GUIDEBOOK NO. 20

QUATERNARY GEOLOGY OF THE INTERLOBATE AREA BETWEEN THE CUYAHOGA AND GRAND RIVER LOBES, NORTHEASTERN OHIO

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The views, terminology, interpretations, and stratigraphic nomenclature expressed in this guidebook are those of the author and contributors. The Division of Geological Survey disclaims any responsibility for interpretations and conclusions.

Cover photo: Stan Totten, the only one of George White's students who continued to work in northeastern Ohio, examines an outcrop of till in the early 1960s.

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PREFACE

The interlobate area of Geauga and Portage Counties has always fascinated the author who spent many of his youthful days cycling on the dirt backroads that wound through its rolling topography. Those days also included attempts to avoid being blown off Ohio Rte. 303 by tractor-trailers hauling high-quality aggregate for Interstates 271 and 480. Although the roads are largely paved now, and some of the gravel pits are reclaimed and sprouting developments, there is still knowledge to be gained through study of this complex area.

The foundations of our existing knowledge of the interlobate area are the early descriptions of glacial geology of this part of northeastern Ohio; these descriptions are found in several groundwater resource reports coauthored by George White. Some of White's early students not only worked on classical studies of the glacial geology of northwestern Pennsylvania, but they also examined the texture, mineralogy, and lithology of tills in northeastern Ohio. One student, Stan Totten, continued to study the glacial geology of northeastern Ohio throughout his academic career at Hanover College in Indiana. This includes the state-mapping program of the 1980s, during which the author worked extensively with Stan on unraveling the Illinoian stratigraphy of north-central Ohio. This guidebook was prepared in recognition of and appreciation of the contributions of Stan Totten to our current understanding of the glacial geology of Ohio.

Please note: metric units are used throughout this guidebook. However, map/road distances in the text are given in English units, followed by the metric equivalent in parentheses. Elevations are given in meters with English equivalents in parentheses. This guidebook was prepared for an author-led field trip in conjunction with the 2006 North-Central Section meeting of the Geological Society of America. Subsequent users of this guidebook must obtain permission of the landowner to visit any of the sites that are on private property.

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PART I: INTRODUCTION

by John P. Szabo

OVERVIEW AND PREVIOUS RESEARCH IN THE AREA

This field trip will examine the hummocky topography and stratigraphy of the interlobate area between the Cuyahoga and Grand River lobes in Portage and Geauga Counties in northeastern Ohio (fig. 1). The area of hummocky topography, consisting of ice-contact deposits that have been overridden by successive glaciations, originates in the drainage of the upper Cuyahoga River in northern Geauga County (fig. 2) and extends as far south as Canton in Stark County south of Akron. The width of the area covered by this type of landscape increases from 5 miles (8 km) in northern Geauga County to 15 miles (24 km) at the glacial boundary in Canton. Although the very hummocky topography is dominated by kames or hummocks of sand and gravel, nearly level outwash terraces are found adjacent to major streams. White (1982) states that the boundaries of this irregular belt reflect stagnation that created a mix of till bodies, outwash, and former ice-block depressions.

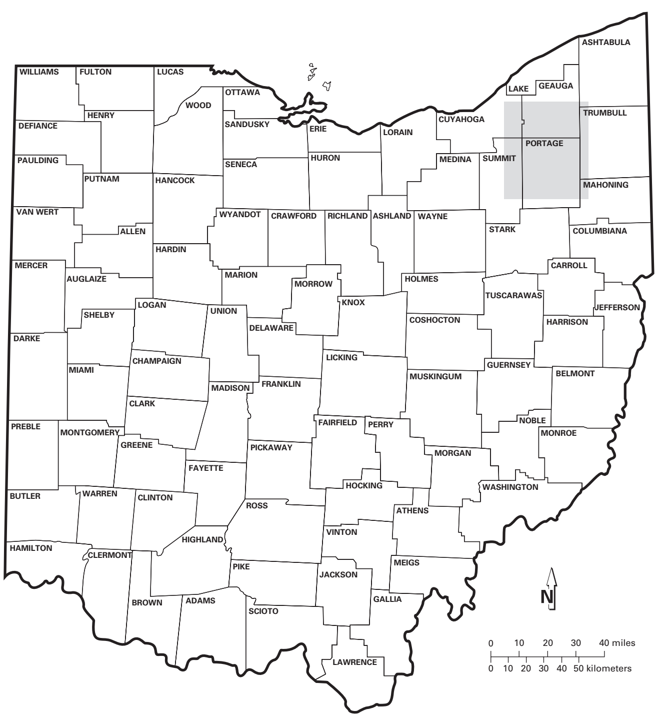


FIGURE 1.—Location of trip area (shaded region) in northeastern Ohio.

As the theory of glaciation gained acceptance, many geologists of the late nineteenth century recognized glacial sediments and traced limits of glaciation through northeastern Ohio. Newberry (1874) not only described glacial deposits in Ohio and adjacent states, but also correctly identified the significance of striations. Chamberlin (1883) traced several of the end moraines cutting across northern Ohio and named the major ice lobes that affected the Midwest. The glacial boundary in the Midwest was traced by Wright (1890) who also recognized the discontinuous nature of the drift along the glacial boundary. Leverett (1902) provided more detail on the distribution of glacial landforms in the Ohio and Erie Basins and was the first person to name the topographically controlled sublobes (herein called lobes) of the main Erie lobe. Major landforms and glacial boundaries were illustrated in detail on a glacial map of Ohio (Goldthwait and others, 1961). About that same time, White (1960, 1961) defined several stratigraphic units of the Killbuck and the Grand River lobes. Some early reports on glacial geology were produced in conjunction with groundwater resource reports (Winslow and others, 1953; Smith and White, 1953; Winslow and White, 1966). George White and Stanley Totten continued to produce reports of the glacial geology of the counties in northeastern Ohio from the mid-1960s to the late 1980s.

An increase in population in the more rural counties of Ohio initiated several studies on the groundwater resources of northeastern Ohio. Studies by the Ohio Drilling Company (1971), funded by the Ohio Division of Water, assessed groundwater resources not only by a careful examination of buried-valley distribution but also by several seismic surveys, test borings, and pumping tests. Several M.S. students of Kent State University examined the hydrogeology of bedrock and glacial deposits on a localized scale (Wells, 1970; Robinson, 1972; Butz, 1973; Stanley, 1973; Perez, 1979; Richards, 1981; Krulik, 1982; Robertson, 1983; Grasso, 1986; MacDonald, 1987). Another predicted wave of population growth resulted in several more recent studies of water resources in Geauga County. Ebert and others (1990) considered water quality and simulated groundwater flow in addition to the general distribution of groundwater resources. Groundwater pollution potentials of several northeastern Ohio counties were determined using the DRASTIC procedure (Williams, 1991; Aller and Ballou, 1991, 1994; Angle, 1994; Barber, 1994). Jagucki and Lesney (1995) examined changes in groundwater levels between 1986 and 1994.

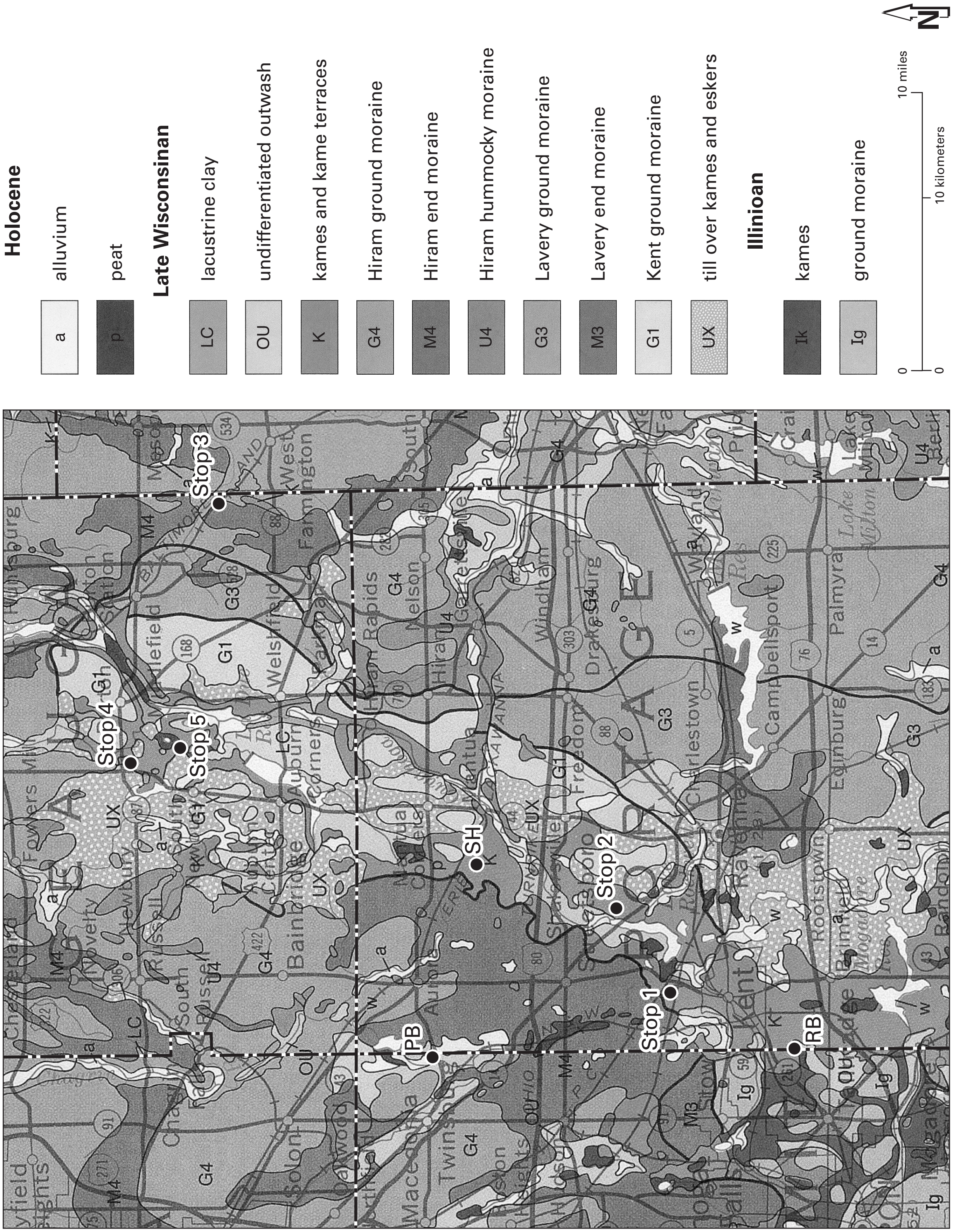


FIGURE 2.—Portion of the glacial map of Ohio (modified from Pavey and others, 1999) showing locations of Stops 1-5, borings (RB and PB), and a measured section in a roadcut (SH).

PHYSIOGRAPHY AND BEDROCK GEOLOGY

The glaciated Allegheny Plateaus (fig. 3A) dominate the physiography of northeastern Ohio. Geauga County is of sufficient elevation that during the Wisconsinan glaciation it split the ice as it flowed southward into two parts: the Cuyahoga lobe to the west, and the Grand River lobe to the east (fig. 3B). The sandstone uplands (Totten, 1988) range in elevation between 372 and 418 meters (1220 and 1370 feet), having as much as 94 meters of local relief and a maximum relief of 190 meters. The relief in northern Portage County to the south is similar to that of Geauga County (Winslow and White, 1966). The high relief of Geauga County and its proximity to Lake Erie place it in the primary snowbelt for lake-effect snows. As a result this county has the shortest growing season in Ohio (Crittenden, 1940) and several areas of relict vegetation. Hemlock are generally restricted to microclimates of north-facing bedrock slopes, and tamarack, yellow birch, and white pine are found around White Pine Bog in the southern part of Geauga County. The climate in Portage County is moderate having a longer growing season and less snowfall than Geauga County (Winslow and White, 1966).

A meltwater stream that drained both the Cuyahoga and Grand River lobes initially formed the upper Cuyahoga River. The upper course of the Cuyahoga River follows the lowlands to Kent, Ohio, where it turns to the west and is superposed on resistant sandstone. This middle reach of the river probably originated as an ice-marginal stream and flows westward cutting a gorge in the Pennsylvanian and Mississippian rocks before joining an ancient bedrock valley that contains the northward-flowing lower Cuyahoga River. An elbow-of-capture and underfit valley suggest that the ice-marginal ancestor of the middle Cuyahoga River flowed southward through Akron to join tributaries of the Ohio River.

The modern drainage system resulted from headward erosion of tributaries of the Cuyahoga River into till-veneered bedrock uplands or ice-contact deposits, but this modern system may not necessarily overlie buried valleys incised into bedrock. The bedrock-valley map (fig. 4) shows a complex network of buried valleys that represents several episodes of bedrock incision. This network may be subdivided into two groups consisting of buried valleys less than 70 meters in depth and another group greater than 70 meters in depth. The latter group includes valleys filled with as much as 200 meters of sediments, most of which are silts and clays containing sparse gravel lenses yielding only enough ground water for domestic use (Szabo, 2002). These valleys generally have glacially-eroded upper valley walls that narrow to a typical V-shaped cross section in their lower parts (Szabo, 1987). These valleys may be preglacial or eroded during some early interglaciation and appear to have been dammed by an early glaciation, during which they were filled with lacustrine sediments. In contrast, the shallower buried valleys contain more extensive outwash deposits from either the Illinoian or Wisconsinan glaciations (Szabo, 2002). The deposits in these valleys have groundwater yields as large

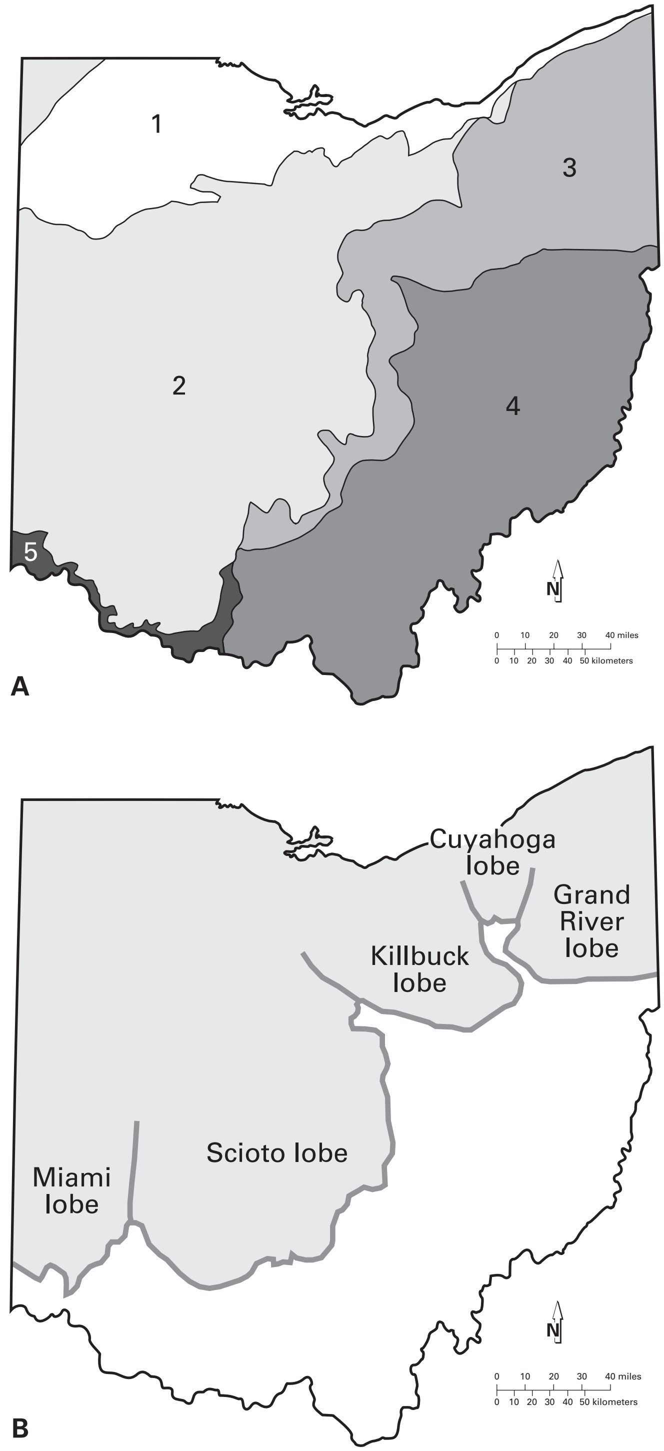


FIGURE 3.—Maps of Ohio showing physiographic provinces and glacial lobes. **A**, map showing generalized physiographic provinces (modified from Brockman, 1998). 1 = Lake Plains, 2 = Till Plains, 3 = Glaciated Allegheny Plateaus, 4 = Unglaciated Allegheny Plateaus, 5 = Bluegrass Section. **B**, map showing distribution of glacial lobes discussed in the text.

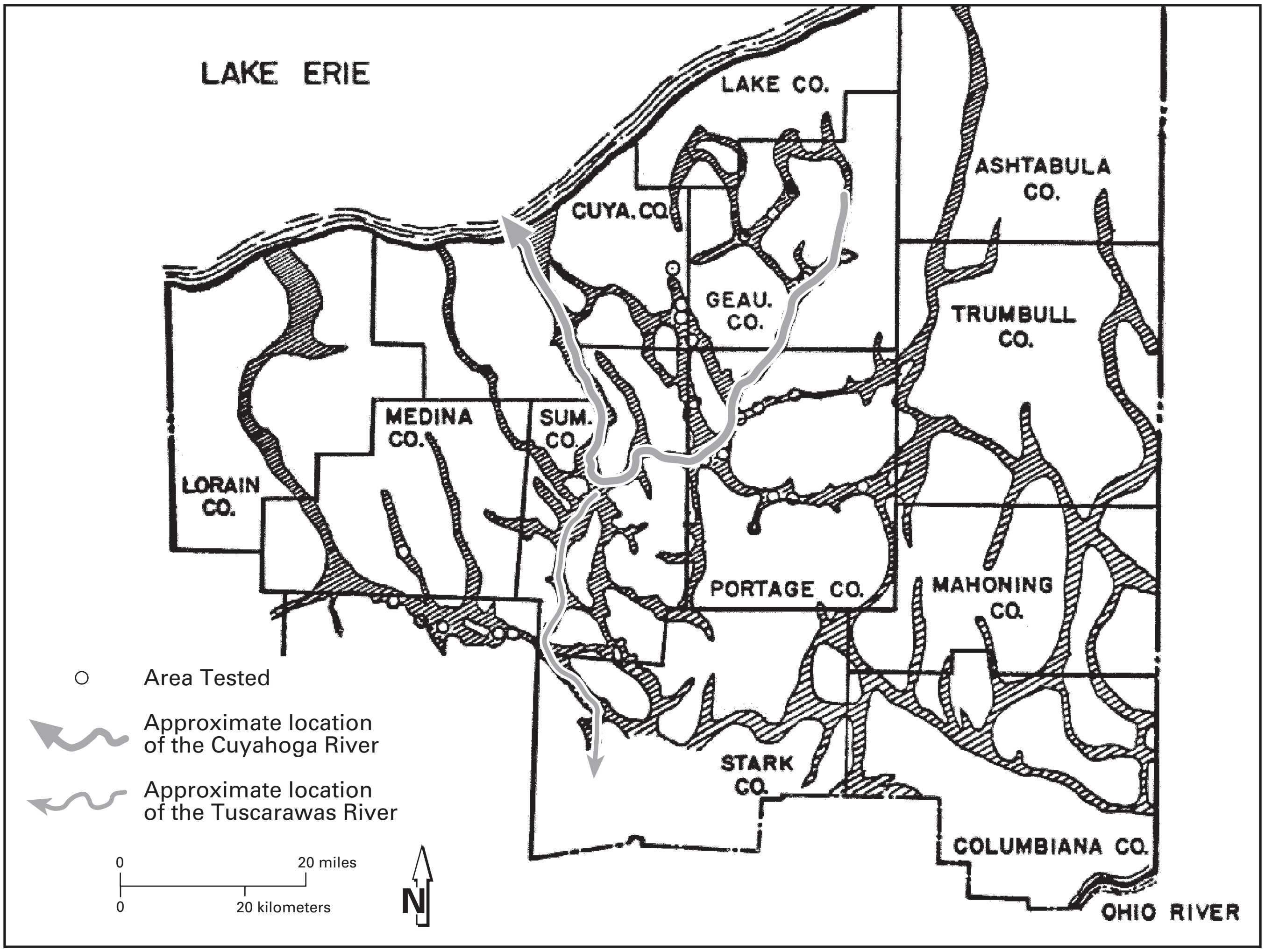


FIGURE 4.—Major buried valleys of northeastern Ohio and present courses of the Cuyahoga and Tuscarawas Rivers (modified from Ohio Drilling, Inc., 1971). Test areas are locations where groundwater capacities of the aquifers were assessed.

as 63 L/sec (Walker, 1978). Ice-contact deposits of the interlobate area may be hydrologically connected to the outwash in the shallow valleys. The ice-contact deposits and valley fills may contain isolated lenses of diamicts and lacustrine clays that may violate assumptions of a homogeneous and isotropic aquifer when conducting pump tests (Ohio Drilling Company, 1971) and modeling groundwater flow.

