt. Using the criteria outlined above (p. 25), however, there is no ground moraine between the two belts in Huntington Township.

Delphi Spur Moraine: An area of morainic topography within which north-northeast trending crests were mapped in southwestern Fitchville Township, Huron County, has been mentioned above (p. 36). A glacial outwash channel (See p. 55) divides the area into two distinct parts and also serves to separate the westernmost patch from the Defiance moraine to the north.

The tract which lies east of the channel is approximately 1.75 miles in width and three miles long. That which lies west of the channel is mapped as extending from State Route 161 to the Shiloh knot at Plymouth. A crest within this western area of moraine can be traced from the northern end near Route 161 to central Ripley Township south of the Delphi cross-roads. West of this point the topography is only weakly morainic and the crest which is shown on the map (Pl. I) as extending southwestward from the vicinity of Delphi to the Shiloh knot is an extremely tenuous one.

The extreme northern limit of the Delphi spur is marked by the outwash channel, and if ever this belt of moraine extended farther northward, it has been overlapped by the Defiance (See p. 36). From the channel border to Boughtonville the boundary between end and ground moraine is easily mapped. West of Boughtonville the blackslope abuts against the old Willard lake bed and a clear-cut boundary is present. North of Plymouth, at the western end of the belt, the boundary is still one between lake bed and end moraine. This western moraine edge is affected by the Berea sandstone which here underlies relatively thin till and hills of stratified drift.

Ground Moraine

The second major catagory of forms resulting from direct glacial deposition is ground moraine. In the area of this investigation the largest expanse of continuous ground moraine lies between the Defiance moraine and the highest Maumee beach. In front of the Defiance, in Huron County, the belt of ground moraine is narrow and much of it has been modified by the lacustrine processes within small pro-glacial lakes.

The surface of the ground moraine is typically flat or gently rolling (10 to 15 feet of relief within a square mile) and represents an area over which the ice edge retreated rapidly without halting. In Erie and Huron counties two types of features interrupt this surface of low relief: bedrock hills and eskers and kames.

The presence of Berea sandstone hills capped by only thin till in southeastern Erie County and northeastern Huron County (Pl. V, Fig. 2) has already been mentioned in connection with the relief of the Low Plateau (p. 13). In Lyme Township, Huron County, within the Till Plain section, the carbonate rocks of the Devonian lie close to the surface and the long low ridges and sharp sinkholes are the result of their presence rather than of glacial deposition.

The Hartland esker lies entirely on the ground moraine and, although its maximum height is not great, it is prominent because of the contrast with the nearly level ground moraine surface which surrounds it (Pl. XIII). Only portions of the Norwalk and Ripley eskers are within the borders of the ground moraine.

Glacio-fluvial Features

The glacial features included under this heading are kames, eskers and outwash. Meltwater from glaciers was the active agent in their formation so that they consist of sorted and stratified material. The eskers, of which there are three in the area of this report, are perhaps the most prominent topographically of these glacio-fluvial features.

Eskers

An esker is defined by Flint (1947, p. 150) as "a long narrow ice-contact ridge commonly sinuous and composed chiefly of stratified drift". There is a rather wide variation in size, i.e. length and height, and the crest may be either smooth or "broadly hummocky".

The locations of the Huron County eskers are shown on plates I and VIII. Leverett first described and named the Hartland esker (1902, p. 616) for the township in which it is located. He also described briefly and gave the name "Norwalk" to the largest of these eskers (1902, pp. 587-588). Later Stout (1943, p. 37 and map opp. p. 20), emphasizing the segmentation of the latter ridge, designated the northern portion the "Norwalk esker", and the southern, the "Fairfield esker". I see no reason for the two names, for the northern end of Stout's Fairfield esker and the southern end of his Norwalk esker are separated by less than three-tenths of a mile, and additional segments have been mapped both to the north and south of those which he recognized. The third and smallest esker ridge does not appear to have been mentioned previously in the literature. The name "Ripley" is, therefore, suggested for it, since it lies entirely within that township. The Hartland and Norwalk eskers lie on the north edge of the Defiance moraine; the Ripley esker is south of it.

Description of the Huron County Eskers: The three Huron County eskers range from approximately one and three-tenths miles to five miles in length and the maximum relief varies from approximately 18 feet to 72 feet. All have a general north-south orientation.

Norwalk Esker: This is the largest of the three glacio-fluvial ridges. It has a total length of four and eight-tenths miles within which distance several segments may be recognized. It is located near the western township lines of Bronson and Fairfield townships. Ridge Road, a county road, follows along its crest.

The valley of the East Branch of the Huron River is just east of the middle segments of the ridge and here the river roughly marks the

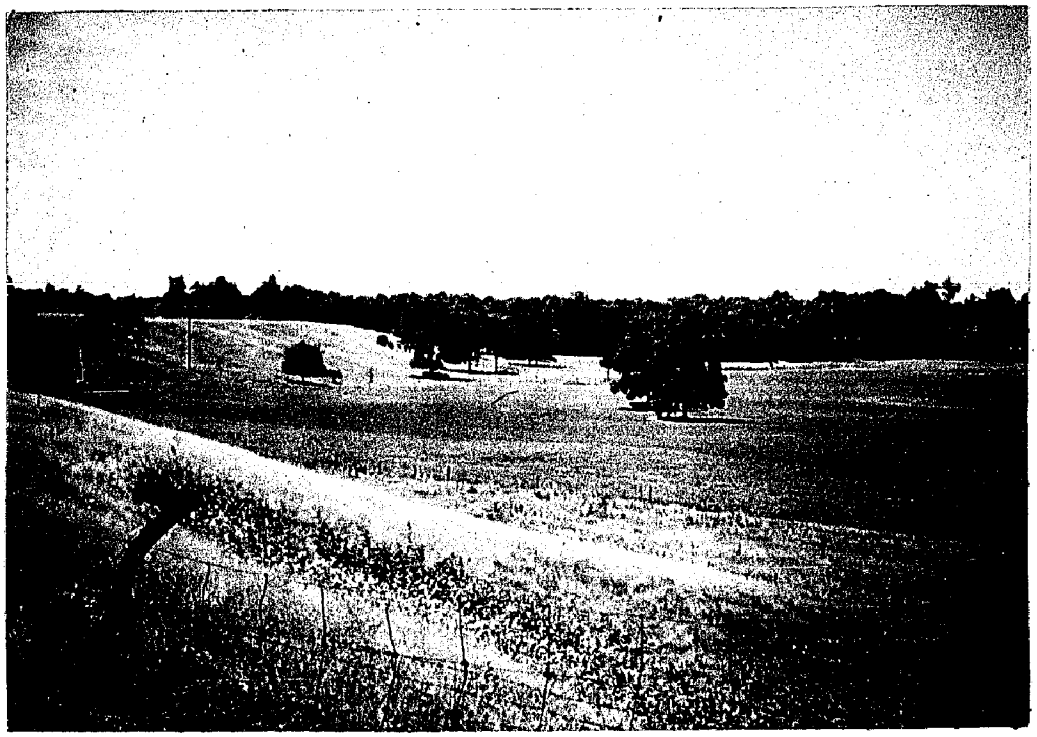


Fig. 1 - Portion of Norwalk esker.

Fig. 2 - View of Norwalk esker showing branches and partially enclosed basin.

updip edge of the Berea sandstone. In other words, the Norwalk esker is located above the contact between the Bedford shale and the Berea sandstone.

The outline of the Norwalk esker, particularly in the middle portions, is highly irregular with numerous short arms branching out along the west side of the main ridge and partially enclosing small basins (Pl. XII). The arms frequently recurve toward the main ridge but never quite merge with it again.

The crest of the main ridge is quite hummocky and the appendages branch out from the higher knobs. The ridge is generally between 40 and 50 feet high and attains a maximum height of 72 feet. The northern segments are separated from the rest of the ridge by the valleys of the East Branch of the Huron River and a small tributary. For about a mile south of the southern end of the esker, as mapped, there is a line of very low conical mounds which consist of sand and gravel, and beyond the northern end of the true esker is a small group of kame hills.

Some of the higher knobs consist of very poorly sorted material which it is perhaps best to call "till". This till, however, is much sandier than the till of the Defiance moraine and has probably been washed to some extent. In sand and gravel pits along the length of the esker the sorted material sometimes lies directly on bedrock (Bedford shale) and sometimes, on blue till.

Two pebble counts (counts of pieces one to three inches in diameter) from pits in the esker show that well over three-quarters of the material of pebble size is from bedrock found in the two counties of this report.

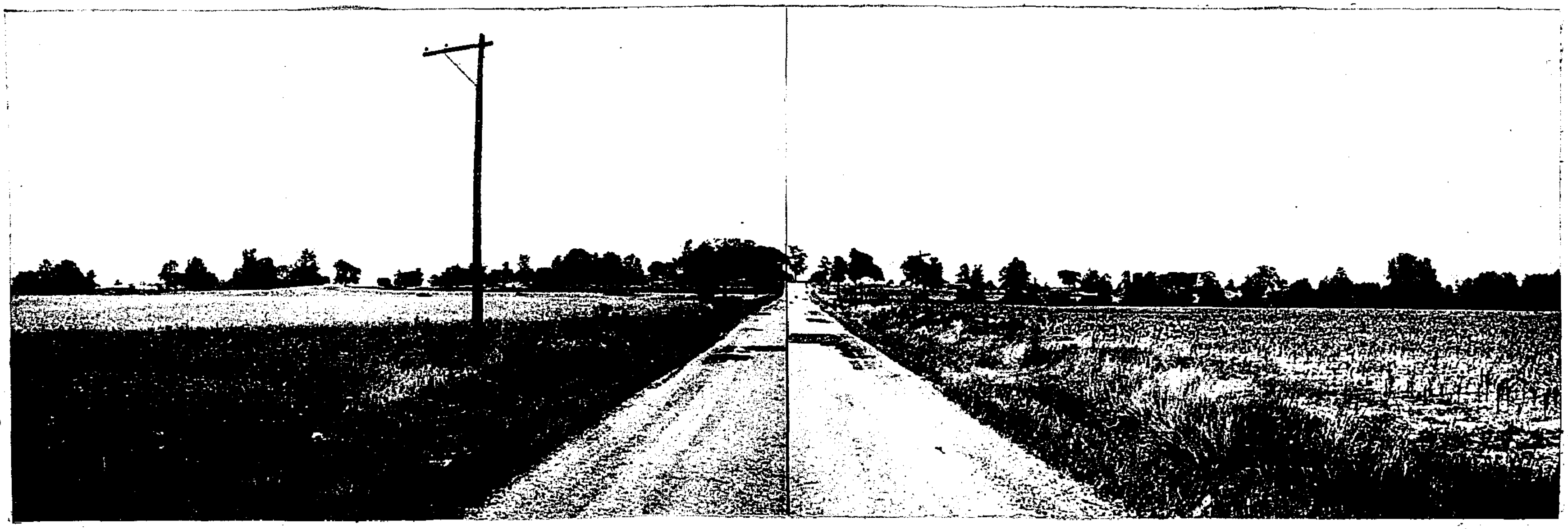
These counts, which were made from localities about a mile and a half apart, were very similar in distribution of rock types. The following table gives the average of the two counts:

TABLE II

Pebble Counts from the Norwalk Esker

Sedimentary rocks		
Mississippian sandstone	32%	
Devonian and Mississippian black shale	29	
Mississippian shale	2	
clay ironstone (from the Huron shale)	1	
Silurian dolomite	6	
Devonian limestone	9	
chert (from Devonian limestone)	3	
TOTAL SEDIMENTARY ROCKS		82%
Igneous rocks		
Acidic	10%	
Basic	4	
	14%	
Metamorphic rocks		
Quartzite	1%	
others	3	
TOTAL CRYSTALLINE ROCKS		18%

Hartland Esker: The Hartland esker is located in the northeastern part of Hartland Township. It has a total length of two and two-tenths miles and a maximum height above the ground moraine of about 20 feet (Pl. XIII). The trend of the ridge is roughly north-south, with the northern portion trending slightly to the east of south, and the southern, slightly to the southwest. DeRussey Road, a county road, follows the crest of the ridge.



Northern end of Hartland esker from the west.

Pl. XIII

This esker is much more regular in outline than the Norwalk esker, lacking entirely the short curved appendages. Its downstream terminus is an abrupt one, although a small kame about three-tenths of a mile to the south may quite properly be considered a part. Another small gravel hill lies a few hundred feet east of the northern end of the ridge.

A number of small pits have been opened in the ridge and within the northern segment these pits show a nice gradation in the size of the material making up the ridge. In the northernmost pit, between State Route 18 and the Wheeling and Lake Erie Railroad, the average size of the material is about three inches in diameter. This cobble is almost entirely of Mississippian sandstone. In excavations to the south a gradual decrease in average size of the material is noticeable. A pit at the northern end of the southern segment once again shows a deposit of cobbly character, however.

No clear-cut evidence of till overlying the sand and gravel was found. On the contrary soil derived from the sand and gravel seemed to extend all the way down the slopes to the level of the ground moraine.

Ripley Esker: The Ripley esker, which is located in eastern Ripley Township, one and a half miles west of the town of Greenwich, is the smallest of the eskers recognized in Huron County. It is one and three-tenths miles long and rises to a maximum height of eighteen feet. Its northern end lies within the border of the Delphi spur and its southern terminus is on the ground moraine between the spur and the Fort Wayne moraine. There are no sand or gravel pits in the ridge, but road cuts show the rudely sorted character of the material.

At the northern end of the esker and en echelon to the west there is a parallel line of small scattered sand and gravel knolls. In the interval of the offset there is an old outwash channel which here contains a small seasonal tributary of the Vermilion River.

Extension of Ripley Esker in Richland County

About eight-tenths of a mile south of the Ripley esker there is a prominent kame which rises 30 feet above the almost level ground moraine (Pl. XIV, Fig. 1). It is one in a series of kames which forms a tenuous connection between the Ripley esker and another short gravel ridge north of Shiloh in Cass Township, Richland County. If the kames and the two gravel ridges are considered part of one esker chain, the chain has a total length of approximately eight miles. Within the borders of Huron County and south to Shiloh this chain is bordered by outwash.

Relationship of the Ripley-Shiloh Esker Chain to the Moraines

The relationship of this esker chain to the Delphi and Fort Wayne moraines gives a clue to the relative age of the two morainic belts. The northern part of the chain lies within the borders of the Delphi Spur; its southern end, on the north-facing slope of the Fort Wayne moraine at the eastern end of the Shiloh knot. The alignment does seem to suggest that they were formed along the same drainage line, although not necessarily contemporaneously. If this interpretation is accepted, the Delphi spur is seen as marking a local halt in the melting back of the ice from its Fort Wayne position.

This origin for the Delphi Spur would also help to explain its generally weak development. Reference has already been made to the possible influence of the Berea escarpment in this respect, but it should also be pointed out that in the case of a halt, such as is here envisioned, the material of the moraine would all be dumped from the moraine front and no ice push or thrust, such as might be expected from readvancing ice, would be involved.

Formation of Eskers: It is generally agreed that eskers are the deposits of glacial streams, but whether these streams were subglacial, englacial or superglacial has been the subject of some controversy. (See Flint, 1947, pp. 151-155 and references.) It is quite possible that all three types of streams have built stratified drift ridges, although the weight of evidence seems to point to streams of subglacial or englacial position.

It would also seem that eskers are formed near the front of glaciers. Evidence for this lies in their frequent orientation roughly at right angles to the nearest recessional moraines. Also many eskers have expansions downstream which represent deltas formed where the streams debouched at the glacier front. It is to be expected, furthermore, that persistent mills and crevasses, through which subglacial or englacial streams are fed, will be restricted to the terminal portions of a continental glacier. Eskers are also believed to be indicative of stagnant, or, at the very most, thin and sluggishly moving ice. The argument for this last point is based on the sinuosity and irregularity of esker outlines generally, for it seems unlikely that such forms could long persist under actively moving ice.

Local Evidence for Mode of Origin: Some evidence regarding the mode of formation of eskers can be derived from the descriptions of the Huron County eskers given above:

The relationship of the Norwalk esker to the line of contact between the Bedford shale and Berea sandstone is an interesting one. It seems to be a case similar to those commented upon by Winchell (1874, p. 247) and Leverett (1902, p. 542). These authors pointed out the coincidence of the position of many (not all) Ohio eskers with underlying bedrock contacts, where there is a relatively soft rock on one side and more resistant beds on the other. Such a relationship seems clearly indicative of bedrock influence and certainly suggests that the esker-depositing stream was flowing on or very close to bedrock.

The presence of till on esker crests has been set forth as evidence that the ridge-forming streams were subglacial, or at least englacial, for when the ice arch above the stream collapsed or melted down till would be let down on the stream gravels. In the Huron County eskers it was pointed out that questionable sandy till is present on the higher knobs of the Norwalk esker, but that nothing which could be identified as till was found on the Hartland esker. The absence of till certainly does not preclude a subglacial origin, however. If flow of water continued after collapse of the ice roof, or if the formation of the esker had been entirely within an ice-wall canal, till falling from the ice surface would be reworked. (See Goldthwait, L., 1939, p. 114)

All of the evidence in this area of northern Ohio seems to support the theory that the glacial ice, at the time the eskers and associated deposits were formed, was stagnant, thin and honey-combed with crevasses and mills. There is the irregular outline of the Norwalk esker ridge, the many kames, the poor development of till moraines where there are eskers and kames and the presence of little if any till on the eskers.

The segmentation of the esker ridges may possibly represent stages in the retreat of the ice, but evidence for this interpretation was found only in the case of the Hartland esker. Here there is the gradation from coarse to fine material in a downstream direction within the northern segment and then somewhat coarser material again within the adjacent parts of the southern segment. This suggests that the two portions of the ridge were developed during two different seasons of melting.

Kames

Kame hills are also ice contact features which consist largely of sand and gravel and show varying degrees of stratification. Kames, however, lack the linearity which characterizes eskers. According to Flint (1947, p. 147-148) the material of kame hills was originally deposited "in or on the surface of stagnant or nearly stagnant ice which later melted away, leaving the accumulated sediments in the form of isolated or semi-isolated mounds".

A number of areas of kame hills have already been mentioned in the descriptions of moraines and eskers. These kames may be enumerated briefly as follows: those of the Defiance moraine spur near the Vermilion River (p. 39), those at the western end of the Shiloh knot (p. 31) and those associated with the esker trends: Norwalk, Hartland and Ripley (pp. 43-49). The latter includes the kame hills north of Shiloh, in Richland and extreme southern Huron counties.

Vermilion Spur Kames: Under this heading are grouped the kames which are present along either side of the Vermilion River in a northward projecting spur of the Defiance moraine.

The most prominent of the kames on the east side of the valley rises 35 feet above the surrounding level and is located in southeastern Hartland Township in the angle formed by the East Greenwich Town Line Road and Exchange Road. Extending southward in a sinuous line from this knoll are other hills which appear to be composed largely of sand and gravel. (There were no pits or excavations in any of these hills at the time of this study and the statements concerning their composition are based in most cases on six-foot auger borings, roadcuts and the reports of farmers.) The line connecting the individual knolls joins the main trend of the Defiance in an area which is truly morainic in topography, but where the till is sandier and the depth of leaching somewhat greater than average for the Defiance belt. (See Pl.XIX) No good continuous crests within the moraine are present in this area.

The position of the northernmost of these kame hills is such as to suggest that they may represent the same line of drainage as the Hartland esker, although the valley of the Vermilion River now cuts through the general trend.

Plymouth Area Kames: Reference has been made to a group of kames which lie along the western edge of the Shiloh knot. For convenience these kames will be referred to as the "Plymouth area kames", the name being taken from the town of Plymouth on the Richland-Huron county line. Like all of the other kames which were recognized in the area of this

Fig. 1 - Ripley kame from outwash channel on west.

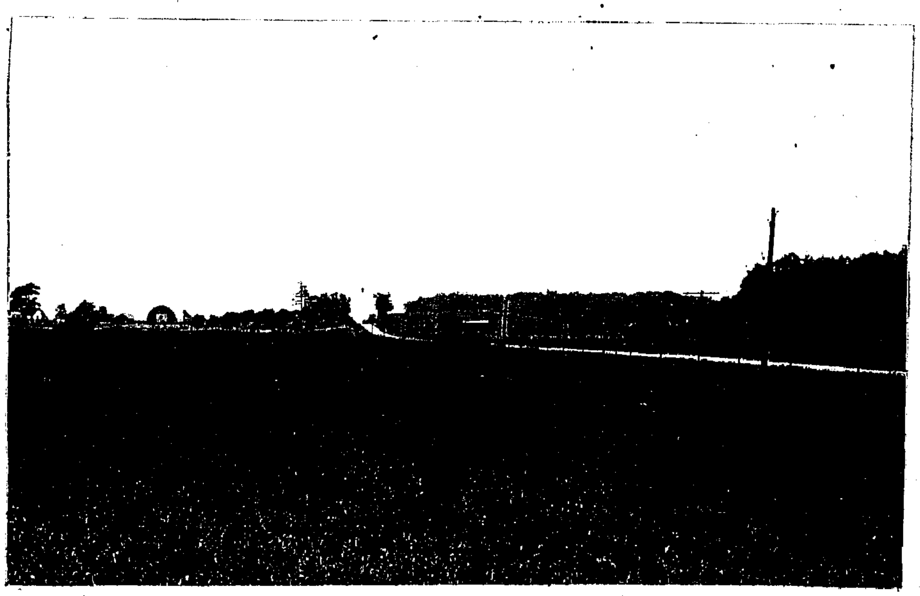


Fig. 2 - Kame along Base Line Road west of Plymouth.

study, these kames, although recognizable as individual hills (Pl. XIV, Fig. 2), have a linear arrangement often apparently related to the trend of an esker. Within the Plymouth kame area no ridge with the degree of elongation necessary for an esker was identified, but the kames do seem to be lined up along the updip edge of the Berea sandstone. (See p. 51).

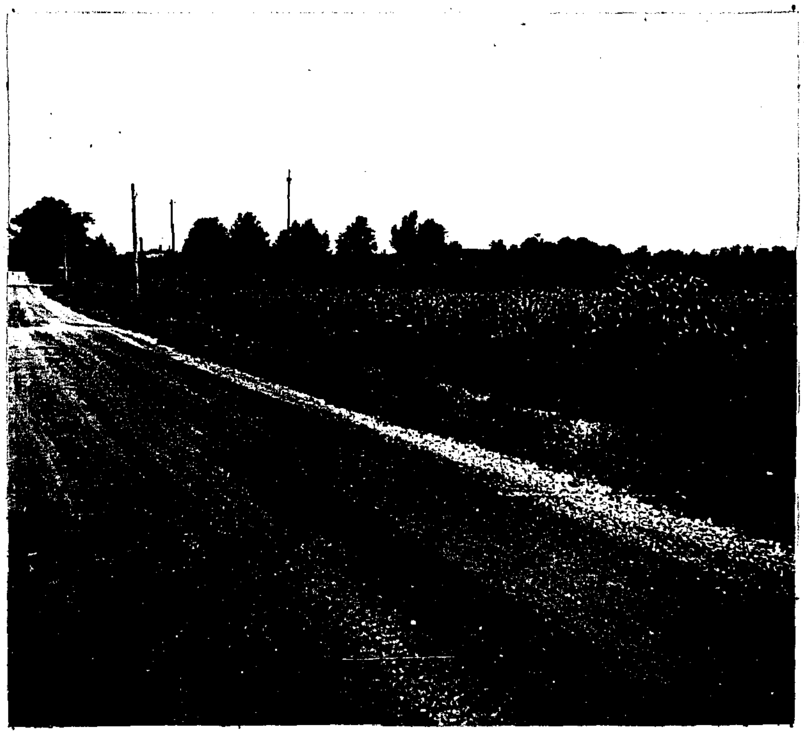
Most of the kames in this group are in Richland County. There are, however, several pits in the kames north of the intersection of the Base Line Road (Huron-Richland County line) and State Route 598, west of Plymouth. Exposures in these pits show rather good stratification although it is interrupted by small faults and slumping.

Shiloh Area Kames: It has already been suggested that this area of sand and gravel hills is related to the Ripley esker (p. 49). In addition it should be pointed out that these washed deposits mark the western edge of the Shiloh knot.

Several small pits near the intersection of the Base Line Road and the Old State Road, show the washed and stratified nature of the material in the hillocks (Pl. XV).

Outwash

A well marked outwash channel was mapped as extending from the front of the Defiance moraine in western Fitchville Township, through the Delphi Spur in Ripley Township. South of the spur moraine there is some expansion of the channel, but it becomes restricted again as it passes through the Shiloh Knot near Shiloh in Richland County. Although no auger borings were made south of the town of Shiloh, the



Kame with old gravel pit north of Shiloh.

topography suggests that the channel continues southward through the Wabash moraine.

At the time this study was made there was a sand and gravel operation within the channel at the angle made by the Greenwich-Milan TownLine Road and the Fairfield Angling Road in the extreme southeast corner of Fairfield Township (Pl. XVI). Here four feet of soil overlies at least 20 feet of outwash sand and gravel. The channel nature of the deposit was clearly shown in the pit for the operation was limited on the northwest by a sharp wedging-out of the sorted material in that direction.

The line of meltwater drainage marked by this outwash is closely associated with the Ripley esker chain. At its northern end it lies east of the kames, and south of the north end of the Ripley esker itself, the outwash is just west of the chain and continues so into the Shiloh Knot (See Pl. I). This close geographic association raises the question as to whether the two drainage lines are genetically related: Was a line of drainage first established by a subglacial stream which then influenced the location of meltwater drainage as the ice retreated from the region, or is the association merely fortuitous? If the former is the case, esker chain and outwash channel belong to the same period of ice advance (or retreat). If the latter is true, different subdivisions of the Wisconsin stage may be represented.

An "Early" Cary age is pretty well established for the esker and kames because they lie in an area south of the finer till which is recognized as Late Cary (p. 90). The outwash channel has its northern end at the south edge of the Defiance moraine, but in an area where the

Outwash channel with sand and gravel operation, southeastern Fairfield Township, Huron County.

Defiance seems to have overridden an earlier moraine. The channel may well have carried some meltwater when the ice stood at the position of the Defiance moraine, but it appears that the main direction of pro-morainal drainage during Defiance time was to the west (p. 36). It is believed, therefore, that the outwash channel through the Delphi Spur was developed when the ice was retreating from the position it had held when the Ripley esker was built and that both are of "Early" Cary age. The northern end of the channel, however, was later incorporated into the pro-morainal drainage of the Defiance moraine (p. 64).

Pro-morainal Lake Beds

Maps of Ohio showing the outlines of the lacustrine plain frequently show a long narrow arm connected with the shoreline of the highest Maumee level and extending eastward from Findlay, Hancock County, to south of New London, Huron County. The interpretation often given is that the shoreline of Lake Maumee I can be traced into southern Huron County. A glance at the topographic maps shows, however, that south of New London, at the eastern extremity of this arm, the lowest elevation is approximately 980 feet, or 180 feet above the level of Maumee I. The representation of this seeming embayment can be traced back to Leverett's 1902 monograph (Pl. XIII). There the legend of the map establishes that what Leverett meant to indicate was an old pro-morainal valley or channel, and the text is very clear on the matter (Leverett, 1902, pp. 610-611).