The bedrock of the Allegheny Plateaus consist of glacially streamlined, resistant Pennsylvanian sandstone and conglomerate units of the Pottsville Group forming topographic highs, and finer-grained siltstones and shales of the Mississippian Cuyahoga Formation underlying intervening lowlands. The Sharon Formation, the basal member of the Pottsville Group (Evans, 2003), forms much of the upland surface surrounding Akron in Summit County, and its sandstone and conglomerate beds form scenic ledges and waterfalls. Sandstones of the Connoquenessing, Mercer, and Homewood formations of the Pottsville Group are found farther east on hilltops in Portage and Geauga Counties. Coal, shale, or limestone members may separate resistant members of these formations, and it is not uncommon to find coal in glacial sediments on this part of the Allegheny Plateaus. Fluvial erosion between successive glaciations has downcut into soft shales and less resistant siltstones of the Cuyahoga Formation that underlie the Pottsville Group. The Devonian Berea Sandstone and underlying shales crop out in the lower Cuyahoga Valley north of Akron and underlie much of the Allegheny Plateaus in northeastern Ohio. Many deep, buried, bedrock valleys on the plateaus are eroded into Devonian shales.

OVERVIEW OF REGIONAL GLACIAL HISTORY

Knowledge of the glacial history of northeastern Ohio is greater than that of many areas of Ohio because of the work of George White and his students, Stanley Totten, and the students of John Szabo. White (1982) summarized nearly 50 years of research in northeastern Ohio, including a period of time during which he traced glacial deposits into northwestern Pennsylvania (White and others, 1969). Students such as Shepps (1955), Sitler (1957), Totten (1960), Heath (1963), Moran (1967), and Gross (1967) not only mapped glacial deposits but also did some primary research on the texture and lithology of tills. Droste (1956) presented some of the first data on the weathering of clay minerals in tills using a site near Streetsboro in Portage County, Ohio. Additional studies on the texture and lithology of tills in northeastern Ohio are summarized in Szabo and Totten (1995). These include research into the provenance of tills (Volpi, 1987; Bruno, 1988; Hofer, 1992; Matz, 1996) and differentiation of Illinoian units (Viani, 1986; Szabo, 1987).

Interpretation of the glacial history of northeastern Ohio has been hampered by poor dating control, uncertain identification of units because of similar texture and lithology, and a lack of paleosols or weathered zones between units. A few radiocarbon dates are available for sediments, such as the sequence at Garfield Heights, deposited before the late Wisconsinan advance (Miller and Szabo, 1987; Szabo, 1997). Additional dates are available for deglaciation; these consist of datable materials in the base of bogs (Totten, 1988), lacustrine and beach sediments of the ancestors of Lake Erie (Szabo and others, 2003), and palynological studies (Shane, 1975, 1987). There are no dates that constrain the timing of the transition from sandy tills to clay-rich tills that occurred during the latter part of the Late Wisconsinan glaciation.

Dreimanis (1957) proposed a tripartite division of the "Wisconsin" glaciation into early, middle, and late substages based on sediments exposed on the north shore of Lake Erie in the Plum Point/Port Talbot area. Other exposures at Garfield Heights, Ohio (White, 1953), and Titusville, Pennsylvania (White and Totten, 1965), provided broader correlations of glacial and purported interstadial deposits (Dreimanis and Goldthwait, 1973; White, 1982; Fullerton, 1986). Tills at these sites were assigned to a middle Wisconsinan advance. Although Goldthwait and Rosengreen (1969) thought that an early Wisconsinan advance deposited the Gahanna Till in southern Franklin County, researchers found no evidence of middle Wisconsinan advance south of the Ohio River/Lake Erie divide (Dreimanis and Goldthwait, 1973).

Interpretations of glacial stratigraphy in the Midwest and reconstructed sea-level curves (Cutler and others, 2003) suggest that the early and middle Wisconsinan glacial ice did not extend in to the southern Great Lakes basins. Kempton and others (1985) and Curry (1989) reclassified middle Wisconsinan deposits in northern Illinois as being deposited during the Illinoian stage. A similar investigation of deposits on the north shore of Lake Ontario limits the extent of ice during the middle Wisconsinan (Eyles and Westgate, 1987). Based on these findings and investigations of type sections, Szabo (1992) argued for an Illinoian age of the Millbrook Till that accounts for the bulk of the till deposits in northeastern Ohio and much of the end moraine topography (Totten, 1969; White, 1982). Additional support of the Illinoian age of materials previously classified as early or middle Wisconsinan in age consists of a ^{10}Be inventory of sediments from northernmost Illinois (Curry and Pavich, 1996). Their studies demonstrated that Illinois was ice free between 155,000 and 25,000 years ago and that formation of the Sangamon Geosol began near the end of marine isotope stage (MIS) 6 and continued into the early part of MIS 3.

These studies do not exclude glaciation during the early and middle Wisconsinan, but limit its southern extent. Curry (1998) inferred the existence of ice in the upper part of the Iowa River drainage basin at about 40,000 yr BP based on the stratigraphy of a site at Lomax, Illinois. This followed a period of warming as suggested by the beetles found at the Titusville site (Cong and others, 1996) and in the British Isles (Coope and Labeyrie, 1987). Additional evidence for warming at this time comes from the Greenland ice core (Johnson and others, 1992). Reinterpretation of classical middle Wisconsinan sites in eastern Indiana and western Ohio suggests that some diamicts were deposited by mass wasting during this time (Hall and Zbieszkowski, 2000). This short warming event fits into the pattern of oscillating temperatures and sea levels, which culminates in the late glacial maximum. During the Wisconsinan stage there were rapid changes in sea level in response to growing or decaying ice sheets. Cutler and others (2003) noted that during MIS 4 at about 70,800 yr BP, sea level was 81 meters below datum, and during MIS 3 at 60,600, 50,800, and 36,800 yr BP sea level was between 85 and 74 meters below datum. This suggests that glaciation did occur, but there was probably not sufficient ice volume to permit flow as far south as the late glacial maximum during which sea level was at least 107 meters below datum (Cutler and others, 2003).

METHODS

Samples cited in this guidebook were collected from outcrops along streams, boreholes, or exposures in gravel pits. Texture, Munsell color, consistency, structure, reaction to dilute HCl, and the nature of lithologic contacts were recorded in field notes. Matrix textures (% < 2 mm) of the samples were determined using settling and pipetting methods of Folk (1974). In this guidebook, the sand-silt break is 0.063 mm, and silt-clay break is 4 μ. The fine-carbonate content (% < 0.074 mm) was determined using a Chittick apparatus (Dreimanis, 1962); this grain size was used because it contains the terminal grades of calcite and dolomite and can be related to provenance of tills. A terminal grade is the smallest grain size to which an entrained clast may be reduced by crushing and abrasion under a glacier. The terminal grade varies among minerals and is dependent on the mineralogical properties and available energy at the base of the glacier. Diffraction intensity ratios (DIs) of the clay fraction (< 2 μ) were calculated by measuring the area under the illite peak at 1.0 nm and dividing it by the area under the kaolinite and chlorite peak at 0.7 nm (Willman and others, 1966; Volpi and Szabo, 1988).

Other parameters were occasionally measured in studies on which this guidebook is based. The lithology of the 1-2-mm sand fraction is representative of the clast content of tills (Anderson, 1957). Data were reduced into three basic categories of origin: carbonate, clastic, or crystalline rock types. Carbonates include limestone, dolomite, and chert, whereas clastics consist of shale, siltstone, sandstone, and rounded quartz grains. The crystalline grouping is composed of igneous and metamorphic rocks and angular quartz fragments. Totten (1960) developed a laboratory method involving staining of feldspars to evaluate the ratios of quartz to feldspar in the 0.250- to 0.125-mm sand fractions of tills. Heath (1963) and Gross (1967) used his method to evaluate the dilution of basal tills by local sandstone incorporated into the ice. Quartz/feldspar ratios in this guidebook were determined using cathodoluminescence (Ryan and Szabo, 1981). The 0.250- to 0.125-mm sand fractions of tills can also be used in heavy-mineral analysis (Sitler, 1963). Hofer (1992) and Matz (1996) used sodium polytungstate having a density of 2.9 g/cm^3 and the method of Callahan (1987) to separate heavy minerals in samples of tills. The heavy-mineral components were mounted in epoxy on petrographic slides, ground, polished to the proper thickness for thin sections, and point counted.

Surficial geology that appears in figures 6-10 of this guidebook is taken from the Cleveland South 30 x 60 minute (1:100,000) quadrangle (Pavey and others, 2000). Subareas were extracted from their map for use in this guidebook. Figure 5 contains the legends and keys to interpreting the surficial geology of these subareas.

TILL STRATIGRAPHY

George White worked in the area glaciated by the Killbuck lobe (fig. 3B) in northeastern Ohio before World War II and extended his studies into the area covered by ice of the Grand River lobe in northeastern Ohio and northwestern Pennsylvania after the war. He recognized the continuity of till sheets across these topographically controlled lobes of the main Erie lobe (fig. 3B). The stratigraphic classifications established for the Grand River lobe (White, 1960) and the Killbuck lobe (White, 1961) of northeastern Ohio became a framework for more detailed mapping and eventual publication of county reports. The Cuyahoga lobe was split from the Killbuck lobe on maps and in reports written in the last quarter of the twentieth century (White, 1979; 1982). High Pennsylvanian sandstone hills separated the Killbuck lobe from the Cuyahoga lobe west of the Cuyahoga River on the Summit-Medina county line and separated the Cuyahoga lobe from the extensive Grand River lobe in Geauga County (fig. 3B). Table 1 illustrates the till stratigraphy used in this guidebook, and table 2 shows average textures and compositions of tills according to physiographic province.

Note: Throughout this guidebook, I refer to diamicts deposited through direct melting of glacier ice as tills, and use the term diamict strictly as a textural term indicating a sediment displaying a possible grain size from clay size through boulder size.

Pre-Illinoian tills

Occurrences of pre-Illinoian tills are rare on the plateaus largely because of erosion during interglaciations followed by glaciations. Information about pre-Illinoian deposits is gained only through fortuitous exposures or samples from deep borings that are brought to the attention of geologists. Even though the Ohio Geological Survey's enabling legislation (ORC § 1505.04 (A)) requires the keeping of careful and accurate logs of <u>all</u> borings or wells, except for drinking-water wells, the Survey has never had adequate funds or human resources to maintain logs for anything other than oil-and-gas wells. So, much subsurface data is unavailable or lost in Ohio because of lack of funding for filing of logs of engineering borings. Fullerton (1986) mentions the exposure of possible pre-Illinoian tills and paleosols in a gravel pit in Garfield Heights, Ohio, but these deposits are no longer available for scrutiny because they are buried under the fill for I-480. Possible exposures of pre-Illinoian tills have been found near the glacial limit in northwestern Pennsylvania (White and others, 1969) and in ephemeral strip-mine exposures in extreme eastern Ohio. Totten and others (1969) discovered extremely weathered glacial sediments underlying Wisconsinan Kent Till and Illinoian Titusville Till in buried valleys exhumed during strip mining southeast of Youngstown, Mahoning County, and concluded that the underlying tills were at least Illinoian and probably older. The pebbles in these tills were extremely rotten and stained with limonite. Volpi and Szabo (1988) noted the presence of two tills that were older than the Titusville Till in several strip mines in Columbiana County, the next county south of Mahoning County. Their upper pre-Titusville till has a variable sand content and a carbonate content averaging 1.3% calcite and 4.1% dolomite ($n = 5$). Clay mineralogy of the upper unit consists of more kaolinite than illite, whereas the lower pre-Titusville till is more weathered containing kaolinite, illite-smectite, and vermiculite as dominant clay minerals (Volpi, 1987). Farther east in Pennsylvania along the glacial boundary, White and others (1969) described the Mapledale Till (table 1) as underlying the Titusville Till and having a well-developed paleosol. White (1982) identified Mapledale Till in several exposures in northeastern Ohio. The Mapledale Till overlies the intensely weathered Slippery Rock Till (White and others, 1969) that has not been positively identified in northeastern Ohio (White, 1982).

Illinoian tills

The number and distribution of tills assigned to the Illinoian glaciation varies across the Cuyahoga and Grand River lobes (table 1). White (1984) noted that there were several exposures of pre-Wisconsinan till or older till south of Akron in Summit County; the majority of these consisted of very coarse diamicts containing angular pieces of local sandstone and siltstone. Although a few foreign pebbles are present in these exposures, it is difficult to determine if these diamicts originated as colluvium derived from the combination of till of a very early glaciation and shallow bedrock, or as glacial sediment. There are few other isolated occurrences of finer-grained diamicts having a glacial origin, but they are older than those that are traceable as lithologic units throughout the lobes.

The oldest till of possible Illinoian age is the Keefus Till (table 1), whose type section is defined in Ashtabula County in extreme northeastern Ohio (White and Totten, 1979). The dusky-red (2.5Y 3/2) color is the most recognizable characteristic of this till that has limited surface exposure. Its unusual color permits its recognition in water-well logs over an area of six townships in Ashtabula County; it is traceable in the subsurface from the Lake Plain across the Portage Escarpment onto the edge of the Allegheny Plateaus (White and Totten, 1979). Bruno (1988) was able to analyze samples from the type section of the Keefus Till where it overlies bedrock and underlies a younger Illinoian till. The upper part of the

Table 1.—*Tentative correlations of lithologic units in north-central and northeastern Ohio*

Time	Killbuck lobe	Cuyahoga lobe	Grand River lobe (Ohio)	Grand River lobe (Pennsylvania)
Late Wisconsinan	Hiram Till Hayesville Till Navarre Till	Hiram Till Lavery Till Kent Till	Ashtabula Till Hiram Till Lavery Till Kent Till	Ashtabula Till Hiram Till Lavery Till Kent Till
Middle Wisconsinan through Sangamonian				
Illinioan	Northampton Till Millbrook Till	Northampton Till Mogadore Till Keefus Till	not found Titusville Till Keefus Till	not found Titusville Till not found
Pre-Illinoian		Mapledale Till?	Mapledale Till unnamed till a unnamed till b	Mapledale Till Slippery Rock Till

Table 2.—*Summary of laboratory data for lithologic units found in north-central and northeastern Ohio and referred to in this guidebook*

Unit location	sand (% < 2mm)	silt (% < 2mm)	clay (% < 2mm)	calcite (% < 0.074mm)	dolomite (% < 0.074mm)	total carb (% < 0.074mm)	DI (< 2 μ)
Ashtabula Till							
Lake Plain	16/233[1]	53/233	31/233	2.2/194	5.6/194	7.8/194	1.3/180
Hiram Till							
Lake Plains	13/29	42/29	45/29	11.5/22	7.0/22	18.5/22	n.a.[2]
Till Plains	15/173	40/173	45/173	4.6/84	7.8/84	14.0/112	n.a.
Portage Escarpment	19/19	48/19	33/19	2.8/19	7.4/19	10.2/19	n.a.
Allegheny Plateaus	18/6	47/6	35/6	4.5/6	4.9/6	9.4/6	n.a.
Hayesville/Lavery Till							
Lake Plains	19/89	42/89	39/89	9.0/73	8.1/73	17.1/73	1.8/14
Till Plains	19/492	43/492	38/492	7.2/387	9.5/387	17.4/478	1.9/36
Portage Escarpment	24/94	45/94	31/94	2.8/95	8.1/95	11.1/95	n.a.
Allegheny Plateaus	11/82	48/82	41/82	8.1/82	7.3/82	15.4/82	n.a.
Navarre/Kent Till							
Lake Plains	20/12	49/12	30/12	6.1/12	5.0/12	11.1/12	n.a.
Till Plains	26/322	43/322	31/322	5.9/314	11.1/314	17.4/322	1.9/10
Portage Escarpment	28/126	44/126	28/126	1.9/126	7.7/126	9.6/126	1.3/3
Allegheny Plateaus	34/254	43/254	23/254	1.4/183	7.2/183	8.6/183	1.6/101
Northampton Till							
Lake Plains	18/15	48/15	34/15	6.1/15	8.1/15	14.2/15	n.a.
Till Plains	19/96	46/96	35/96	6.0/85	9.6/85	16.0/92	1.4/29
Portage Escarpment	30/20	41/20	29/20	5.5/20	9.9/20	15.4/20	n.a.
Allegheny Plateaus	10/445	48/445	42/445	3.5/450	6.6/450	10.1/450	1.5/87
Millbrook/Mogadore/ Titusville Till							
Lake Plains	28/5	49/5	23/5	0/1	4.2/1	4.2/1	1.5/1
Till Plains	28/44	44/44	28/44	0.3/44	6.6/44	6.9/44	n.a.
Portage Escarpment	31/81	45/81	24/81	0.1/85	4.8/85	4.9/85	1.4/20
Allegheny Plateaus	34/265	45/265	21/265	0.3/216	4.1/216	4.4/216	0.9/216
Keefus Till							
Lake Plain	33/5	48/5	19/5	2.4/5	6.7/5	9.1/5	1.4/5

[1]Numerical sequence is mean/number of samples.
[2]n.a. = not analyzed.

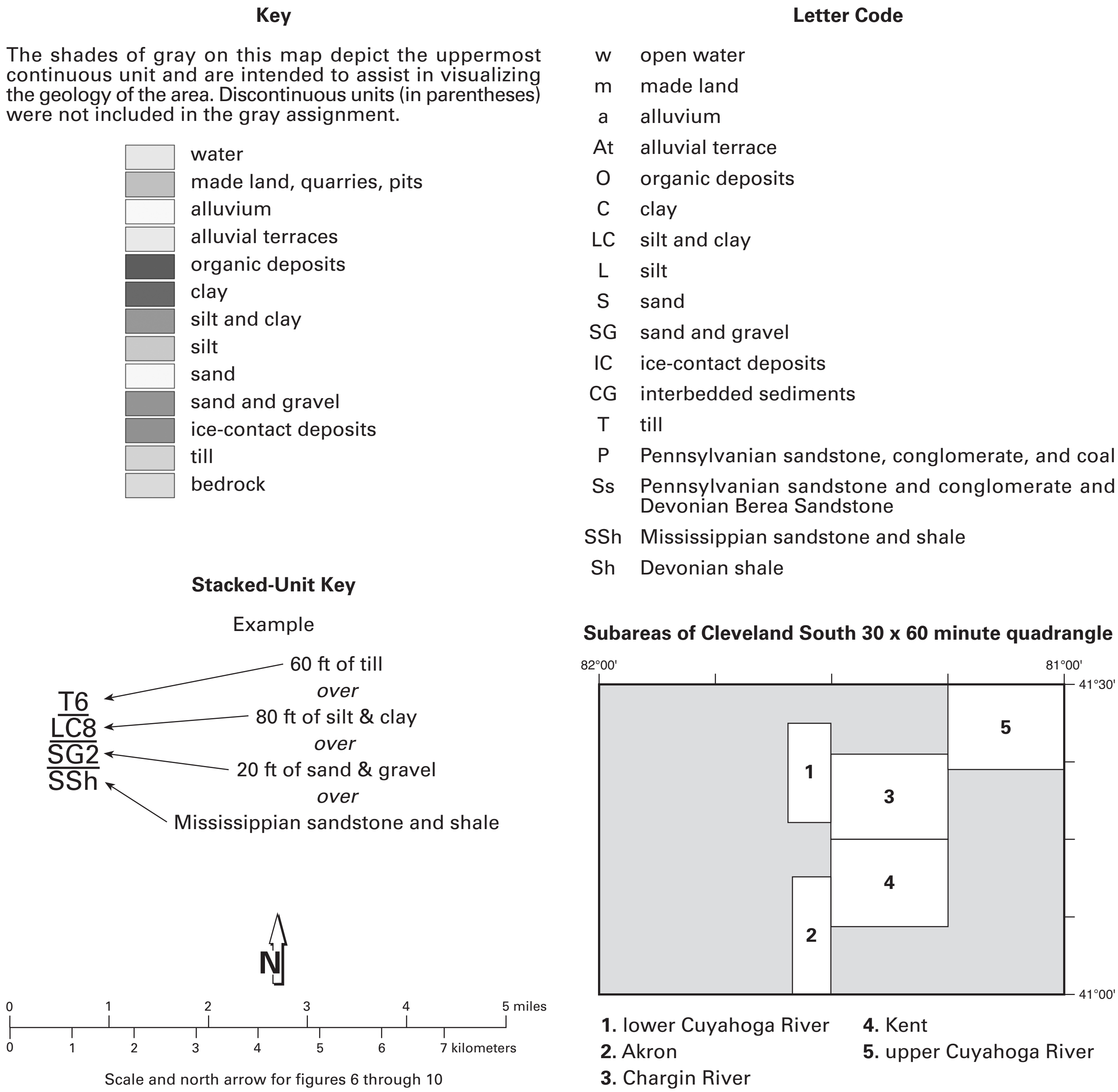


FIGURE 5.—Key for the materials shown on subareas of the surficial geology map of the Cleveland South 30 x 60 minute quadrangle (modified from Pavey and others, 2000). Outlines of the subareas (bottom right) referred to in the text are also shown.

unit consists of massive, matrix-supported diamict (Dmm) that overlies the same type of diamict that additionally has been sheared (Dmm(s)). Although the number of analyzed samples is small (table 1), the fine-carbonate content of the Keefus Till is radically different than that of the overlying Titusville Till, but its clay mineralogy is similar to that of the Titusville Till along the Portage Escarpment. Bruno (1988) determined that most of the red color of the Keefus Till and red layers in the Wisconsinan Ashtabula Till were derived from comminuted Grimsby Formation eroded from outcrops in the Niagara Falls and Lake Ontario area. That formation and the red glacial sediments have nearly identical clay mineralogies and fine-carbonate contents, and both contained hematite. The only other possible occurrence of Keefus Till may be 34 meters beneath the floodplain surface of the Cuyahoga River in downtown Cleveland. Szabo and others (2003) noted occurrence of a till having a similar fine-carbonate content as the Keefus Till underlying the Mogadore Till (table 1) in borings for the Eagle Avenue Bridge in downtown Cleveland made in 1927.

The Mogadore Till of the Cuyahoga lobe (table 1) and its equivalent, the Titusville Till, in the Grand River lobe (White, 1960, 1961) is the most widely recognized Illinoian till in northeastern Ohio. It is a very firm, pebbly, sandy, dense, gray diamict that reacts weakly to dilute HCl and contains a large proportion of local bedrock clasts. Pebbles are extracted from outcrops with difficulty and leave well-formed "sockets" that may be iron stained (White, 1982). The combination of a small calcite content and the dominance of dolomite (table 2) in its fine-carbonate content make it a unique marker bed on the Allegheny Plateaus and along the Portage and Allegheny Escarpments. This property extends to its equivalent, the Millbrook Till of the Killbuck lobe and the eastern Scioto lobe in central Ohio (Szabo and Totten, 1995; Frolking and Szabo, 1998). The ice that deposited Mogadore Till and its equivalents advanced farther onto the plateaus than any other Illinoian advance (Szabo and Totten, 1995), and in many cases it directly overlies bedrock on uplands. As a result, its clay mineralogy has been altered by the incorporation of Pennsylvanian bedrock (Volpi and Szabo, 1988). Average DIs of Ohio tills generally range from 1.3 to 1.9 (table 2), suggesting the predominance of illite derived from lower Paleozoic shales, but the Mogadore and Titusville Tills of the plateaus have DIs less than 1.0, reflecting the abundance of kaolinite in the Pennsylvanian rocks.

Szabo and Ryan (1981) discovered an unnamed diamict unit of possible Illinoian age overlying extensive proglacial deltaic deposits in Northampton Township, north of Akron. Initially this unit was traced northward to Independence, Ohio, at the southern edge of Cleveland. This unit has been found in borings as far east as the north-south buried valley (figs. 6-8) that is parallel to Ohio Rte. 8 between Akron and Walton Hills (Wilson, 1991). The unit has been traced as far west as Sandusky County in north-central Ohio where Angle (1987) correlated it with the middle Millbrook Till, an informal unit. This Illinoian unit crops out as far south as Morrow County north of Columbus in central Ohio. Multiple beds separated by thick lacustrine clays are found north of the Defiance Moraine and near the southern city limit of Cleveland where Wisconsinan Kent Till overlies this unnamed diamict (Szabo and Fernandez, 1984).

This very firm, calcareous, dark-gray diamict is named the Northampton Till (Szabo, 1987) and forms the cores of the Summit County morainic complex north of Akron and the Defiance Moraine farther north. The presence of oxidized fractures extending deep into unweathered dark-gray diamict is one of the identifying characteristics of the Northampton Till in valleys of the many tributaries of the Cuyahoga River (Szabo and Angle, 1983). The matrix texture of the till is dominated by clay and silt (table 2) derived from the incorporation of lacustrine sediments as the Northampton ice advanced into an ancestor of the Cuyahoga Valley. This till can be confused with clay-rich late Wisconsinan tills because of its fine matrix texture and its tendency to form similar soils to those developed in the younger tills. The Northampton Till is more consolidated and thicker than the late Wisconsinan tills and contains rounded, black pebbles of Niagaran dolomite, whereas the younger tills contain black Devonian shales as a common lithology. Its fine-carbonate content is dominated by dolomite, having average calcite/dolomite ratios ranging from 0.50 to 0.75; its illitic clay-mineral fraction reflects erosion of Devonian and Mississippian shales (Szabo and Fernandez, 1984).

Late Wisconsinan tills

The Kent Till is the oldest Wisconsinan till found in northeastern Ohio (White, 1982). White applied the name to a sandy diamict found in areas glaciated by both the Cuyahoga and Grand River lobes. Unweathered Kent Till is a firm to friable, sandy, gray diamict that reacts weakly to dilute HCl. Fractures in this till are slightly stained with iron, and pebbles in this till may be extracted freely from their sockets. Kent Till is a common surficial unit in the interlobate area between the Cuyahoga and Grand River lobes where it can be traced beneath younger units. This till is found in few outcrops in the Cuyahoga Valley between Akron and Cleveland (Szabo and Fernandez, 1984), but it is widespread in interstate cuts in eastern Cuyahoga County (Ford, 1987) and east of the north-south buried valley parallel to Ohio Rte. 8 (figs. 6-8) between Bedford and Akron (Wilson, 1991). Kent Till is traceable in the subsurface to the eastern edge of the Cuyahoga lobe and may underlie sand and gravel beneath younger clay-rich tills (area UX, fig. 2). Along the western margin of the Grand River lobe, Kent Till likewise underlies sand and gravel, but there is also a narrow belt of Kent ground moraine (area G1, fig. 2).

Much of the Kent Till in the interlobate area is associated with stagnant ice, and it is often discontinuous and interbedded with sand or gravel bodies. As a result, most of the diamicts recognized as Kent Till were probably formed by melt out rather than by lodgment, especially along the margins of the former lobes. Moderately drained, loamy soils form on the Kent Till, and the sand content of its matrix texture is similar to that of the Titusville Till (table 2). The Kent Till has larger average clay and fine-carbonate contents when compared to the Titusville Till. On the plateaus its average calcite/dolomite ratio is about 0.20, whereas this ratio for the Titusville Till in the same area averages 0.07. The clay mineralogy of the Kent Till is dominated by illite in all physiographic regions (table 2).

Clay-rich tills overlie the sandy tills of the first late Wisconsinan advance throughout most of northern Ohio. In some areas northwest of Kent, the clay tills completely obscure the former Kent ice margin of the Cuyahoga lobe, whereas later advances of the Grand River lobe did not extend as far west as the Kent advance (fig. 2). The Lavery Till (areas M3 and G3, fig. 2) is the oldest of the clay tills and is largely buried by a younger till in the area glaciated by the Cuyahoga lobe; Pavey and others (1999) mapped a small area of Lavery end moraine near Stow in the southwestern part of figure 2. In the southeastern part of the same figure, a large area of Lavery Till forms the ground moraine in that part of the former Grand River lobe.

Lavery Till differs significantly from the underlying Kent Till. Weathered Kent Till is yellowish brown (10YR 5/4), whereas weathered Lavery Till is dark brown (10YR 4/3). In many county reports White refers to the "chocolate" brown color of the weathered Lavery Till. This till is often completely oxidized throughout its thickness making occurrences of unweathered Lavery Till rare on the plateaus. Where found,

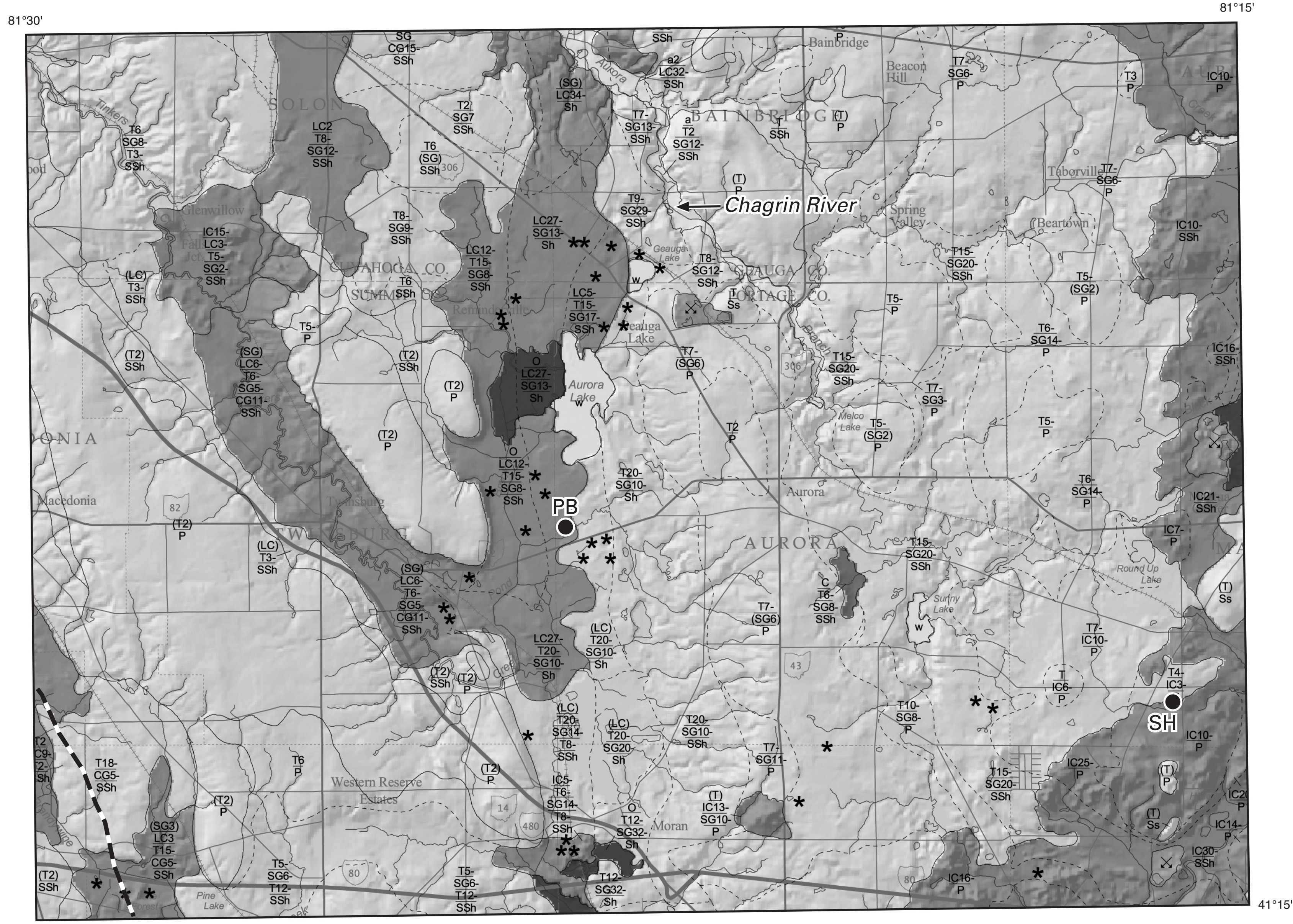


FIGURE 6.—Chagrin subarea of the Cleveland South 30 x 60 minute quadrangle (from Pavey and others, 2000). Lacustrine deposits fill a possible Sangamonian(?) valley indicated by the dashed line in the southwestern corner of the map. Lacustrine deposits also fill the valley of the northward-flowing Chagrin River. PB is a location of a boring through Late Wisconsinan sediments, and SH is measured section in a road cut exposing Kent Till.

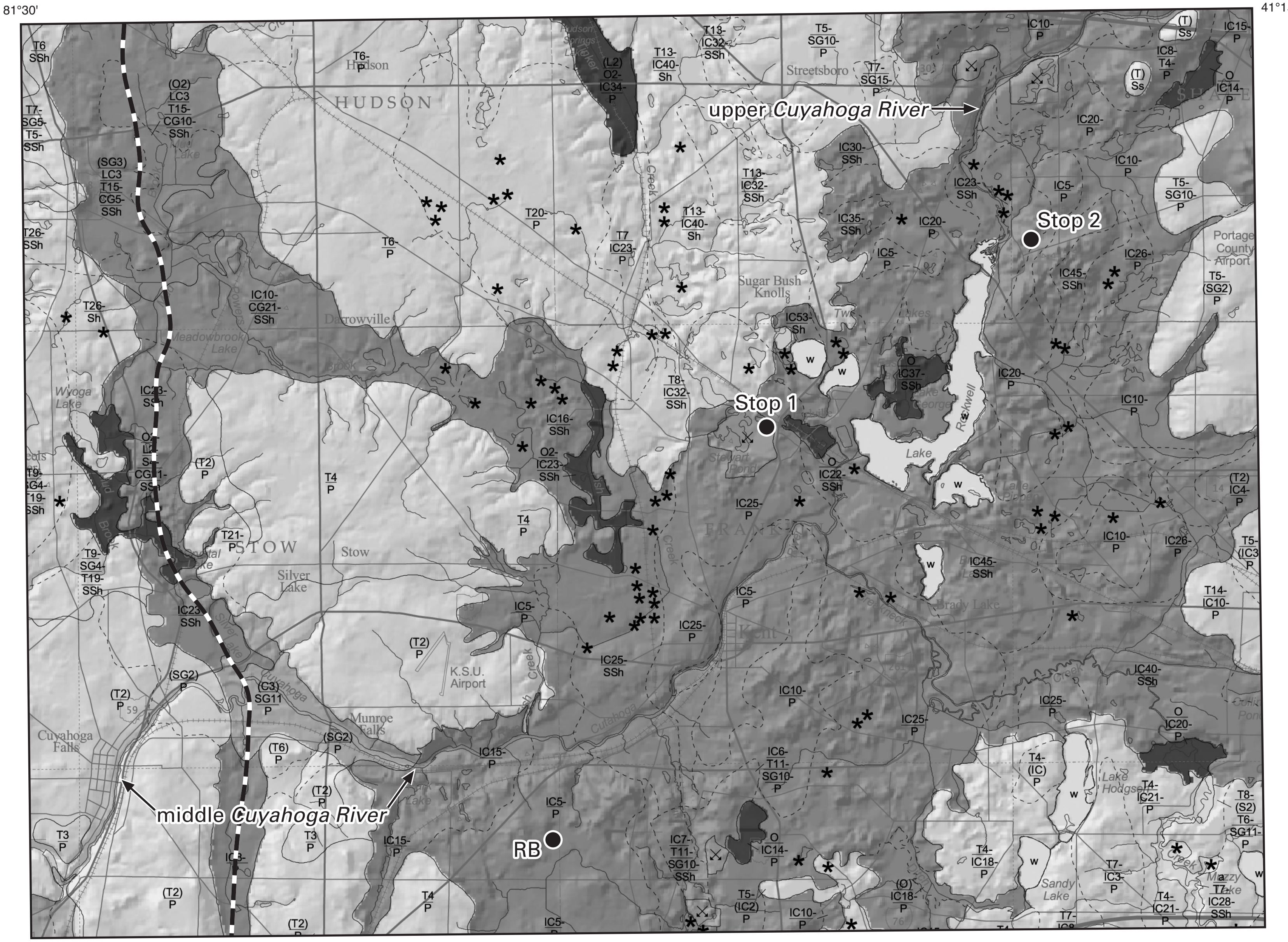


FIGURE 7.—Kent subarea of the Cleveland South 30 x 60 minute quadrangle (from Pavey and others, 2000). A large area of ice-contact deposits is found in the interlobate area between the Cuyahoga and Grand River lobes. Lacustrine sediments, sand and gravel, and ice-contact deposits fill a possible Sangamonian (?) valley indicated by the dashed line in the northwestern corner of the map. RB is the location of rotosonic borings into > 50 meters of Kent-age lacustrine sediments between Tallmadge and Kent.

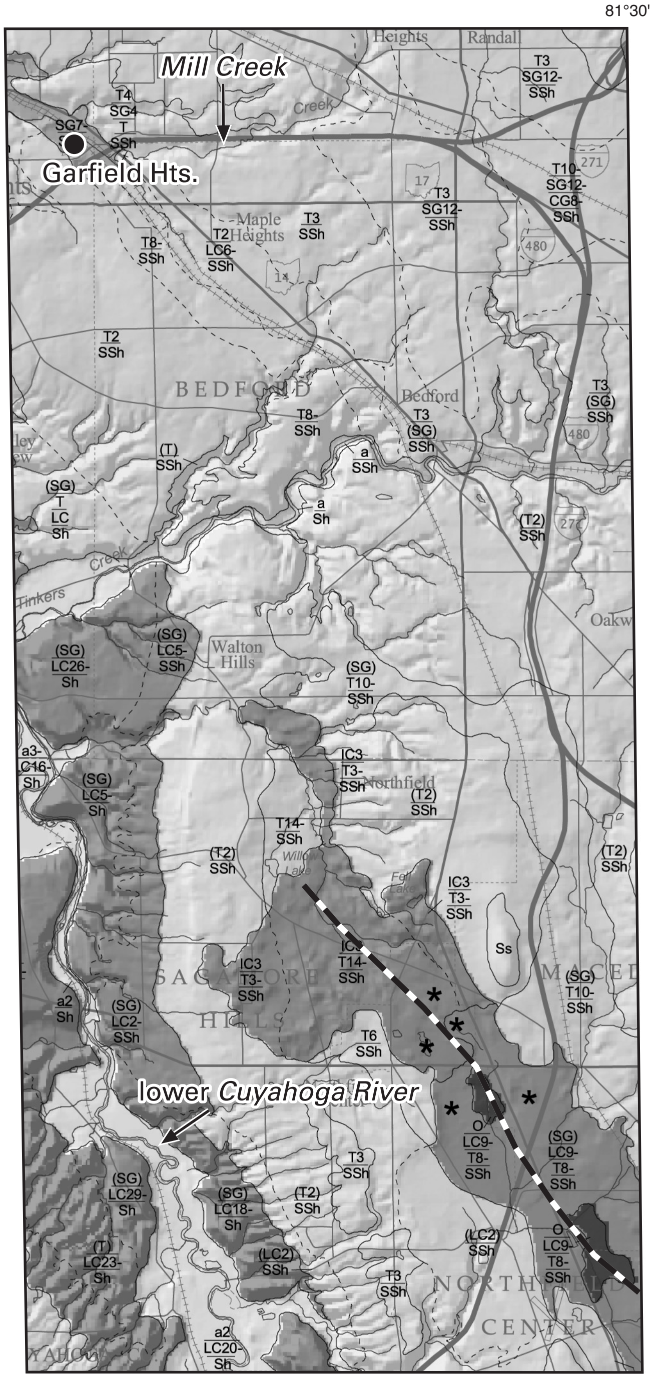


FIGURE 8.—Lower Cuyahoga River subarea of the Cleveland South 30 x 60 minute quadrangle (from Pavey and others, 2000). The possible Sangamonian(?) valley (dashed line) is parallel to, and within 3 miles (5 km) of, the lower Cuyahoga valley. Interfluves of the dissected Illinoian lacustrine deposits of the Cuyahoga valley are capped by late Wisconsinan fine-grained tills (Szabo, 1987).

unweathered Lavery Till is a firm, clay-rich, sparsely pebbly, calcareous, dark-gray diamict; on the plateaus, this till averages 11% sand, 48% silt, and 41% clay (table 2). Its total fine-carbonate content is almost twice that of the Kent Till, and there is an overall tendency for calcite to be slightly more abundant than dolomite. Secondary carbonate nodules form on manmade slopes in road cuts and give the surface the appearance of being covered by popcorn (White, 1982). Because of complete oxidation in most sections, no x-ray diffractograms for unweathered Lavery Till from the plateaus have been examined, but its clay mineralogy from sparse outcrops in other provinces (table 2) is dominated by illite and chlorite.

The Hiram Till (areas G4 and M4, fig. 2) is the youngest late Wisconsinan till in the field trip area and appears to have overridden the Lavery margin along the eastern edge of the Cuyahoga lobe. The actual boundary appears uncertain in southern Geauga County where an area of kames veneered with till has been mapped (area UX, fig. 2). Areas of Hiram ground moraine and end moraine border lacustrine deposits within the Grand River lowland along the northeastern edge of the field trip area. The area east of Hiram, the type area of the Hiram Till, is mapped as nonlinear hummocky moraine (area U4, fig. 2).

Hiram Till is usually thoroughly oxidized and may be entirely leached of carbonates throughout its entire thickness. The median thickness of the Hiram Till on the plateaus is 1.2 meters (White, 1982). It has been eroded from most sideslopes of valleys and is most frequently preserved on flat uplands or the crests of divides (Szabo, 1987). Weathered Hiram Till has the same "chocolate" brown color as the Lavery Till, but often contains black Devonian shale fragments. Its texture is similar to that of the Lavery Till (table 2), and there are not enough unweathered samples to draw a valid conclusion about its fine-carbonate and clay-mineral contents on the plateaus (table 2). The heavy-mineral assemblages of the Hiram and Lavery Tills are identical, having a source area in the eastern Grenville Subprovince (Hofer and Szabo, 1993).