> "The position of the Defiance moraine being in large part on the slope toward Lake Erie, the facilities for discharge of glacial waters during its production are not likely to have been so good as in the preceding moraines. It is probable that small

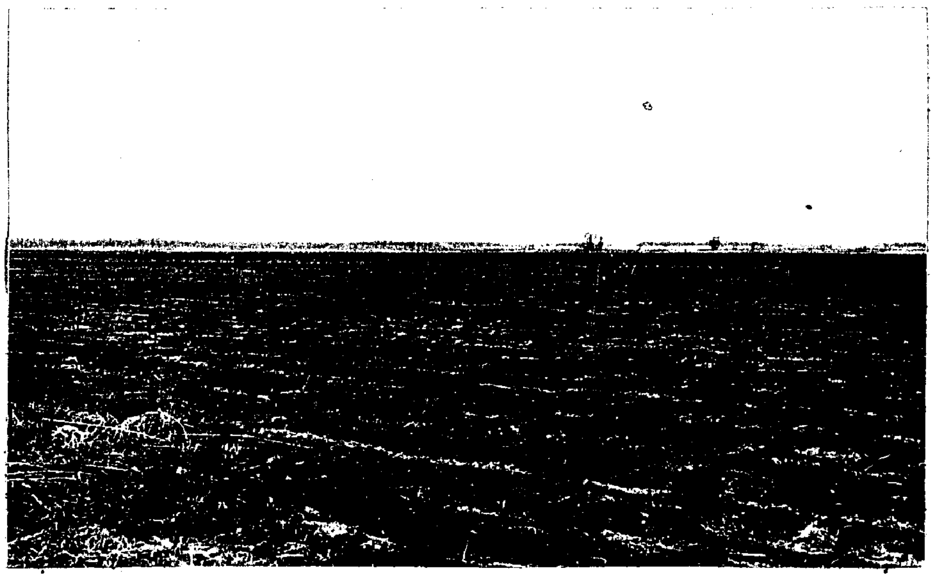
lakes were formed along the south border of the ice which found discharge either southward across low places on the divide or westward along the front of the ice sheet."

"From the Vermilion River westward there was drainage along the ice margin to Lake Maumee, but the water leading westward from the Vermilion drainage basin was apparently gathered into a narrow lake in the Huron River basin near New Haven that discharged past Attica to another narrow lake in the Sandusky basin. The latter discharged westward from Carey to Lake Maumee at Findlay. The line of discharge past Carey is marked by a definite channel brought to notice by Winchell. The chain of lakes and connecting channels just outlined show a decrease in altitude in passing from east to west. The channel in the Vermilion drainage basin is estimated to have an altitude above 950 feet above tide and decends about 25 feet to reach New Haven in the Huron River basin. The extensive New Haven Marsh, which extends westward from the Huron River basin near New Haven to the head of Honey Creek ... near Attica stands about 925 feet above tide, and probably represents nearly the level of the lake in the Huron basin. There was a descent of about 100 feet along Honey Creek from this lake to the one in the Sandusky basin...."

Willard Lake

In the above excerpt mention is made of the lake in the Huron River basin. Today one of the most extensive peat deposits in Ohio lies within this old lake bed (Pl. XVII) and supports truck gardening enterprises from which celery, onions and similar garden products are shipped to markets all over the state. This area is variously referred to as the "New Haven Marsh", "Huron Marsh", "Willard Marsh", "Celeryville Muck area" or simply, "the Muck". In this paper the name "Willard Marsh" will be used to designate the present peat area, both drained and undrained; and "Willard Lake bed", the entire basin of the old pro-morainal lake of which the peat deposits cover only a relatively small part.

Extent of Willard Lake: In keeping with the method of mapping other features the lake bed was delineated on the basis of topography (Pl. I).



View northward across the Willard Lake bed to the Defiance moraine.

Hubbard and Rockwood (1942, p. 224) mapped this lake area on the basis of silt distribution, so that portions of what is here called end moraine are considered by them as part of a 90-square mile lake bed. According to these authors silts are found at elevations of 980 to 985 on the south shore of Willard Lake, but are approximately 10 feet lower along the northern boundary on the Defiance moraine. This is interpreted to mean that at the time of the 980-foot water level the lake water lapped directly against ice on the north.

If the distribution of silts is as reported by Hubbard and Rockwood, I was unable to corroborate it. All of the soils present along the Defiance moraine here are developed in till and I could not distinguish the presence of lacustrine silts in the profile. It is true (see p. 93) that the till of the Defiance belt west of the Huron River (East Branch) is siltier than that of the eastern part of the county, but this difference is here interpreted to be the result of bedrock source materials.

In the summer of 1951 a mastodon was unearthed during the deepening of a drainage ditch on the farm of J. R. Stockley on the Fort Ball Road just east of the Baltimore and Ohio Railroad. The site of burial is topographically a kettle hole near the front of the moraine, although on the basis of Hubbard's 970-foot figure for lake level the location would be within the borders of the lake bed.

At the present time the area covered by the peat of the Willard Marsh is approximately 12 square miles. When settlers first came into the area it was larger by several thousand acres, but has since been reduced by burning.

<u>Lacustrine Sediments</u>: Dachnowski (1912, p. 83) reports a thick-

ness of approximately 17 feet of peat in the center of the marsh, southwest of Celeryville. Using a six-foot auger the peat could be passed through completely only along the edges of the marsh. Several sections there, however, showed one or two feet of silty clay below the peat, which in turn was underlain by well laminated material.

The southwest corner of the marsh is bordered by extensive deposits of sand and gravel. These are not to be confused with beaches, although the lake water undoubtedly reworked some of the material. These are the kames which have previously been referred to under the discussion of the Plymouth area kames (p. 53).

Present Drainage: The divide between the Sandusky and Huron River basins lies within the Willard Marsh. Honey Creek, a tributary of the Sandusky River, drains about two-thirds of the present marsh, while the eastern portion is drained by Marsh Run in the Huron River basin. Man-made drainage ditches have perhaps shifted the original divide somewhat so that Honey Creek gets more of the waters than it originally did.

New London Lake

In addition to the easily recognizable pro-moraine Willard Lake bed, evidence was found for a smaller and shorter-lived lake in the Vermilion valley between Fitchville and New London at the eastern end of the pro-moraine channel described by Leverett (1902, pp. 610-611). M. C. Read (1878, p.298) had noted the lake bed-like nature of the area in his report on the geology of Huron County. The rather prominent front of the Defiance moraine in this sector has already been described (p.36). Its prominence here is due in great part to the contrast between the moraine topography and the level lake bed to the south (Pl. XI).

Auger holes and stream cuts within the area here called "New London Lake bed" showed no clearly laminated silts or clays, but the soils are developed in material which may either be interpreted as a silty clay till with only rare pebbles or as a silty lake clay. Since the silt content is considerably higher than that of any undoubted till in the immediate neighborhood and the altitude to which the silty soils extend is rather constant at 990 to 995 feet, the latter interpretation is supported. No peat was found within this lacustrine bed, however.

What is believed to be the first outlet for this lake is to be found along the north central edge of the Greenwich Township at an elevation of 990 feet. From this point the drainage seems to have been north around the Delphi spur and then southwest to Willard Lake. When the ice retreated from the position of the Defiance moraine a lower outlet toward the north was found, the post-glacial Vermilion River came into being, and the lake was drained.

Tabor School Lake

Only brief mention will be made of this lake bed as it lies entirely outside the borders of Huron County, between the New Washington and Fort Wayne moraines (Pl.,X, Fig. 2). The area of this lake has been mapped by Hubbard and Rockwood (1942, p. 247), and Dachnowski reports that the peat deposits here once covered 2,000 acres, which are now completely drained and largely under cultivation (Dachnowski, 1912, p. 46).

The lake sediments observed in auger holes and stream cuts here are clearly laminated. The section seen in a stream cut one-half mile south of the New Washington moraine front near State Route 39 showed 18 inches of till above four feet of laminated lake sediments, indicating a readvance of the ice after the lake had existed for some time.

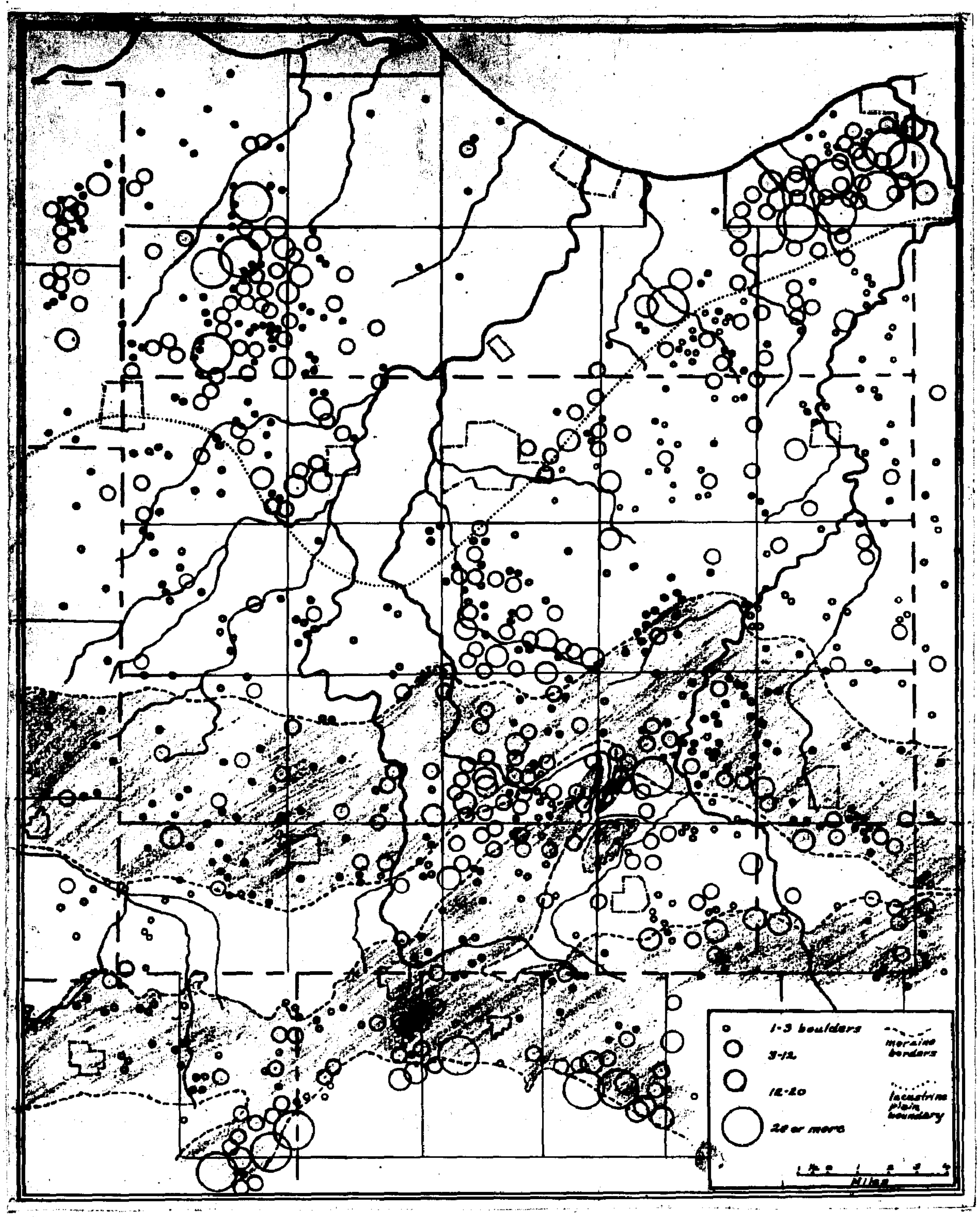
ERRATIC BOULDERS

The relative distribution of boulder-sized material in the two counties of this report and parts of adjacent counties is shown on Plate XVIII. Some of the larger concentrations are obvious in the field, for example, the larger number of boulders along the southern face of the Wabash morainic belt in Richland and eastern Crawford counties can hardly go unnoticed by anyone who drives along the roads here. The accumulation near Rome, Richland County, is of particular interest for this is the area of the tillite and varved slate erratics upon which Dr. White (1939) has reported.

The concentration of boulders on the surface along the front of the Defiance belt between the Huron and Vermilion rivers was not recognized until the results of the count were plotted. I believe that in this area they offer evidence that the late Cary till here was subjected to more than usual washing by glacio-fluvial waters. (See p.90below.)

The accumulations on the lake plain are obviously residual accumulations left after the finer materials had been washed away by wave action, and they thus mark the areas which were strongly affected by wave erosion at various lake stages. (See p. 140below.)

None of the boulders observed in Erie County were notable for size, but one stands out in this respect among those seen in Huron County. It is located on the Defiance moraine along the west side of Chenango Road, Pl. XVIII



Boulder distribution. Map showing relative concentration of glacial boulders.

between State Route 162 and Town Line Road (Huron-Ashland county line). The size of this boulder was estimated at about 100 cubic feet and its weight at approximately eight tons.

STRIAE

Several measurements of striae were made during the field work for this report, but the directions of ice movement indicated by them add nothing to that known from earlier reports (see Chamberlin, 1883, Pl. XXXI). The following is a tabulation of bearings recorded in the literature for this part of Ohio with the addition of several new ones:

TABLE III
Bearings on Striae in North Central Ohio

Location	Bearings	Source	Remarks
West Amherst, Lorain Co.	S. 30 W.	Leverett	
Henrietta, Lorain Co.	S. 20-25 W.	Leverett	
Birmingham (2 miles south of - on Lorain-Erie county line).	S. 19 W. & S. 77 W.	Leverett	
Townsend Twp., Huron Co.	S. 45 W.	Read	
Sandusky, Erie Co.	S. 75-81 W.	Newberry	
Sandusky (quarry south of Soldiers' Home), Erie Co.	S. 67-80 W.	Campbell	S. 70-74 dominant
Castalia (south of Bogart-Maple Ave. intersection), Erie Co.	S. 65-87 W.	Campbell	S. 70 W. the strongest
Castalia (abandoned quarry south of S.R.12), Erie Co.	S. 67-82 W.	Campbell	S. 67-70 W. dominant
Bellevue, Sandusky Co.	S. 65 W.	Gilbert	
Flat Rock, Seneca Co.	S. 55 W.	Campbell	
Republic (4 miles east of-), Seneca Co.	S. 25 W.	Gilbert	

These locations are not closely enough spaced to indicate whether the Berea escarpment in Erie County offered significant protection for the area immediately to the south. The general picture, however, is that in the last stages of glaciation, at least, the ice, once past the edge of the Berea outcrop, here turned southward into the Scioto lobe.

CHARACTERISTICS AND CORRELATIONS OF TILL SHEETS IN NORTH CENTRAL OHIO

DIVISION OF THE PLEISTOCENE EPOCH

The expansion or contraction of an ice sheet is in no sense a continuous movement, i.e., it does not expand continuously until the maximum extent is reached and then contract steadily to a relatively small nucleus. Rather the ice front oscillates back and forth, retreating at one time and then advancing to cover an almost equal, greater or smaller area. This oscillation may be in terms of a few hundred feet and be restricted to a few miles along the ice front, or it may be in terms of hundreds of miles along the whole edge or a wide sector of it.

The periods of ice retreat serve to divide the Pleistocene epoch into stages and substages. In the intervals between the stages it seems likely that the continental ice sheet may have disappeared entirely or have shrunk to small and isolated ice caps. The retreats which serve to divide the stages into substages are harder to define; they are probably measurable in hundreds of miles, however.

Within the glaciated areas evidence for the advances lies in the deposits of the ice sheets; for the retreats, in forest beds, buried profiles of weathering etc. At the present time detailed studies of these deposits in some areas are making it possible to recognize further subdivisions within the subdivisions. Such detail is limited to the Wisconsin stage, for in the earlier divisions evidence has been obscured by time as well as overlying deposits. In this last stage, however, it is possible to speak of "late" Cary, "early" Mankato, etc. The amount of ice retreat involved between these divisions is apparently quite variable. In some cases it may be on the order of a hundred miles; in others, such as that which preceded the late Cary advance here in Ohio, it appears to have been a matter of several hundreds of miles, or as much as separates the Mankato from the Cary substage.

Of course, in defining the time units of the Pleistocene factors other than the amount of retreat in a local area must be considered. The time involved is important as is also whether or not the entire ice front was affected or only a small portion of it. It is possible, nonetheless, that with the continued growth of knowledge it may be necessary to reevaluate the categorical levels to which the various divisions are assigned.

AGE OF THE PLEISTOCENE DEPOSITS OF OHIO

On the basis of evidence present within the state, deposits of at least two stadial advances of the ice are recognized in Ohio. Whether or not a pre-Illinoian advance is represented has been the subject for some debate (Stout et al, 1943, p. 23 and 1953; White, 1942 and 1951, p. 976), but the presence of deposits of both Illinoian and Wisconsin age is well established. The Wisconsin deposits, being the most recent, have masked much of the earlier drift, although beyond their outer limits there are areas where the Illinoian (and pre-Illinoian ?) drift is present at the surface.

Within the Wisconsin stage in the midwest a series of substages is identified, each marking an advance after a rather extensive retreat. In chronological order from the earliest to the most recent these are Farmdale, Iowan, Tazewell, Cary and Mankato. Tazewell and Cary drifts have long been recognized in Ohio and recently George White (1953, p. 366) has identified a pre-Tazewell loess in the Cleveland area as Farmdale (?). The Iowan has not been recognized east of the Mississippi River and the Mankato readvance did not reach as far south as Ohio.

Erie and Huron counties are north of the Wisconsin boundary and at the outset of this study it was felt that in all probability the glacial deposits exposed would represent the Cary or Tazewell substages of the Wisconsin. Furthermore, if George White's correlation of a distinguishable late Cary till with the readvance to the Defiance moraine was correct, it was reasonable to expect that the two Cary tills, recognized in northeastern Ohio, could be differentiated here.

DIFFERENTIATION OF TILL SHEETS

Perhaps the best basis for distinguishing different till sheets is to have a fossil or buried soil in a multiple till section. Unfortunately no buried zones of subaerial weathering were found. The tests which were applied, and which gave generally satisfactory results, in differentiating till sheets in the absence of such a zone can be considered under three major headings: degree of chemical weathering (especially leaching of carbonates), texture and lithology.

Chemical Weathering as a Criterion

Leighton and MacClintock (1930) studied the effects of chemical weathering on till sheets of various ages in Illinois. They recognized the results of the chemical processes of oxidation, hydration, leaching of carbonates and decomposition of silicates as being reflected in that which they termed a "profile of weathering". This profile of weathering is based on the same concept as the soil profile which was originated by K. D. Glinka, the Russian pedologist, and further developed in this country by C. F. Marbut, but it differs in number and definition of horizons. The basic concept, stated in very general terms, is that a soil - or a weathered glacial till - is a body whose singular characteristics are determined by a combination of factors. The effects of these combined factors are reflected in a vertical section of recognizable horizons (a profile), and if the importance of any element varies from locality to locality, the profiles developed will be different.

Factors Which Control Chemical Weathering

The factors concerned in the development of a profile of weathering are given below. The list is based on an enumeration by Leighton and MacClintock (1930, p. 38).

Factors involved in the development of the profile of weathering

1. Length of frost free season
2. Amount of rainfall
3. Temperature of water
4. Kind of vegetation
5. Amount of carbon dioxide and other acid making substances which water obtains from the air and humus.
6. Amount of oxygen lost by water in passing through humus and other deoxidizing material.
7. Kind and amount of soil bacteria present.
8. Topographic position in which soil profile has developed
9. Chemical composition of material (especially with regard to free carbonates).
10. Rate of downward passage of water
11. Degree of comminution of material
12. Length of time during which process of weathering has been active.

With this rather long list of factors concerned if the profiles of weathering are to be used for comparative purposes, it is necessary to control some of them or to assume that they are constant for other reasons.

Factors 1 through 7 can be grouped together under the general heading of climate and vegetation and for a local area such as the two counties of this report can be considered constant, and therefore, ignored. Factor 8 is easily controlled by choosing the same topographic position for all measuring and sampling. In this study the position chosen was a well drained one, on or near the top of a rise.

Most of the till of Erie and Huron counties can be classified as low lime till. In northwestern Huron County there is some moderate lime till where the underlying bedrock is Devonian limestone, but in comparing the relatively small area with the rest of the till plains no difference in the depth of leaching assignable to the higher original lime content was noted. The till is thus all calcareous and for the purposes of this study factor 9 can be regarded as constant.

Factors 10 and 11 relate to the permeability of the till to percolating waters and the amount of particle surface exposed to the action of the aqueous solutions. Factor 10 is dependent to a large degree upon the texture of the till and factor 11 is entirely textural. Although caution was taken to avoid local areas where the till may have been washed by melt water, till texture variation was recognized in the course of the field work and later supported by mechanical analysis of till samples.

That this textural variation does affect the weathering profile is suggested in Table IV. Here the greater depths of leaching are, with but few exceptions, associated with the tills whose particle size analyses placed them in the sandier till group which George White has identified as Early Cary. Furthermore, when the locations of over 200 measured depths to unleached material are plotted on a map (Pl. XIX) it can be seen that the distribution of the deeper profiles generally coincides with the area of coarser textures definitely established by mechanical analysis of till samples (Pl. XXII).

The question then arises, of course, as to whether the influence of the textural variations negates the use of the weathering profile as an index of relative age (Factor 12). On the basis of field evidence it was independently shown that the two definitely established textural groups were the product of two different ice advances (p. 82) so we can assume that although the coarser texture does play an important part in the development of the deeper profiles, a somewhat greater age is also reflected. Whatever the relative importance of age and texture, however, the profile of weathering is a valuable aid in determining different till sheets in the area of this study.

The Profile of Weathering

The profile of weathering or soil profile is like a geological section in that it consists of horizontal zones or horizons arranged in a vertical sequence. These horizons, however, have developed in response to the factors which control weathering (see above), and because weathering is a dynamic process the horizons are not static.

The idea of this profile is a useful one to the geologist as well as the pedologist, although in a sense the points of view of the two scientists are diametrically opposed; the geologist is apt to see it as representing the breakdown of the rock and mineral material with which he works, while the pedologist sees it as an alteration which develops the soils with which he is concerned.

The established horizons of the pedologist's soil profile, A, B, C & D and the sub-horizons, are well defined and of general value in understanding the physical and chemical changes which take place in a body of unconsolidated rock and mineral matter as it develops, in response to environmental conditions, into a soil. Because the limits of these horizons are so well established, however, some difficulties arise in using them for geological field investigations. One is that delineating the horizons according to the criteria set up sometimes requires laboratory tests. This is not too serious an objection, however, as the practice of setting tentative limits in the field, as the soils men do, can be followed. Another objection of particular importance to the glacial geologist is that in the designation of horizons, A through D, there is no room for unaltered till - unoxidized and unleached. Again here in the midwest, at least, the glacial geologist is particularly interested in the depth of carbonate leaching and this depth does not fit the limits of any one horizon.

The weathering profile of Leighton and MacClintock (1930) meets all of these objections, but its details of horizon definition do not entirely fit the tills of Ohio (R. P. Goldthwait, personal communication). For this study, therefore, a profile modified and simplified from that of the soils scientist has been used. The following table gives the horizons recognized and the criteria used for setting their limits:

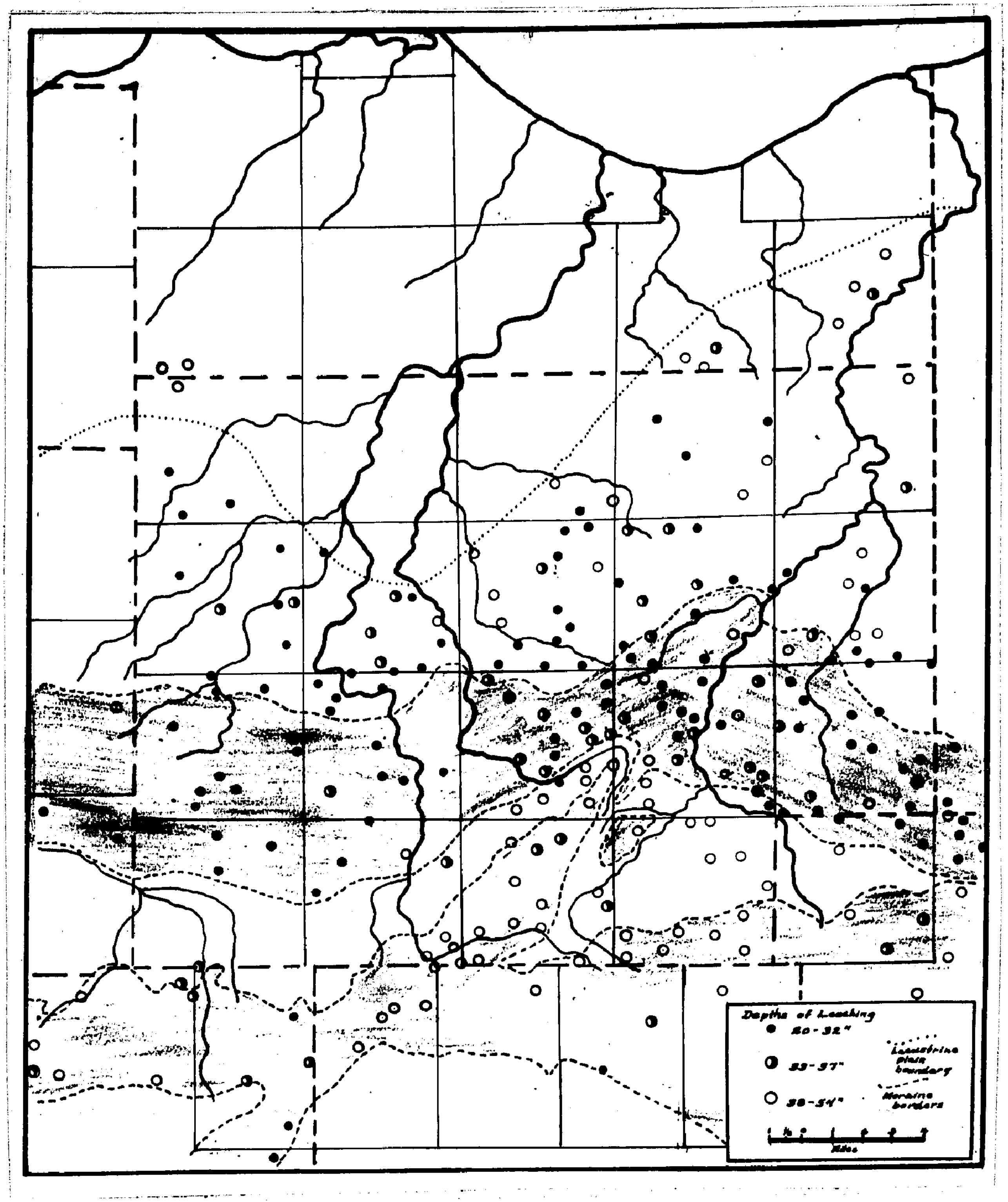
Horizon A ---	topsoil; relatively high in organic matter; dark brown or black color.
Horizon B ---	generally clayier in texture than the horizons above or below; yellow or yellow brown color; leached of carbonates.
Horizon C ---	contains free carbonates, oxidized.
Horizon D ---	unaltered till.

<u>The Use of the Profile of Weathering in This Study</u>

The boundary between horizons A and B was determined on the basis of a change in texture and color. The thickness of this first horizon was used as an index of whether or not the profile had been truncated by erosion. A normal thickness for this zone in the tills and for the topographic position used varied from eight to twelve inches. The depth to the B-C boundary, or the depth of carbonate leaching, was recorded for all auger holes and measured sections. (See below.) The depth to unaltered till was of less value because of the depth limitations imposed by a six-foot auger. In the tills of the Till Plains and the Low Plateau sections unoxidized till was below six feet, although in the lacustrine plain it was often within six feet.

<u>Determination of Depth of Leaching</u>: The depth to unleached till was recorded for all auger holes and sections. A ten percent solution of hydrochloric acid was used in making the determinations and the depth recorded was that at which the till showed a strong effervescing reaction.

Pl. XIX



*Locations of sections with recorded depths of carbonate leaching.

Observed Depths of Carbonate Leaching: The locations of 230 measured profiles are shown on Plate XIX along with the observed depths of leaching for each location. The depths range from 20 inches to 59 inches, and when the number of profiles with equal depths to unleached till is plotted against the various depths the distribution diagram shown in Plate XXIV results. This diagram shows quite clearly that there is no well defined break in the sequence of depths. The discussion of this matter will, however, be delayed until after an examination of the use of textural criteria for till sheet differentiation.

Till Texture as a Criterion

The texture of a sedimentary rock, the category to which, in the broad sense, till belongs, is defined by Pettijohn (1949, p. 8) as "the size, shape and arrangement of the component parts". In this paper, however, the term is restricted to the first of these - the size of the component parts - although it is recognized that a complete picture of till texture should include a study of grain shapes and till fabric also.

Factors Which Determine Till Texture

W. C. Krumbein (1933, p. 404) first noted that texture, in this restricted sense, offered possibilities for the correlation of tills under favorable conditions. The original texture of a till is dependent first upon the texture of the source material and then upon the amount of comminution this material has undergone in the course of transportation by the ice. The amount of comminution is, in turn, determined by the resistance of the rock material to abrasion, frost action and the general conditions of weathering under a glacial regime, as well as the length of time it is subjected to these processes. Then, too, although two major classes of glacial deposits are recognized, the unsorted and the sorted, all degrees of variation between these two are possible, so that even in what is called till there may have been some washing away of the finer materials.

Till Sources

The ice sheets which deposited the till of Ohio and other midwestern states first moved across a wide area of the Canadian Shield, eroding great quantities of crystalline rock. The erratic boulders picked up by the glaciers from outcrops north of the Great Lakes and now found as far south as northern Kentucky give evidence of the effectiveness of glacial transportation for long distances. Nevertheless the statement originally mady by R. D. Salisbury (1900, p. 425) that "normal till is made up of materials which have not been transported far" is generally accepted (Flint, 1947, pp. 114-116).

Evidence for Importance of Locally Derived Material: If locally derived material is as predominant in the drift as the statement above indicates, it is difficult to see how texture can be of any value in identifying a till sheet over an area where bedrock and earlier glacial deposits vary widely. There are, however, at least two lines of evidence which suggest that the importance of local material in determining the composition of a till may have been given undue emphasis.

The first is somewhat empirical: various studies (Krumbein, 1933; White, 1952 and Shepps, 1953) have shown that in areas where the surface beneath a till sheet is quite heterogeneous, similar till texture is, nevertheless, maintained within the sheet. Furthermore the present study has added approximately 850 square miles to the 4800 or so over which White and Shepps found the same texture to be more or less constant. It should be pointed out, however, that while in northeastern and north central Ohio the bedrock is heterogeneous, in that it consists of various shales, siltstones and sandstones, in neither area is limestone of any importance in the bedrock sequence. In western Ohio the ice, although still moving out from the center of Erie basin, crossed wide areas which are underlain by limestone and it will take further investigation to see if the same texture groups are recognizable there.

The second line of evidence comes from the recent work by Gravenor (1951) who made a study of the petrology of Wisconsin till in southwestern Ontario. It seems that the statements of Salisbury and others regarding the predominantly local origin of till materials have been based largely on the pebbles in the tills. (Pebble counts made in connection with this study show that the greater percentage of pebbles is, indeed, of local origin. See page 99 and Table V.) Gravenor found, however, that in the till near Lindsay, Ontario, the pebbles presented a one-sided picture. The bedrock is limestone and 80 per cent of the pebbles are limestone, yet the sand size grains and the boulders have a crystalline source. The percentage of clay is low at Lindsay, five to eight per cent, yet where shale is the underlying bedrock the percentage of finer material increases rapidly.

This last observation does not agree with the results of Krumbein's study (Krumbein, 1933, p. 397), for he found that the median size increased even when shale was predominant in the pebble material.

Relative Importance of Consolidated and Unconsolidated Material: In regard to the relative importance of bedrock and unconsolidated material in causing variation of a till sheet, Krumbein (1933, p. 397) concluded from his studies in Illinois that the latter was of greater importance. This is not surprising, for in addition to serving as a protective cover over the bedrock, such material is already prepared for mixing and transportation.

Because the position of bedrock contacts is generally known with a fair degree of accuracy it is a simple matter to evaluate the influence of bedrock on till textures. It is, however, more difficult to appraise the effect of older glacial deposits. The first ice advance of the Wisconsin stage over the two counties of this report found the surface already covered with the deposits of at least one other ice sheet, the Illinoian, and each advance, whether of major or minor rank, resulted in a greater diversity of surface materials, one pattern being superimposed on the other, but perhaps not entirely masking it. A single pattern might be made up of glacio-fluvial and lacustrine sediments, as well as till. The sorted deposits which contribute a limited range of grain sizes in concentrated amounts may contaminate the till of an overriding glacier to such an extent as to cause a wide variation from the normal texture, and yet today it may be extremely difficult to reconstruct or recognize the source. The possibility of a textural variation having originated in this manner must always be kept in mind, however.

Factors Controlling the Importance of Local Material: The importance of local material, consolidated and unconsolidated in determining the composition of a till will, of course, vary from place to place depanding upon the relationship of areas of erosion to those of deposition; upon the nature of the material available; and upon the topography which a region presents to the advancing ice. In the latter case, for example, it is to be expected that rough topography would offer greater opportunity for erosion by a glacier than a level plain. (See Thwaites, 1939, p. 21.)

Jahns (1943, p. 81) suggests that isolated hills are particularly susceptible to glacial erosion. There are two areas in Erie and Huron counties where hills, separated from each other by flat land, exist: (1) southeastern Erie County and northeastern Huron County where the Berea sandstone forms hills which are prominent on the ground moraine, and (2) the area around Castalia where the limestone hills stand out above the general level of the lake plain. This latter area extends northward to include the bedrock highs which today exist as islands in Sandusky Bay and Lake Erie. In both cases these bedrock hills probably stood above the pre-glacial surface also. They certainly were not areas of glacial deposition for they are covered with little or no till. The well known glacial grooves on

Kelleys Island, just north of the area of this study, have long been cited as evidence of the erosive power of glaciers.

Till Textures in North Central Ohio

The use of texture as a means of differentiating till sheets was a generally successful, but not infallible, method in the area of this study. Early in the course of the field work it became apparent from purely qualitative methods of comparison that there was a variation in the texture of tills examined. The question remained, however, as to whether the sandier till was due to some local cause, such as washing by melt waters, the influence of Berea and Bedford sandstones, or assimilation of older beach or glacio-fluvial material.

Some weight was given to the first of these possible causes of textural variation by the occurrence of kames, eskers and outwash in the general area of sandier till. A number of sandier till sections also are closely associated with shallow sandstone bedrock, and as has been mentioned the possibility of older sorted material locally contaminating the normal till of an advance is always present, but difficult to prove or disprove.

The best evidence that the different textures were the result of two different advances was found in several deep exposures which will hereafter be referred to as multiple till sections. Examination of these sections (see Appendix B) suggested that a silty clay till was underlain by a somewhat sandier till. In most cases this interpretation was borne out by subsequent mechanical analyses of the samples. In the multiple till sections examined no buried weathering profile, or portion of one, was found and the tills were identified on a purely textural basis.

The analyses of the lower tills of the multiple till sections showed the sand, silt and clay distribution to be similar not only to the sandy type of till recognized at the surface, but also to the Early Cary of George White in northeastern Ohio. The analyses of the overlying tills on the other hand placed them in the textural group which White has called Late Cary.

Till Sampling: Samples of unleached till which were later analyzed for the particle size distribution were collected from some of the profiles measured - both those in cuts and in auger holes. When possible unoxidized till was sampled, but since the depth to unoxidized material was usually not within reach of the six-foot auger, many were oxidized till. Samples H-77 and H-78 (see Table IV.) were samples of the same till taken from a deep cut. Sample H-77 was of oxidized till, however, and H-78 was unoxidized. The analyses show so little difference in the sand, silt and clay percentages for the two samples that it would appear that no error is introduced by using both oxidized and unoxidized till for the analyses.

Till sample collections were made from cuts only after the surface had been cleaned and as nearly vertical a section as practical exposed. The total amounts of the samples collected varied from about 150 to 400 grams, the smaller amounts coming from auger holes. Auger hole samples were used for analysis only when no other source was available in the immediate neighborhood, for the possibility of con-

TABLE IV

RESULTS OF ANALYSES OF TILL SAMPLES

Sample	Percentages Sand	Silt	Clay	Depth of Leaching
Tazewell				
C-2b	46	38	16	47"
"Early" Cary				
H-24	27	45	28	41"
H-27	38	35	27	41"
H-50	32	44	24	—
H-52	33	42	25	—
H-59	26	44	30	35"
H-60	28	46	26	50"
H-67	20	49	31	—
H-87	24	55	21	—
H-94	22	48	30	46"
H-95	25	48	27	48"
H-100	37	38	25	42"
H-104	32	40	28	45"
H-105	24	48	28	44"
H-B	27	55	18	—
A-1	32	41	27	52"
A-2	24	46	30	35"
A-4	21	51	28	42"
E-5	32	43	25	49"
E-6	18	53	29	37"
R-1b	28	44	28	—
C-2a	26	48	26	—
C-9	22	52	26	44"
?				
H-42	23	41	36	46"
R-1a	24	40	36	—
Late Cary				
H-2	7	40	53	35"
H-4	24	43	33	27"
Late Cary (cont'd)				
H-6	23	43	34	27"
H-9	16	47	37	—
H-10	23	39	38	30"
H-11	6	59	35	—
H-13	18	43	39	52"
H-14	20	40	40	24"
H-20	24	42	34	32"
H-21	16	43	41	—
H-26	24	38	38	35"
H-29	16	44	40	27"
H-37	17	38	45	32"
H-47	18	37	45	25"
H-49	14	47	39	33"
H-62	23	43	34	26"
H-65	22	39	39	20"
H-77	8	54	38	29"
H-78	8	53	39	—
H-79	17	42	41	—
H-82	11	49	40	—
H-83	20	38	42	20"
H-84	19	36	45	31"
H-86	14	57	29	—
H-89	17	40	43	26"
H-90	13	41	46	30"
H-98	18	39	43	22"
H-99	19	44	37	29"
H-101	4	48	48	32"
H-102	24	38	38	28"
A-3	11	49	40	34"
E-W	21	43	36	—
C-10	12	53	35	41"
Se-1	15	53	32	29"

tamination by material falling down the hole from higher levels is always present.

Mechanical Analysis of Till Samples: Although complete particle size distribution analyses (from coarse sand through fine clay grades) were made of the lacustrine sediments (p. 180), tills were analyzed only in terms of the total amounts of sand, silt, and clay. Shepps (1953, p. 35) had already found such an abbreviated mechanical analysis satisfactory for problems of till differentiation in the nearby counties of northeastern Ohio, and Dreimanis (personal communication; see also Dreimanis and Reavely, 1954, pp. 244-246) reported sand, silt, and clay determinations suitable for distinguishing various Wisconsin tills in southwestern Ontario. It was felt, therefore, that this type of size distribution determination would be satisfactory for the area of this study where conditions are generally similar to those in northeastern Ohio and southwestern Ontario. The results obtained bear this out.

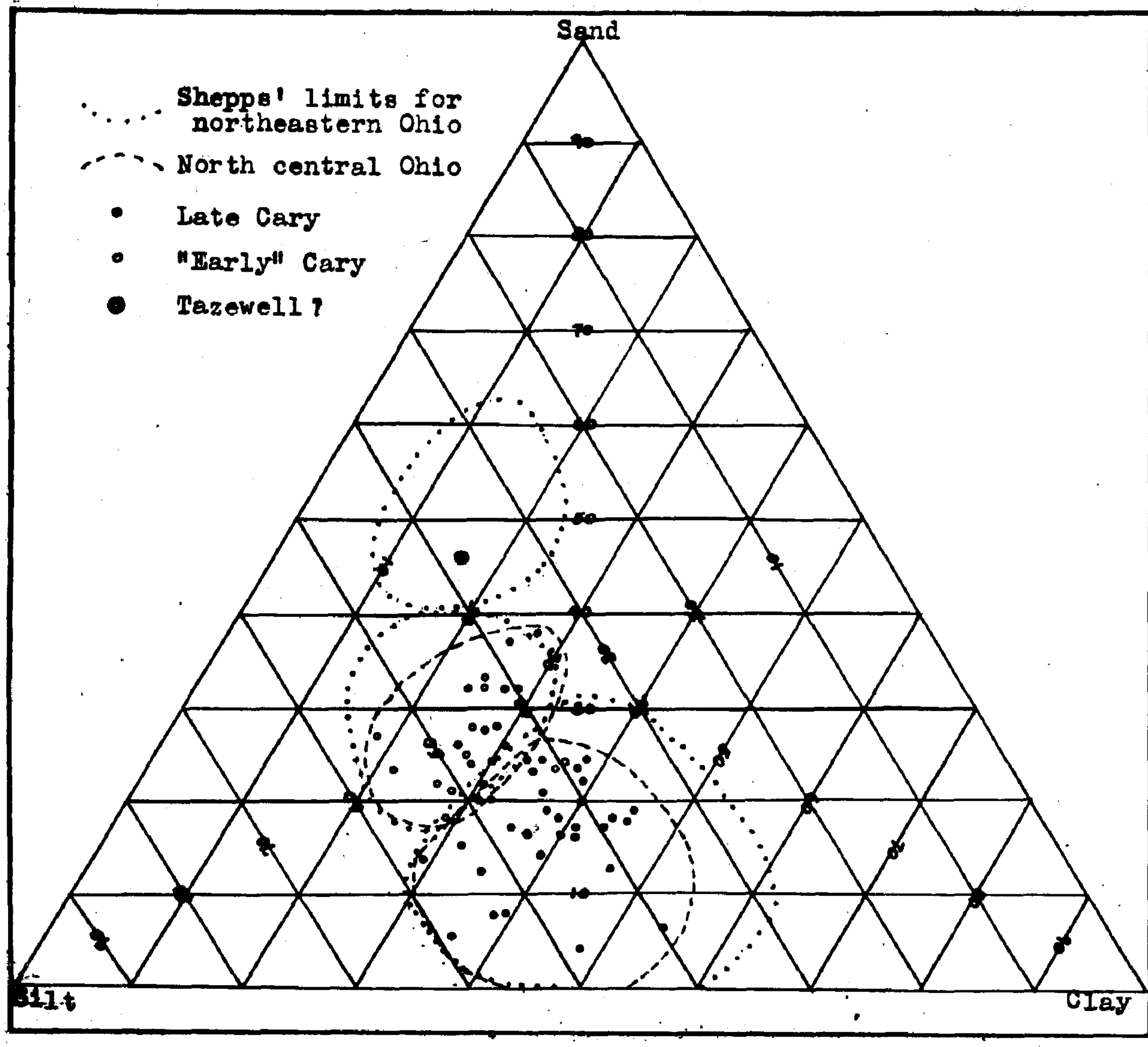
Laboratory Methods: The methods used for making particle size distribution determinations are discussed in Appendix A of this paper. At this point it will suffice to say that all till analyses were made by the Bouyoucos hydrometer method in conjunction with sieving of the coarser fractions.

Results of Analyses: White and Shepps have found that three texturally different till sheets can be mapped in northeastern Ohio

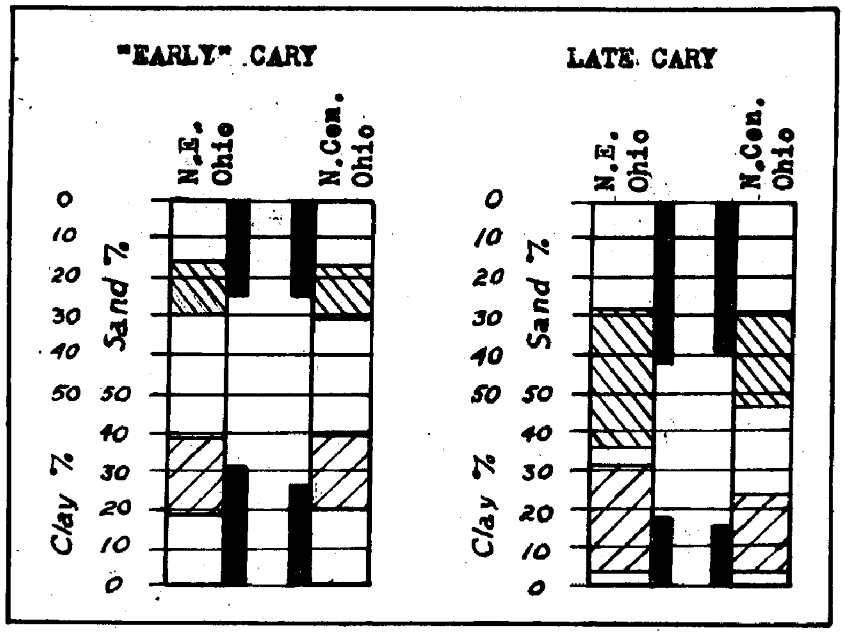
(White, 1951a and Shepps, 1953, p. 39); a sandy till which is identified as Tazewell; a silty till which White calls Early Cary, but which is apparently not as early as the Early Cary in western Ohio (R. P. Goldthwait, personal communication) and which, therefore, will be referred to in this paper as "Early" Cary; and a third which displays a greater textural variation than the other two and ranges from a silt till to a clay till, and is assigned to the Late Cary advance. (The descriptive terms used above are those of Shepps.) On a purely textural basis all three of these tills can be recognized in north central Ohio also (Pls. XX, XXI and Table IV).

Tazewell Till in North Central Ohio

On the basis of this study alone it would not be possible to recognize a Tazewell till and the name is applied here only because one sample, C-2b, meets the textural requirements of the Tazewell sheet in northeastern Ohio (Pl. XX). Some corroborating evidence is supplied, however, by the section from which the sample was collected. The location (Pl. XXII) is a Pennsylvanian Railroad cut near the front of the merged Fort Wayne and Wabash morainic belts, just southwest of the Shiloh knot. (See Appendix B, Section 1.) The Tazewell (?) till occurs in the lower part of this section and the analysis of the overlying till, from which it is separated by six inches of distorted and laminated silt and clay, suggests that it is part of the "Early" Cary till sheet. Because of the limited nature of the evidence as seen here, however, the presence of Tazewell till cannot be considered to have been definitely established.



Sand-silt-clay composition of 59 till samples.



Comparison of data from north central and northeastern Ohio tills.

The lined bars show the range in percentages of sand and clay among the till samples assigned to the two Cary tills. The solid bars indicate the average percentage for each group. Data for northeastern Ohio are from Shepps (1953).

A Comparison of "Early" and Late Cary Tills in North Central and Northeastern Ohio

Texturally the two till sheets whose presence is well established in north central Ohio are very similar to the "Early" and Late Cary sheets of the northeastern counties. Plate XXI is a comparison of the range in percentages of sand and clay in the "Early" and Late Cary tills as defined by Shepps' analyzed samples with those shown by analyses from the area of the present study. In only one instance does the range established from north central Ohio extend beyond the percentage limits of the northeastern Ohio samples and then only a very insignificant amount: the samples of "Early" Cary till from northeastern Ohio showed a variation from 17 to 30 percent in the clay fraction; in those analyzed for this report the range was from 18 to 31 percent. In all other cases the variations were within Shepps' limits. The smaller variation found for Huron and parts of adjacent counties may be due in part to the smaller area investigated.

Plate XX shows the difference in the percentage limits of sand, silt and clay established by White and Shepps' work and those of this writer for north central Ohio when both sets are plotted on triangular coordinate paper. Two things are apparent: (1) The limits of the "Early" Cary are slightly different for the two areas. (2) The Late Cary variation is considerably less in north central Ohio than in the northeastern part of the state.

"Early" Cary Till in North Central Ohio

Of the 59 till samples analyzed 20 fall within the textural limits of George White's "Early" Cary till as outlined on the triangular diagram (Pl. XX), and when these limits are adjusted to fit evidence gathered from north central Ohio, 22 samples fall in the "Early" Cary group. The mechanical composition of the group is fairly homogeneous and can, I believe, best be described as a sand-silt-clay[5] till.

In addition to the textural similarity of the sand-silt-clay till to the till sheet identified by White as "Early" Cary, field relationships indicate that the "Early" Cary designation is justified.

Till with this particle size distribution occurs in several multiple till sections (See Appendix B.) As has already been mentioned (p. 86) in one section it lies above an older till whose texture suggest that it is Tazewell. In all other multiple till sections the "Early" Cary type till is overlain by a generally finer till which meets the qualifications of the Late Cary till sheet.

The evidence afforded by the geographic distribution (Pl. XXII) is not entirely clear, but it seems to bear out White's findings that the "Early" Cary is the normal till at the surface south of the Defiance moraine, although it is also present at the surface in an area within the Defiance belt and north of it here in Huron County. The interpretation of this will be discussed more fully below (p. 93), but it can be said that it is apparently the result of little deposition of Late Cary till.

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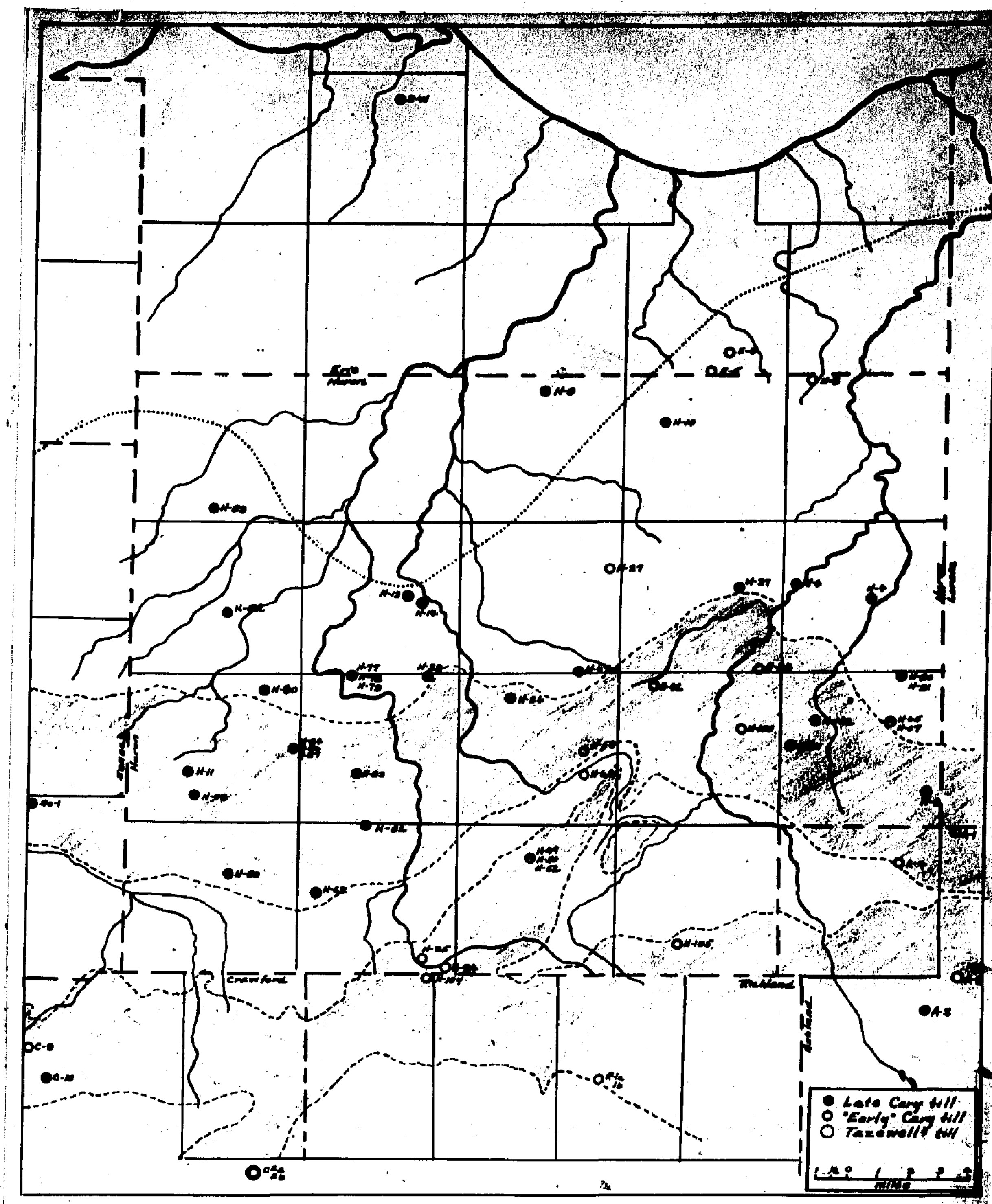
5. This designation and the others which follow are in accordance with the nomenclature described by F. P. Shepard (1954).



Locations of sections from which till samples were analyzed.

The till of the Delphi spur, the northward facing slope of the Fort Wayne moraine and the ground moraine between the Defiance and Fort Wayne moraines is of this sand-silt-clay texture. Too few samples from the New Washington and Wabash morainic belts were analyzed to permit any definite statement regarding the till of which they are built, and what evidence there is, is contradictory. A more detailed study is necessary for clarification of the distribution of the till types and their relation to the various moraines

Late Cary Till in North Central Ohio

In both north central and northeastern Ohio the textural variation shown by the till samples assigned to the Late Cary drift sheet is greater than that observed among the "Early" Cary samples. Indeed, the spread shown by samples from north central Ohio makes it difficult to find a concise textural description for the upper till. Included are tills which are sand-silt-clay tills (but less sandy than "Early" Cary), clayey silt and silty clay tills and one sample which is a sandy silt till.

Shepps was able to eliminate much of the apparent heterogeneity in his Late Cary samples by relating the samples to the secondary lobes present along the Late Cary ice front in northeastern Ohio (Shepps, 1953, pp. 43-45). White has called these lobes the Grand River, the Cuyahoga and Medina, the latter being the westernmost and closest to Huron County.

Such lobation as there was along the Wisconsin ice front in north central Ohio had largely disappeared by the time of the readvance to the Defiance moraine, although the belt of poor moraine development between the Huron and Vermilion river may well represent the last vestige of interlobate conditions, conditions which it is believed reflected the interference of the basin-facing Berea escarpment to ice flow. . . . .

In order to test the hypothesis that ice movement controlled by local lobe centers accounted for the wide variation in Late Cary samples in the area of this study, the position of the analyses on the triangular diagram was examined from the point of view of whether the samples had been collected east or west of the area of irregular moraine development. No definite division along this line was indicated. However, the majority of the Late Cary samples from the Defiance belt in eastern Huron County were texturally similar to the Medina lobe samples. It can also be said that the more silty tills were from western Huron County. Whether or not this siltier character is maintained westward from Huron County is not known, nor is it possible to state that this difference reflects lobation. On the basis of the evidence it may just as well record the difference in underlying bedrock, for in eastern Huron County the till lies over Bedford, Berea and Cuyahoga shales and sandstones, whereas in the western part of the county the bedrock consists of Huron and Cleveland, black, carbonaceous, silty shales.