LOCAL GLACIAL HISTORY

The complex network of buried valleys (fig. 4) may be indirect evidence of multiple pre-Illinoian glaciations throughout the Glaciated Plateaus. Several major, subparallel, buried valleys are found very close to each other, and it seems unlikely that all the valleys were functioning at the same time (Frolking and Szabo, 1998). Any attempt to connect these valleys creates an unrealistic drainage system having many knickpoints. As a result it may be possible that these valleys were formed during different interglaciations. For example, Illinoian Mogadore Till is found in the streambeds of tributaries at nearly the same elevation as the flood plain of the lower Cuyahoga River north of Akron. As much as 60 meters of proglacial deltaic and lacustrine deposits overlie the Mogadore Till, and the Illinoian Northampton Till overlies this proglacial depositional sequence (Szabo and Ryan, 1981; Szabo, 1987). There is a little evidence that this part of the Cuyahoga River valley was eroded during the Sangamonian Interglaciation because late Wisconsinan tills are found on the crests of interfluves of the dissected valley fill. A previously mentioned buried valley (figs. 6-8) of possible Sangamonian age may be found 3 miles (5 km) to the east, running parallel to Ohio Rte. 8 (Wilson, 1991). This valley deepens southward towards eastern Akron and joins a buried valley system associated with the ancestral Tuscarawas River. This buried valley is filled with sand and gravel at depth that serves as water supplies for Hudson and Cuyahoga Falls; the upper valley fill is a sequence of late Wisconsinan diamicts, sand, lacustrine sediments, and peat (Wilson, 1991). Thus, these adjacent valleys functioned at different times during the late Pleistocene, and it may be likely that similar scenarios exist throughout northeastern Ohio.

Ice flowed into northeastern Ohio at least three times during the Illinoian glaciation. The earliest advance deposited Keefus Till along the Portage Escarpment from Ashtabula southwestward to Cleveland. The second advance during the Illinoian stage was very extensive as ice rode over the escarpment and crossed the plateaus as far south as an east-west line approximated by U.S. Rte. 30 between Canton and the Ohio-Pennsylvania state line. Ice eroded and streamlined bedrock highs composed of Pennsylvania sandstone and deposited the sandy Mogadore Till in the Cuyahoga lobe and the more kaolinitic Titusville Till in the Grand River lobe. These equivalent units incorporate large quantities of local bedrock that probably diluted their fine-carbonate content until only a few percent of dolomite remained. Within the area of the Cuyahoga lobe, a third advance overrode proglacial deltaic sediments deposited in a large lake, Lake Cuyahoga, that was dammed by ice-contact features (fig. 9) associated with the Mogadore advance at Akron (Rau, 1969). This last Illinoian advance deposited the Northampton Till and formed the core of the Summit County morainic complex north of Akron (Szabo and Ryan, 1981; White, 1982; Szabo and Miller, 1986; Szabo, 1987). As Northampton ice melted back toward the present Erie Basin, another proglacial lake, Lake Independence, formed in the lowland that is now the lower Cuyahoga Valley, and several streams flowing from the uplands into the valley deposited deltas in this lake. Northampton ice advanced to Peninsula, Ohio, about half way between Akron and Cleveland to deposit the core of the Defiance Moraine (Szabo, 1987). It is not known if there was an equivalent advance in the Grand River lobe because the internal structure of moraines has not been investigated in that area.

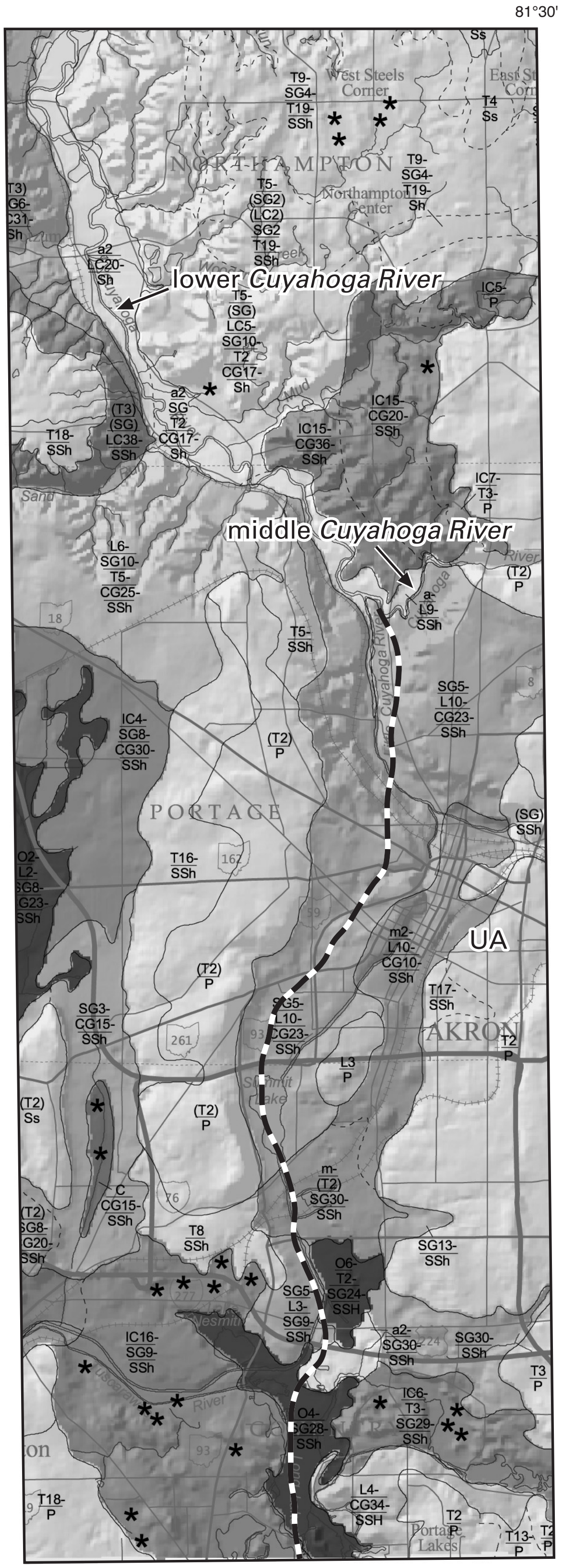
Evidence for weathering during the Sangamonian interglaciation is limited in northeastern Ohio. Evidence for leaching of fine carbonates and weathering of chlorite to vermiculite in the upper part of the Northampton Till where it is overlain by younger deposits has been noted (Szabo, 1987), but the only occurrence of a possible Sangamonian paleosol is found in the valley of Mill Creek in Garfield Heights, Ohio (fig. 8). A reddish-brown, truncated, B horizon of a well-drained soil is developed on a hill composed of Illinoian outwash (White, 1968; Szabo and Miller, 1986; Miller and Szabo, 1987; Szabo, 1997). As climate deteriorated during the early and middle Wisconsinan, colluvial materials were eroded from the hillslope of sand and gravel, transported downslope, and deposited at the footslope and toeslope as an accretion gley. Alternating layers of heterogeneous swelling material and better-organized clay minerals and bands of Fe and Mn staining suggest that colluviation was cyclical (Szabo, 1997).

Loess was deposited over the accretion gley during the latter part of the middle Wisconsinan in a severe boreal climate (Berti, 1971). The overall weathered appearance of the loess, its lack of carbonates, degraded clay minerals, and magnetic minerals (Peck and others, 2003) suggest that it was either derived from a weathered source or weathered in place over a long duration. The presence of an organic zone in this loess having a minimum age of 27,000 radiocarbon years indicates a short period of stability before additional loess deposition (Szabo, 1997).

The advance of late Wisconsinan ice was preceded by renewed loess deposition between 24,000 and 27,000 radiocarbon years ago. Magnetic signatures in the upper parts of both the older and younger loesses indicate similar environments of deposition (Peck and others, 2003). The younger loess contains more carbonates and better-organized clay minerals than the lower loess. Terrestrial gastropods, wood, pollen, and insects from the upper part of the younger loess represent a boreal climate having scattered trees (Morgan and others, 1982; 1983). About 24,000 years ago before the arrival of the Kent ice, substantial hillslope erosion washed loess and organic detritus downslope. These materials were inundated and buried by laminated silts and clays in a shallow lake or pond. Plant fossils suggest forest-tundra conditions (Berti, 1971), and the gastropods and insect remains imply that the pond dried up during summers (Coope, 1968). Thus, the record at Garfield Heights suggests local cooling as Kent ice flowed into the area about 23,000 radiocarbon years ago.

In the area glaciated by the Grand River lobe, Kent ice flowed to within a few miles (few kilometers) of the Illinoian boundary, but in the area of the Cuyahoga lobe, the Kent limit is uncertain. There is no Kent Till present on the Akron upland south of the misfit valley of the Little Cuyahoga River, which may represent either an Illinoian or Kent limit. As ice advanced, melt water may have drained through interglacial valleys that may have become blocked. Rotosonic borings for a potential well field on the Summit-Portage county line near Tallmadge (RB, fig. 7) penetrated at least 50 meters of interbedded lacustrine deposits and diamicts of sediment flows having fine-carbonate contents similar to those of the Kent Till.

Physiography limited the initial advance of late Wisconsinan ice. In the lowlands of western Ohio, ice of the Scioto and Miami lobes flowed almost as far south as the latitude of Cincinnati and underwent a series of millennial-scale retreats and readvances between 16,000 and 21,000 radiocarbon years ago (Dreimanis and Goldthwait, 1973), whereas ice of the Kent advance appeared to stagnate because it could no longer advance any farther south on the higher Allegheny Plateaus. Stagnation may be suggested by the abundance of numerous kames and outwash channels throughout the interlobate area (figs. 7, 10). Road cuts through some of these ice-contact features show extensive layers of medium-grained sand having lenses of silt and clay. Multiple layers of Kent diamicts suggest minor reactivation



of the ice, but by far, stagnation features dominate the landscape in southeastern Summit, Portage, and Geauga Counties. The upper Cuyahoga River may have originated as an interlobate meltwater stream as Kent ice retreated from its maximum extent. This meltwater river drained southward east of Akron eventually into the Ohio River.

Ice melted back into Canada about 16,000 radiocarbon years ago (Larson and Schaetzl, 2001) during a poorly time-constrained, warmer period referred to as the Erie Interstade, having a possible duration of 500 to 800 years (Morner and Dreimanis, 1973). Late Wisconsinan tills deposited before this interstade are relatively sandy diamicts, whereas those deposited after the interstade are clay rich (Pavey and others, 1999). An interstadial lake formed in the Erie basins, and as ice readvanced, it eroded interstadial lake clays that were then deposited as clay-rich diamicts through the northern half of Ohio. The first ice advance after the Erie Interstade flowed as far south as north Akron in the Cuyahoga lobe, but in the Grand River lobe ice flowed about 25 miles (40 km) farther south to Canton. After a retreat into the Erie basin, ice readvanced to nearly the same position as the Lavery ice in the Cuyahoga lobe and extended to within 12 miles (20 km) of the Lavery limit in the Grand River lobe. This advance deposited another clay-rich diamict, the Hiram Till that is quite thin. These two advances must have occurred in a limited time frame because bog-bottom dates from kettles in the Defiance end moraine and dates on twigs in lacustrine deposits of Lake Maumee average about 14,500 radiocarbon years ago (Szabo and others, 2003). Another advance essentially confined to the Erie basin deposited the Ashtabula Moraine against the Portage Escarpment east of Cleveland about 14,000 radiocarbon years ago (Szabo and Bruno, 1997; Szabo and Chanda, 2004). By about 13,500 radiocarbon years ago, the boreal forest containing spruce and northern white cedar was growing along the shores of the ancestors of Lake Erie (Shane, 1987; Szabo and others, 2003).

As ice retreated toward the Niagara Escarpment, the drainage pattern on the landscape became better integrated. The upper Cuyahoga River was captured by the middle Cuyahoga River that originated as an ice-marginal stream along the Hiram margin north of Akron. At this time the Cuyahoga River drained through Akron into the Tuscarawas River. Also during this time, the ancestor of the lower Cuyahoga River, as were many ancestors of other northward-flowing rivers in northern Ohio, was downcutting into the postglacial landscape in response to changing levels of the ancestors of Lake Erie. Many of the northward-flowing riv-

FIGURE 9.—Akron subarea of the Cleveland South 30 x 60 minute quadrangle (from Pavey and others, 2000). The buried valley of the lower Cuyahoga River (dashed line) southwest of Akron is filled with Illinoian ice-contact and outwash deposits that may have dammed meltwater of successive glaciations (Rau, 1969). UA = The University of Akron.

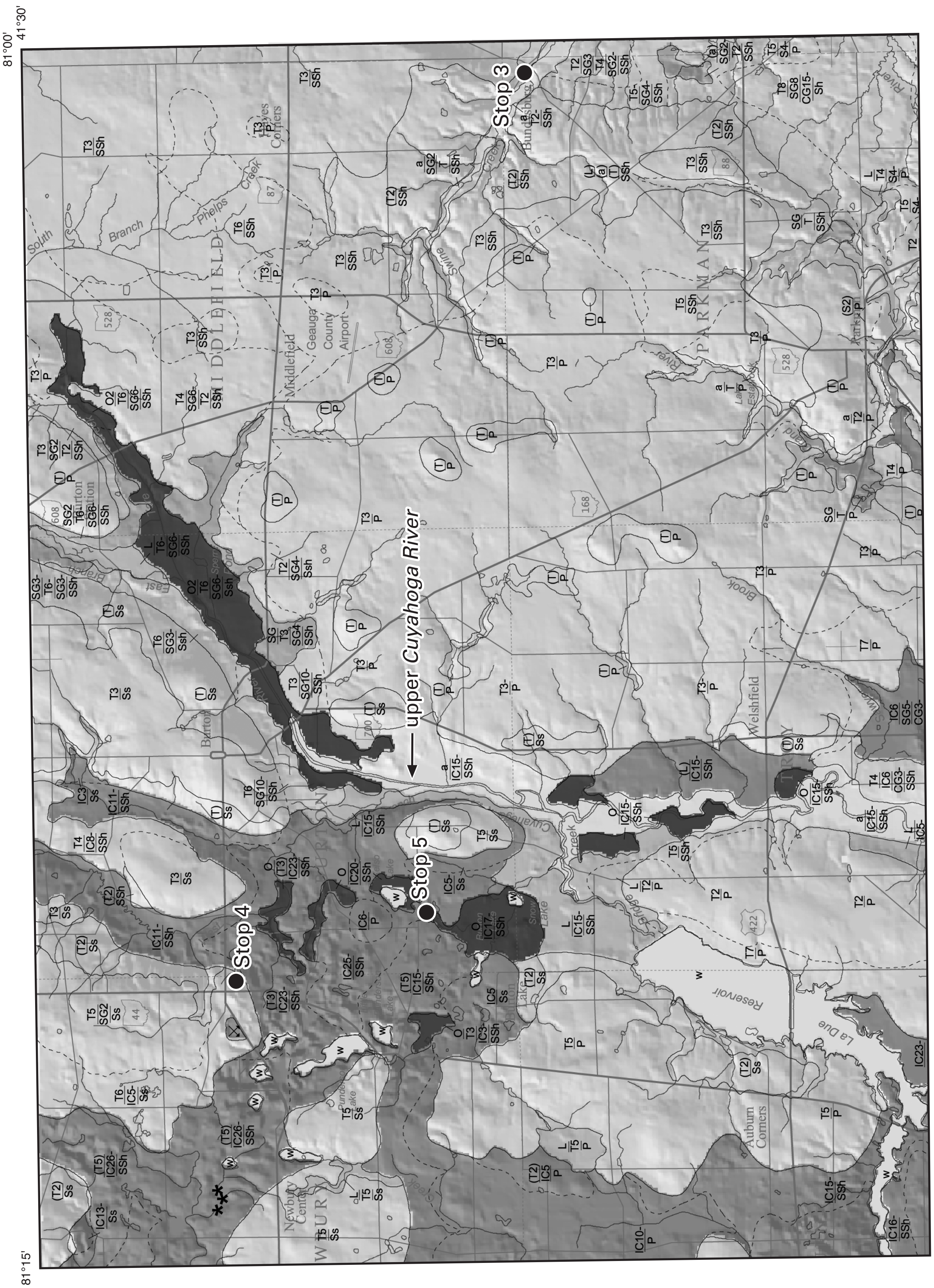


FIGURE 10.—Upper Cuyahoga River subarea of the Cleveland South 30 x 60 minute quadrangle (from Pavey and others, 2000). This map displays the surficial materials of the interlobate area in the area of Stops 3-5.

ers have terraces graded to these ancestors (Trembczynski, 2000). As the Niagara Escarpment was deglaciated, the level of water in the Erie basin dropped by as much as 40 meters about 12,500 radiocarbon years ago (Szabo and others, 2003). This rapid drop in base level sent a wave of downcutting southward, upstream in the valleys of northward-flowing rivers; these rivers eroded indiscriminately downward into bedrock as well as valley fill. Some rivers such as the Rocky River west of Cleveland formed extensive entrenched meanders in soft Devonian shale, whereas others such as the lower Cuyahoga River removed large amounts of lacustrine sediments and till. The lower Cuyahoga River extended itself by headward erosion capturing southward-flowing streams and breaching the Defiance Moraine. It eventually captured the middle and upper reaches of the Cuyahoga River diverting their southward flow towards Early Lake Erie (Szabo and others, 2003). As the Niagaran peninsula underwent isostatic rebound, Early Lake Erie was able to retain more local runoff, and its level rose. The rise in water level caused the northward-flowing rivers to build deltas and slowed erosion in the tributary basins of these rivers. Floodplains eventually stabilized during the Holocene as many rivers entered maturity (Szabo and others, 2003).

PART 2: GEOMORPHOLOGY AND ORIGIN OF THE INTERLOBATE AREA

by Mandy J. Munro-Stasiuk

INTRODUCTION

Whereas there is a significant body of work that describes the tills of the interlobate region (see previous section), there has been very little work undertaken on the geomorphology of the glaciofluvial deposits in the region. Surficial geology maps (see previous section) show that large areas of sand and gravel near the ground surface represent the zone described as interlobate. This section gives an overview of previous work on sand and gravel-dominated interlobate complexes and the geomorphology of this interlobate complex, and a brief overview of the sand and gravel deposits and their relationship with surface geomorphology. Many of the landforms are illustrated using digital elevation models.

PREVIOUS WORK ON SAND AND GRAVEL DOMINATED INTERLOBATE AREAS

Over the last few decades, “interlobate moraines,” also known as kame moraines, have gained quite a bit of attention in the scientific literature. They have been recognized in many formerly glaciated regions such as Canada (Veillette, 1986; Karrow and Paloschi, 1996), the United States (Carlson and others, 2005), Scandinavia (Punkari, 1997), and Great Britain (Thomas and Montague, 1997). They are believed to represent glaciofluvial deposition between two ice lobes of a continental ice sheet which converged from somewhat opposing directions. The exact mode of deposition (subglacial, proglacial or supraglacial) is poorly understood and several opposing theories are discussed below. In contrast to the glaciofluvial models, Evans (2000) indicated that hummocky topography in Alberta, Canada, was the result of the stacking and deforming of glaciogenic deposits against highland areas between two different lobes of ice.

Morphologically, interlobate moraines can be described as long, somewhat linear complexes of sand and gravel with hummocky or ridged topography (see, for example, Carlson and others, 2005). Most recognized interlobate regions have lengths on the order of hundreds of miles long. For example, the Harricana-Lake McConnel Complex extends approximately 625 miles (1,000 km) north to south across Quebec with a maximum width of 6 miles (10 km) (Brennand and Shaw, 1996). The Leaf Rapids Moraine, approximately 440 miles (700 km) long, formed between the Keewatin and the Hudson lobes of the Laurentide Ice Sheet (Kaszycki and DiLabio, 1986). Carlson and others (2005) described the Kettle Moraine in Wisconsin as a single ~1.9-mile (3-km) wide, hummocky ridge that extends for ~125 miles (200 km) that somewhat parallels the western shoreline of Lake Michigan. A 15.6-mile (25-km) length of this feature has a double ridge present. Zoltai (1965) described many eskerlike ridges having variable crest morphology in the interlobate areas of Ontario.

Only a few detailed studies have been undertaken on the sedimentology of interlobate areas. Zoltai (1965) in one of the first studies of interlobate areas recognized the presence of stratified glaciofluvial sediments. Most other papers simply describe the interlobate sediments as varying from clay- to cobble-sized particles with cross-beds, ripples, and lamination. One very detailed study on the Harricana-Lake McConnel Complex (Brennand and Shaw, 1996) describes facies that are similar to eskers (compare to Brennand, 1994). Facies are dominated by coarse heterogeneous unstratified gravels, imbricate gravels, cross-bedded gravels, and plane-bedded gravels which are occasionally enclosed by a fine silt-sand matrix. Brennand and Shaw (1996) describe four prominent types of macroforms in the complex: (1) composite macroforms typically indicative of dune formation, (2) oblique avalanche-bed macroforms which represent migrating bedforms, (3) pseudoanticlinal bedforms that represent broad low-angled arched structures which indicate a downflow paleoflow, and (4) gravel-and-sand couplets that represent high rates of transport and deposition within a subglacial conduit. Carlson and others (2005) describe thick beds (some collapsed) of well-sorted and well-rounded gravels, and mounds that are composed of relatively poorly sorted, more angular gravel and diamict.