The distribution of this finer textured till seems to bear out White's correlation of the Late Cary till with the advance to the Defiance, although between the two rivers the Late Cary has a scattered distribution so that "Early" Cary is frequently present at the surface. This and the large number of kames and eskers here suggests thin and stagnant ice, and it is believed that in the Late Cary advance the Berea escarpment in southeastern Erie County shunted the main flow of the ice away from this region directly to the south.

Relationship of Depth of Leaching and Till Texture

The diagram of Plate XX shows clearly one of the difficulties that arises in applying a textural criteria for field identification of the tills in the area of study: a variation of a few per cent among the three particle size classes is almost impossible to detect qualitatively, and yet it may be enough to suggest a different till sheet.

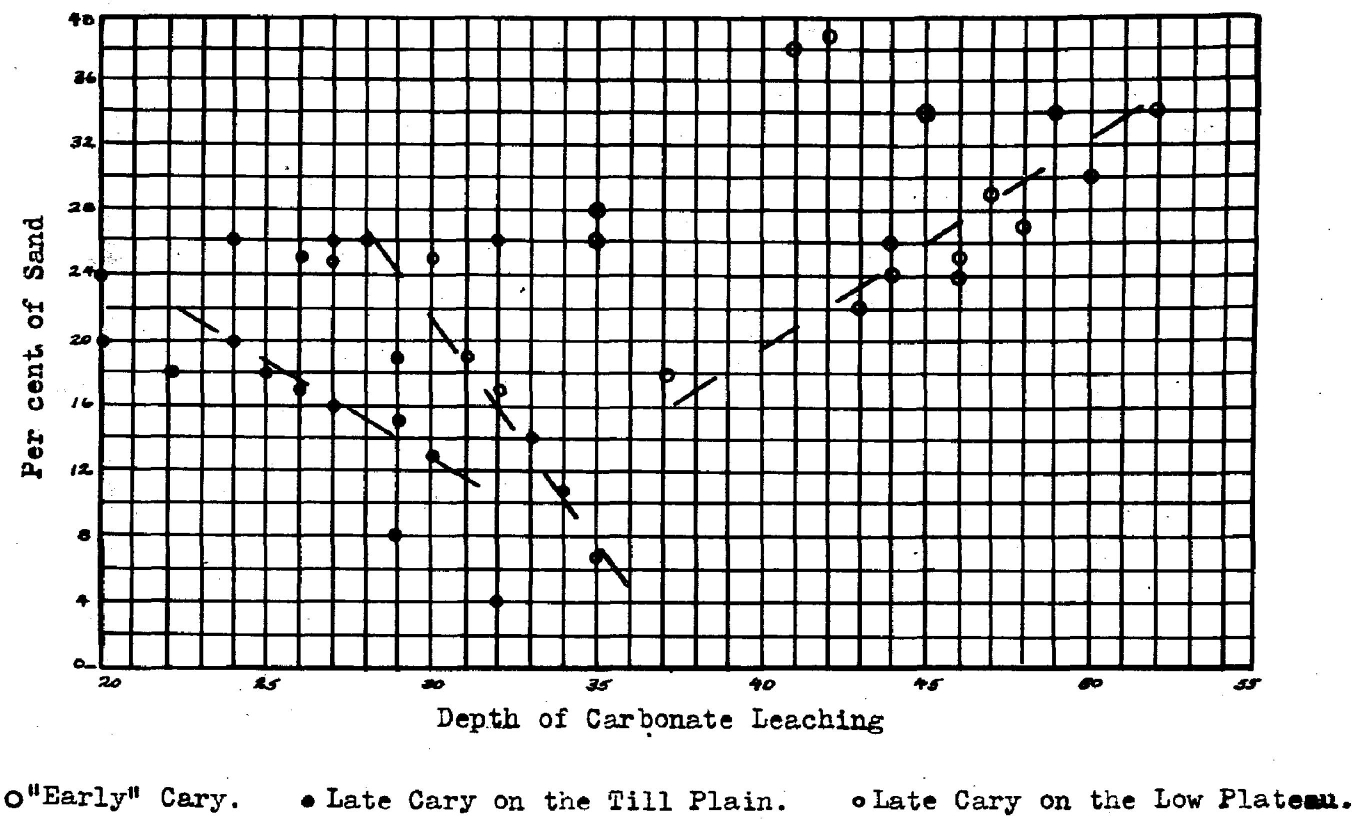
Depth of Leaching and Texture in "Early" Cary Till

It has already been said that the amount of weathering, or more specifically, the amount of carbonate leaching, was used for till sheet identification (p.70) and also that texture is one of the factors which controls the rate of leaching (p.72). In order to evaluate the role of texture in determining the depths of leaching observed, the latter was plotted against the percentage of sand in analyzed till samples. The scatter diagram shown in Plate XXII resulted. It is quite clear from this diagram that in the sand-silt-clay till ("Early" Cary) texture is important and the relationship is that which is to be expected: the greater the percentage of sand the greater the depth of leaching.

Depth of Leaching and Texture in Late Cary Till

At first glance there seems to be little if any correlation between the percentage of sand and the depth of leaching in the Late Cary samples. But when these samples are divided into two groups, one of the samples from the Low Plateau and the other, from the Till Plain section, two lines of regression are suggested.

The lines of regression for both groups show an unexpected relationship, however; the depth of leaching increases with a decrease



Scatter diagram showing relationship of depth of carbonate leaching to percentage of sand.

Pl. XXIII

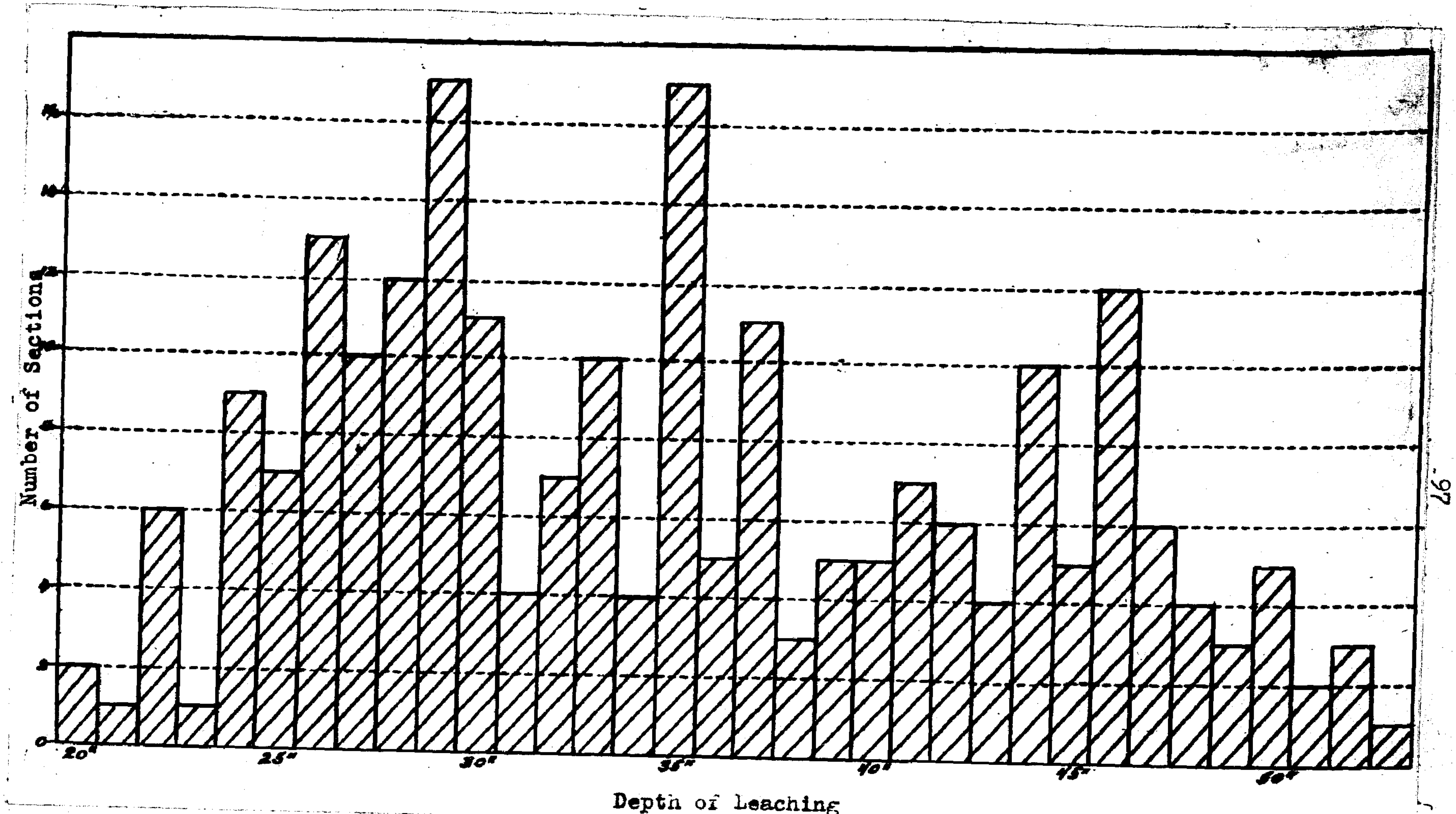
in the amount of sand. The line of regression also is steeper for the Late Cary till of the Low Plateau than for that of the Till Plains. This latter circumstance probably reflects the influence of bedrock, for it seems probable that the till overlying the Bedford, Berea, Cuyahoga sequence contained less original carbonate.

There is no evidence for an explanation of the unusual relationship between texture and depth of leaching. It is possible, however, that the greater part of the original free carbonate in the Late Cary till may be associated with the coarser fractions, but that there is not enough sand present to bring the effects of greater permeability into play. If this should prove to be the case, and total carbonate determinations would have to be made to test the idea, different paths of ice movement would seem to be indicated for the "Early" and Late Cary ice. It is difficult to imagine a shift of the magnitude required, however, when one considers the nearness of the whole area to the axis of the Erie basin.

Plate XIII established the validity of the depth of carbonate leaching as an index of texture for the "Early" Cary, but the question still remains, "Can leaching be used as an aid in distinguishing the "Early" Cary from the Late Cary"?

Frequency Distribution of Recorded Depths of Leaching

The frequency distribution of 230 recorded depths of leaching is shown graphically in Plate XXIV. There are three ranges of depths into which a majority of the profiles fall: 26 to 30 inches, 33 to 37 inches, and 44 to 46 inches. Considering the geographic distribution



Frequency distribution of depths of carbonate leaching in tills of north central Ohio.

Pl. XXIV

and the association of the lesser depths of leaching with the finer till samples as shown in Table IV, I believe it is established that depths of 26 to 30 inches are generally indicative of the Late Cary till sheet, while those from 44 to 46 inches suggest an "Early" Cary age.[6]

There are several possible explanations for the peak at 35 inches. The first that comes to mind is that it represents a third till sheet, but since there is no other evidence within the area of study for this, the idea was discarded. Is it the result of a profile in a thin Late Cary till being superimposed upon a truncated "Early" Cary profile? If this were the case, the unaltered till in such a profile would be definitely "Early" Cary but the textural data does not bear this out. Does the clustering of depths of leaching in the mid-thirties then represent a range within which the depths of leaching of the two till sheets are coextensive, i.e. both the greater depths of the Late Cary sheet and the lesser from the older till sheet are represented? In my opinion this is the case, and for purposes of till identification depths of leaching within the range from 33 to 37 inches were considered as indicating neither one till sheet or the other.

<u>Possible Till Sheet Assignment of Profiles with Leached Depths in Mid-Thirties</u>

On the basis of the diagram of Plate XXIV it is possible that a workable field criteria could be developed, however. A Late Cary

6. These depths are less than those recorded for the seemingly correlative till sheets in northeastern Ohio. White and Shepps (1952) report depths of two and one-half feet to three and one-half for the Late Cary, and four and one-half feet and above for the Early Cary.

till with a depth of leaching in this range should be enough finer than the normal "Early" Cary type of till with a similar depth of leaching to be recognizable. Since the apparent relationship between texture and depth of leaching in the Late Cary tills of Huron County was not discovered until the completion of the field work, this application of weathering and textural evidence could only be applied where field notes made mention of unusually clayey or silty till.

Depth of Leaching as a Means of Identifying Till Sheets

Even though there is some difficulty in interpreting depths of leaching which fall in the mid-thirties it can be seen by comparing plates XIX and XXII that the picture of till distribution arrived at by plotting depths of leaching in the other two groups is similar to that gained from the textural data. Therefore, it appears that the value of the depth of leaching as an aid in correlating the tills of this area is substantiated.

Till Lithologies

A complete study of the lithology of the various till sheets was not attempted. A few pebble counts were made, one in each moraine element, and the results are given in Table. V. On the basis of these few certainly no conclusive statements can be made. It does appear, however, that the pebbles largely reflect local bedrock: four are high in sandstone and each of these is from a locality within three miles of the updip edge of the Berea sandstone; numbers 6 and 7 are relatively high in number of clay ironstone pebbles and each of these was from till overlying the black shale sequence.

The high percentage of limestone in the count made in the Defiance moraine belt of eastern Huron County is difficult to explain and taken as a whole this count differs greatly from the one made in the same till in the western part of the county.

The count from the Delphi Spur is far below the others in total crystalline rocks represented and those from the New Washington spur moraine and the Defiance moraine in eastern Huron County are very similar in the percentages of crystalline rocks.

The two banded slates recorded for the count within the Shiloh knot are of interest chiefly because of Dr. White's find of the varved slate erratics near Rome, Richland County, at the southeastern edge of the moraine knot.

TABLE V

PEBBLE COUNTS FROM NORTH CENTRAL OHIO

	1.	2.	3.	4.	5.	6.	7.[a]
Sedimentary Rocks							
Limestone	26	20	29	20	29	22	18
Dolomite	19	6	9	9	18	11	4
Sandstone	16	26	43	27	13	14	27
Shale	11	28	6	20	20	22	5
Clay ironstone	1	1	3	2	1	6	11
Chert	-	3	1	3	2	-	13
Total Sedimentary	73	82	91	81	83	75	78
Igneous Rocks							
Acidic	12	9	4	7	9	11	8
Basic	7	5	5	8	5	5	9
Metamorphic Rocks							
Quartzite	8	2	-	1	2	8	5
Others	-	1	-	3[b]	1	1	-
Total Crystalline	27	18	9	19	17	25	22
Total	100	100	100	100	100	100	100

a. Locations:

1. Defiance moraine, 1 mile south of 1040 corner, northeast Ruggles Twp., Ashland County.
2. Defiance moraine, just south of New Haven-Greenfield Town Line Rd., 1 mile west of Peru Center Rd., Huron County
3. Delphi spur moraine, B.& O. R.R. cut, east of Old State Rd., Ripley Twp., Huron County
4. Shiloh moraine knot, NE$\frac{1}{4}$, Sec. 8, T.23N., R.19W., Richland Co.
5. Wabash moraine, SE$\frac{1}{4}$, Sec. 4, T.21N., R.20W., Crawford County (upper till)
6. New Washington spur moraine, SE$\frac{1}{4}$, Sec. 18, T.23N., R.20W., Crawford County
7. lake plain, Darrow Rd., Vermilion Twp., Erie County

b. One of these three was a varved slate pebble.

The general physiographic aspect of the lacustrine plain in north central Ohio has been discussed (p. 18). It is a unit, easily distinguished topographically, and one which has long been recognized as presenting agricultural possibilities and problems different from those elsewhere in the state.

A REVIEW OF EVENTS AFFECTING THE ERIE BASIN

The lake plain bordering Lake Erie was overridden by glacial ice during at least two stages, Illinoian and Wisconsin, and striae, grooves and similar evidence of glacial erosion are to be found on bedrock surfaces within its borders. Till, deposited by the glaciers, is present almost everywhere, sometimes at the surface and sometimes overlain by lacustrine sediments.

It was not glacial action, however, which developed the distinctive features of the lowland which surrounds Lake Erie, but rather subaqueous and shoreline processes in a series of large glacial lakes which formed in front of the ice sheet as it melted back from the eastern half of the United States and southern Canada.

Origin of the Great Lake Basins

The origin of the Great Lake basins has been the subject of controversy in the past, and there is still disagreement as to the relative importance of pre-glacial stream action, glacial erosion and lacustrine processes in shaping the present basins which, with the exception of the Superior basin, are topographic features only. It is generally agreed, however, that there was nothing comparable to the present lake system prior to the Pleistocene. During the Mesozoic and early Cenozoic streams carved a number of erosion surfaces here in the central part of the continent. Uplift or changes in sea level generally initiated a new cycle before an advanced old age surface had been achieved. Erosion was always more rapid along the belts of weak rock and in the cycle which was interrupted by the advent of the glaciers apparently a wide open lowland had already been carved on the upper Devonian and lower Mississippian black shale which underlies much of the Michigan, Huron and Erie basins. When the ice spread southward it seems to have been channeled through these shale lowlands and their influence upon the movement of the ice, at least during the Wisconsin glaciation, can be seen in the lobate character of the moraines south of the lake basins.

Pre-Wisconsin Great Lakes

There is evidence which seems to suggest that in some of the basins, at least, great lakes existed during interglacial times. In the Ontario basin the sections at Scarborough Bluffs and in the Don valley at Toronto, which were made famous by the work of A. C. Coleman (1933 and 1941), show lacustrine sediments interbedded with several layers of till. Coleman (1941, p. 88) believed that at least two interglacial stages were represented by the lake clays and sands, and that the lower of the two series of lacustrine beds was Yarmouth in age.

Within the Erie basin the question of interstadial lakes has received little study until quite recently. Coleman (1941, pp. 69

and 70) listed the reports of interglacial sediments in the Erie basin, but, in the light of present knowledge concerning Wisconsin stratigraphy in the lower lakes region, it seems probable that a number of the suspected interglacial horizons which he mentioned are intra-Wisconsin rather than pre-Wisconsin. Dreimanis and Reavely (1952, p. 5) state that some of those mentioned by Coleman as exposed in the cliffs along the north shore of Lake Erie appear to occur within the Wisconsin. On such is a (gyttja) horizon exposed near Port Stanley, Ontario (Dreimanis, 1953a). This is described as interbedded between two tills, which Dreimanis correlated with White's Early and Late Cary tills. The radiocarbon date of 10,900 years plus or minus 400 is definitely Wisconsin, but it suggests that the upper of the two tills is Mankato rather than Late Cary. Other radiocarbon dates from horizons along the north shore at Plum Point (Libby, 1951, p. 292) and Port Talbot (Suess, 1954) may be pre-Wisconsin, however.

Here in Ohio C. T. Bagley (1953) made a study of samples from bore holes in the Cuyahoga valley in Cleveland and identified a lower till, which is overlain by silty lacustrine clay, as Illinoian. If Bagley's correlation of this till with the Illinoian advance is correct the lake sediments may be either those of a Sangamon (Illinoian-Wisconsin interstadial) or of a pro-Tazewell (early Wisconsin) lake. In the latter case the lake would be a glacial lake whose existence was due to the damming of drainage by an advancing ice sheet.

George White (1953) has recognized in several sections near Cleveland, Illinoian till beneath laminated silts. White's interpretation is that these silts may be either Late Cary or pro-Tazewell. It is still not known, however, from these bits of local evidence whether the waters in which the silts were deposited were of an extent to fill a large part of the Erie basin or whether they were confined to the Cuyahoga valley.

Ross (1950) made a number of borings in the vicinity of the Bass Islands of western Lake Erie and, although several of the cores went to bedrock, no lacustrine sediments were found beneath the Wisconsin till. Their absence here does not, of course, eliminate the possibility that lacustrine waters were present elsewhere in the basin. (The Bass Island area is underlain by resistant dolomite and the present lake is shallow here.) It may also have been that subsequent ice advances locally removed all pre-Wisconsin glacial and lacustrine material.

Late Wisconsin History of the Erie Basin

Much of the evidence for late Wisconsin and post-glacial history of the lake basins lies on the surface today so that the chronology is fairly well known. This phase of the history of the Erie basin began when the ice retreated from the Fort Wayne moraine. In this retreat the north-facing slope of the divide which now separates drainage to the Ohio River from that which ultimately finds its outlet through the St. Lawrence River was uncovered.

Small Pro-glacial Lakes

Presumably the first lacustrine stage was the formation of small pro-glacial lakes in the low areas in front of the ice. These lakes drained southward to the Ohio River when their waters attained the elevation of the cols in the divide. Since there is little evidence for this stage it must be regarded as of short duration.

Lake Maumee I

With the continued retreat of the ice front several of these lakes coalesced in the western end of the basin to form what is called Lake Maumee I. This lake was not only the first definitely known "great" lake of the Erie basin, but it probably was also the first to form in any of the five basins during the Late Wisconsin. Lake Maumee I had a level of about 800 feet and drained to the Wabash River through an outlet at Fort Wayne, Indiana. The maximum extent of this lake is not known. It existed while the ice front moved back a considerable distance in the basin, then readvanced to build the Defiance moraine, and again retreated, this time to uncover a lower outlet and so initiate a new lake stage.

Indirect evidence that prior to the beginning of the readvance to the position of the Defiance moraine Lake Maumee I extended as a large body of open water into the eastern end of the basin is given by the finer texture of the Late Cary till. White and Shepps (Shepps, 1953, p. 46) postulated that this texture may in part be due to a large admixture of lacustrine material in the debris carried by the Late Cary ice. This hypothesis has recently received support from the work of Dreimanis and Reavely (1953, p. 258) whose petrographic studies show that the upper till in southwestern Ontario contains more material of the Erie basin (both lacustrine and shale) than the lower. Presumably deposits of Maumee I supplied the lacustrine clay and silt.

Other "Great" Lakes of the Erie Basin

Following Lake Maumee I a whole series of lakes is recognized in the Erie basin. These are summarized in Table VI (p. 108). Although this table is entitled "Great Lake Stages in the Erie Basin" it should be realized that all lake stages with levels above 580 feet involved the southern end of the Huron basin as well, and that when the Grand River was the outlet the waters of the Saginaw basin were also merged with those of the Erie basin.

Taylor (Leverett and Taylor, 1915, p. 386) believed that the Lake Wayne shoreline was built by waters rising from a level at or below the present lake level. The Wayne shoreline was then submerged as the water rose still higher to the Warren levels. This sequence has been the accepted one for many years, but recently Hough (1953, pp. 46-48) has proposed that both Lake Wayne and the postulated low stage were intra-Warren. His chronology (Table VI) shows two successively lower Warren stages following Lake Whittlesey than a drop in level of an unknown amount to the pre-Wayne low water level first postulated by Taylor. Hough correlates this low water level with the Two Creeks-Bowmanville stage in the Michigan basin and submits that this is the time of maximum retreat preceding the Mankato readvance. Lake Wayne then came into being during the readvance and at the time of the Mankato maximum when the eastern outlets were closed and the drainage

TABLE VI

GREAT LAKE STAGES IN THE ERIE BASIN

Stage	Level	Outlet	Correlated Moraines
Maumee I	800'±	Ft. Wayne, Ind.	Defiance
Maumee II	760'±	north of Imlay, Mich.	-?-
Maumee III	775-785'±	Imlay and (?)Ft. Wayne	Flint, Milverton and Ingersoll
Arkona I	708-710'	Grand River, Mich.	Chesaning, Wyoming I and Tillsonburg
Arkona II	690-694'	Grand River, Mich.	N. Chesaning, Wyoming II and Paris
Whittlesey	735-740'	Ubly, Mich.	Port Huron, Wyoming III, Galt and Hamburg
Warren I	690'±	Grand River, Mich.	Bay City, Singhampton and Waterloo.
Warren II	680'±	Grand River, Mich.	Tawas, Gibralter and Niagara
--low level--	570'±	-?-Niagara R.	-?-
Wayne	655'±	south of Syracuse, N.Y.	-?-
Warren III	675'±	Grand River, Mich.	Vinemount, Oswego, Niagara and edge of Valders
--low level--	570'±	-?-	-?-
Lundy			
Grassmere	635-640'±	south of Syracuse, N.Y.	-?-
Elkton	615-620'±	south of Syracuse, N.Y.	-?-
unnamed	590-600'±	south of Syracuse, N.Y. (?)	-?-
Erie I	570'±	Niagara R.	(ice no longer directly influences the Erie basin)
Erie II	540-550	Niagara R.	
Erie III	570'±	Niagara R.	
Erie IV	560'±	Niagara R.	
Erie V	570'±	Niagara R.	

of the lakes was once again through the Grand River; a third phase of Lake Warren existed in the Erie basin.

The correlation of Lake Warren in the Erie basin and the Mankato maximum in the Michigan basin is in agreement with Bretz (1951a) who has shown that, contrary to previous opinion, the Port Huron moraine and the lake which it dammed (Lake Whittlesey) were earlier than the Mankato (Valders) maximum.

Another low water stage preceding Lake Lundy is also shown in the table. This is postulated here to explain the sequence of deposits observed in the Castalia Prairie of northwestern Erie County. (See p. 153.)

The name "Lake Erie" is applied when the waters of the Erie basin finally escaped the direct influence of the ice, drained over Niagara Falls, and became separated from the waters of the Huron basin. It will be noted, however, that changes in level are shown within the Lake Erie period. Taylor (Leverett and Taylor, 1915, pp. 442, 462 and diagram p. 397) assigned these low-water stages to the time of Lake Algonquin II and the Nipissing Great Lakes in the upper basins when the drainage of the upper lakes was diverted across the Ontario peninsula. Taylor estimated that 85 per cent of the total Lake Erie outflow is ultimately derived from the upper lakes. A decrease of this much in the total discharge volume would mean some lowering of lake level and he believed that additional lowering was possible because of the bottom configuration of the Niagara River channel: "Where Niagara River passes over the ledges of the Onondaga limestone at Black Rock its channel contains a narrow and rather deep passage which probably carried the whole of the stream at the low stages, and this resulted in a lowering of the lake level more than if the sill had been broad and even" (ibid p. 442).

A well-developed old shoreline near Fort Erie, Ontario, is part of Taylor's evidence (ibid, pp. 443-444 and 465) for low water since the Niagara outlet was last opened. Fort Erie is north of the Algonquin hinge line and the beach is tilted so that it can be followed only for a short distance to the west. Taylor pointed out that its continuation could be the submerged beach reported by Moseley from the Sandusky area, but he felt that the Fort Erie shoreline should be more deeply submerged here. Moseley's submerged beach would presumably, therefore, represent a second and later low stage.

The moraine correlations shown in Table VI are dependent upon the acceptance of Bretz's (1951) theory that downcutting of outlets took place during retreats of the ice and static levels, registered in shorelines, occurred when the ice readvanced. The moraines listed, therefore, are those which are believed to mark the farthest readvance during any one lake stage. The correlations themselves are based largely on the recent work of Chapman and Putnam (1951) in Ontario, Bretz (1951) in Michigan, and Fairchild (1932) in New York.

SHORELINES OF THE VARIOUS LAKE STAGES IN NORTH CENTRAL OHIO

On Plate I the higher shorelines, i.e. Warren and above, as shown for the Vermilion, Bellevue, and Sandusky quadrangles are essentially as mapped by Dr. Frank Carney (1911, 1913 and field maps).

I have added the Wayne and Lundy shorelines and the Whittlesey and Maumee beaches within the Huron River embayment on the Norwalk and Siam quadrangles.

Identification of Shorelines

The work of Leverett and Taylor as well as that of Carney established the fact that west of Ashtabula, Ohio, the abandoned shorelines on the southern side of the Erie basin are essentially horizontal. This region thus has apparently not been affected by the crustal movement which has tilted the beaches at the eastern end of the Erie basin and those of the upper lake basins. That statement may not be true for the time of Lake Maumee I, but evidence for the presence of this lake east of Findlay, Ohio, is too scattered and questionable to allow any measure of uplift. Taylor (1915, pp. 337 and 343-348) noted two exceptions to the horizontality of the later Maumee beaches also (near Findlay and on the Oberlin quadrangle) but these are local departures and do not appear to be part of the general upwarping to the northeast. It is, therefore, quite satisfactory to identify the various shorelines here in Erie and Huron counties on the basis of the elevations given in Table VI. (See, however, pp. 154-157.)

Huron River Embayment

Just west of the Berea escarpment in southeastern Erie County a rather sharp indentation of the shorelines is present for all lake levels above the present one. The names "Huron River embayment" and "Monroeville embayment" were used by Dr. Carney at various times to refer to this area. Since the Huron River entered the lakes through this bay and was a primary factor in controlling the sedimentation within the area, the term "Huron River embayment" seems the more appropriate of Dr. Carney's two terms and it will be used here. The body of water within this area at the various lake stages may then be referred to as "Huron Bay".

In terms of bedrock the embayment represents an area of lower elevation carved out of the black shale belt. While the bay existed the belt of more resistant limestones to the west was frequently expressed either by a northeastward trending peninsula or a string of islands. The eastern edge of the embayment was controlled by the position of the Berea escarpment.

Maumee I

The time during which Maumee I existed may be divided into three phases: first, origin to maximum extent; second, time of shrinkage as ice readvanced to the position of the Defiance moraine; and third phase, enlargement of lake before a retreating ice sheet. This last phase ended when the ice had retreated far enough to uncover an outlet lower than that at Fort Wayne and so bring a new stage into being.

Shorelines developed during the first and second phases in a position now within the loop of the Defiance moraine were, of course, destroyed by the readvance to that moraine. These features formed during the third phase should, however, be readily identifiable. Leverett and Taylor (1915, pp. 334-335) found a well-developed Maumee I shoreline on the back slope of the Defiance in Michigan, but did not observe any in a similar position in Ohio. Taylor (1915, p. 335) suggested that the absence here was the result of overlapping or destruction by the waters of Maumee III. Such an explanation may be applicable where the lakeward slope is relatively steep, but where it is so gentle that the approximately 20 feet of difference in the elevation of the two lake levels is spread over a mile or more, such destruction does not seem likely. Under conditions of very gentle slope it is, of course, possible that the off shore zone was too shallow to allow the transportation of beach materials. In some areas also, particularly those near the major streams, dissection of the upland by small tributaries may have destroyed the shorelines.

The total lack of a recognized Maumee I shoreline in north central Ohio cannot be accounted for in this manner, however, for the conditions suggested above are essentially local and as such also apply to the later lake stages for which, generally speaking, we do have a well-developed shoreline record. Therefore, if no evidence of a Maumee I shoreline had been found the conclusion would necessarily have been that in its third phase Maumee I did not cover this area for any length of time. There is some evidence for its existence here, however.

Possible Shoreline Features

Although Dr. Carney did not mention the highest Maumee I shore (his "highest Maumee" is the Maumee III stage) he did map several sand ridges in eastern Erie County just southeast of Berlin Heights which, I believe, belong to the first stage of Lake Maumee. (See Plate I.) A small dune tract lies south of the beach ridges.

Within the Huron River embayment several more questionable remnants are assigned to this stage. In southwestern Peru and southeastern Sherman townships, Huron County, there is a short sand ridge about four-tenths of a mile long on the upland just west of the West Branch of the Huron River. At its western end it is connected to a "step" cut into the backslope of the Defiance moraine. The elevation of the sand ridge at its highest point is approximately 810 feet (by hand level from a railroad bench mark), and that at the base of the "step", 814 feet. These are tentatively identified as a wave-cut cliff and a spit built out from it across the mouth of the Huron River.

Still within the embayment, but at its southeastern end south of Settlement Road in northeastern Peru township, is an area of dunes. The dunes themselves are, I believe, the result of accumulation at the time of the Maumee III stage, but along the southeastern edge of the tract are knolls of coarser material at about 800-810 feet elevation. The position is about on the Berea-Bedford contact and near the north end of the Norwalk esker. No well-exposed section was available and no bedding was observed. The knolls are about seven to ten feet high and consist of coarse sand and gravel. Dissection here has been great enough to destroy any continuity in the deposits, so whether they are remnants of the Maumee I shoreline or have a sub-glacial origin and are associated with the Norwalk esker is uncertain.

South and west of Bellevue windblown sand covers the surface for several miles south of the Maumee III beach. Dr. Carney (1913, p. 237) postulated that this sand mantle so far behind the highest beach was the result of more extensive waters than Maumee III. Presumably these waters would be these of Maumee I.

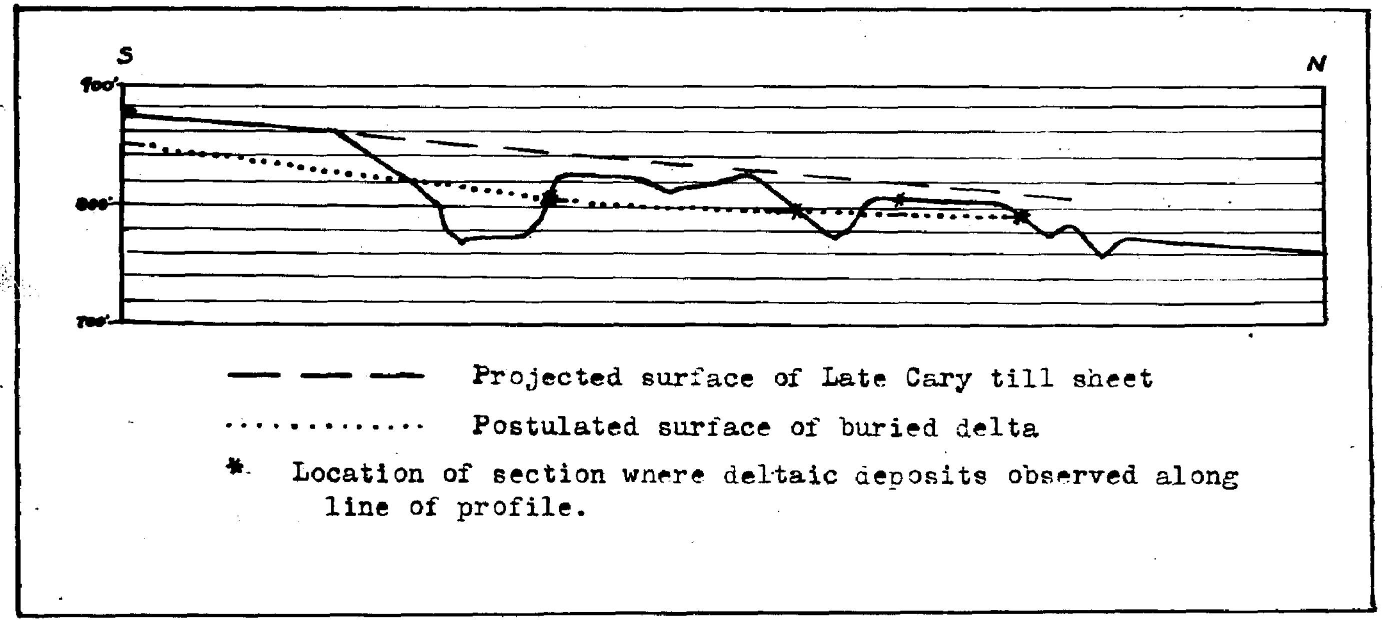
The evidence for Lake Maumee I during its third phase is certainly scattered and much of it is questionable, but I believe, there is justification for the statement that the early Maumee lake did cover this area for a short time as the ice retreated.

Maumee I Delta of the Huron River

Reference was made in the discussion of the Defiance moraine (p. 38) to an area in northern Greenfield and southern Peru townships where the topography may be characterized as rolling. Leverett (1902, p. 588 and Pl. XIII) included this within the boundaries of the Defiance moraine. My interpretation is, however, that the surface here is the result of destructional processes rather than constructional.

Evidence for a Buried Delta: Within this area auger holes and exposures very frequently reveal medium grained to coarse sand at or close to the surface. Several sections showed laminated silt, fine sand, and clay. The sorted material which seems to extend from the vicinity of Steuben northward to the Maumee III beach is apparently a continuous deposit with a gentle northward slope (Pl. XXV). The interpretation here offered is that it represents a delta of the Huron River built during the early phases of Maumee I and subsequently buried under a thin covering of till as the ice advanced to build the Defiance moraine.

Dissection of Delta: The greater part of the dissection which gives the area its rolling character today is believed to have occurred when base level stood nearby during Maumee III. (See pp. 147-148.)



Profile along buried delta in Peru and Greenfield townships, Huron County.

Maumee II and III

The beaches marking the levels of Maumee II and III enter Huron County in the northwestern corner at Bellevue. At the county line the individual beaches are somewhat obscured by dunes as well as by sink hole topography.

Maumee III Shoreline West of the Berea Escarpment

After crossing the Wheeling and Lake Erie Railroad at the eastern edge of Bellevue U.S. 20 follows the upper beach as far as the Sand Road intersection where the trend of the shoreline bends abruptly southward into the Huron River embayment. Between Bellevue and Sand Road the beach consists largely of fine sand. Near the eastern end some shale gravel occurs.

Southward from U. S. 20 along the western side of the embayment to Pontiac the Maumee III shore is a well-developed beach ridge, which serves as the site of Hill Road. In that portion between U.S. 20 and State Route 547 the height of the ridge is augmented by dunes, and from Opperman Road south to Frink Run there are two beach ridges, the second or westernmost also being covered with dunes. An accumulation of boulders in front of the easternmost ridge gives evidence of effective wave erosion near shore.

The continuity of the Maumee III shoreline is broken for about a mile southeast of Frink Creek, but from the Sherman-Peru township line to Pontiac there is a good sand beach. From the valley of Slate Run at Pontiac to the upland east of the East Branch of the Huron River only discontinuous segments mark the level of Maumee III. This is in contrast to the Maumee II beach here in the southern end of the embayment. The latter is unusually strong and shows little effect from reworking by the waves of the higher Maumee III.

Between Cole Creek and the East Branch a sharp beach ridge is present at the middle Maumee level and provides the site of Garrison Road. East of Cole Creek it continues as an easily discernible ridge through the southern outskirts of the town of Norwalk. At the reservoir in the southeastern section of that town the two beaches, Maumee II and III, are less than two-tenths of a mile apart and they continue northeastward along the edge of the Berea escarpment in close proximity.

Maumee II Shoreline West of the Berea Escarpment

The Maumee II shoreline in this same region is unusually well preserved for a beach that underwent submergence subsequent to its development. (See Pl. XXVI, Fig. 1) East of Bellevue it can be traced along State Route 113 for about a mile beyond Strongs Ridge (intersection with State Route 4). At Strongs Ridge it consists of a cliff cut into the Prout limestone member of the Plum Brook shale. This cliff is certainly one of the prominent features of the lacustrine plain in this area and is readily discernible to any one traveling along either state routes 113 or 4. Material at the base of the cliff is sand and coarse cobble.

In the area between State Route 113 and U. S. 20 where the Maumee II shoreline is trending southward into the embayment, there is a series of short discontinuous beach segments. Dr. Carney (field notes)

Fig. 1 - Maumee II shoreline east of Bellevue.

Fig. 2 - View northward from Maumee III beach to beach of Maumee II, southwest of Berlinville.

interpreted the conditions here as showing the lakeward growth of the land through stages of off-shore bar and spit development.

In northern Peru Township sharp sand ridges on the uplands between the river valleys represent the lowest Maumee level. One such segment between the East Branch of the Huron River and Cole Creek is utilized as the site of Johnson Road. Along the southern edge of Norwalk, north of the County Home the Maumee II beach has a washed appearance, but at the reservoir again presents a sharp profile.

Lower Maumee Shoreline along the Berea Escarpment

From Norwalk to Berlinville the two Maumee beaches are less than three-tenths of a mile apart and the depression between them frequently contains muck deposits which are used for small truck gardens. (Pl. XXVI, Fig. 2). Throughout almost this entire distance both shorelines are shorelines of deposition, the material being typical beach sand with little coarse material. One known exception is found where State Route 601 crosses the upper beach. The Berea sandstone is very close to the surface and at the time of Maumee III there was probably a low cliff here.

For about two and a half miles southwest of Berlinville, State Route 61 follows along the top of the middle Maumee beach ridge. Dunes cap the ridge and wind blown sand covers the surface for some distance back of the ridge.

If we consider a rough triangle whose apices are marked by Milan, Berlinville and East Norwalk, we have an area in which the

Warren, Whittlesey and Maumee branches are converging toward the northeast. In this area all are well-developed sandy ridges and there is considerable dune accumulation associated with the beaches. The topography in fact is largely the reflection of dune forms on and between the beaches. Such an accumulation of wind blown material is common along the southern shores of the Erie basin when the beaches face northwestward into the prevailing winds. Conditions are particularly favorable here, of course, because of the ample supply of sand furnished by nearby outcrops of the Berea sandstone.

From Berlinville to the eastern limits of Erie County the lower and middle Maumee branches lie on top of the Berea escarpment. Areas of shallow bedrock which were present as shoals or small islands have considerably increased the complexities of the beaches. Both shorelines are marked by wave transported material of considerable coarseness, so that agriculturally they are best suited for orchards.

Stretching NNW from Axtel for one and a quarter miles along the top of the escarpment there is a spit made up of the coarse cobble. It might better perhaps be described as a tombolo, for it seems to have tied the height of land on the Berea outcrop at the intersection of Thompson and Darrow Roads to the mainland. This undoubtedly was above water during the Maumee II stage but during the higher water of Maumee III it was more likely a shoal. The surface material here is almost entirely coarse pebble material which is but slightly rounded.

Maumee Islands in Western Erie County

In addition to this island on the Berea outcrop at the time of Lake Maumee, two small areas on the bedrock highs in the vicinity of

Castalia also stood above water. The largest of these lies on the present Sandusky-Erie county line and is mentioned below as the tip of a Whittlesey level promontory. (p. 124). The surface here is covered with wind blown sand and the Maumee shoreline itself is indicated by cliffs along the northern and eastern sides. Northeastward in the direction of strike lie two other hills of Columbus limestone. (See Pl. I) The southernmost of these formed an island at least during the period of Maumee II. The northern hill was undoubtedly a shoal area during this period, and the sand covering the hill appears to be wind deposited and as such accumulated during the Lake Whittlesey stage.

Arkona Lakes

The fact that the Arkona beaches represent temporary halts when the lake level was being lowered by the erosion of the outlet means that they were probably not too well developed to begin with. Their subsequent submergence beneath the waters of Lake Whittlesey then modified or completely destroyed whole segments. These factors plus the closeness of the beaches to the later Warren levels undoubtedly account for the weak and fragmentary nature of the shorelines assignable to the Lake Arkona interval in the Erie basin.

On the Bellevue quadrangle in western Sandusky County a discontinuous ridge juat above the main Warren beach may belong to this lake stage (Carney, 1913, p. 245 and Leverett, 1902, p. 764). It does not seem to have the characteristics of a submerged beach, however, and I believe that it probably represents a Lake Warren level.

A rather careful search, with the aid of the soils map of Huron County, within the area of the Huron embayment did not reveal any beach ridges at the Arkona level or areas of beach sand spread out by waves at or near the 694 to 710 foot elevations. The conditions here, as well as in the region northeast of Bellevue, are not particularly favorable to the formation of shoreline features, however. There is a very gently sloping surface and bedrock is close to the surface.

In the Castalia vicinity it is quite possible that the cliffs assigned to the Lake Warren stage may be in part the work of Arkona waves. In like manner the cutting of the Lake Warren cliffs along the front of the Berea escarpment may have destroyed any evidence of Arkona shorelines there.

There do seem to be several short beach segments in Erie County, which are assignable to the period of the Arkona stages, however. One lies just west of Sand Hill in northern Groton Township. It is a low fragmentary sand ridge at an elevation of about 710 feet. In Vermilion Township a low till cliff with coarse wave-worked gravel at its base is present at this upper Arkona level also. (See Pl. I)

Lake Whittlesey

The general statement that along the southern shore of Lake Erie the Whittlesey shoreline is one of the best developed certainly holds true in the area of this study.

Mainland Shore

Across eastern Sandusky County from Clyde to the Erie County line the character of the Whittlesey beach as well as its trend is remarkably constant. Near Clyde there are sometimes two ridges, separated by several hundred yards. The northernmost ridge is continuous throughout the entire distance and provides the site for County Road 175. A layer of woody material which occurs at the base of the beach deposit here is of particular interest. (See p. 165)

At the Erie County line this stretch of Whittlesey shoreline culminates in a promontory of Columbus limestone. The bedrock high here has already been mentioned (p.122) as forming an island during the Maumee II and III stages. Rather bold cliffs are present at the Whittlesey level on the northward facing shore, but along the eastern and southeastern side the shoreline is marked by deposits of cobble, gravel and sand, the material becoming progressively finer southward and away from the cliffs. South and east of Sec. 11, York Township (Sandusky County) there is no evidence of a Whittlesey shoreline for about five miles. The area involved is one of organic soils covering shallow limestone. It appears that during the period of Lake Whittlesey the shallow waters here were protected from the direct force of the wind and waves by the promontory and several islands so that marsh conditions existed.

Just east of the Columbus-Sandusky Road (State Route 4) a low ridge is apparent at the 740 foot level. The ridge becomes stronger eastward to North Monroeville where it bends southward into the embayment. At the point where the direction changes from east to south a spit developed. Its first growth was toward the northwest, but within a quarter mile of the main shoreline there is an abrupt change to a northeasterly direction. The total length of the spit is about one and three-quarters miles, and although it becomes gradually lower toward its northeast terminus (725 feet by altimeter measurement) it is otherwise well-developed throughout the entire distance. The material of which this spit is built is almost entirely shale fragments.

State Route 99 follows the Whittlesey beach ridge southward from North Monroeville to Monroeville. (See Pl. XXVII, Fig. 1.) The beach itself is sandy, although shale fragments and erratic boulders are common at its base. Between Monroeville and Norwalk U. S. 20 lies atop the Whittlesey shore ridge which is for the most part sandy.

Within the city of Norwalk the beach ridge character of Route 20 (Main Street) is clearly discernible in spite of man's activities.

From the eastern edge of Norwalk to East Norwalk State Route 61 is on the Whittlesey beach. In places along this stretch there are two ridges with muck deposits between. Beyond East Norwalk as far as Berlinville the Whittlesey beach is within the area of large dune sand accumulation mentioned in connection with the Maumee levels (p. 121) and the actual shoreline is somewhat difficult to trace.

At Berlin Heights Lake Whittlesey is represented by a step cut into the escarpment and the shoreline is alternately cliff and beach from Berlin Heights eastward to Chappel Creek. From Chappel Creek to State Route 60 Darrow Road follows a Whittlesey beach built of rather coarse material (Pl. XXVII, Fig. 2). The large boulder accumulation (See Pl.XVIII) in front of both the Whittlesey and Warren shorelines in Vermilion Township attests to the fact that at these lake levels the area was subject to vigorous wave erosion.

Fig. 1 - Whittlesey beach ridge north of Monroeville.

Fig. 2 - Whittlesey beach at intersection of Risden and Darrow roads, Vermilion Township, Erie County.

From State Route 60 to the Erie-Lorain county line there are two Whittlesey shorelines. The southernmost seems to be entirely constructional in origin, but at the county line the northern is a low cliff cut in till.

Islands in Lake Whittlesey

During the time of Lake Whittlesey several islands existed in western Erie County. That the largest of the Lake Maumee islands in this area had become a part of the mainland has been pointed out above. The two smaller Maumee islands or shoals were, of course, increased in size at the Whittlesey stage. That which is now astride the Groton-Margaretta township line shows a strong cliff facing the northwest. Small quarrying operations appear to have changed the profile somewhat, however. Elsewhere around this island coarse beach deposits are present. At the time of the field work for this report the deposits at the southern end of the island were being exploited for road ballast. The pit showed cobble at the top with the water worn pieces of limestone averaging about three to four inches in diameter. Downward the material became coarser until at the base it was truly a boulder accumulation and erratics were not uncommon.

The Whittlesey level is largely marked by beach deposits on the smaller and more northerly island. On the west and northwest the beach consists of coarse sand and gravel, while along the eastern side it is of relatively fine sand. Separating the two areas is a short stretch of cliff face on the northeast shore. Dr. Carney (1913, p. 244-245) mapped two sand spits at the southeastern end of this island. In my opinion the recognition of these features is somewhat questionable because of a sink hole that occupies the area between these "spits". I would rather interpret the accumulation as a thin mantle of sand over a wave-cut terrace.

During Lake Whittlesey time another island was present in this general region. It is the hill now known as Sand Hill about five and a half miles northeast of Bellevue in Groton Township.

The surface of Sand Hill is capped with wind blown sand and dune forms are evident. The northern side of this island displays a cliffed shoreline at the Whittlesey level and in front of the cliff lies a wave-cut terrace covered with numerous erratic boulders. Dr. Carney (1913, p. 243-244) has given quite a detailed description of hooked spits at the southern end of the Sand Hill island. His discussion was apparently based on a careful and detailed study, but it should be noted that the spits are now practically indiscernible as surface forms.

Lake Wayne

The shoreline of Lake Wayne is among those which were submerged beneath the waters of a higher lake level; in this case, Warren. Even under these circumstances Lake Wayne seems to have left a better record in the Erie basin than Lake Arkona and this fact is used as an argument that Lake Wayne was built under conditions of rising waters, i.e. was preceded by a low water stage.

Just west of the Erie County line in Sandusky County I have mapped the Wayne shorelines as a low till cliff. At the county line the bedrock highs which appeared as islands during Whittlesey time are encountered. They are part of the mainland at this level, however, and the shoreline is marked by cliffs which are quite discernible to anyone driving along State Route 12 west of Castalia. The cliffs continue for a short distance east of Castalia but are much lower and in the vicinity of Maple Avenue the shorelines bend southward. Here the Wayne level is represented by scattered and fragmentary sand deposits. During Lake Wayne these were probably bars and spits built by opposing currents around the Castalia headland. The conditions are similar to those found where the Maumee II beaches turn into the Huron River embayment and are in contrast to the more mature shorelines found under similar conditions at the Maumee III and Whittlesey levels.

North of Sand Hill there is a sandy ridge at a level slightly above 660 feet (by altimeter check). This is assigned to Lake Wayne as is its apparent continuation east of Patton Tract Road through the Plum Brook Ordanance Works. The mapping of the Wayne shoreline within the property of the Ordnance Works is somewhat doubtful, however. At the time of this study (1951-52) installation of the various chemical plants had considerably changed the face of this portion of Perkins Township and the conditions of my admittance to the area were not particularly favorable for mapping.

At the Wayne level along the western side of the Plum Brook reservation there is a low cliff in the Prout limestone. Dunes and beach sands mantle the top surface. Dr. Carney mapped this as part of the Warren shore (field map), but as he apparently did not recognize the Lake Wayne stage there is no contradiction in accepting it as the work of the earlier lake.

Just west of Bogart the trend of the Wayne shoreline changes from an east and northeast direction to one that is south southeast along the western shore of a much reduced Huron River embayment. In this area also there seem to have been numerous spits and bars during the period of Lake Wayne and the pattern is similar to that already discussed for the region east of Castalia (see above).

In northeastern Oxford Township a low till cliff blanketed with sand represents Lake Wayne. Beyond this segment no further trace of the Wayne beach was found in the Huron valley.

At the western limits of Berlin Township a rather thick mantle of fine beach sand is present along the 650-foot contour. This is interpreted as representing the material of the Wayne beach later reworked by the waters of Lake Warren. This deposit can be traced to Old Woman Creek where the edge of the escarpment is encountered and then for several miles eastward at the base of the escarpment. With the exception of two short segments of cobble beach south of Ashmont no good Wayne shoreline was mapped in eastern Erie County, however.

Lake Warren

In the early references to the Warren stage within the Erie basin mention is frequently made to the multiplicity of beaches. These accounts are somewhat confusing to read today because a number of beaches, now recognized as belonging to different stages, were grouped together under the heading of "Warren beaches". These included the Arkona beaches, the Warren and sometimes the Wayne.

However, even when these other levels are eliminated from consideration, the shoreline of Lake Warren in Erie County is rather complex. The more continuous beach segments seem to be equally as strong as the Whittlesey beach so that it would seem that there was an almost equal amount of time for their formation. On the other hand the Warren level is marked more frequently by off-shore bars and short poorly developed spits.

There are definitely two recognizable Warren strands in Erie County. The strongest one at 675 to 680 feet elevations, and one at 685 to 690 feet. From evidence seen here I do not believe that the second or intermediate stage is recognizable, however. If this Warren II is a valid stage for the Erie basin, it appears that evidence for it here has been destroyed by Warren III.

On the Bellevue quadrangle in western Sandusky County the main Warren beach (Warren III) lies parallel to the Whittlesey and like the latter is a site for a county road, in this case, Sandusky County 101. A discontinuous beach ridge which lies several hundred yards behind the main ridge and at an elevation of about 690 feet was tentatively assigned to Lake Arkona by Carney (field notes and map) but as has already been pointed out (p. 122) I believe it is better referred to the higest Warren level.

At the county line the mainland shore of Lake Warren, like that of Lake Wayne, was extended into a promontory which included the hills of Columbus limestone near Castalia. The northward facing Warren shore of the promontory is marked by a steep cliff which is easily seen to the south of State Route 12, west of Castalia. At the point of the promontory just east of Castalia is a Warren beach of coarse sand and gravel behind which are several well-developed dunes. From this point a spit made up of coarse material was built out eastward for about six-tenths mile.

Just south of the intersection of Maple and Bogart roads there is a Warren ridge made up of coarse cobble. The material of this ridge was exposed in a newly opened pit and there were eight to ten feet of cobble overlying limestone. The surface of the limestone still retained glacial striae, so that it was evident that little wave erosion had occurred here.

Southward along Maple Avenue the material of the ridge becomes progressively finer and occasional dunes lie atop the beach. For about a mile west of Weyer and across the depression now drained by a tributary of Mill Creek there does not seem to be any evidence of the Lake Warren shore. Along the north slope of Sand Hill, however, the Warren level is represented by cliffs, and on the eastern side there are two Warren beaches. The northernmost seems to have come into being as a spit, built out from the hill across a small stream. The spit achieved an elevation of 680 feet while the shore ridge back of it is at 690 feet. Wind-blown sand augments this height so that locally the surface is within the 700-foot contour.

From Bloomingville east for about four miles the Warren shoreline has a northeasterly trend. It then bends southward into the Huron River embayment. The northeastward-trending segment lies largely within the Plum Brook Ordnance Works. There are two Warren beaches here and dunes cover the surface between.

Southward along the western side of the Huron River embayment the shoreline is more complex. In some places there are three parallel ridges all representing the Lake Warren levels. South of Strecker Road Thomas Road is built atop the strongest of the ridges and this ridge seems to have terminated in a spit built across the mouth of the West Branch of the Huron River.