The formation of interlobate areas is, at present, poorly understood. There is no consensus as to whether the sand and gravel in these areas was deposited proglacially, subglacially, or by supraglacial letdown. There are at least three main theories that explain interlobate sedimentation: (1) splitting of ice due to internal conditions and the subsequent proglacial deposition of sediment (see, for example, Punkari, 1997; Veillette, 1986), (2) concentration of meltwater at the base of the ice which then flows towards the ice margin (see, for example, Brennand and Shaw, 1996), and (3) predominant supraglacial letdown of sediment from the ice surface (see, for example, Carlson and others, 2005). Most researchers have noted that these interlobate zones are intimately associated with the former ice margins as they terminate at those margins. The following sections provide a brief overview of the three main theories noted above.

Glacial splitting at the ice front

Veillette (1986) suggests that the Harricana Complex in Quebec was related to nothing more than a zone of splitting in the ice. He surmised this as striations on either side of the complex document two main flow directions. The first is a dominating flow that crosses the entire region from the NNE to the SSW. With no evidence of ice retreat, to the west of the complex, the ice flow direction changed to a NNW to SSE flow with flow apparently converging on the Harricana Moraine. Veillette hypothesized that during deglaciation ice flow to the west of the complex was abruptly diverted to the SSE as a large reentrant formed between the Ontario and Quebec ice lobes. Subsequent melting back of the reentrant resulted in proglacial deposition in front of the ice. Punkari (1997) proposed a similar model of formation, and Carlson and others (2005) also partly subscribe to this model (see below).

Subglacial meltwater model

Brennand and Shaw (1996) are the main proponents of the subglacial model of formation. The presence of macroforms along the length of the Harricana Complex in Quebec led them to propose that all sediments in the complex formed synchronously, rather than over a length of time. They proposed that the complex represented concentration of meltwater subglacially as the last event that occurred during a broad subglacial flood.

Supraglacial model

Several researchers have described supraglacial letdown as the main mode of formation for interlobate regions. Perhaps the best articulated is the recent paper by Carlson and others (2005) who studied the Kettle Moraine in Wisconsin, which was deposited between the Green Bay lobe and the Lake Michigan lobe of the Laurentide Ice Sheet. They hypothesized that the Kettle Moraine formed as ice thinned to initiate formation of the interlobate area. This thinning forced lobes of the ice to expand laterally, resulting in basal debris being carried up into the upper portions of each ice lobe. As the now-joined ice lobes melted, supraglacial debris was let down to form the interlobate deposits. Relatively debris-free areas melted more rapidly producing supraglacial channels that moved parallel to the length of the interlobate complex. Glaciofluvial sedimentation took place in the channels and the deposits were subsequently lowered, resulting in bed collapse.

GEOMORPHOLOGY AND ORIGIN OF THE CUYAHOGA/GRAND RIVER INTERLOBATE AREA

The interlobate area discussed here is dominated by hummocky and ridged topography composed mostly of thick beds of sand and gravel, and small linear to curvilinear channels. This hummocky zone marks the region between the Grand River and Cuyahoga lobes, both of which were large sublobes of the Erie lobe of the Laurentide Ice Sheet (LIS) that flowed through the Lake Erie Basin, spread southward, and split into topographically controlled sublobes. The moraines of the former Grand River lobe can easily be seen to the east of the interlobate area as can the moraines of the former Cuyahoga and Killbuck lobes to the west (fig. 11). The older glacial map of Ohio (Goldthwait and others, 1961) plots striations that coalesce on the interlobate zone, demonstrating that ice once coalesced on this zone.

The entire interlobate sand and gravel complex is ~56 miles (90 km) long and extends from north-central Geauga County to central Stark County just south of Canton at the Late Wisconsinan ice margin (fig. 11). The northern 38 miles (60 km) of the complex is on average about 4 miles (7 km) wide (figs. 12, 13), whereas the southernmost 19 miles (30 km) widens to ~16 miles (25 km) across (fig. 14). All the sites visited on this field trip are in the northern portions of the complex, either directly in the sand and gravel dominated zone or adjacent to it in the till-dominated zone. The Kent Interlobate Complex is still significantly longer than it is wide, but its configuration differs from the very large interlobate zones described by other researchers in that its length-to-width ratio is significantly smaller.

The cross section (fig. 11C) demonstrates that the entire interlobate complex sits on the Glaciated Allegheny Plateaus, an average of 200 to 250 meters above the level of Lake Erie, at elevations between 340 and 390 meters (1,115 and 1,280 feet) above sea level. The complex has hummocky topography and ridges that are interpreted as eskers. Hummocks are small (~10-100 meters in diameter) without a discernable orientation. Eskers are short (< 0.6 miles (1 km)) and broad crested and are scattered throughout the hummocky zones. One well-developed esker, which is 1 mile (1.5 km) long and over 10 meters tall, separates Lake Pippen from the dammed Lake Rockwell (fig. 13). Eskers typically are oriented NNE to SSW, the same direction as the overall trend of the interlobate complex.

Hummocky topography in the northern portions of the interlobate zone typically mantles channels that are oriented along the length of the interlobate complex (figs. 12, 13). This pattern changes as the southern extent of the complex is reached: channels dissect through zones of hummocky topography leaving the topography stranded on higher ground (fig. 14).

Obviously, genesis of individual hummocks, and hence also the interlobate zone, cannot be determined without examining the sediment in the landforms. Well-sorted beds having varying grain sizes that range from fine silts to large boulders dominate most gravel pits. Santos (2003) documented many bedforms at the Beck Pit (Stop 2) including large cross-beds representing dunes and thick sequences of ripples representing fluvial transport (flow directions are predominately southward with a range of about 70°). These are also present at another adjacent pit. Several small pits are dominated entirely by fine-grained sand and silt, whereas in the southern portions of the interlobate zone, pits show very large cobble and boulder beds.

The precise origin of the interlobate zone is uncertain, but it is least likely to have originated as supraglacial letdown of sediment. Most sedimentary beds at most locations are in-situ, and only minor slump structures are present.

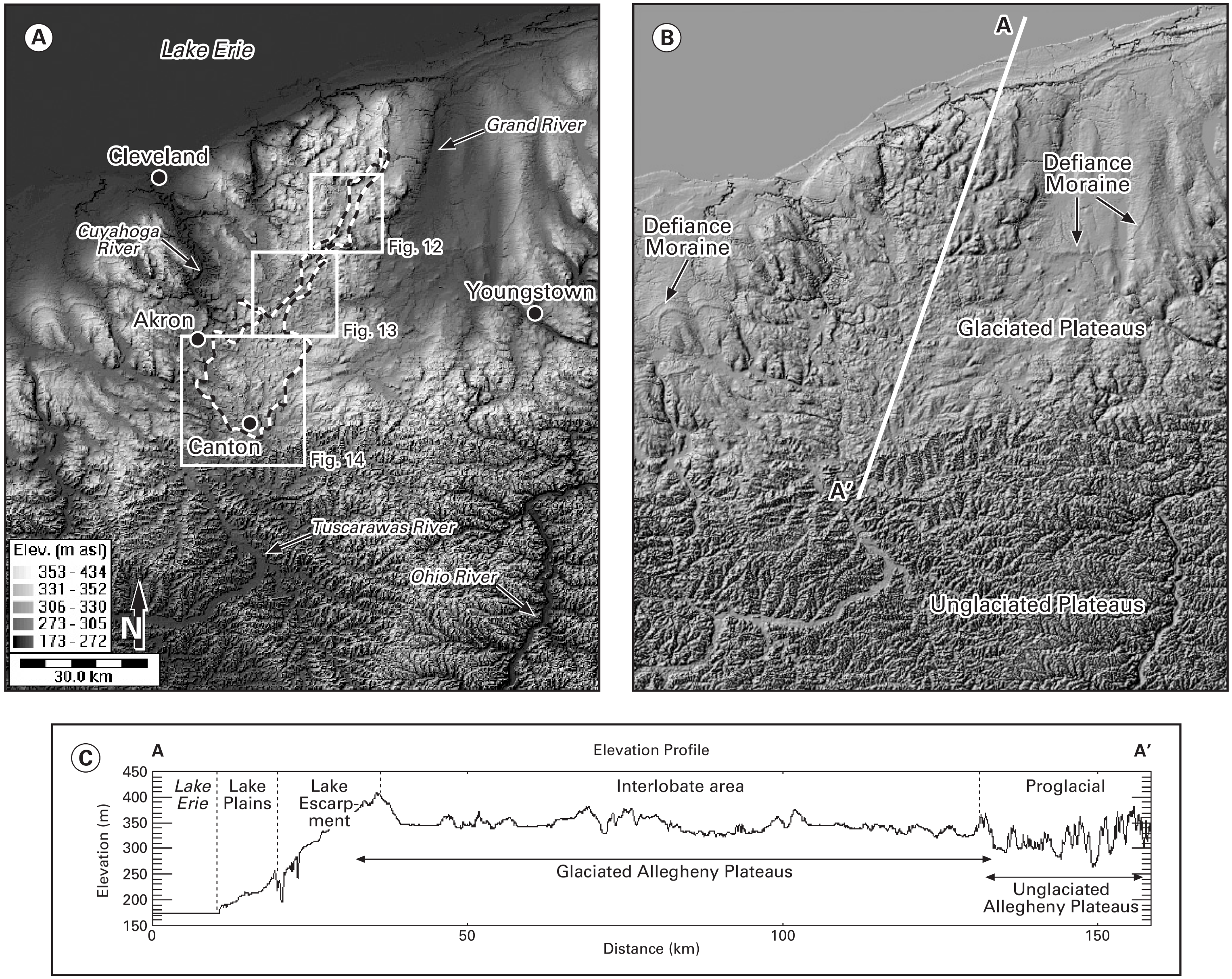


FIGURE 11.—Digital elevation models (DEMs) and topographic profile of the interlobate area in northeast Ohio. **A**, classed-elevation DEM. The dashed line shows the approximate extent of glaciofluvial deposits. Inset boxes show the locations of figures 12 to 14. **B**, hillshade DEM. **C**, topographic profile of the interlobate region from Lake Erie to the ice margins.

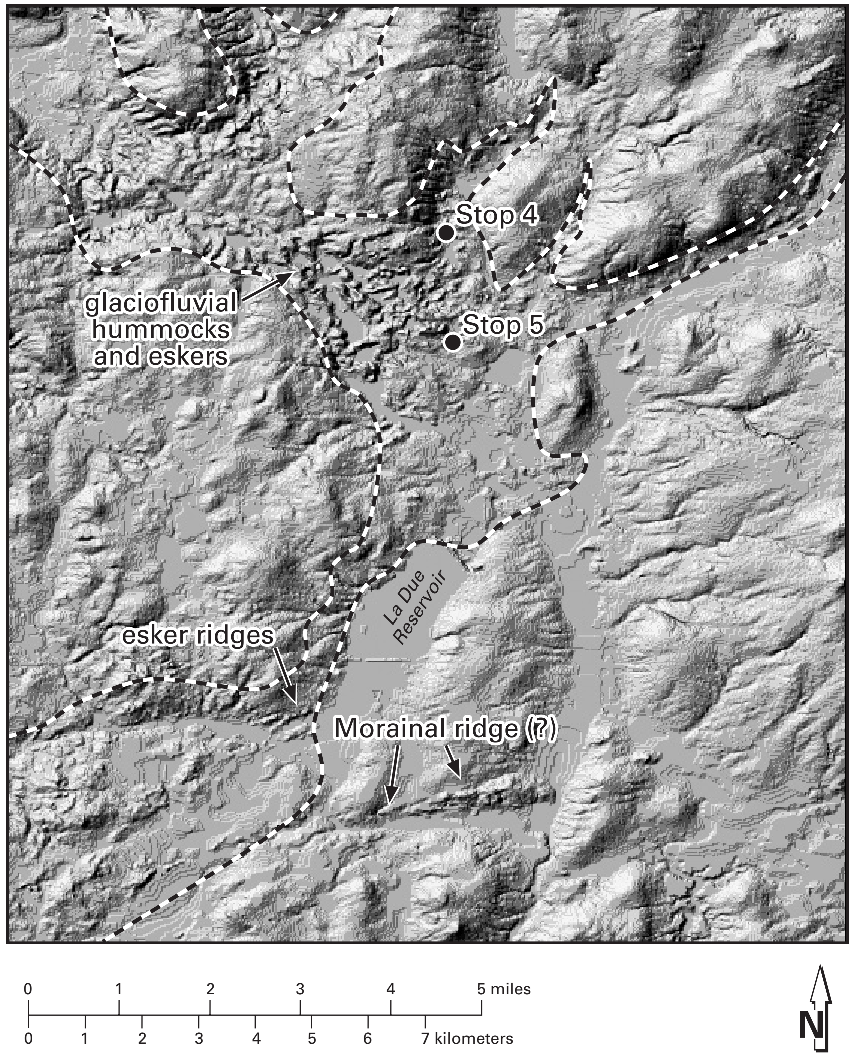


FIGURE 12.—Hillshade digital elevation model of the Upper Cuyahoga River subarea, the northernmost extent of the interlobate region. Dashed lines show the extent of the glaciofluvial deposits. Typically they mantle the bottom or the edges of the channels. Topography is typically hummocky and a few esker ridges are partially aligned with the channel orientation.

This does not represent the degree of failure expected in a let-down model (see, by way of comparison, Carlson and others, 2005). Generally, hummocky topography appears to be constructional; that is, beds in the hummocks appear to conform to the landform surface. Also, based on esker and bed-form orientations, the complex appears to have been constructed by water that flowed from the NNE to the SSW. It is uncertain at this time if the landforms are proglacial or subglacial. Significantly more work in the region needs to be undertaken to determine the precise origin of this irregular topography.

PART 3: DESCRIPTION OF FIELD TRIP STOPS

ROAD LOG: UNIVERSITY OF AKRON TO STOP 1

This guidebook uses generalized road logs that describe the general geology between stops. These descriptions include the route of the trip as illustrated in figure 15. The area around The University of Akron was glaciated during the Illinoian stage during which the Mogadore Till was deposited. On campus its thickness ranges from 0 to 5 meters, and it overlies sandstone near the east end of campus and shale on the western end of campus. Following a long interglaciation, Late Wisconsinan stage glaciation reached Cleveland about 23,000 years ago (White, 1982) and ice flowed southward toward the present location of Akron. The Wisconsinan limit of glaciation is on the north side of the valley of the Little Cuyahoga River north of campus.

As we follow Ohio Rte. 8 northward, we cross the pre-Wisconsinan valley of an ancestor of the Cuyahoga River. The Little Cuyahoga River, a tributary of the Cuyahoga River, now occupies this misfit valley. In Cuyahoga Falls, Ohio Rte. 8 follows the modern Cuyahoga River where it erodes through Pennsylvanian Pottsville sandstone. The valley in this location probably formed between 15,000 and 23,000 years ago; the river flows westward from Cuyahoga Falls where it joins the lower Cuyahoga River flowing north-

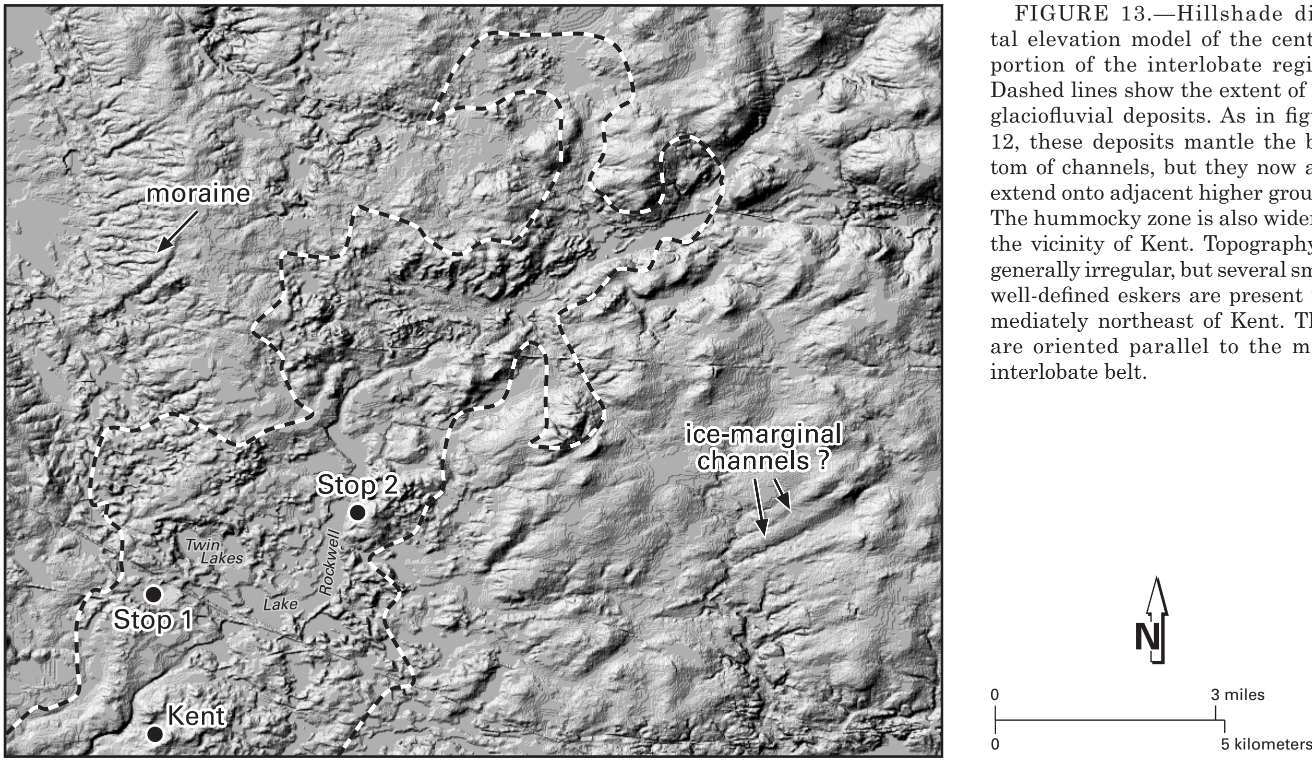


FIGURE 13.—Hillshade digital elevation model of the central portion of the interlobate region. Dashed lines show the extent of the glaciofluvial deposits. As in figure 12, these deposits mantle the bottom of channels, but they now also extend onto adjacent higher ground. The hummocky zone is also wider in the vicinity of Kent. Topography is generally irregular, but several small well-defined eskers are present immediately northeast of Kent. They are oriented parallel to the main interlobate belt.

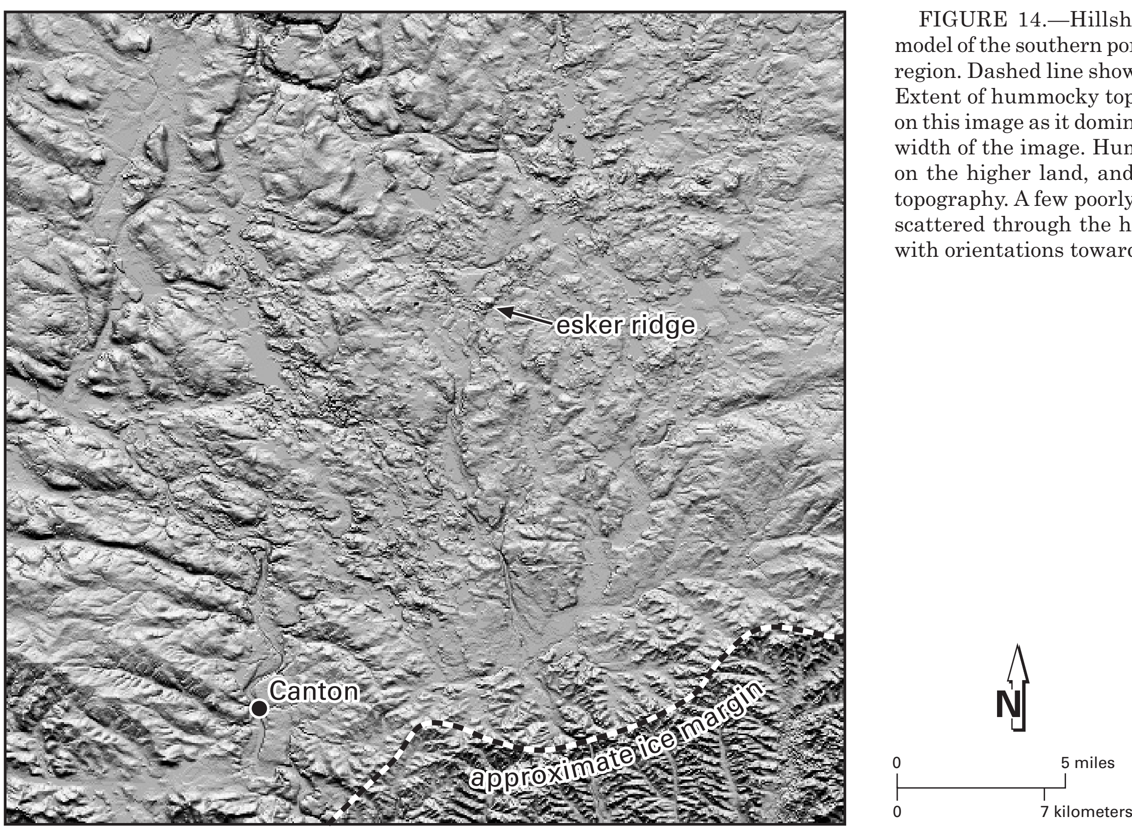


FIGURE 14.—Hillshade digital elevation model of the southern portion of the interlobate region. Dashed line shows extent of glaciation. Extent of hummocky topography is not shown on this image as it dominates almost the entire width of the image. Hummocky topography is on the higher land, and channels dissect the topography. A few poorly developed eskers are scattered through the hummocky topography with orientations towards the ice margin.