The Warren shore is the lowest shoreline which can be traced across the Huron River valley. On the upland between the two branches of the river a fairly good beach ridge remains although it is somewhat dissected by small streams. East of the East Branch the shoreline has suffered even greater post-Warren fragmentation, although it was apparently well-developed originally.

Southeast of Milan, where State Route 601 crosses the Warren shore, several gravel pits have been opened in the beach ridge. The beach sands are well stratified and overlain by three to eight feet of wind blown sand. A small dune area also lies behind the beach ridge proper.

From Milan to the West Fork of Old Woman Creek the Warren stage is represented by two beaches. As far east as Millman Road the northern one has the character of an off shore bar, being lower in elevation near the Huron River valley. From Wikel Road to Chapin Road the southernmost ridge is lost among the dunes which are part of the dune complex already mentioned in connection with the Whittlesey and Maumee strands. West of Chapin Road Lake Warren cut cliffs in the face of the Berea escarpment. The cliff phase continues with but little interruption as far east as the Berea hill northwest of Axtel. The one exception is a stretch of about three-quarters of a mile between Chappel Creek and Sugar Creek where there is a sandy beach ridge.

The surface of the ground for several miles in front of the escarpment in Vermilion Township is covered with a large number of boulders (Pl. XVIII). This surface indicates active wave erosion during all the middle lake stages. Over much of this area shale is within six feet of the surface.

Eastward from State Route 60 there are two shorelines at the Warren level. The more southerly is a low cliff cut in till and shale and mantled with sand, while the northern one is a sand ridge.

Lake Lundy

Between the easily observed Warren shoreline and the present lake level fragments of two, sometimes three, shorelines can be observed in northern Ohio. The two uppermost are at approximately 640 and 620 feet and correspond to two generally recognized states of Lake Lundy, the Grassmere and Elkton stages, respectively. The third here in Erie County, lies between 590 and 600 feet.

In the Erie basin and the southern end of the Huron and Saginaw basins the Lake Lundy levels represent stages in the transition from the Warren level to the first stage of Lake Erie. The shorelines were thus made under conditions of a falling water level as were Maumee II and the Arkona beaches, but unlike these higher beaches the Lundy shoreline was never submerged. The fact then that they are fragmentary and not too well developed even when present is due then solely to the conditions of their formation.

<u>Description of shore features</u>: In eastern Sandusky County where the well-developed Whittlesey and Warren beaches trend northeastward parallel to each other the conditions of slope and orientation to wind direction were presumably similar for the Lake Lundy levels and here if anywhere the Lundy beaches should be strongly developed. There is evidence of both shorelines here, but it certainly is not overwhelming. The Elkton level is sometimes represented by a low sandy ridge (beach sand overlain by a thin cover of wind blown sand) as in Section 29 and Section 22 of Townsend Township. The only evidence of the Grassmere shoreline in the area, however, seems to be the greater than normal number of boulders strewn over the surface.

Within the limits of Erie County and west of Castalia both of the upper Lundy levels cross the marl deposits of Castalia Prairie (p. 153). Several short, low sand ridges along the southern border of the prairie fall at the level of the Grassmere shoreline and are assigned to it. Dr. Carney (1913, map p. 233) assigned one of these to the Warren (Wayne?) level as a cusp built out from the cliffs. This may have been the original status of the deposit, but its lakeward facing terminus seems to have a low ridge parallel to the other shorelines and is at an elevation of about 640 feet.

At the northern edge of the thick marl deposits of the prairie and about a mile and a half south of the present shore of Sandusky Bay another short sandy ridge segment crosses the County Line Road. The elevation of this is below 600 feet and it clearly does not belong to the Elkton level. It seems to represent, however, another short pause in the drop to the level of Lake Erie. Fairchild (1907, pp. 74-76) mentions a number of shore features in western New York that are within 20 to 40 feet of the present level. These presumably developed at about the same time.

East of Castalia, between State Route 12 and Bogart Road is an area of bedrock with little or no soil covering. Just northeast of the buildings in Castalia a steepening in the bedrock profile may represent the work of waves at the Grassmere level. Otherwise no beach deposits or cliffs were found at any of the Lundy levels between Castalia and the Columbus-Sandusky Road (State Route 4).

South of the city of Sandusky there is a wide sandy belt. Within this area short beach segments are present at the Elkton level, but not at that of Grassmere.

In the vicinity of Bogart the strongest segments of both the Grassmere and Elkton shorelines in Erie County are to be found. A number of sand dunes are also present, associated with the beach ridges. East of Bogart the shorelines are extended northeastward so as to form a short promontory at the northwest corner of the Huron River embayment. The promontory is a reflection of the presence of the Prout limestone member of the Plum Brook shale. The shoreline at the Grassmere level along Boss Road is a low sand ridge as is the Elkton about a half mile to the north. Near the intersection of Boss and Camp Roads, however, at the tip of the promontory, there is a low cliff cut in shale at the Elkton level.

Both shorelines can be traced southwestward from the points of their respective promontories for a short distance along the western side of the embayment. They cannot be followed across the Huron River valley, however.

In this same Bogart vicinity the surface in front of the Elkton beach is sandy. No other beach ridge was observed but south of Perkins Road and either side of Galloway Road there are dunes, whose elevations suggest a water level at about 600 feet.

An old beach ridge along the modern Cedar Point spit was shown to me by Raymond Metter. The maximum elevation of this ridge is 590 feet and as Metter (1951, p. 44) pointed out it apparently represents a level transitional between Elkton and Lake Erie I and as such can be grouped with the 600 ± foot beach segment northwest of Castalia, the dunes along Galloway Road, and with a dune covered beach ridge east of the Huron River near Ceylon.

East of the Huron River valley the Elkton level is represented by a low beach ridge which extends to Old Woman Creek north of Shinrock. The surface in front of this ridge to the lake is sandy but no lower ridge is discernible. About a mile south of Shinrock and just north of Mason road is a low till cliff mantled with sand. This may be a fragment of the Grassmere shoreline.

With the exception of the area near Ceylon which has already been mentioned in connection with the 590 to 600 foot level there is little evidence for the lower Lundy levels in Erie County east of Shinrock.

LAKE BOTTOM SEDIMENTS
OF THE EASTERN LAKES SECTION

The term "bottom sediments" is here used to indicate the subaqueous deposits of the various lakes other than those which are recognized as barrier bars, spits or similar features more logically associated with the shorelines even if they did not extend above the water level.

For the area of this study these bottom sediments can be divided into several categories: well laminated sediments, silts or silty clays showing little if any laminations, sand, marl, and peat or muck.

The areas where these sediments were deposited certainly do not include all of the area of the lacustrine plain, however. This fact as well as the difficulty which sometimes arises in recognizing but slightly reworked till is pointed out in the following statement taken from Coffey (1915, p. 82).

> (It is) ... "often difficult and in some cases practically impossible to determine just how much reworking of the material has been effected by the lake waters.... Instances were noted where the surface material to a depth of a few inches undoubtedly has been reworked, while that below shows unmistakable evidence of having been deposited by the ice. Over a large part of the old lake bed very little deposition or reworking of materials has taken place."

Such a situation is, of course, to be expected. Areas of dominant deposition must be supplied from areas of dominant erosion. In the discussion of shoreline features mention has already been made of localities where the surface is covered with boulders washed from the till, bedrock platforms planed by waves and cliffed shorelines. These are the areas of dominant erosion and they make up a large portion of the lacustrine plain here in north central Ohio.

AREAS OF NON-DEPOSITION

In the course of the field work it was noted that undeniably lacustrine bottom sediments seemed to be limited to the area in front of the Lake Warren shorelines. The region of the Huron River embayment is something of an exception but even here away from the valley itself the silts and silty clays are relatively thin.

The question immediately arises, of course, as to whether the observed relationship between the Lake Warren level and the lake deposits had been noted elsewhere in the Erie basin. As far as I could discover Chapman and Putnam (1951, p. 71) are the only ones to have published a similar observation. They state that most of the silts in southwestern Ontario are deposits of Lake Warren.

There is some additional support for the idea from workers in other fields and other states, however. Dr. William Wayne (personal communication) said that although he had made no attempt to map lacustrine sediments during his work in northeastern Indiana it was his general impression that most of the material at the surface in the Maumee lake plain there had suffered little if any reworking. More recently Dr. Nicholas Holowaychuk of the Agronomy Department, The Ohio State University, stated that new soil surveys begun in northwestern Ohio seemed to suggest that soil profiles developed entirely in lacustrine material were generally limited to elevations below 720 feet. This last figure indicates that in the western end of the basin the correlation is with the Whittlesey level rather than the Warren, however. This difference may be real or it may result from the fact that the agronomists' criteria for judging what constitutes appreciable evidence of reworking is somewhat more delicate than I used.

There are also areas of little or no lacustrine deposition in front of the Warren shoreline. These are shown rather well on the map of boulder distribution (Pl. XVIII). One such area is in front of the Berea escarpment in Vermilion Township, Erie County. Here the bedrock is the Cleveland shale, which frequently lies within six feet of the surface. The soil is formed in till that shows but little reworking of its upper portions.

South and east of Castalia, in Margaretta Township, Erie County, the limestone is but thinly covered by till (or shore deposits) and boulder accumulations are frequently all that is left of till eroded from wave-cut platforms.

THE LAMINATED SILTS OF THE HURON RIVER VALLEY

Along the western side of the Huron River and north of Avery, there is an area of rolling topography which contrasts strongly with the generally flat surface of the lake plain (Pl. XXVIII, Fig. 1). At first glance the hills give the impression of dunes but the road cuts clearly show well-laminated sediments within three feet of the surface. Furthermore these laminae are truncated by the hill slopes indicating that the topography is the result of erosion rather than deposition. The upper foot or so, of course, may have been, and probably has been, reworked by the wind.

Description of the Laminated Sediments

The coarser layers in these laminated deposits consist of fine sand or coarse silt, while the finer are clay or silt clay and similar in grain size distribution to the unlaminated or poorly laminated lake sediments found either side of this Huron River belt. (See Pl. XXIX.) In several sections oscillation ripple marks were observed on the upper surface of coarser layers.

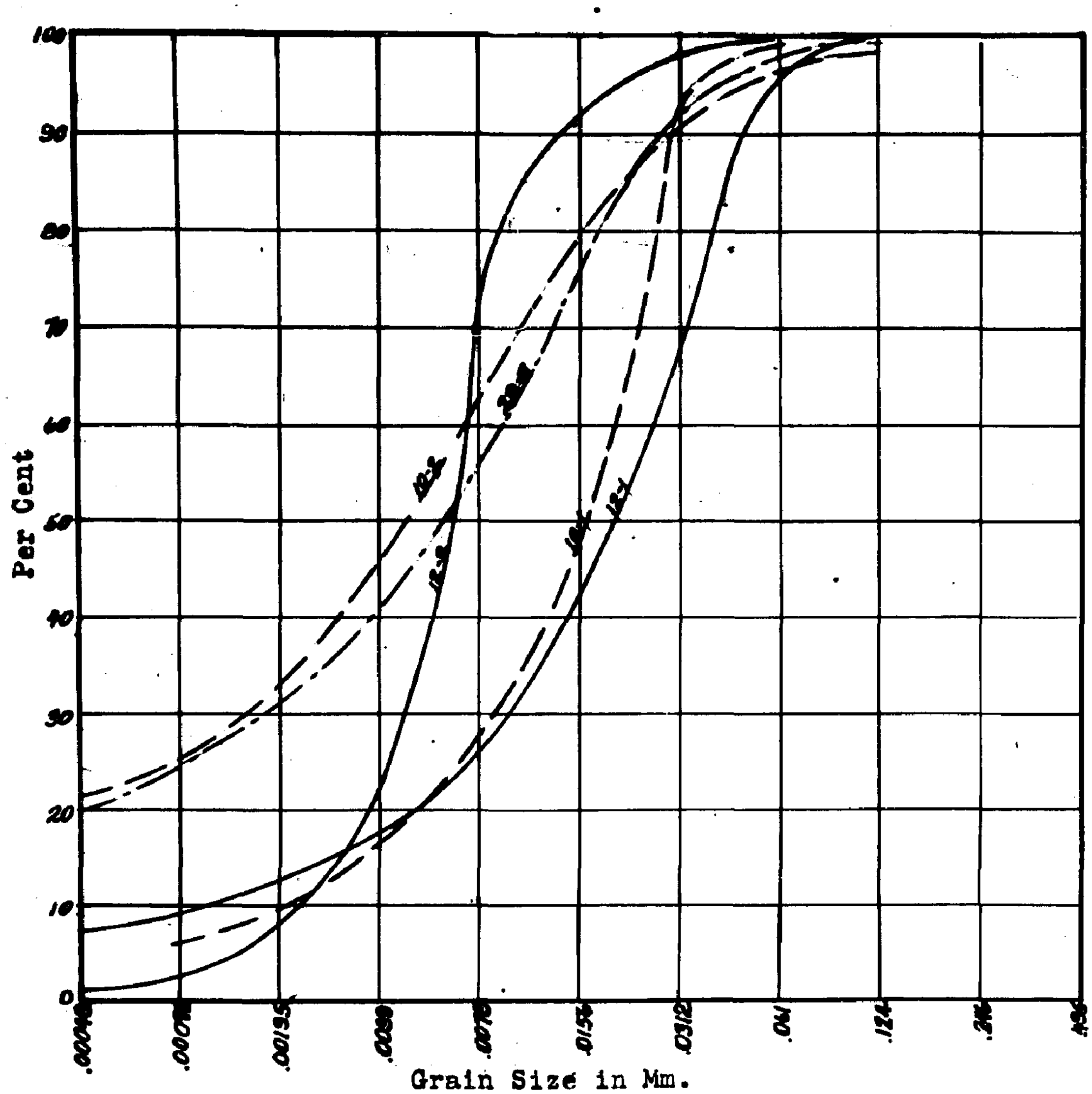
For the most part the laminae are regular and can be traced across the surface of a cut. The thickness of the individual layers varies from about one-sixteenth to one-quarter inch with the clay silt layers tending to be the thicker. The upper and lower boundary of each lamina is quite distinct, i.e. there is not the diatectic structure of the glacial varve, and for this reason I do not term the sediments varved. If, however, the term "varve" is understood to mean any cyclical deposition, these are undoubtedly varved sediments. (See, however, pp. 157-162.)

Extent and Thickness of Laminated Silts

In addition to exposures in road cuts in the area delineated above, these laminated silts can be seen in cliffs along the present lake shore from Grand Forest Beach, east of Sandusky, to within the city limits of Huron. A thick section was also observed in an abandoned clay pit behind the Lavey Pottery at Milan. South of Milan there are a few exposures along the Huron River, where the silts directly overlie the black shale in some cases, and in others

Fig. 1 - Topography along lower Huron River valley.

Fig. 2 - Distorted laminae at Grand Forest Beach.



Composition of representative lacustrine sediments.

Samples 12-1 and 10-1 are from coarse layers of the laminated sediments of the Huron River valley; 12-2 and 10-2 are from the fine layers. Sample 28-3 is from the unlaminated lacustrine sediments. A pipette reading was taken for each of the Wentworth grades given.

are separated from it by relatively thin till. In these latter sections the laminated material was never more than 10 feet thick and the laminations were not as regular as those observed farther north.

The thickest section seen was at the Lavey Pottery pit where a 65-foot section was exposed. Beneath the B zone of the profile of weathering there is about 20 feet in which the laminae are well-developed and fit the description above. Downward the layering becomes less regular and the layers of the finer material increase in thickness until at about 15 feet above the base of the section the material is a homogeneous silty clay with none of the coarser material present.

In the lake front sections the thickness is considerably less, being eight and one-half feet where measured at Grand Forest Beach and four feet at Huron Cliffs. The thickness at the latter location is quite variable within short distances, however, as the upper surface is irregular and the irregularities are filled with sand. The channeling of this surface seems to be the work of ground water moving laterally.

At Grand Forest Beach the laminated silts are seen in contact with the underlying till (Pl. XXVII, Fig. 2). The till (about 18 inches was exposed above lake level) is mixed with the lower layers of the silts which are contorted. The nature of the deformation and the fact that the contorted layers grade upward into regular laminae without any apparent break suggest that the agent of deformation was ice flows pushing against a shore or dragging in shallow water.

Eastward and westward from valley of the Huron River the laminations become less distinct and although most of the lake silts in Erie County contain the seams of coarser silt or fine sand these seams are irregularly spaced and discontinuous.

Along the Huron River valley the area underlain by these sediments is somewhat like the shape of a partially closed fan with its apex just behind the Warren beach. The present river north of Milan seems to lie a little east of the center line.

Coffee (1915) described a soil profile, similar to that developed in these laminated silts bordering the Huron River, along both the Rocky and Cuyahoga rivers to the east, but whether the parent material is as well laminated as that under discussion here, I do not know. Winchell (1873, p. 606) described laminated lacustrine sediments along the Sandusky River valley near Fremont, and Wilson (1943) discussed "varves" in the bottom sediments of Sandusky Bay. Here in Huron County, at least, the well laminated silts are definitely related to the Huron River and as seen above there is a strong suggestion from the literature that similar deposits are associated with other major streams in northern Ohio.

<u>Origin of the Laminated Silts of the Huron Valley</u>

I believe that these silts represent the filling of an earlier

Huron River valley. Since nowhere is till known to overlie the silts, the filling (and cutting) of the valley may be dated as entirely subsequent to the last retreat of the ice. The thickness of the valley filling at Milan (65+ feet) would seem to indicate a base level for the cutting at least as low as the present Lake Erie level. The first such level indicated in the chronology (Table VI) is the pre-Wayne low stage. It makes little difference whether this stage and Lake Wayne are pre-Warren as postulated by Leverett and Taylor or intra-Warren as suggested by Hough.

As a continuous deposit the laminated silts are recognized as far south as two miles behind the Warren III beach. That they extend south of the Warren shore presents no difficulty. A rising lake level such as Hough's Warren III would mean estuarine conditions behind the shoreline. In front of the shoreline the Huron River entered the lake through the protected area of the Huron River embayment and it may be that the more regular laminations here reflect this protection from the forces which affected the bottoms in more exposed localities.

Mature Dissection in Area of Huron River Laminated Silts

In the introduction to this subject of the laminated silts of the Huron River valley mention was made of the rolling topography which contrasts strongly with the flat surface of the lacustrine plain on either side. This topography can legitimately be described as mature and its development here raises a number of questions, not all of which can be answered.

Extent of Area

The area of this mature topographic development is entirely within the region underlain by the laminated silts, but is by no means co-extensive with it. The former is limited to the lower portion of the Huron valley and is roughly outlined by Mason Road on the south, State Route 299 (Huron-Avery Road) on the north and west, and the Huron River on the east. It is thus an area of about ten square miles.

Description of Area

The entire region is drained by Mud Creek and its tributaries, which make up a well-developed dendritic drainage pattern. This feature is also in contrast to most of the lake plain where small streams are only beginning to develop tributary systems and are still best described as parallel. The texture of the drainage is quite fine, and except for the lower two miles of the Mud Creek valley, which is drowned, the stream flow is intermittant. In these respects the drainage is similar to that developed in areas of loess.

Mud Creek enters the Huron River less than a mile from the mouth of the latter and throughout its length is roughly parallel to the larger stream. Indeed, in some cases the divide is less than a tenth of a mile from the Huron River.

Possible Factors in the Development of the Mature Topography

The porous nature of the silts and sands (The bottom sands of Lake Lundy were apparently once continuous across the region, but now only a few remnants remain.) is undoubtedly a factor in the formation of the surface forms, as is the closeness of the area to regional base level, but these do not provide the whole answer.

Unanswered questions are why the dissection is limited to the west side of the Huron River, when the laminated silts and bottom sands are present to the east also, and why such mature dissection is not found associated with the other major streams of the lake plain. In the case of the Sandusky River, laminated silts are known to be present and the literature strongly suggests that similar deposits are associated with the other streams, particularly the Rocky and Cuyahoga rivers.

Comparison with the Area of the Maumee I Delta of the Huron River

Whatever the causes of more rapid erosion in the lower Huron River valley, it is suggested that the area of more mature dissection just south of the Maumee III beach in the Huron embayment (p. 115). resulted from similar conditions. The drainage texture is not so fine there, but this may be accounted for by the thin covering of Late Cary till which overlies the porous sands and silts.

MARL AND PEAT SEQUENCE OF THE CASTALIA PRAIRIE

North and west of Castalia in Margaretta Township, Erie County, and in Townsend Township, Sandusky County, there is what was formerly an extensive wet prairie, but which is now drained. Underlying 3,500 to 4,000 acres here and at elevations between 610 to 630 feet is an interesting sequence of marl and peat beds.

The marl has been exploited for many years for the manufacture of Portland cement and at the present time excavating is being carried on by the Medusa Cement Company for its plant at Baybridge, Ohio. The stripping of the marl and the digging of drainage ditches has exposed the section over a wide area.

Marl is also known to underlie the waters of Sandusky Bay and at the turn of the century some of this was mined for cement purposes.

Description of Deposits

Within the area of the present operations which is roughly outlined by Oxbo, Heywood and County Line roads and State Route 269 there are three layers of peat which are continuous over the area although their thickness is quite variable. (See Plate XXX.) The following is a composite section for the area outlined:

Castalia Section

Unit	Description	Thickness
8	Peaty soil (removed over much of the area).	0' 0" - 0' 6"
7	Fine grained white marl; shells of mollusca common; increasing amount of vegetable material toward the base, giving the marl a gray color; irregularly cemented masses of marl present.	1' 0" - 2' 6"
6	Black peat with numerous shells of molluscs	0' 6" - 1' 0"
5	Buff colored marl consisting largely of Chara stems and nodules; much shell material. Encrusted stems of the reed grass, Phragmites, common; pebbles of calcareous tufa in the lower few inches.	1' 6" - 3' 0"
4	Black peat (quite variable in thickness).	0'3/4"- 0' 4"

3	Alternating and irregular layers of relatively pure marl and marl containing much organic material. Stems of reed grass common.	1' 0" - 3' 0"
2	Marly peat containing large quantities of wood among which that of the red cedar, <u>Juniperus virginiana</u> is the most characteristic.	0' 6" - 0' 8"
1	Blue clay silt	35' ±

In the course of digging the marl thicker sections which seem to be channel fillings are encountered. They are linear and have a general northwest trend as does the natural surface drainage at the present time. The sequence along these lines is the same as that given above, i.e. the "red cedar" layer directly overlies the lacustrine silts into which the channels are cut (Mr. Arthur Little, personal communication).

Records of wells and drill holes within the prairie show 38 to 55 feet of lacustrine silts overlying thin till and Silurian dolomite.

Wood from the Peat

Dr. George Burns (1954) made a study of material collected from two of the peat horizons (Units 2 and 6 above) and identified a number of genera: <u>Acer</u>, <u>Fraxinus</u>, <u>Populus</u>, <u>Ulmus</u>, <u>Quercus</u>, <u>Carpinus</u>, <u>Carya</u>, <u>Cornus</u> and <u>Juniperus virginiana</u>. Except for the last named, which was identified only from the lower peat, the associations in the two layers are similar and like the historical swamp forest communities of northern Ohio.

Juniperus virginiana from the lower peat is often interpreted as indicating a relatively low water table and firm soil conditions, but according to Dr. Burns this is not necessarily so, for the species is reported from the lake borders and peaty swamps in Michigan. Nonetheless, the peat layers do represent times of lower water table than do the marl horizons.

A piece of this "red cedar" collected by Dr. Goldthwait was dated by the radiocarbon method at 8,513 plus or minus 500 years (Libby, 1951, p. 292).

Origin of the Marl

The subterranean waters issuing forth through the Blue Hole and other springs in the region of Castalia are saturated with calcium bicarbonate, and calcium carbonate is being deposited today around these springs and along the courses of the streams which they feed. Physico-chemical reactions undoubtedly cause some of the precipitation, but the lime precipitating stoneworts (Characeae), which are present, are also a factor. The great abundance of *Chara* stems in the marl deposits of the Castalia prairie indicates that these plants were also an important factor in causing carbonate deposition in the past. E. M. Kindle (1927) enumerated as conditions favorable to the growth of the various species of *Chara* a temperate climate, relatively shallow water, and protection from the full force of storms.

Section within Castalia Prairie.

Correlation of the Castalia Sequence with Events in the Erie Basin

Pre-Lundy Low Water Stage

With the exception of the postulated pre-Wayne low stage and Lake Wayne itself it does not appear that the conditions necessary for luxuriant *Chara* growth could have been fulfilled here before the time of the Lundy levels. Today the Marblehead Peninsula separates Sandusky Bay from the open lake, but the bedrock highs on the peninsula have maximum elevations of 650 to 664 feet. Little protection could have been afforded waters covering northwestern Erie County by these highs when the lake levels were at or above 675 feet. Also the depth of water at the higher levels would have been too great for the growth of the Characeae. Furthermore neither the peat or marl deposits are to be found south of the Grassmere shoreline.

The date of 8,513 years can thus safely be asigned to the general period of Lake Lundy. The lower peat horizon itself does, of course, represent a low water stage. Whether this stage occurred prior to or after the Grassmere level is perhaps open to question. Dr. Goldthwait's sections measured here in the Castalia prairie contain reference to a sandy shore deposit overlying the clay silt and underlying the first peat layer. This sand would presumably represent deposition while the lake stood at the Grassmere level. In my own experience the material immediately underlying the "red cedar" horizon was clay silt with a layer of silt and fine sand eight to twelve inches below the peat. Below this unit there seems to be a continued and irregular alternation between clay silt and the coarser silt, an alternation such as is typical of the poorly laminated lacustrine silts found elsewhere. For this reason I have placed the low water stage in a pre-Lundy (pre-Grassmere) position in the chronology (Table VI). It is recognized, however, that it may have occurred after the Grassmere level.

Suggested Causes of Continued Alternation of Deposition

A well founded correlation of the remainder of the Castalia sequence with events in the Erie basin is impossible at the present time. Dr. Paul Sears has collected material for pollen analysis from the whole section of lacustrine and swamp deposits and the results of his study can be expected to help clarify the situation.

Undoubtedly during some of the time the peat-marl sequence was being deposited Lake Erie existed within the Erie basin. It is perhaps worth suggesting that Units 4 and 6 of the composite section may represent the periods of postulated low Erie levels.

It may also be that the alternation of peat and marl horizons is simply the result of a fluctuating water table caused by climatic conditions. Poor interior drainage is the rule in the portions of the lacustrine plain which are underlain by clay silts and clays such as those of Unit 1.

At least one other possibility exists and that is that the sequence of horizons here at Castalia is the result, in part at least, of earth movements within the Great Lakes region.

The fact that the southern and western shores of Lake Erie are being progressively inundated while the northern and eastern shores are rising has long been recognized. It would be difficult to escape the evidence that the river mouths along the southern shore are drowned while those on the opposite shore of the lake are not. Furthermore the abandoned beach ridges of the Erie basin east of Ashtabula, Ohio, in common with the glacial lake shorelines of the northern lake basins, give evidence of progressive uplift to the northeast. G. K. Gilbert (1898) was the first to attempt to assemble lake level records to show that this uplift is continuing today and is actually measurable over the short time for which records are available.

Gilbert's interpretation of the water gauge records indicated a regional uplift of about 0.42 foot per 100 miles per century. His stations were few, however, and he did not look for any tilting where the beaches were believed to be horizontal. The submergence of the south shore, he explained, was the result of the upwarping of the northeastern end of the lake and the Niagara River outlet. His report (ibid, p. 639) of maximum inundation at Toledo and Sandusky did not negate the concept of the "area of horizontality" southwest of a region which was being upwarped to the northeast, for the first named locality is at the extreme western end of the lake and the second station is located near the southernmost point on the lake shore.