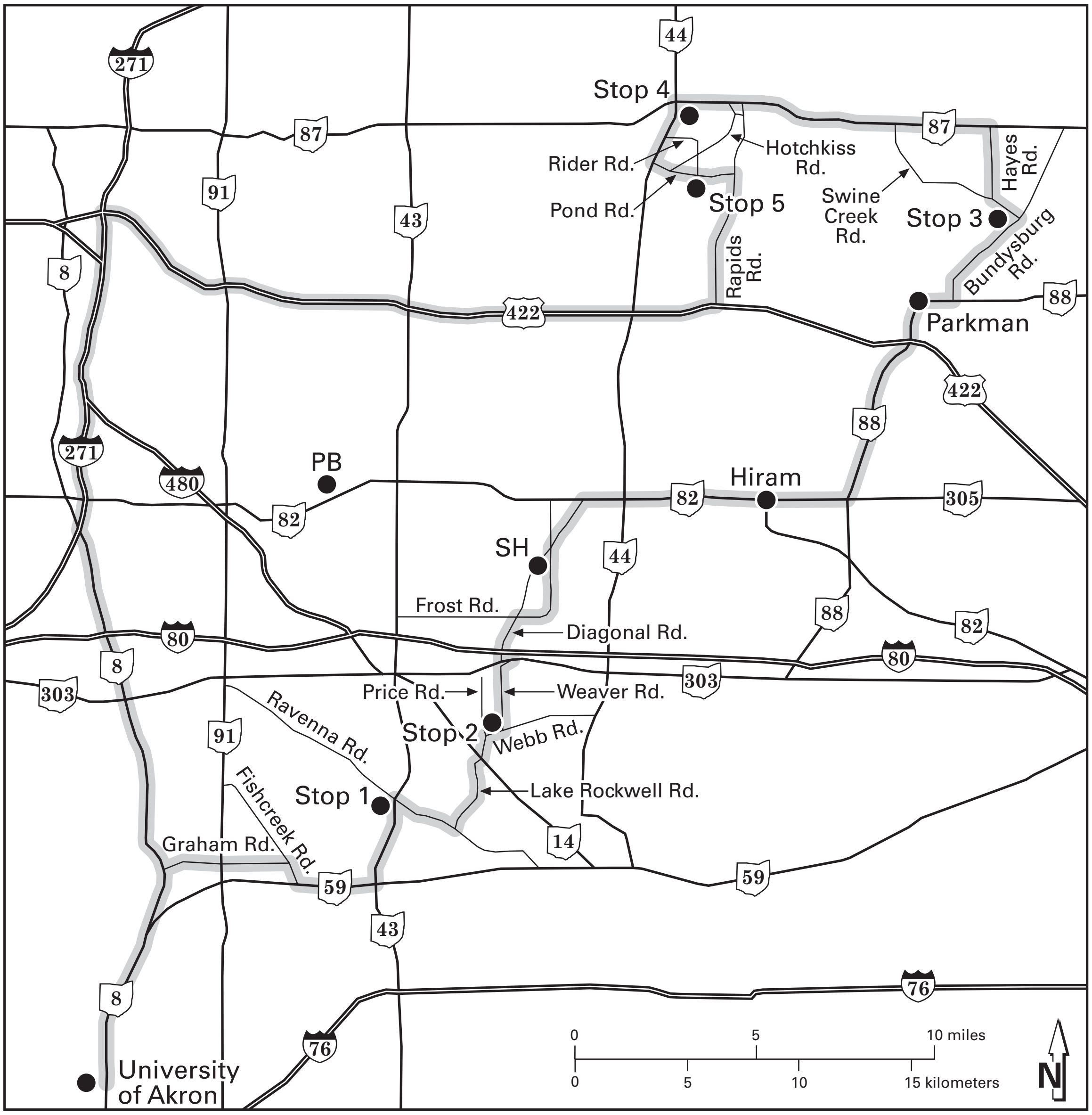


FIGURE 15.—Field trip route and stops.

ward to Lake Erie. Most of the drainage in the Akron area was southward before the Holocene.

As we exit to the east (right) on Graham Road, we cross a buried valley filled by Illinoian outwash and Wisconsinan outwash and lacustrine deposits. Crystal Lake is a kettle lake that lies near the Wisconsinan boundary and which is bordered by kames to the north and east. Eastward, in Stow, the topography is constructional end moraine and ground moraine, composed of Wisconsinan Hiram and Hayesville Tills, overlying Pottsville sandstone. As we follow Graham Road towards Kent, we are crossing part of an interlobate moraine formed between the Cuyahoga lobe and the Grand River lobe. The rolling hills consist of well-drained soils formed in sand and gravel. We turn southeast (right) off Graham Road onto Fishcreek Road and then east (left) onto Ohio Rte. 59. In Kent, before the bridge over the Cuyahoga River, we turn north (left) onto Ohio Rte. 43 and follow the moraine northward towards Twin Lakes. The flat area north of Kent is part of an outwash terrace associated with the upper Cuyahoga River, which flows southward through Kent before turning west. North of Kent, the kames of the interlobate moraine cause the rolling topography. The kames are primarily associated with the Kent ice advance during the early part of the late Wisconsinan. At the intersection of Ohio Rte. 43 and Ravenna Road in Twin Lakes, the younger Lavery and Hiram Tills cover the kames. At the intersection the Hugo Sand & Gravel Company is mining both Wisconsinan and Illinoian gravel.

STOP 1. HUGO SAND & GRAVEL COMPANY

by John P. Szabo

The Hugo Sand & Gravel Company has been a major supplier of sand and gravel in Portage County (Hull, 1980) for over 75 years and covers over 450 acres (182 hectares) of land northwest of Kent (fig. 16). The pit is excavated in ice-contact deposits and lies at the mapped limit of Hiram ice (fig. 17). Hiram and Lavery ice overrode Kent-age ice-contact deposits along the southeastern edge of the Cuyahoga lobe in northwestern Portage County (Winslow and White, 1966). This is apparent on the county soil map where Ellsworth soils are developed in the clay-rich Hiram and Lavery Tills and are adjacent to Chili and Bogart soils formed in outwash (Ritchie and others, 1978).

Most of the surficial late Wisconsinan deposits have been mined, and probable Illinoian-age sand and gravels (Winslow and White, 1966; McQuown, 1988) are currently mined by dredging. Most of the knowledge of the subsurface distribution of glacial deposits is derived from a seismic survey (Ohio Drilling Company, 1971) of a northwest-trending buried valley that parallels the railroad tracks (fig. 16) and from the M.S. thesis of M. Scott McQuown (1988), who worked for the Hugo Sand & Gravel Company for 6 years. The Ohio Drilling Company (1971) ran a seismic profile across the buried valley because a well in the sand and gravel pit yielded 71 L/sec during a pumping test (Winslow and White, 1966). A cross section prepared by the Ohio Drilling Company (1971) shows the presence of a buried valley containing over 100 meters of sediment (fig. 18). The cross section shows sands and sands and gravels interbedded with clay and sandy clay, which may represent diamicts or lacustrine sediments having abrupt lateral changes. The clays that overlie the granular deposits in the central part of the cross section are probably the Hiram and Lavery Tills.

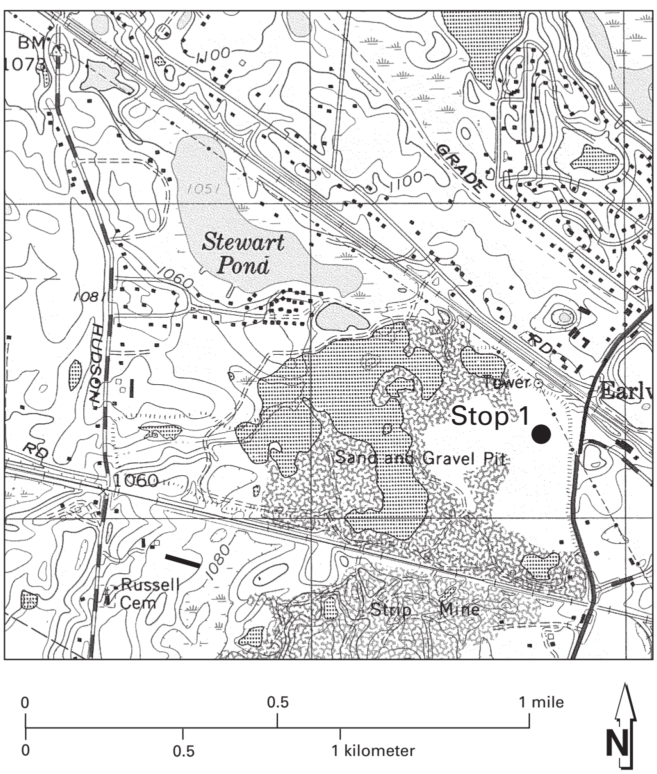


FIGURE 16.—Portion of 1994 U.S. Geological Survey Kent, Ohio, 7.5-minute quadrangle showing the location of Stop 1, the Hugo Sand & Gravel Company, north of Kent in southeastern Portage County. Dark line south of the railroad tracks (to the lower left of map) is the location of the resistivity profile illustrated in figure 19. Contour interval is 10 feet (slightly more than 3 meters).

McQuown (1988) produced a comprehensive study of the property of the Hugo Sand & Gravel Company to delineate favorable locations for future sand and gravel production. He employed seismic and resistivity surveys, borings, and gamma-ray logs of oil wells to reconstruct the subsurface distribution of sediments. He collected some samples for size and carbonate analysis and others for petrographic analysis to insure that the gravel met ASTM standards. Figure 19 illustrates the abrupt lateral and vertical changes in sediment distribution found in most of his electrical resistivity surveys. He also determined that the Illinoian Mogadore Till overlies sandstone bedrock at depths ranging from 30 to 45 meters below the surface. McQuown (1988) agreed with Winslow and White (1966) that the bulk of the 6- to 20-meter thick subsurface gravel was Illinoian outwash. A complex of Kent-age lodgment tills, sediment-flow deposits, lacustrine deposits, and outwash suggest a stagnant ice margin of buried ice ridges and meltwater channels (McQuown, 1988). Excavation in the pit also revealed faulted, folded, and sheared sediments suggesting superglacial melt out and topographic inversions typical of a stagnant ice margin; these account for the abrupt lateral and vertical changes in sediment types. Mineable sand and gravel deposited by Kent meltwater ranges from 3 to 12 meters in thickness (McQuown, 1988).

McQuown (1988) attempted to correlate some of his diamict and lacustrine sediments using carbonate analysis. I performed the grain-size analysis and fine-carbonate analysis in the sedimentology laboratory of The University of Akron and was able to compare my correlations of his diamict samples with his inferred correlations. I agree with most of his correlations except for those from two borings in the northwest corner of the pit near the Hiram margin. He concluded that the upper 1 to 5 meters of diamict in these two holes were correlated with the Kent advance, but using an extensive database, I correlate this diamict with the Lavery Till. It may be possible that some of the surficial sand and gravel deposits in the pit may be younger than the Kent advance because of the proximity of the Hiram and Lavery margins.

Shultz (2005) provides representative laboratory data for Late Wisconsinan deposits sampled from an auger boring located in a degraded wetland near Pond Brook, about 9 miles (14.5 km) north of Stop 1 (PB, figs. 2, 7, 15). This wetland overlies the same buried valley present beneath the Hugo Sand & Gravel Company, but is well behind the Hiram-Lavery margin. The auger of the Giddings soil probe was advanced 1.25 meters at a time and samples taken every 0.6 meters; coring was impossible because of excessive water produced by sand seams in the upper part of the boring.

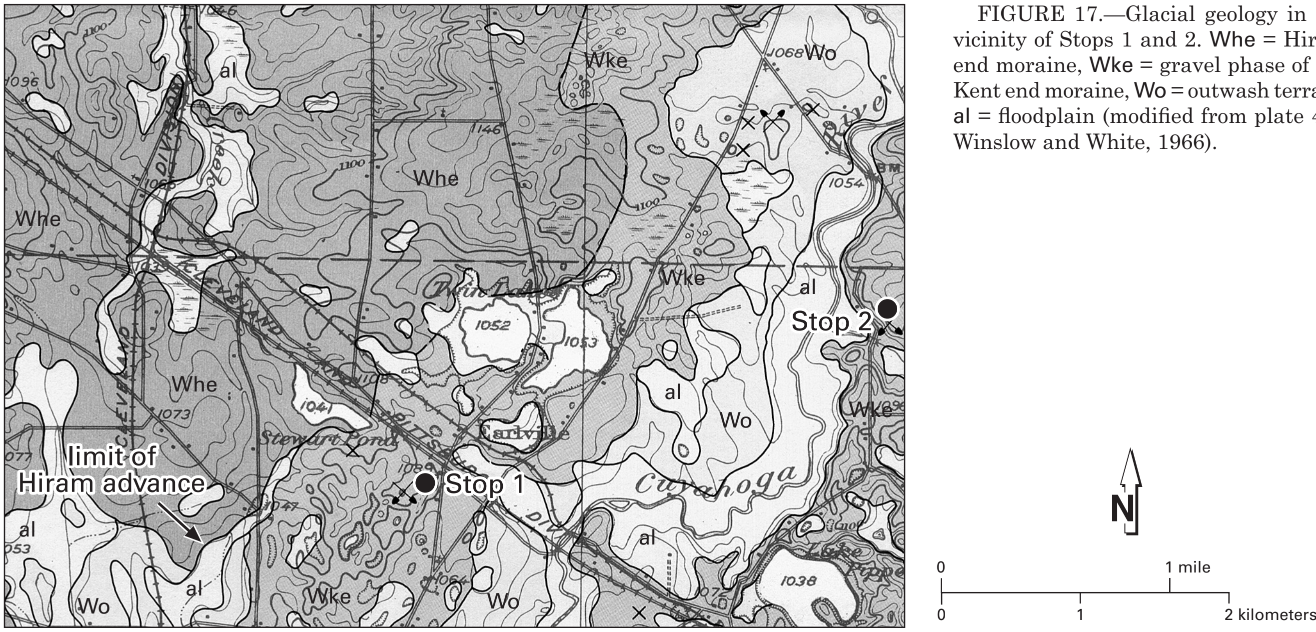


FIGURE 17.—Glacial geology in the vicinity of Stops 1 and 2. Whe = Hiram end moraine, Wke = gravel phase of the Kent end moraine, Wo = outwash terrace, al = floodplain (modified from plate 4 of Winslow and White, 1966).

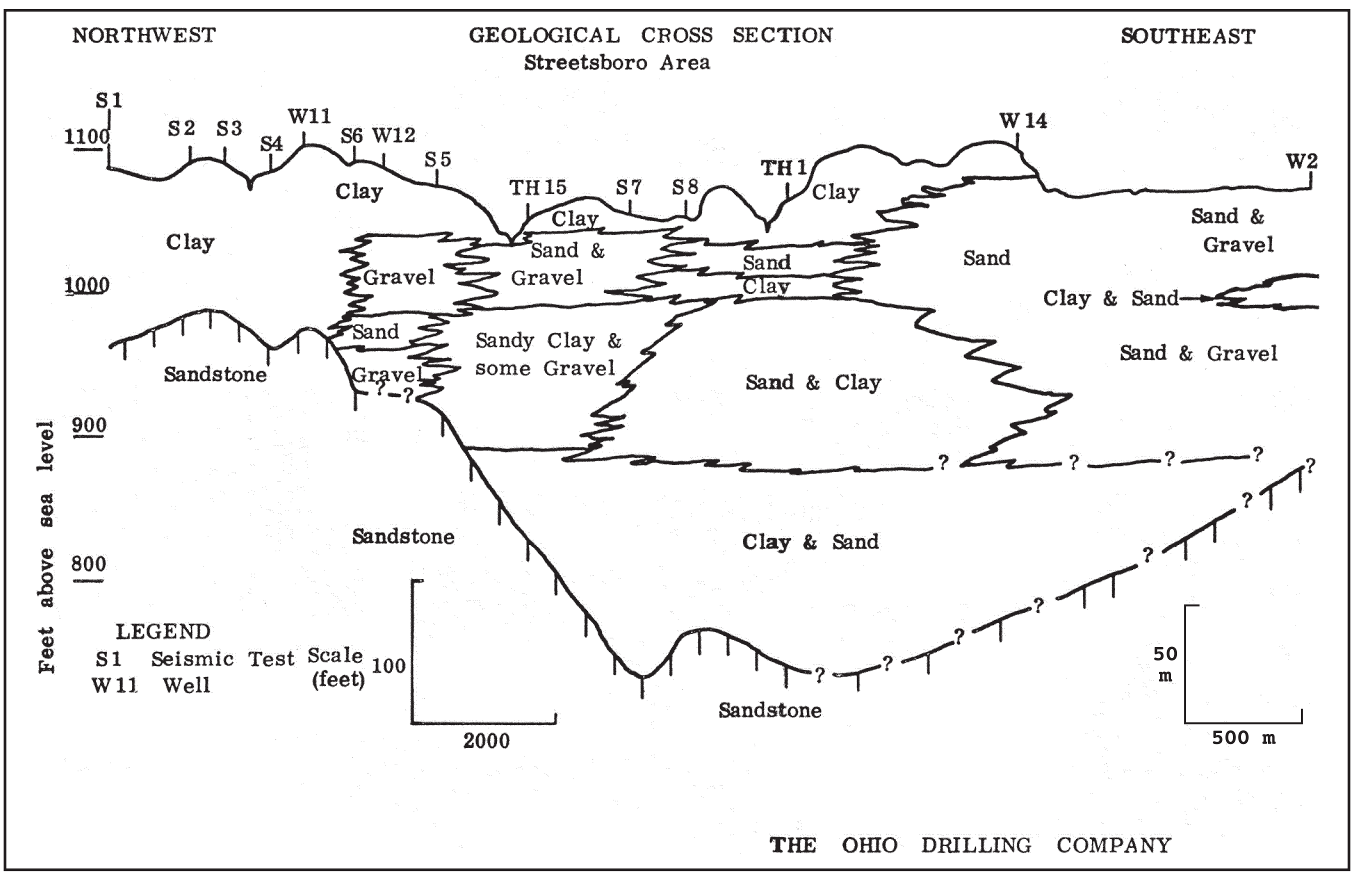


FIGURE 18.—Cross section constructed from seismic and well-log data parallel to Ravenna Road (fig. 16) showing the variable nature of the fill of the buried valley (modified from Ohio Drilling Company, 1971).