Gutenberg (1933) with records from additional stations and for a longer period of time reevaluated the evidence for crustal movement in the Great Lakes region. The results of his calculations for the

Erie basin were but little different from those of Gilbert. On an isobase map (ibid, p. 458), however, he showed northwestern and north central Ohio as being within the region of crustal movement.

Moore (1948) with still additional information interpreted the matter of crustal movement in the Great Lakes region somewhat differently than had previous workers. Instead of uplift north of hinge lines located on the basis of beach elevations, he felt that the evidence showed that all of the Great Lakes area, except for the extreme northwestern portion of the Superior basin, is subsiding and that within the Erie basin subsidence is greatest at Port Clinton, and least at Buffalo. Not only is water being "poured" to the southern edge of the lake, but the actual volume of water within the basin is also increasing.

In accepting Moore's data and the interpretation he places upon them one is immediately faced with the difficulty of fitting it in with the evidence of the beaches and the concept of the "area of horizontality" derived from them. His map (ibid, Pl. I) definitely indicated unequal inundation (differential movement) along the south shore of Lake Erie and yet all of the abandoned beaches apparently maintain rather constant elevations. During this study a number of checks were made with an altimeter on the water levels indicated by the various beach ridges in Erie County. All the readings fell within the ranges recognized for the same beaches at the western end of the lake basin. True, the amount of movement Moore calculated for the various stations along the south shore during the period of the records falls within the limits of accuracy of the altimeter, but presumably this movement began thousands of years ago and by now it should be reflected in deformed beaches.

This question of the validity of the "area of horizontality" deserves further study but whether or not Moore's hypothesis is correct, it seems certain that the Erie basin is affected by earth movements. The rate of movement does not appear to be constant, however, and another possible explanation of the Castalia sequence may be this warping. On this basis the periods of marl deposition may represent periods of accelerated inundation of the south shore. The swamp forest would then reflect times of less movement when deposition of marl had built up the surface.

Perhaps all three suggested causes - climatic fluctuation, changes in lake level, and earth movements - may have played a part in developing the section of alternating horizons within the Castalia prairie. At the present time, however, all that can be said is that the immediate cause lies in a fluctuating water table.

LAMINATED SILTS OF THE SANDUSKY BAY REGION

West of Castalia Prairie and apparently all along the southern shore of Sandusky Bay and for two or three miles south of it, ditches and excavations show laminated sediments of silt, clay silt and silty clay immediately below the A zone of the soil profile. It is not knownwhether these silts are continuous with those mentioned by Winchell (1874, p. 606) in the vicinity of Fremont, but from the known distribution it appears that these laminated deposits, like those of the Huron River valley, are associated with the valley of a trunk stream. (Sandusky Bay is the drowned mouth of the Sandusky River.)

Description

The regularity of the laminae is not as good generally as in the Huron valley sediments, either in regard to horizontal continuity or thickness. The thickness of the individual laminae vary from about one-sixteenth inch to six inches or more; the very thin layers (less than one-sixteenth inch) are usually of the coarser material while the thicker layers may be either silt or clay silt. When viewed under the microscope the silt is seen to consist almost entirely of quartz grains. No diatactic structure was observed.

Comparison with Wilson's Sandusky Bay "Varves"

As nearly as I can tell from the illustrations and descriptions these sediments are similar to those recovered by Ira T. Wilson from cores in Sandusky Bay (Wilson, 1943) and by Ross (1950) near the Bass Islands. Wilson believed that these laminations were glacial varves, but from his description and that of Dr. Paul B. Sears (1948, p. 542) it is evident that diatactic structure was lacking. Wilson counted the pairs of laminae in the cores, however, and derived a figure of 12,223, which he postulated was the length of time that glacial lakes had existed in the Erie basin.

Validity of Wilson's "Varves"

As in the case of the Huron valley sediments the lack of diatactic structure casts doubt on an interpretation which recognizes the pairs of laminae as varves, although it is true that under certain conditions this may be lacking in bona fide glacial varves. Antevs (1953, p. 218) commented, however, that the Sandusky Bay sediments did not resemble glacial varves.

<u>Conditions of Deposition</u>

The association of the laminated sediments in both the Sandusky Bay and Huron River areas with the valleys of extended consequent streams suggests that land derived waters should have had a far greater influence than did glacial melt waters, particularly since the ice front positions, as determined by moraines, were at least 150 miles distant during all post-Whittlesey time.

Antevs (1925, p. 29) felt that Lake Algonquin had been essentially a temperate lake and that even material brought into it by ice-fed streams was flocculated too rapidly to allow the formation of varves, and he stated, furthermore, (ibid, p. 33) that varved glacial clays seemed to be formed only of material brought by melt water streams. More specifically the same author (Antevs, 1953, p. 218) expressed the opinion that the Sandusky Bay area was too far removed from the ice front during Lake Warren and Lake Lundy for deposition to have been influenced by the glacier.

My own experience that in north central Ohio there was no appreciable deposition of lacustrine sediments prior to Lake Warren and the fact that the profile of weathering is developed in the laminated sediments seems to indicate that they are not pre-Warren in age either.

A number of authors (Hansen, 1940; Antevs, 1951; and Wood, 1947) have described the formation of short term clay-silt couplets under locally controlled conditions. In these cases two or more couplets are deposited during the course of a year, so that counting of pairs of laminae gives an exaggerated picture of the length of time represented.

<u>Comparison of Radiocarbon Dates with Wilson's Varve Years.</u>

The table of radiocarbon dates for the Erie basin is inserted here (p. 161) for purposes of comparison with Wilson's varve year figure of 12,223. It is true that many age determinations based on the carbon-14 ratio are questionable and some dates are undoubtedly erroneous, the errors sometimes being due to contamination of material, and sometimes, to incorrect interpretation of the stratigraphic framework from which the material was collected.

There is little doubt regarding the stratigraphic position of the horizons from which the fossil material for date "b", "c" and "d" were taken, although there is some danger in the correlation between lake basins involved in transferring date "c" to the Erie basin. All three dates, however, do give an acceptable span of time for the events involved and this is one argument for the validity of the correlation.

The transference of date "f" is more tenuous, however. The material dated is from a human occupation site in New York State which post-dates the draining of Lake Iroquois. Most authorities believe that this occurred while Algonquin III existed in the upper lake basins and Erie III is presumably a correlative of Algonquin III. Dates "a" and "e" are estimates only.

TABLE VII

CHRONOLOGY FOR THE ERIE BASIN
BASED ON RADIOCARBON DATES

Approximate Beginning of-	Years before 1950	Estimated years since Maumee II began
a. Maumee II	(15,000)	
b. Whittlesey	13,600±500	1,400
c. Wayne	11,404±350	3,596
d. Lundy	8,513±500	7,487
e. Erie I	(6,000)	9,000
f. Erie III	4,930±260	10,070

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a. estimated

b. wood from the base of Whittlesey beach in northeastern Ohio (Suess, 1954, p. 469)

c. wood from "red cedar" layer in front of the Grassmere level, Castalia Prairie, Ohio (Libby, 1951, p. 292)

d. wood from Two Creeks forest bed (= pre-Wayne low stage) near Manitowoc, Wisconsin (Libby, 1952, p. 88)

e. estimated

f. charred wood from Frontenac Island, Cayuga Lake, N.Y. (post Iroquois draining) (Flint and Deevy, 1951, p. 283)

Even if Wilson's assumption that conditions for varve formation were present in the Sandusky Bay area during all of the period of the glacial lakes in the Erie basin was acceptable, the length of time seems excessive when compared with radiocarbon chronology, but as shown above such conditionsprobably did not exist here during most of the glacial lake period.

Carbonate distribution in the laminated deposits of the Sandusky Bay region

In northeastern Sandusky County and northwestern Erie County auger holes revealed a curious condition in the laminated silts: the finer layers were leached of calcium carbonate to a depth sometimes as much as 20 inches below that of the coarser silt layers in the same hole. This condition was not recognized until the last weeks of the lake plain phase of the field work and time did not allow a return to localities already studied, so it cannot be said that this is the only area where the situation exists. It was not universal everywhere in the Sandusky Bay area and the difference, if present elsewhere, was certainly not as great.

Antevs (1925, p. 4) listed a difference in the original carbonate content of the laminae as one of the criteria for the recognition of annual layers. It is difficult to imagine, however, that the original difference could have been so great as to allow 15 inches of variation in the depth of leaching at the present time. Also the silt consists largely of grains of quartz.

It seems possible that the ground water moving downward and lakeward from the Castalia area is still highly charged with calcium bicarbonate and as it moves along the more permeable silt layers it deposits calcium carbonate instead of removing it.

HOMOGENEOUS CLAY SILTS

Under the heading of homogeneous clay silts are included lacustrine sediments which have occasional and irregularly spaced streaks or lenses of coarser silts and fine sand. In Erie County such sediments are found mainly north of the Lake Warren shore and between the Sandusky Bay and Huron River valley areas of laminated deposits (Pl. I). The sand, silt, clay percentages of several representative samples of this material are plotted on the diagram of Plate XXIX, Figure 2. The diagram shows that the grain size distribution is the same as that of the finer layers of the laminated sediments.

The homogeneous clay silts are interpreted as the normal type of deposition away from the direct influence of the rivers.

BOTTOM SAND DEPOSITS

Reference is made here to water deposited sands which are spread out over the flat lacustrine plain and cannot definitely be associated with any beach ridge. Not included are the sandy aprons which sometimes extend out in front of the ridges for a distance of several hundred yards.

These bottom sands are often only a thin mantle over lacustrine silts, but in several localities the thickness is sufficient to make stripping for use as molding sand feasible.

Distribution

The entire area from the western edge of Perkins Township to Ceylon in Berlin Township, Erie County, is largely a belt of bottom sand deposits. West of State Route 4 (Sandusky-Milan Rd.) the sands do not extend to the present shore, but east of Sandusky, except where the marsh deposits behind Cedar Point are present, they cover the surface between the Lundy shorelines and the present lake. It is not quite clear whether the southern limit of this belt is the Grassmere or Elkton shoreline. In some cases the bottom sands seem to extend almost to the 640-foot level, but more commonly, I believe, only to the 620-foot Elkton level. Neither stage is, of course, represented by more than a few fragmentary beaches. It can be said, however, that the areas of thickest sands lie north of the Elkton contour.

Description

The sand is medium to fine grained and there is little evidence of stratification. The greatest observed thickness was six feet in a pit just east of the Huron River and along the River Road.

Molding Sand

Since at least 1900 much of this sand has been removed and shipped to Lorain or Cleveland for use as molding sand. The general method is just to strip it from the surface and after a few years, when the fields have been returned to cultivation, there is very little apparent change in the landscape.

ORGANIC REMAINS

Recovery of the remains of plants and animals from Pleistocene and early post-glacial deposits has taken on a new importance with the advent of radiocarbon dating. In addition to this new value such material still retains its old usefulness in giving information concerning environmental conditions at or just preceding the time of burial.

MASTODON FROM THE DEFIANCE MORAINE BELT

In 1951 the remains of a mastodon were uncovered in a drainage ditch 500 feet east of the B & O R. R. crossing on the Ft. Ball Road, southeast of Willard, Huron County. The animal had apparently fallen into a small bog developed in a kettle hole near the front of the Defiance moraine. The mammoth, an inhabitant of coniferous forests, obviously post-dates the development of the moraine.

SHELLS ASSOCIATED WITH THE BEACH DEPOSITS

Whittlesey (1850, p. 35) made a general reference to gastropod shells found in the sand of the beach ridges. I spent several days in various gravel pits searching for molluscan shells but did not find any. Farmers on whose land the pits are located report that such fossils are to be found and were frequently collected in the days before mechanized methods of excavation.

WOOD ASSOCIATED WITH BEACH RIDGES

Whittlesey (1850, p. 49) also referred to wood at the base of the beach ridges. His specific reference was to the middle ridge (Whittlesey) in the region east of Erie County. I was able to collect a small piece of wood which had been removed from the base of the same beach ridge in eastern Sandusky County. The wood was subsequently identified by Dr. George W. Burns as spruce, "...in all probability black spruce (*Picea mariana*)". It was wood from the base of this same beach farther east, which was collected by Dr. White and dated by radiocarbon analysis at 13,600 years, plus or minus 500 (Suess, 1954, p. 469).

The specimen which Dr. Burns indentified was part of a large log taken from a well in 1950. The well is located on the Whittlesey ridge in the NW$\frac{1}{4}$, Sec. 10, T4N, R17E, Sandusky County. The log was removed during a cleaning operation and thrown into the farmyard where it disintegrated rapidly during the following winter and spring, until at the end of the summer of 1951 only a few fragments remained.

According to accounts of the farmers along the Whittlesey ridge northeast of Clyde, there is an extensive deposit of woody debris at the base of the sand and overlying (?) till ("blue clay with pebbles"). In the past numerous shallow wells were dug to the base of the sand where water was encounterd. Water from these wells tastes so strongly of decaying vegetable matter that it has never been used other than for livestock.

The wood undoubtedly represents forest growth during the Arkona stage, and then when the waters rose to the Whittlesey level it was washed to the shore of the new lake.

Dr. Burns' identification of the wood as black spruce fits in nicely with a pollen sequence reported by Loren Potter (1947, pp. 415-417) from a shallow bog north of the Whittlesey beach, four miles northwest of Norwalk. The bog material overlies sand, believed by Potter to represent Maumee deposition, and the bog profile begins with a clear predominance of spruce pollen. This layer of peat is overlain by another sand deposit correlated with Lake Whittlesey, which in turn is followed by more peat in which the pine maximum is reached quite close to the bottom.

Both in the pollen sequence and in the wood from the base of the Whittlesey ridge we have evidence which points to the fact that the climate during the Lake Arkona stage was extremely well suited for the growth of spruce. Cool wet climatic conditions are believed optimum for spruce, and in pollen profiles from the United States its maximum is generally found at the base of the bog sections. In this country the tundra phase is usually not represented (Deevy, 1949, p. 1356).

WOOD REPORTED FROM OTHER BEACH DEPOSITS

N. H. Winchell (1873, p. 605) reported finding sticks and bark of the "white" birch. (the North American white birch is Betula papyrifera) in a 12 foot bank of fine sand exposed in the quarry of Jacob Bachman at Bellevue, Sandusky County. Although I could not identify the quarry and was unable to find a similar deposit of wood, it would seem from the general location that the sand is that of one of the Maumee levels. Betula papyrifera is a tree of the more northern latitudes and today extends north to the edge of the tundra. The individual members of the family are not identified in pollen studies, but the Betulacea are recognized at an early stage in many bogs.

CASTALIA COLLECTIONS

Wood from the Castalia Prairie Deposits

Collections of wood were made from two of the peat layers at Castalia. In 1950 Dr. R. P. Goldthwait obtained a piece of the wood from the lowermost and it was dated by the radioactive carbon method at the Argonne Laboratory of the University of Chicago. The date arrived at was 8,513 years, plus or minus 500 (Libby, 1951, p. 292). The stratigraphy at Castalia would place the period of growth of growth of the trees at a time between the development of the Warren III beach and the Grassmere beach of Lake Lundy.

I collected root material from the third peat layers, but as it lay within two feet of the surface and had been penetrated by roots of recent plants it was unsuitable for carbon-14 analysis. The material collected was also greatly impregnated with calcium carbonate and it proved impossible to make a generic identification of the wood. Dr. Burns did report, however, that there was little doubt that it was an angiosperm.

Subsequently Dr. Burns has identified more material from peat layers at Castalia. The results of this study were discussed in connection with the sequence of deposits (p. 150).

Vertebrate Remains

In addition to the plant remains the Castalia deposits contain a fair amount of bone material. Some of this was collected and later identified for me by Dr. Claude Hibbard. Although none of the material was found in place, it would seem to have come largely from the lower peat layer or at least from the base of the first marl bed, for the marl is excavated by power shovel and everything down to the basal peat is taken. The bones are now found scatteredupon the worked over surface which is also littered with the "red cedar" debris.

The largest percentage of the bones identified belong to the Virginia deer (Odacoilus virginianus virginianus) and at least half of this was from fawns. The following is the list of vertebrate species collected. With the exception of No. 1, which was identified by Dr. H. B. Tordoff of the Museum of Natural History, University of Kansas, the identifications are those of Dr. Hibbard.

1.	Branta canadensis	Canada goose, large male
2.	Cervus canadensis	Elk, fragments of antlers
3.	Chelydra serpentina	Snapping turtle, plastron
4.	Odacoilus virginianus virginianus	Virginia deer, many antler fragments and leg bones
5.	Ondatra zibethica zibethica	Muskrat, jaw
6.	Rangifer caribou	Caribou, antler fragment

This list is not particularly helpful from the point of view of interpreting environmental conditions. All the species listed, with the exception of No. 6, have wide ranges today and of these only the elk is not found within the area at the present time and it could have and probably did exist in northern Ohio just prior to its settlement.

Invertebrate Remains from Castalia

As the section on p.149 shows shells are common in both the peat and marl. Some of this material was collected from each unit but no identifications were made. A study of the Castalia invertebrates might be helpful, however.

Pollen Analysis of the Castalia Dêposits

The most valuable approach to the changing environments and the events they indicate within the Erie basin is, I believe, that offered by pollen analysis. This has recently been undertaken by Dr. Paul Sears who collected not only from the peat and marl but from all the lacustrine sediments overlying the till and bedrock. This study should yield much of interest and can be expected to help clarify the sequence of the later lake levels as well as to show whether the hypothesis put forth in these pages that the major portion of the lacustrine sediments in the north central portion of Ohio are associated with Lake Warren and later stages is correct.

ECONOMIC GEOLOGY

Quite properly the discussion of the economic geology of Huron and Erie counties could include a discussion of the soil and agricultural potentialities, and this would be particularly appropriate as an appendage to a report on the glacial geology of the two counties. Such a discussion is beyond the capabilities of the writer, however. Huron County has been mapped in detail in the last ten years by the Soils Survey of the United States Department of Agriculture, but to date the report and map have not been published. At the time of this study (1954) nothing but Coffey's (1915) reconnaissance survey of the soils of the state was available for Erie County as a whole, however.

BEDROCK RESOURCES

At the beginning of this report it was stated that all of the major types of sedimentary rocks were represented within the two counties. It cannot be claimed that the black shale has made much of a positive contribution to the economy of the region, but limestone, dolomite and sandstone are definite assets.

Limestone and Dolomite

Western Erie County and the extreme northwestern tip of Huron County are located on the belt of mid-Paleozoic carbonate rocks. At the present time there are major quarrying operations in these beds at both Sandusky and Bellevue. In the latter area the present quarries are outside of the Huron and Erie county borders, however. The only large Erie County quarry now operating is that of the Wagner Stone Company just south of the Old Soldiers' Home at Sandusky. In past years the region of Castalia was the site of fairly large operations in both the Devonian limestones and upper Silurian dolomites. These old quarries have been abandoned; however, a new one just has begun operation.

Sandstone

The Berea sandstone here in northern Ohio is an excellent building stone and is shipped rather widely. Also it was once used extensively for the manufacture of grind stones. At one time several Berea quarries were operated in southeastern Erie County and northeastern Huron County with the one at Berlin Heights being the largest. At the present time the Berea is not quarried within the area of this study, although the large quarries are but a few miles east of the county line near South Amherst, Lorain County, where the thickness of the sandstone and the even quality of the rock are most favorable.

Some Berea sandstone was also quarried for local use at Plymouth a number of years ago.

Gypsum

The Tymochtee shaly dolomite (Bass Island, Upper Silurian) is quite gypsiferous in northern Ohio and today a large gypsum quarry is operated on the Marblehead Peninsula, just across Sandusky Bay from northwestern Erie County. The Tymochtee is present beneath a considerable thickness of lacustrine sediments in this portion of Erie County and it is reported (Ralph Bernhagen, personal communication) that a small amount of gypsum was mined from it at one time near the present junction of U. S. Route 6 and State Route 269.

UNCONSOLIDATED ROCK RESOURCES

Sand and Gravel

With the construction and maintenance of roads on the scale necessitated by the modern age of automotive travel deposits of sand and gravel are of considerable importance, and the numerous esker, kame and beach ridge deposits give Huron and Erie counties a large supply of such material. There is one drawback to the deposits of gravel found over much of the area, however.

Everywhere east of the western edge of the black shale belt the gravel contains too much shale to meet the state road specifications. The counties do use the gravel, however, and the sand is generally acceptable.

In the description of the various shorelines, mention was made of coarse cobble beaches around the bedrock highs of Castalia. These deposits consist almost entirely of limestone and are used for road metal. The material does require crushing, however, and the extent of these cobble beaches is somewhat limited.

Molding Sand

The stripping of the thicker deposits of bottom sands for molding sand has already been discussed (p. 164).

Low Grade Ceramic Clay

The Lavey Pottery plant at Milan did use the laminated lacustrine silts of the Huron valley for the manufacture of drainage tile and unglazed pottery, but in 1951 they abandoned this source and opened a pit in the Mississippian shale (Bedford sh.?). At the time of my inquiry they had found this more satisfactory than the lacustrine material.

Marl

The operations of the Medusa Cement Company at Castalia have already been mentioned in connection with the section there (p.149). The marl at Castalia certainly has not been exhausted, but the company estimates show that over one-half of the usable marl has been extracted. In addition to the lease now being operated the company holds one in Sec. 14, T6N, R17E, Sandusky County. This area is much smaller than that at Castalia and is associated with the drainage line of Little Pickerel Creek. Marl also has been taken from beneath the waters of Sandusky Bay.

Peat

The only peat deposit within either Huron or Erie counties of such an extent as to offer any fuel possibilities is that of Willard Lake bed, and Dachnowski (1912, p. 83) reported that this peat averaged 29.30 per cent fixed carbon (moisture free). However, under our present cultural conditions there is little doubt but that the best use of this and similar deposits is for truck gardening as is now being done. In addition some of the peat is utilized for peat moss and as a filler in artificial fertilizers.

SUMMARY OF CONCLUSIONS

As a result of this study a number of conclusions were reached and some few hypotheses have been suggested. In many cases the evidence needed for the proof or disproof of the latter requires further checking outside the area of this study or more detailed laboratory work. These ideas and hypotheses are summarized below:

A LOW PLATEAU SECTION

Work on the glacial geology of these two counties has led me to believe that the recognition of a Low Plateau section of the Central Interior Lowlands province is justified. The Low Plateau subdivision was suggested by George White (1934, pp. 367-368) on the basis of a study made just south of Huron County. The reasons he advanced for its recognition are equally valid here and perhaps more so, for the Berea escarpment which generally marks its western and northern boundary seems to have been of significance in controlling glacial deposition in the two counties.

"EARLY" AND LATE CARY TILLS

This study also extends westward the area in which Dr. White's two Cary tills can be recognized. The results of the sand, silt and clay separations I made were similar to those arrived at by Vincent Shepps for Dr. White and extremely gratifying in this respect. Evidence for the accuracy of the hydrometer method of analysis is also offered by these results for Shepps' analyses were done by the pipette method while the Bouyoucos hydrometer was used in this study.

THE DEFIANCE MORAINE OF LATE CARY AGE

White's correlation of the Late Cary clay till with the advance to the Defiance moraine was also verified, although in a few areas the clay till is known to extend south of the moraine front. In fact it is recognized in somewhat spotty distribution over the north end of the Delphi spur and occasionally on the back slope of the Fort Wayne moraine as it regains its identity at the eastern edge of the Shiloh knot. It may be that the greater than average concentration of boulders along lines here (Pl. XVIII) marks the farthest advance of Late Cary ice.

CONTINUITY OF THE DEFIANCE MORAINE

The question of the continuity of the Defiance morainic belt across Huron County has, I believe, also been answered. It will be recalled that the poor development of some morainic features between the Huron and Vermilion rivers had given rise to doubt as to whether the Defiance moraine of western Ohio was continuous with the moraine called "Defiance" in eastern Ohio.

Although the typical Late Cary till is somewhat spotty in its distribution here and although no continuous moraine crests were present across the area it is believed that the moraine is continuous and that these conditions can be accounted for as the result of stagnant and thin ice in this sector at the time the moraine was being built. It also seems that there was concentrated glacio-fluvial drainage here so that much of the fine clay material was washed out of the deposit.

Several factors are believed to have contributed to these conditions. One is the presence of an older moraine ("Early" Cary) which was overriden in the questionable sector. This is the Delphi Spur which trends northeastward out of the Shiloh knot in northern Richland County.

It is believed that the most important factor, however, is the presence of an unusually well developed escarpment on the line of the Berea outcrop in southern Erie County and north of the moraine sector under discussion. The hypothesis is advanced that it presented enough of an obstacle to ice, which at its maximum advanced only 16 miles byyond, to account for the thin and less active ice.

TILLS AND THEIR RELATIONSHIP TO OTHER MORAINIC BELTS

Some hypotheses regarding the relationships of ice movement to the various moraine belts south of the Defiance are also developed. The Delphi spur seems to have been formed during a halt in the retreat from the Fort Wayne moraine. Both are constructed of "Early" Cary till and are further tied together by the drainage line of the Ripley-Shiloh esker chain.

On the basis of the short reconnaissance in northern Richland and Ashland counties no definite statements can be made concerning the relationship of till distribution and moraines there. Within the Shiloh knot, which represents a merging of the major Wabash and Fort Wayne morainic belts, the till is "Early" Cary, although in many places it has apparently been washed by meltwater streams. Sorted deposits of sand and gravel scattered throughout the knot support the hypothesis that meltwaters have frequently altered the till.

In one section (see Appendix B, section 1) near the front of the Wabash belt, a questionable Tazewell till was recognized beneath the "Early" Cary till at an elevation slightly above the level of the ground moraine in front, and it may be that here an older moraine has been overridden.

MAUMEE I SHORE FEATURES

Although this study was primarily concerned with the bottom sediments of the lacustrine plain, the review in the field of Dr. Carney's careful and detailed study of the shorelines did lead to several minor revisions and additions. Most important perhaps was the recognition of several shoreline fragments which apparently belong to the time of the last phase of Maumee I. It is also suggested that the area of Greenfield and Peru townships in Huron County which Leverett (1902, p. 588) mapped as a spur of the Defiance is an area of destructional topography where thin till overlies the sediments of a buried delta. The delta is believed to have been built during the early phase of Maumee I, to have been buried during the advance to Defiance moraine, and the area to have been dissected when base level was near by at the time of Maumee II and III.

GREAT PART OF LACUSTRINE DEPOSITS LIMITED TO
THE AREA NORTH OF THE WARREN SHORE

It was discovered that south of the Lake Warren shorelines the greater portion of the lake plain is mantled with but little altered till. The majority of the typical lacustrine silts and clay silts lie in front of this shoreline. The laminated silts of the Huron River valley are also believed to be largely the result of Warren III deposition.

ADDITIONAL CHANGE IN LAKE LEVEL RECOGNIZED

The sequence of marl and peat beds in the Castalia Prairie gives strong evidence for a pre-Grassmere low water stage. The immediate cause of the continued alternation of deposits is ground water fluctuation. Whether or not this fluctuation was associated with changes in lake level is not known. It is suggested that lower lake level resulting from diversion of upper lake waters from the Erie basin during Algonquin II and the period of the Nipissing Great Lakes may have caused a lowering of the water table here. Another possibility is that earth movements may have inundated the southern shore of Lake Erie more rapidly at some periods causing higher ground water level and dominant marl deposition until the surface was built up to a higher level.