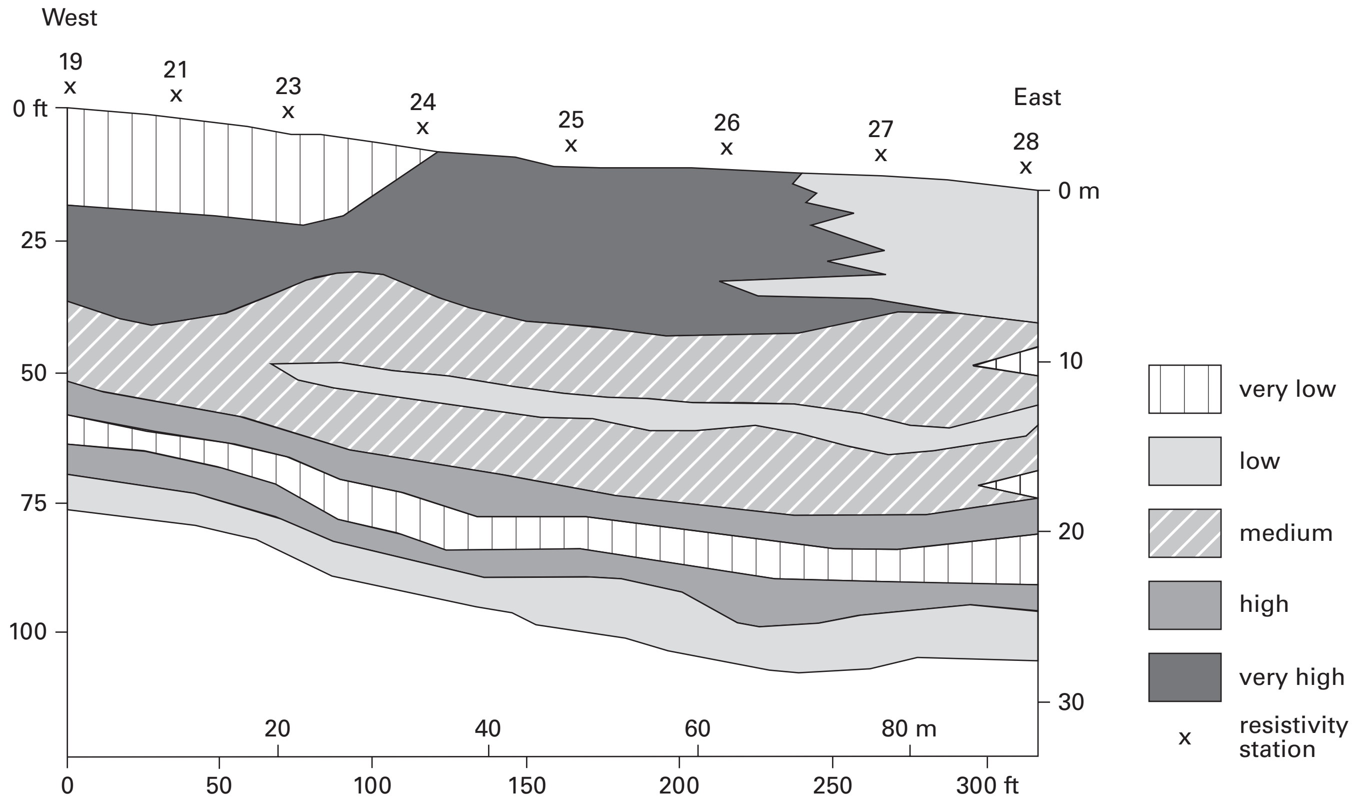


FIGURE 19.—Resistivity profile showing abrupt lateral and vertical changes in sediment type at Stop 1 (modified from McQuown, 1988).

Although the samples were disturbed, it could be roughly determined whether sediments were bedded or massive. Changes in total carbonate content and calcite/dolomite ratios were used to distinguish between the units. The lower 5 meters of the boring (fig. 20) consist of lacustrine deposits associated with the Kent advance; these are characterized by having no grain sizes larger than sand, large silt contents, and a total fine-carbonate content averaging about 6% and a calcite/dolomite ratio of 0.3. A diamict correlated with the Lavery Till (fig. 20) overlies the Kent-age sediments and contains granules and pebbles, about 20% sand and 30% clay, a total fine-carbonate content greater than 12%, and a calcite/dolomite ratio greater than 1.0. The upper 9 meters of sediment in the boring are correlated with the Hiram advance. The lower part is composed of coarsening-upward, lacustrine sediments, rarely containing grain-sizes larger than sand. The upper half of this sequence contains diamicts separated by sand seams. Total fine-carbonate contents approach 10% and the calcite/dolomite ratio averages 0.8. The ratios of illite to kaolinite and chlorite (DI) in the Hiram sediments (fig. 20) shows the classical changes in DI associated with a weathering profile (Willman and others, 1966). The DI is small in the uppermost part of the profile as illite is degrading and shows a sharp increase before decreasing to the values of the unweathered sediments in which illite and chlorite are well crystallized. The average DI of 1.8 is characteristic of unweathered glacial sediments derived from Paleozoic shales (Szabo and Fernandez, 1984).

ROAD LOG: STOP 1 TO STOP 2

Leave Stop 1, follow Ravenna Road east (fig. 15) and proceed past the Akron Water Treatment Plant, owned by the city since 1915. Lake Rockwell is on the north side of Ravenna Road and is one of three impoundments on the upper Cuyahoga River owned by the city of Akron to insure an adequate municipal water supply. Turn left (north) on Lake Rockwell Road at the X-shaped intersection; this road is parallel to the reservoir and follows the crest of an esker separating Lake Rockwell on the left from Lake Pippen on the right. Be prepared to turn left (northwest) on Ohio Rte. 14 just after Lake Rockwell Road turns right (east). Follow Ohio Rte. 14 a short distance, turn right (north) onto Price Road, and continue to its intersection with Webb Road. Turn right (east) onto Webb Road and enter the property of the Beck Sand & Gravel Company, Stop 2. We are now in an area glaciated by the Grand River lobe.

STOP 2. BECK SAND & GRAVEL COMPANY

by Mandy J. Munro-Stasiuk

Stop 2, the Beck Sand and Gravel pit, sits just off of Webb Road to the NE of Lake Rockwell and Ohio Rte. 14 (figs. 21, 22). The entire area surrounding Lake Rockwell has well-developed hummocky topography with interspersed eskers. Hummocks are on average 650-1,000 feet (200-300 m) across

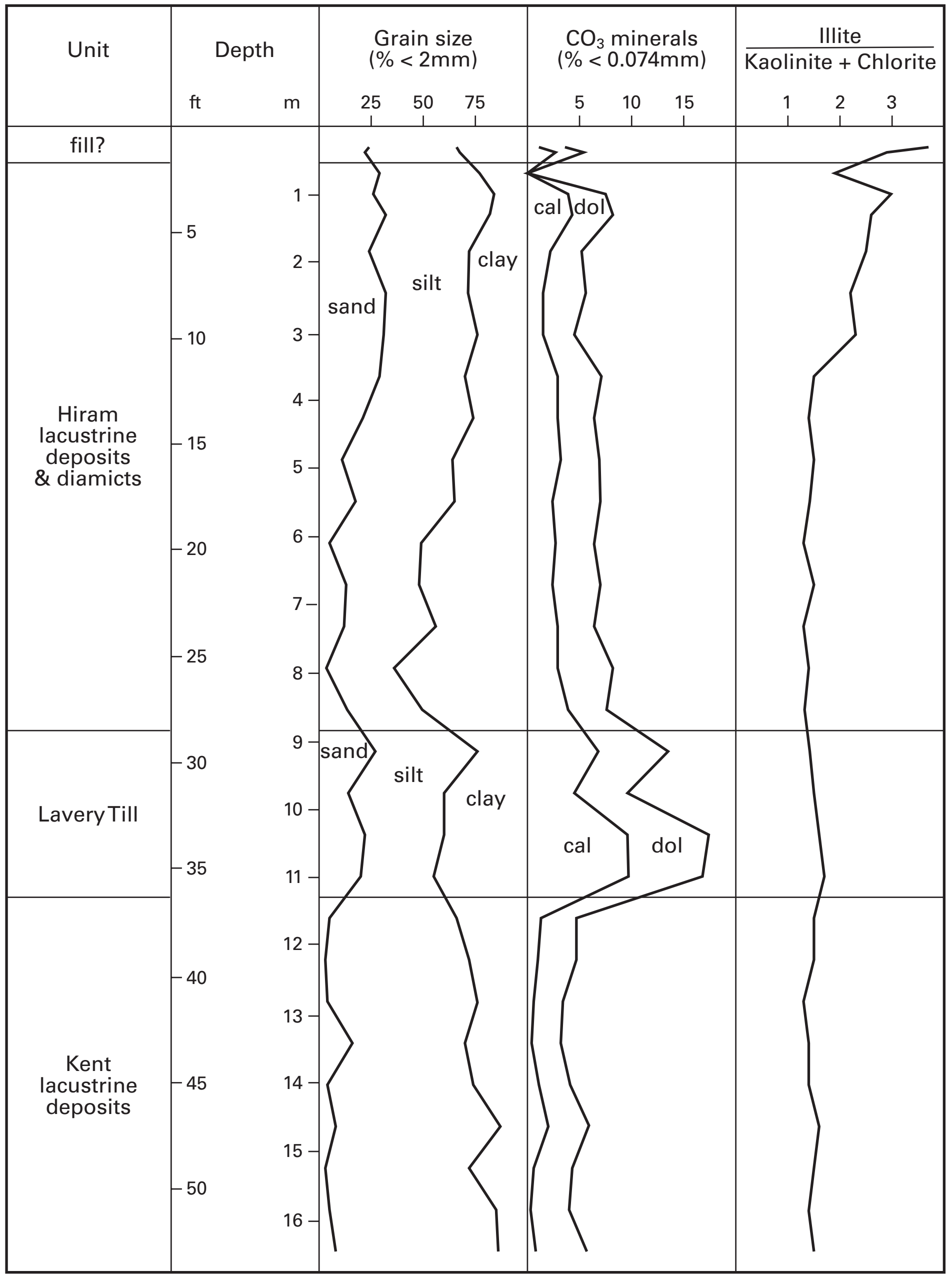


FIGURE 20.—Laboratory analyses of Late Wisconsinan sediments illustrating their typical texture and composition. Boring is from a degraded wetland near Pond Brook (Shultz, 2005) that overlies the same buried valley as in figure 18, but 9 miles (14.5 km) farther north (PB, fig. 6).

and range from ~5 to 30 meters in height. The Beck Pit excavation is in a hummock complex approximately 1,650 feet (500 m) in diameter having a maximum relief of about 35 meters (fig. 21).

Exposures at the pit range from 3 to 7 meters in height, and all exposures are dominated by well-sorted beds of rippled sands, cross-bedded gravels and sheets of gravel (fig. 23). Bed architecture is mostly comprised of low-angle cross-bedding. Each set of cross-beds has an erosional contact with the underlying beds. Typically, beds are present as couplets: pebble and cobble beds, containing well-rounded, highly spherical clasts of both local and shield-derived lithologies; and sand and silt beds that have planar or rippled bedding. The coarse beds grade abruptly into the sand and silt units. This demonstrates that the site was dominated by pulsing flows, perhaps seasonal, that flowed quickly at first and then waned to deposit silt and sand only. In almost every case, the upper portions of the sand/silt beds are eroded away so the last stage of sedimentation in the quiescent phase is unknown. Orientations derived from ripple beds at this site and a nearby pit (the Cruise Sand & Gravel pit, fig. 22) show that flow azimuths ranged from approximately 160° to 200°.

The exact origin of these beds is yet undetermined. However, it is highly unlikely that they have a supraglacial origin. Minor slump structures and minor displacements along normal faults show that some settling of the beds

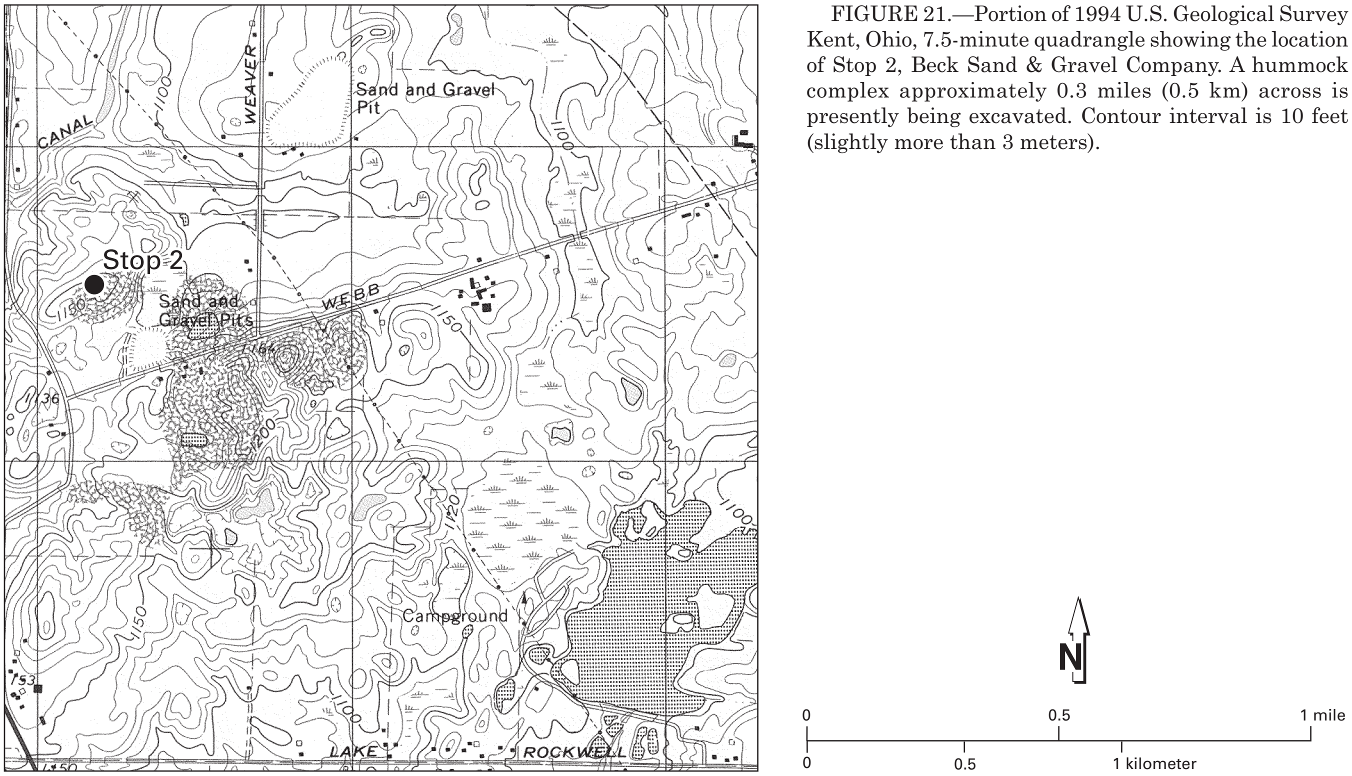


FIGURE 21.—Portion of 1994 U.S. Geological Survey Kent, Ohio, 7.5-minute quadrangle showing the location of Stop 2, Beck Sand & Gravel Company. A hummock complex approximately 0.3 miles (0.5 km) across is presently being excavated. Contour interval is 10 feet (slightly more than 3 meters).

FIGURE 22.—Aerial photograph of Stop 2, Beck Sand & Gravel Company and nearby Cruise Sand & Gravel pit. Arrows represent flow directions derived from ripple orientations.

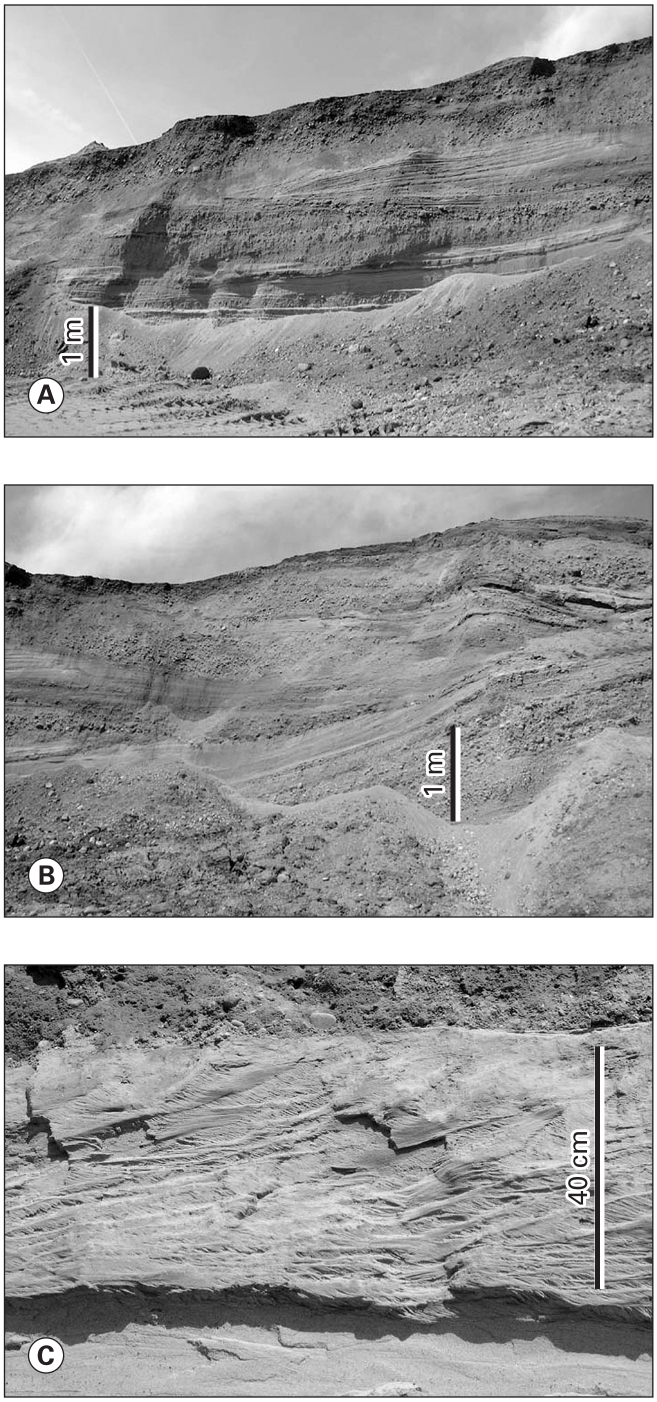


FIGURE 23.—Typical exposures in the Beck Sand & Gravel pit. **A**, 4-meter high exposure dominated by broad, low-angled cross beds. Sand units are typically rippled. The dark material at the top of the exposure is not in-situ. **B**, 5-meter high exposure of large cross-beds of alternating sand and gravel units. **C**, unit showing well-developed erosional-stoss climbing ripples (most silt and sand beds at the site are rippled). Note the abrupt erosional upper contact with the overlying massive unit. Depositional-stoss climbing ripples are also common across the site.

occurred. This however, does not resemble the wholesale slumping noted at sites dominated by supraglacial letdown. Sedimentation was most likely as proglacial outwash, or deposition in proglacial fans. However, at this point in time deposition in a broad subglacial channel cannot be ruled out because the sedimentary relationships between gravel pits are poorly understood.

ROAD LOG: STOP 2 TO STOP 3

When leaving Stop 2, turn left (east) on Webb Road and then immediately left (north) onto Weaver Road (fig. 15). Follow this road northward as it passes out of ice-contact topography into the flat topography of the outwash terraces of the Cuyahoga River. Note the large gravel pits that have supplied gravel for most of the interstate projects in this part of Ohio. At the intersection with Ohio Rte. 303, turn left (west) and follow the state route across the river to its intersection with Diagonal Road. Turn right (north) and cross over I-80 onto a narrow outwash terrace and follow Diagonal Road northeastward through ice-contact topography having numerous sand and gravel pits. Turn right (east) onto Frost Road and follow its right-angle bend past a large gravel pit as it turns northward.

A section (SH, figs. 6, 15) was measured in the ditch on the west side of Frost Road before its intersection with Mennonite Road. This section is typical of upland sites near the Cuyahoga River in the interlobate area of Portage County. Loamy till, correlated with the Kent Till, generally overlies the sand and gravel of ice-contact deposits resulting in the well-drained soils of the Wooster Series. Yellowish-brown, friable, platy diamict becomes darker and more massive and firm with depth. Its upper meter may contain yellowish-red mottling, and it is devoid of fine carbonates to at least 2.25 meters. The diamict in the drainage ditch contains over 50% sand and becomes more clay rich at the bottom of the section (fig. 24). X-ray diffractograms show that chlorite has altered to vermiculite, and the 1.0-nm illite peak is asymmetrical throughout the profile; heat treatment of samples showed that very little kaolinite is present. Because of the weathering of illite, diffraction intensity ratios are well below 1.0 (fig. 24), showing that the diamict is more weathered than

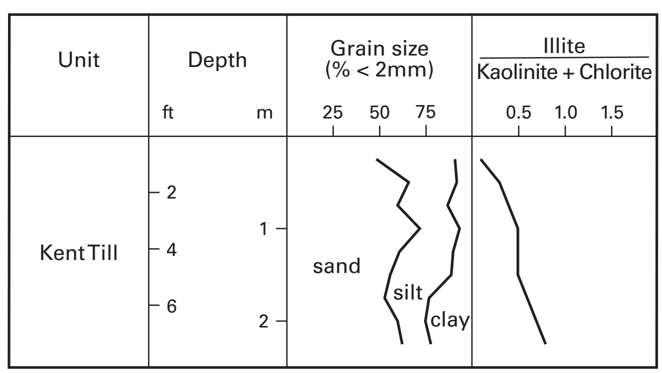


FIGURE 24.—Laboratory analyses of Kent Till exposed in a ditch along Frost Road (fig. 15) in Shalersville Township, Portage County, Ohio.

the clay-rich diamicts found at other stops on this trip. This site is adjacent to an area in which the Chili-Wooster soil complex dominates. This series is characteristic of hummocky topography containing both till and sand and gravel (Ritchie and others, 1978). The Kent Till at many locations in the interlobate area could be interpreted as a superglacial melt-out till.