LAMINATED SEDIMENTS OF SANDUSKY BAY REGION

After a review of the conditions which existed during the various lake stages it is decided that the laminated sediments which Wilson felt were varved are more likely the result of short term local conditions. The pollen analyses of the Castalia sediments now being made by Dr. Paul Sears should offer valuable information on this subject, however, as well as clarifying some of the other questions regarding events in the Lake Erie basin.

APPENDIX A

LABORATORY METHODS

Three methods of grain size analysis were used in this study: pipette, hydrometer and sieving. Analyses of the lacustrine silts and clays were made by pipette and the sand, silt and clay determinations of the glacial tills by Buoyoucos hydrometer. A number of samples of beach sands also were sieved for determination of grain size distribution and sieving of the "sand" fraction of the glacial tills was done in conjunction with the hydrometer analyses. All grain size determinations were for the Wentworth grades except that the "sand" of the till analyses included granules and small pebbles (up to 10 mm.) as well as the sand of the Wentworth classification.

PIPETTE ANALYSIS OF LACUSTRINE SEDIMENTS

The pipette employed for the particle size distribution analyses was an ordinary 25 c.c. pipette. A description of the method of preparation of samples for the analyses follows. In general it is based on that given by Krumbein (Krumbein and Pettijohn, 1938, pp. 72-75).

Crushing and Splitting of Field Samples

The air dried field sample was crushed in a ceramic mortar with a rubber tipped pestle. When sufficiently broken up the sediment was put through a Jones sample splitter until about 25-35 grams had been separated. This amount comprised the sample to be analyzed and so it was weighed accurately on an analytical balance and the weight recorded.

Dispersion

The next step in the preparation involved soaking of the sediment in approximately 400 c.c. of peptizing solution. The peptizer employed was N/100 sodium oxalate. For these unconsolidated sediments 24 hours of soaking was generally sufficient to bring about dispersion. In doubtful cases the degree of dispersion was checked under the microscope and in those samples where dispersion was incomplete at the end of this time a longer period of soaking was allowed. The maximum soaking period was three days.

When the suspension seemed to be completely dispersed the sample was washed into a one liter cylinder and the volume increased to 1,000 c.c. by the addition of peptizing solution (ordinary tap water was used in all preparations of the lacustrine sediments). The suspension was then agitated with a stirring rod for one minute and the first of the pipette samples taken. From this point on the procedure was that described by Krumbein (Krumbein and Pettijohn, 1938, pp. 165-168) and it will not be discussed here.

Flocculation of Suspensions

In several cases flocculation of the suspension occurred before completion of the pipetting. Additional samples were then split out, prepared, heated in the peptizer to about 90 degrees centigrade, and allowed to soak for the full three day period before diluting and transferring to the cylinder.

HYDROMETER ANALYSIS OF GLACIAL TILLS

The hydrometer used was the Buoyoucos streamlined hydrometer and only two readings were taken to ascertain the total of "sand", silt and clay. The times of the readings for these determinations were calculated from Stokes' Law, but before the calculation could be made it was first necessary to determine the effective depth, or center of buoyancy of the hydrometer, which was being used, for various concentrations of the suspension. This was done by graphing the hydrometer according to a method described by Morey (1947, p.382).

Determinations of Times of Readings

When the effective depths of the hydrometer at different concentrations had been determined and a graph made, four samples were prepared and analyzed. Three of these seemed to represent texturally the average and two extremes of the till samples to be analyzed and the fourth was a lacustrine silty clay which had already been analyzed by pipette. The readings were taken at arbitrary intervals (three in the first two and one-half minutes and at ever increasing intervals until 30 minutes apart) over a period of three hours. The effective diameters of the particles which had settled out at the time of each reading were then calculated, the height of fall factor in Stokes' Law being derived from the previously prepared graph. When the readings had been corrected for temperature and viscosity (See A.S.T.M. Standards, 1949, p. 1159) it was seen that a first reading at 30 seconds would give the amount of material less than 0.062 millimeters within the accuracy of o.001 millimeters for materials of the textural range beingtested. The settling time for particles of 0.0039 mm. varied from 143 to 157 minutes for the four samples. (The 143 minute period was calculated for the finer lacustrine clay.) On this basis the time of the second reading was placed at 150 minutes or two and one-half hours. This median figure introduced a maximum error of 0.001 mm. or less for all four samples.

Comparison of Pipette and Hydrometer Curves

In order to test the relative accuracy of the hydrometer method, two cumulative curves of the same lacustrine silty clay, one based on a pipette analysis and the other on a hydrometer analysis, were compared. The curve derived from the hydrometer data did not extend beyond the range of coarse clay, but throughout the silt range there was less than four percent difference in the two curves. This was not considered serious especially since the method of preparation of the two samples varied and it is believed that used in preparing the sediment for the hydrometer analysis was the better.

Preparation of Samples for Hydrometer Analysis

The samples to be analyzed were air dried and then crushed with a rolling pin or oak muller on paper over a wooden table. In keeping with the practice of Vincent Shepps (1953, p. 34) in analyzing the tills of northeastern Ohio with which these tills were to be compared, all material larger than 10 mm. was removed by hand at the time of crushing. The crushed field sample was then put through the Jones sample splitter until a 50-65 gram portion was split out. Because with the hydrometer a five percent suspension is considered optimum the variation in total sample was based on a rough estimate of the coarse material present in the till, the larger samples being of the more sandy tills.

Mechanical disaggregation with the rolling pin was continued after splitting. At this time all material from two to ten mm. was removed by hand sieving, for it was felt that it was undesirable to have these coarse particles disturbing the suspension, when the first reading was to be taken after only 30 seconds of settling time. The procedure here was to sieve through a 10 mesh Tyler screen and to pick out of that material which remained on the screen the pebbles and granules. Several sievings were required with further crushing in between, until the material less 2 mm. had all been disaggregated and the coarser removed. The 2 to 4 mm. particles separated in this way were weighed separately and stored until completion of the hydrometer analysis of the fines. The weight of this material was then added to the gram weight of sand determined by hydrometer to give the total "sand".

Dispersion

Following this separation the remaining fine fraction was weighed, placed in a beaker with about 400 c.c. of distilled water. After soaking in water for a few minutes the till was stirred and 10 ml. of peptizing solution consisting of sodium hexametaphosphate buffered with sodium carbonate (see Kilmer and Alexander, 1949, pp. 21 to 23) was added.

The till sample was allowed to stand overnight in the dispersing solution and was then transferred to a mixer cup with baffles and stirred on a mechanical mixer for 10 minutes. The suspension was next washed into a 1-liter cylinder and the volume increased to 1000 c.c. (All water used in the preparation of the till samples was distilled water.)

Readings

When the volume of the suspension had been increased the suspension was stirred with a stirring rod for one minute, then allowed to settle for thirty seconds when the first reading was taken. This reading was repeated as a check. After the second 30 second reading had been taken the suspension was agitated again and then allowed to settle for two and one-half hours. In the case of the first eight analyses this reading was also repeated, but since the two readings agreed in all cases within limits of one and one-half grams, it was not felt necessary to continue this check. (Although the hydrometer is scaled in grams, readings were estimated to the one-half gram.)

The hydrometer was removed between readings and each time a reading was made the temperature of the suspension was also recorded. No constant temperature bath was available, but under the conditions of the laboratory the temperature variation was within 12 degrees from the 67 degrees Fahrenheit for which the hydrometer was calibrated. A temperature correction taken from the curve presented in the A.S.T.M. Standards (1949, p. 1159) was applied to each reading.

Sieving

After completion of the hydrometer readings the contents of a cylinder were wet sieved through a 28 mesh screen and the fines discarded. The material coarser than 0.062 was then dried in a drying oven, shaken on the Ro-Tap to remove any fines which still remained, and weighed. The amount of sand recovered in this manner was then used as a check against the first hydrometer reading. If the difference was less than 4 per cent of the total sample the results of the analysis were considered satisfactory. In the several cases where the difference was greater a second analysis was made and satisfactory results obtained.

DIFFERENCES IN PREPARATION OF SAMPLES FOR
PIPETTE AND HYDROMETER ANALYSIS

The pipette analyses were made after the first season of field work, and I felt that the method of preparation of the samples of lacustrine sediments was not entirely satisfactory. Therefore, several changes were made in the preparation of the till samples.

The use of the rolling pin for crushing was much more satisfactory and less time consuming than the rubber tipped pestle and ceramic mortar.

The distilled water used in the preparation of the tills was a precautionary measure. The flocculation of the lacustrine sediments was probably not due to the use of tap water, but it may have been a factor.

A mechanical mixer was not available at the time the pipette analyses were made. It is a valuable tool, however, in securing more rapid and complete dispersion.

The use of sodium hexametaphosphate as a dispersing agent was suggested to me by Dr. Nicholas Holowaychuk. No effort was made to evaluate the relative merits of this peptizer as opposed to the sodium oxalate, but considerable attention has been given to this matter by soil scientists and the hexametaphosphate seems to be one of the better peptizers for calcareous soil materials (Tyner, 1939, pp. 106-113). It can be said, however, that of the 59 till samples prepared, only one flocculated, and this was apparently due to faulty preparation, since when a second sample was prepared no flocculation was observed. It is, of course, true that the time necessary for the abbreviated hydrometer analyses was less than that for the pipetting, however, some of the suspensions were allowed to stand for as long as 48 hours after completion of the hydrometer analyses to see if there would be flocculation. There was none.

At least two factors other than those already mentioned would have to be considered before any evaluation of the methods used could be made: 1. The concentration of the hydrometer suspensions was greater than those used for pipetting. In general the greater the concentration the more difficult to maintain dispersion. 2. The higher clay content of some of the lacustrine sediments presumably would increase the difficulties of dispersion.

APPENDIX B

MULTIPLE TILL SECTIONS FROM WHICH SAMPLES WERE ANALYZED

1. Pennsylvania Railroad cut, 80 yards east of S. R. 598, Vernon Township, Crawford County. SW¼, Sec. 4, R20W, T21N. Front of Wabash moraine.

Unit	Description	Thickness	Sample No.
6.	Covered	6'8"	
5.	Yellow brown calcareous till.	1'9"	
4.	Gray blue calcareous till, grading into yellow till above	4'4"	C-2-52a
3.	Calcareous laminated silt and clay silt in distorted layers.	0'6"	
2.	Dark blue calcareous stony till with lenses of sand.	1'3"	C-2-52b
1.	Covered and slumped	3'0"	
	Total Thickness	17'6"	

2. Stream cut, east of Niver Road and 2/10 mile south of S.R. 161, Greenfield Township, Huron County. Defiance moraine.

Unit	Description	Thickness	Sample No.
8.	Leached soil developed in till.	2'7"	
7.	Yellow calcareous till	2'5"	H-84-52
6.	Calcareous silt	0'10"	
5.	Oxidized clayey till; calcareous	16'9"	
4.	Oxidized calcareous till, somewhat more silty than above, but with no distinct contact.	1'6"	H-86-52
3.	Sand with some laminated silt and clay	3'9"	
2.	Blue gray calcareous till	4'0"	H-87-52
1.	Poorly sorted sand and gravel becoming coarser downward. Base of section made up of ironstone concretions up to 14" in diameter.	16'5"	
	Total Thickness	48'3"	

3. Baltimore and Ohio Railroad cut, 100 yards west of Old State Road, Ripley Township, Huron County. North end of Delphi spur.

Niver Road section.

Unit	Description	Thickness	Sample No.
5.	Leached soil developed in till.	2'9"	
4.	Yellow calcareous till	1'5"	H-49-52
3.	Yellow calcareous till, somewhat coarser in texture.	2'0"	H-50-52
2.	Clean calcareous yellow silt.	3'1"	H-51-52
1.	Blue gray calcareous till	2'0"	H-52-52
	Total Thickness	11'3"	

4. Stream cut, northeast corner of Chenango and Fayette roads, New London Township, Huron County. North flank of Defiance moraine.

4.	Leached soil developed in till.	1'8"	
3.	Yellow calcareous till	11'3"	H-65-52
2.	Laminated sand and silt	3'2"	
1.	Blue gray calcareous till	2'10"	H-67-52
	Total Thickness	18'11"	

5. Roadcut, SE$\frac{1}{4}$,NW$\frac{1}{4}$, Sec. 19, R21W, T23N, Blooming Grove Township, Richland County. Wabash moraine.

4.	Leached soil (truncated profile) developed in till	2'0"	
3.	Yellow calcareous till	1'5"	R-1-52a
2.	Reddish yellow sand; leached	0'3"	
1.	Oxidized calcareous till, somewhat coarser than #3.	2'9"	R-1-52b

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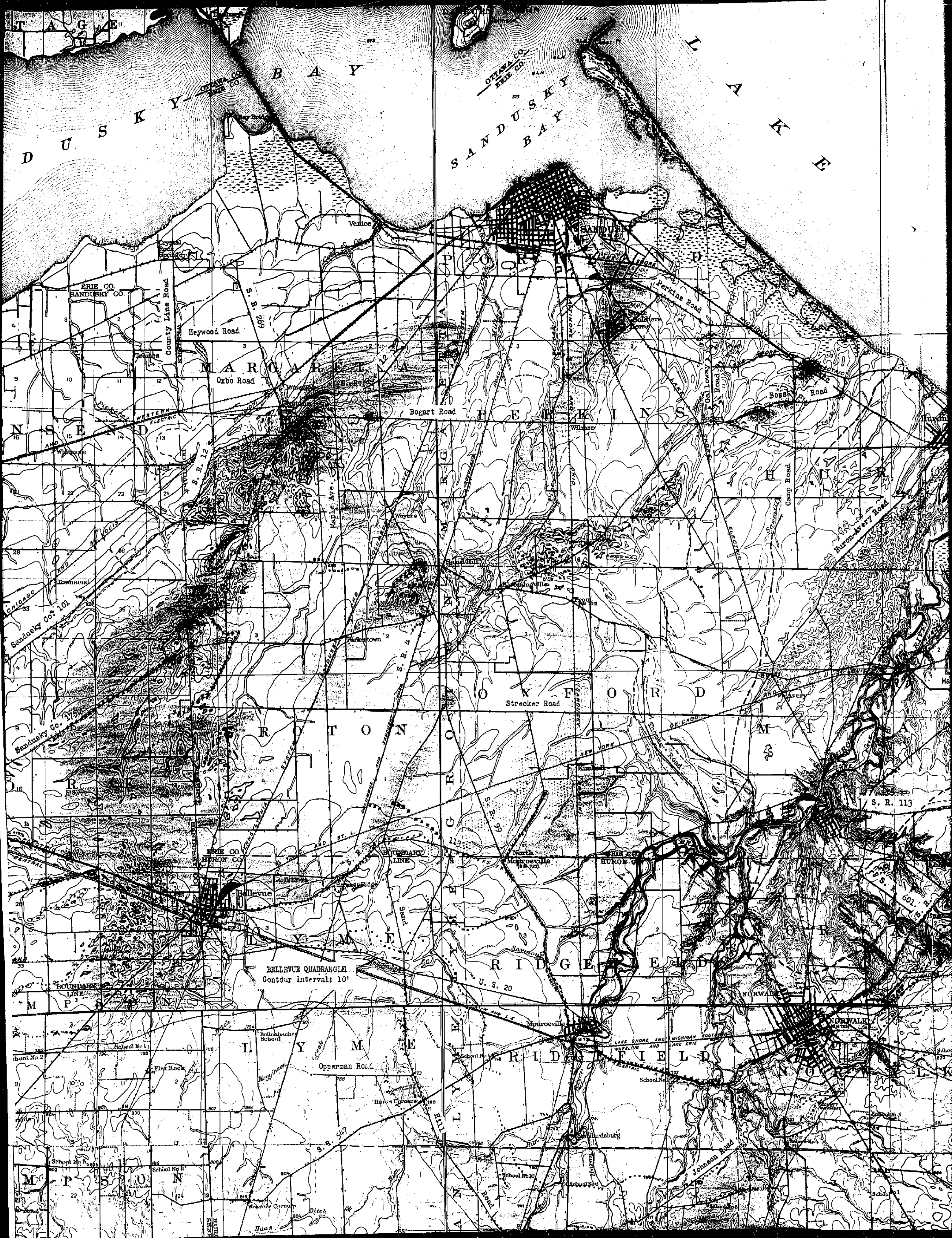
AUTOBIOGRAPHY

I, Lois Jeannette Campbell, was born in Toledo, Ohio, on November 16, 1923. I received my secondary school education in the Toledo public schools. My undergraduate training was obtained at the University of Michigan, from which I received the Bachelor of Science degree in 1944. Upon graduation I was employed by the Humble Oil and Refining Company as a junior geologist. In September 1949 I entered The Ohio State University for graduate work in the Department of Geology. While in residence I served for two years as a graduate assistant. In 1951-52 I received an appointment as Bownocker Scholar and in 1952-53 was appointed to the Bownocker Fellowship in the Department of Geology.

PLATE I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ERIE CO.
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Perkins Road
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County Line Road
Heywood Road
S. R. 269
MARGARET
Oxbo Road
Bogart Road
PERKINS
Galloway Road
Camp Road
Huron-Avery Road
Bloomingville
Parkertown
Sandusky Co. 101
Strecker Road
OXFORD
ROTON
Kimball
S. R. 113
S. R. 99
ERIE CO.
HURON CO.
North Monroeville
Bellevue
LYME
BELLEVUE QUADRANGLE
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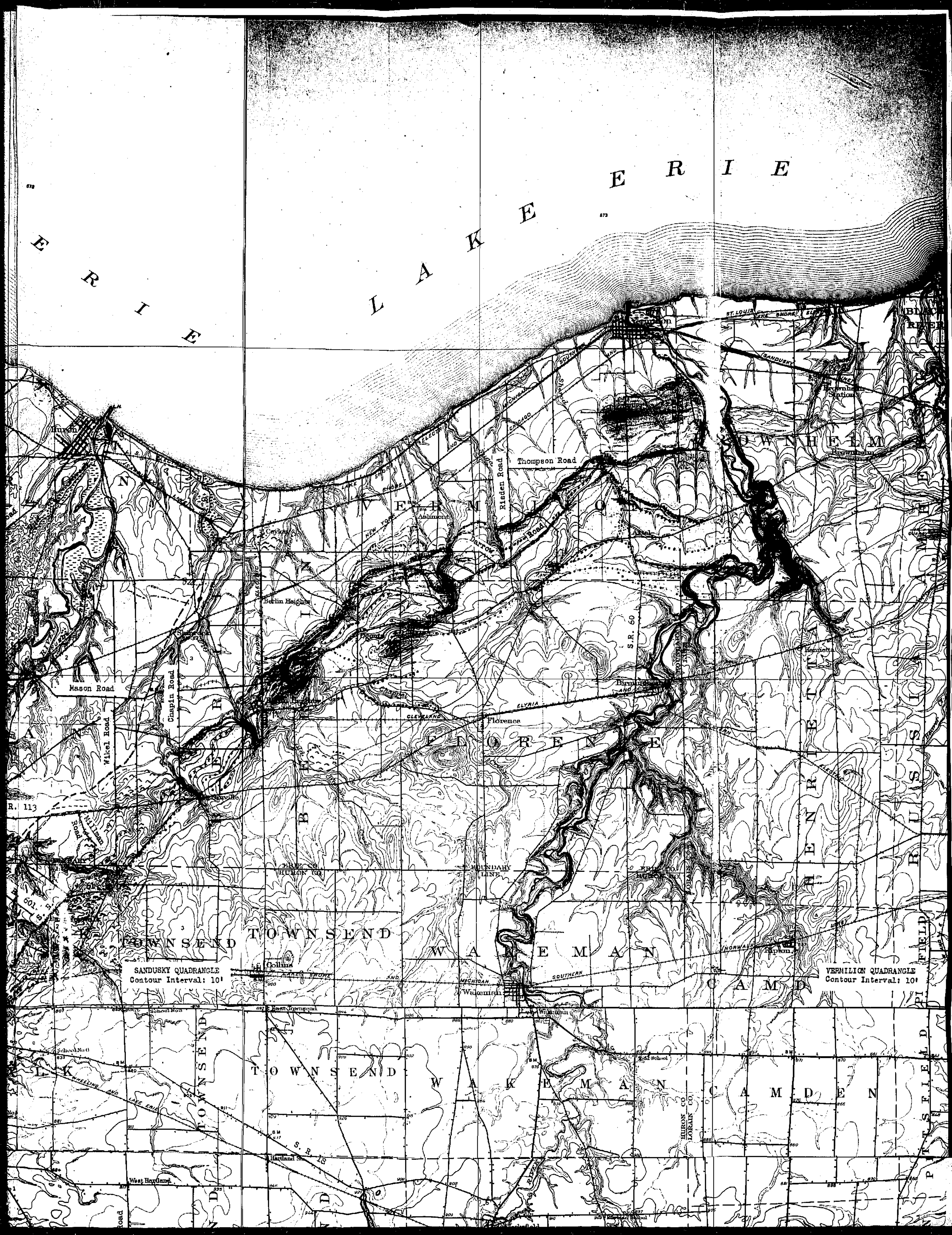
U. S. 20
RIDGEFIELD
Monroeville
NORWALK
LAKE SHORE AND MICHIGAN SOUTHERN
WHEELING AND LAKE ERIE
Opperman Road
Flat Rock
Johnson Road

L A K E E R I E
E R I E
Huron
V E R M I L I O N
B R O W N H E L M
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Thompson Road
Risden Road
Mason Road
Chapin Road
Wikel Road
Berlin Heights
S.R. 60
Florence
F L O R E N C E
H E N R I E T T A
BOUNDARY LINE
ERIE CO.
HURON CO.
T O W N S E N D
W A K E M A N
C A M D E N
Collins
Wakeman
SANDUSKY QUADRANGLE
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VERMILION QUADRANGLE
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East Townsend
West Hartland
S. R. 18
HURON CO.
LORAIN CO.
R. 113


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BRONSON
BURIED DELTA
Peru Center Road
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Havana
NORWALK ESKER
NORWICH
GREENFIELD
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North Fairfield
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S. R. 61
River Road
Attica Junction
Siam
Centerton
DEFIANCE MORAINE
Attica
Chicago Junction
Boughtonville
Old State Road
RICHMOND
NEW HAVEN
New Haven
Delphi
RIPLEY
DELPHI SPUR MORAINE
MORAINE
WILLARD LAKE BED
SIAM QUADRANGLE
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SHILOH MORAINE KNOT
Shiloh
North Auburn
New Washington
PLYMOUTH
Auburn Center
TABOR SCHOOL
LAKE BED
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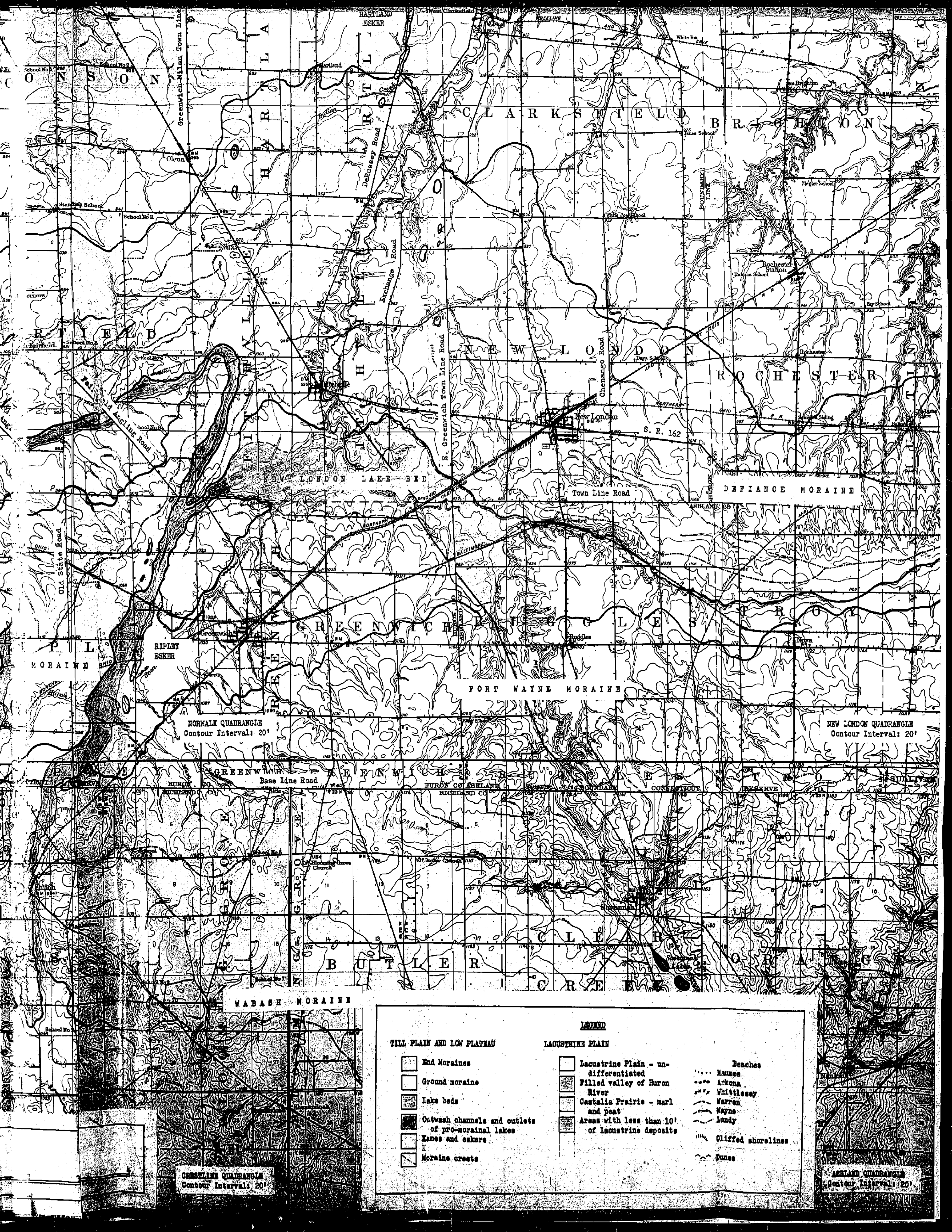
HARTLAND ESKER
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BRIGHTON
NEW LONDON
ROCHESTER
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DEFIANCE MORAINE
Town Line Road
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E. Greenwich Town Line Road
Exchange Road
DeRussey Road
Greenwich-Milan Town Line
Fairfield Angling Road
Old State Road
S. R. 162
GREENWICH
RUGGLES
TROY
RIPLEY ESKER
MORAINE
FORT WAYNE MORAINE
NORWALK QUADRANGLE
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NEW LONDON QUADRANGLE
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Base Line Road
HURON CO
RICHLAND CO
HURON CO ASHLAND
ASHLAND CO
BUTLER
CLEAR
CREEK
ORANGE
WABASH MORAINE
LEGEND
TILL PLAIN AND LOW PLATEAU
End Moraines
Ground moraine
Lake beds
Outwash channels and outlets of pro-morainal lakes
Kames and eskers
K
Moraine crests
LACUSTRINE PLAIN
Lacustrine Plain - undifferentiated
Filled valley of Huron River
Castalia Prairie - marl and peat
Areas with less than 10' of lacustrine deposits
Beaches
Maumee
Arkona
Whittlesey
Warren
Wayne
Lundy
Cliffed shorelines
Dunes
CRESTLINE QUADRANGLE
Contour Interval: 20'
ASHLAND QUADRANGLE
Contour Interval: 20'