Continuing north on Frost Road, turn right (northeast) onto Diagonal Road and follow it to Ohio Rte. 82 where the upland topography is controlled by resistant bedrock. Turn right (east) on Ohio Rte. 82, cross the Cuyahoga River and a wide outwash terrace, and climb onto the upland. Proceed through Hiram where White (1960) defined the type section of the Hiram Till of the Grand River lobe. Ohio Rte. 82 turns due south in Hiram, but continue eastward on Ohio Rte. 305 to its intersection with Ohio Rte. 88. Turn left (north) onto Ohio Rte. 88 and travel across an extensive upland towards Parkman. Ohio Rte. 88 crosses the Grand River along which a high section of Illinoian till (discussed at Stop 3) is exposed. Ohio Rte. 88 jogs to the north just before its intersection with U.S. Rte. 422. Cross the intersection, and continue north on Ohio Rte. 88 along end moraine formed at the limit of the Hiram advance in the Grand River lobe. Follow Ohio Rte. 88 as it turns right (east) to its intersection with Bundysburg Road. Turn left (northeast) onto Bundysburg Road and cross end moraine and ground moraine. The view of the Grand River lowland to the east is spectacular as the road drops into the valley of Swine Creek. At Swine Creek Road, turn left (northwest) and follow the road to a small county park on the west side of the road.

This is Stop 3. The section is a short hike to the west along the stream. Notice the large concentrations of cobbles in the streambed. They originated from active erosion of the Illinoian tills of the section, which are exposed along the outside of a meander. There was a hiking trail along an abandoned railroad grade at the top of the bank, but it has fallen into the creek. You will see large pieces of slag from the old bed in the creek. The section contains sand lenses, and the intervening till beds can be quite hard when dry. It may be difficult for your boots to grip the slope if it is too dry.

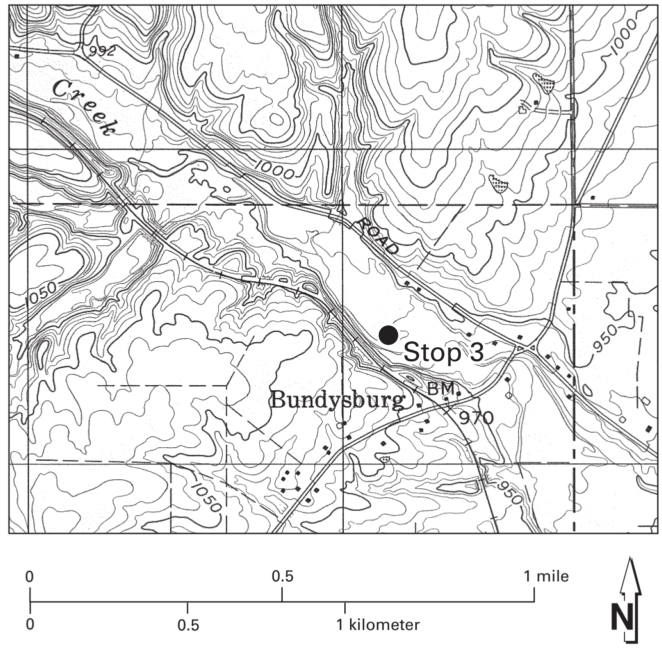


FIGURE 25.—Portion of the 1994 U.S. Geological Survey Middlefield, Ohio, 7.5-minute quadrangle showing the location of Stop 3, the Swine Creek section, near Bundysburg in southeastern Geauga County. Contour interval is 10 feet (slightly more than 3 meters).

STOP 3. SWINE CREEK

by John P. Szabo

General description

The section is located along a 15.5-meter-high cut bank of Swine Creek about 0.3 miles (0.5 km) northwest of Bundysburg in the northeastern corner of Parkman Township, Geauga County, within the area glaciated by the Grand River lobe (fig. 25). The upland is covered by till (fig. 10) in the form of the Hiram end moraine (fig. 2). Baker (1957) originally described this section, and tracks of the Baltimore and Ohio Railroad ran across the top part of the section. Since that time, the railroad right-of-way was abandoned and lateral migration of Swine Creek has eroded the former railroad bed. Baker (1957), Totten (1988), and Matz (1996) have measured and described this section. I analyzed matrix texture, the mineralogy of fine carbonates and clays, and ratios of quartz to feldspar and alkali feldspar to plagioclase of samples collected in 1987 for Totten (1988). Matz (1996) analyzed matrix texture, fine-carbonate mineralogy, and heavy minerals in his set of samples.

The upper 5 meters of the section contain Late Wisconsinan deposits. Baker (1957) and Totten (1988) originally measured about one meter of clay-rich diamict correlated to the Late Wisconsinan Hiram and Lavery Tills. These tills were separated from the Kent Till by a stone line. Unfortunately, this part of the section was just above the railroad grade and is no longer preserved. The weathered part of the Kent Till is olive-brown, friable, sandy, pebbly, and partially leached, whereas the unweathered lower part is gray, firm, platy, and unleached. Sand stringers and mottles are common throughout this unit and range in color from yellowish brown in the weathered till to olive brown in the unleached till. The average sand content of the Kent Till at this section is 40% (table 3), and dolomite, averaging 4.2%, dominates the fine-carbonate mineralogy. Kaolinite and chlorite dominate the clay mineralogy of the Kent Till having an average diffraction-intensity ratio of 0.8. Samples of this till have heavy-mineral contents averaging 14% garnet, 3% epidote, 7% pyroxene, 32% amphibole, and 5% opaques (Matz, 1996).

The remaining 11.5 meters of the Swine Creek section consists of multiple layers of Illinoian Titusville Till separated by layers of sand or sand and gravel. The upper meter of the Illinoian section is weathered olive-yellow, firm, platy, partially leached till containing brownish-yellow mottles. The unweathered Titusville Till is olive gray to dark gray, very firm, platy, and stony. Yellow-gray sand and sand and gravel

Swine Creek: detailed section description

Elevation of top of section at abandoned railroad grade: 297 meters (975 feet);
height of section: 15.5 meters (50.8 feet) (modified from Matz, 1996)

Depth (meters)	Description
Pleistocene Series, Wisconsinan Stage	
Kent Till	
0.00-1.25	5Y 5/4, olive-brown, friable, sandy, partially leached diamict.
1.25-1.50	2.5YR 5/1, gray, platy, unleached diamict having 2.5YR 5/2, grayish-brown mottles, and 10YR 5/4, yellowish-brown sand stringers.
1.50-2.00	10YR 5/8, yellowish-brown, friable, platy, unleached, diamict separated from overlying unit by 10YR 5/4, yellowish-brown sand.
2.00-4.00	2.5Y 4/1, dark-gray, firm, platy, unleached diamict having 2.5Y 6/8, olive-yellow mottling and sand stringers that increase in frequency with depth.
Pleistocene Series, Illinoian Stage	
Titusville Till	
4.00-5.00	2.5Y 6/8, olive-yellow, very firm, very platy partially leached diamict containing 10YR 6/6, brownish-yellow mottles.
5.00-5.50	5Y 4/1, dark-gray, very firm, very platy, unleached diamict having 2.5Y 6/8, olive-yellow mottles and sand at its base.
5.50-8.00	2.5Y 6/2, light-brownish-gray, firm, sandy, unleached diamict containing 2.5Y 6/8, olive-yellow mottles. Sand content increases with depth.
8.00-8.40	2.5Y 6/8, olive-yellow, friable sandy diamict.
8.40-10.00	5Y 5/1, gray sand lens that is gravelly at its contact with overlying diamict and becomes siltier with depth.
10.00-12.00	2.5Y 5/2, grayish-brown, silty, platy, very firm, unleached diamict having 2.5Y 5/1, gray sand stringers at depth. Pebble content increases in the lower meter.
12.00-13.00	5Y 5/2, olive-gray, sandy, platy, very firm, less pebbly, unleached diamict.
13.00-14.00	5Y 5/2, olive-gray, poorly sorted, gravel lens.
14.00-15.50	5Y 5/2, olive-gray, massive, very firm, unleached, diamict containing striated carbonate, bullet clasts.

lenses ranging in thickness from 1 to 1.5 meters separate till layers that vary from 2 to 4.5 meters in thickness (fig. 26). Till is mottled and oxidized yellow gray near contacts with sand or gravel lenses (Matz, 1996). Striated cobble-size carbonate clasts are common as are crystalline rock types; a pebble count (Baker, 1957) contained 34% carbonate, 51% clastic, and 15% crystalline rock types. The textural components of Titusville Till samples display great variability (table 3); the average sand content of the till is 42%. Its mean dolomite content, 3.4%, is similar to that of the Kent Till. Samples contain average heavy-mineral contents of 16% garnet, 3% epidote, 6% pyroxene, 29% amphibole, and 7% opaques (Matz, 1996).

Comparison to the Parkman section

The multiple nature of the Titusville Till sequence differs significantly from the large section exposed at Parkman

Table 3.—*Summary of laboratory data for the Swine Creek and Parkman sections in Parkman Township, Geauga County*

Section Unit	sand (%)	silt (%)	clay (%)	cal (%)	dol (%)	carb (% total)	carb (%)	clst (%)	xtln (%)	DI	Q/F	A/P	gar (%)	epi (%)	pyrox (%)	amph (%)	opaq (%)
Parkman																	
Lavery Till[1]	18	47	35	2.5	3.8	6.3	7	91	2	2.1	5.9	1.6					
Kent Till[1]	53	35	12	0.0	1.7	1.7	2	97	1	1.8	10.7	3.3					
Titusville Till																	
x[2]	44	40	16	0.0	3.2	3.2	5	91	4	0.6	19.4	2.7					
SD	4	4	4	0.0	0.5	0.5	2	3	1	0.1	4.8	2.3					
n	11	11	11	10	10	10	11	11	11	10	11	11					
Swine Creek																	
Kent Till																	
x	39	34	27	0.7	3.5	4.1	10	86	4	0.8	6.6	3.0	14	3	7	32	5
SD	10	23	23	0.6	0.6	0.9	8	8	1	0.1	0.5	1.1	3	1	1	3	1
n	10	10	10	10	10	10	2	2	2	2	2	2	5	5	5	5	5
Titusville Till (all)																	
x	42	41	17	0.4	3.4	3.8	11	86	3	0.7	8.3	2.2	16	3	6	29	7
SD	14	15	11	0.7	0.6	0.7	3	3	2	0.1	5.2	1.0	4	2	2	5	4
n	18	18	18	18	18	18	8	8	8	8	8	8	7	7	7	7	7
Titusville Till III																	
x	49	35	16	0.6	3.1	3.7	12	86	2	0.8	5.9	1.7	17	2	5	26	10
SD	17	20	15	0.9	0.6	0.8	2	3	2	0.1	1.1	0.2	4	1	2	1	3
n	9	9	9	9	9	9	3	3	3	3	3	3	4	4	4	4	4
Titusville Till II																	
x	36	47	18	0.5	3.6	4.1	9	87	5	0.7	5.2	2.1	19	1	7	34	8
SD	3	8	8	0.5	0.3	0.3	4	6	2	0.0	1.1	0.5					
n	5	5	5	5	5	5	2	2	2	2	2	2	1	1	1	1	1
Titusville Till I																	
x	37	46	18	0.1	3.6	3.7	10	88	7	0.7	12.8	2.7	13	5	9	36	3
SD	2	3	4	0.2	0.7	0.8	2	2	1	0.2	6.7	1.5	1	1	1	1	1
n	4	4	4	4	4	4	3	3	3	3	3	3	2	2	2	2	2

[1]Only one sample analyzed.

[2]*x* = mean, SD = standard deviation, *n* = number of samples, cal = calcite, dol = dolomite, carb (total) = total carbonate, carb = carbonates, clst = clastics, xtln = crystallines, DI = diffraction intensity ratio, Q/F = quartz/feldspar, A/P = alkali feldspar/plagioclase, gar = garnet, epi = epidote, pyrox = pyroxene, amph = amphibole, opaq = opaques.

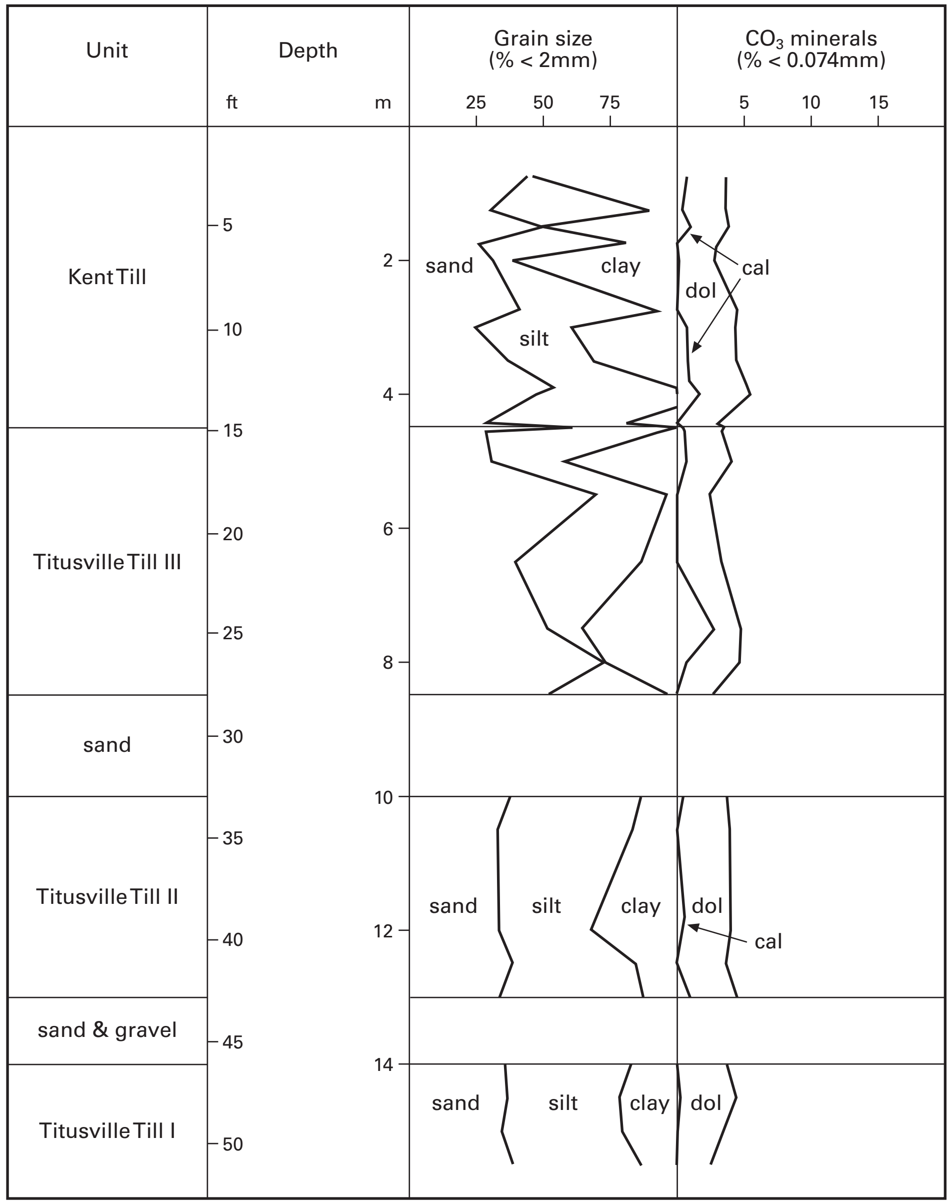


FIGURE 26.—Laboratory analyses of the Swine Creek section, Geauga County.

(fig. 27) nearly 5 miles (8 km) southeast of the Swine Creek section, but is similar to sections described by Moran (1967) in Mahoning County, southeast of Geauga County. The section in a cut bank of the Grand River in Parkman is over 40 meters high and consists of 35 meters of nearly uniform Titusville Till (Totten, 1988) overlain by Late Wisconsinan tills (fig. 28).

Thin, weathered Hiram Till and partially leached Lavery Till overlie about 3 meters of yellowish-brown, friable, sandy, slightly calcareous Kent Till (Totten, 1988). These Late Wisconsinan tills are separated from the thick Titusville Till by a boulder zone composed of local Pennsylvanian sandstone blocks. About 3.5 meters of yellowish-brown, very firm, sandy, partially leached till overlies 28 meters of gray, very firm, sandy, weakly calcareous till containing occasional 5- to 25-centimeter thick sand lenses. The only thick sand body is found at the base of the section where it overlies at least 2 meters of Titusville Till (fig. 28).

There are both similarities and differences in laboratory data between the two sections. Overall the matrix texture of the Titusville Till at Parkman is statistically similar ($P \leq 0.05$), but standard deviations of the textural components are small compared to those of the Titusville Till at the Swine Creek section (table 3). The fine-carbonate content at both sites is dominated by dolomite, but small amounts of calcite are present at Swine Creek. The amounts of clastics and carbonates in the 1-2-mm sand fraction differ significantly ($P \leq 0.05$), whereas the clay mineralogy of the tills at the two sections is nearly identical (table 3). The mean quartz/feldspar ratio of the Titusville Till at Parkman is more than twice that of the same till at Swine Creek, but the ratios of alkali feldspar to plagioclase are statistically similar.

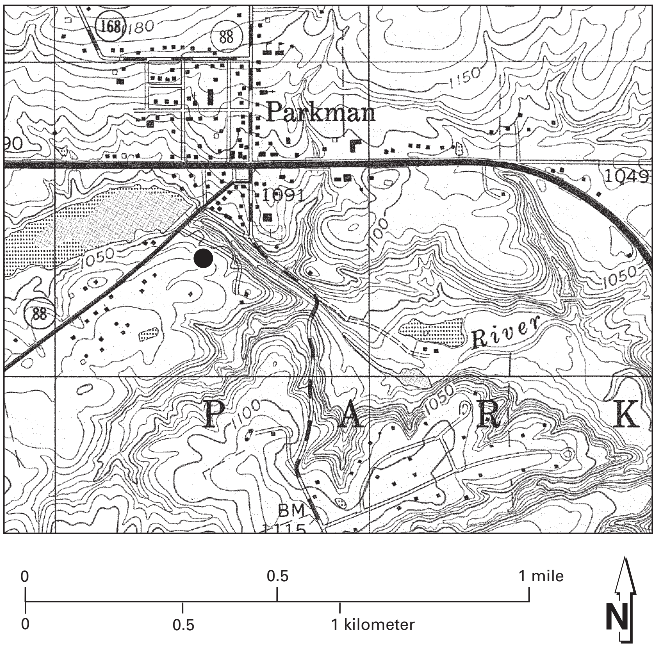


FIGURE 27.—Portion of the 1994 U.S. Geological Survey Garrettsville, Ohio, 7.5-minute quadrangle showing the location (large black dot) of the Parkman section south of U.S. Rte. 422 in southeastern Geauga County. Contour interval is 10 feet (slightly more than 3 meters).

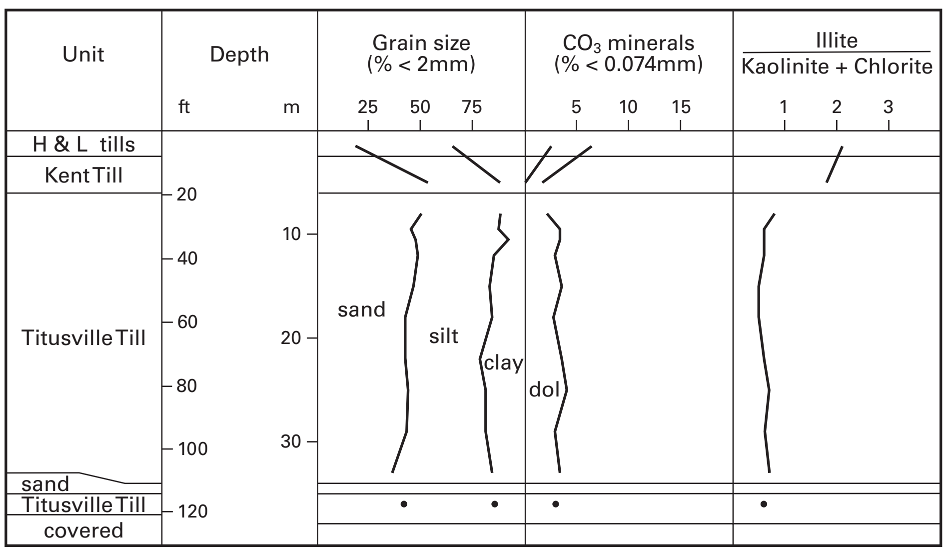


FIGURE 28.—Laboratory analyses of the Parkman section. Hiram (H) and Lavery (L) tills may be present at the top of the section (Totten, 1988)

Mode of deposition

The differences and similarities between the two sections may be explained by the combination of local bedrock topography, glacial processes, and provenance. The section at Parkman was exposed by downcutting of the Grand River into a buried valley that was transverse to ice flow (Totten, 1988). The presence of thin sand stringers within the Titusville Till at this section may indicate that the valley was filled with till deposited by subglacial melt out (Benn and Evans, 1998). The boulder zone of angular sandstone blocks may have been eroded from local topographic highs, transported a short distance, and deposited as Titusville ice melted. An average of 91% clastic rock types in the 1-2-mm-sand fraction and large quartz-feldspar ratios also suggest a very strong local bedrock component in the Titusville Till at Parkman.

The mode of deposition may have been different at Swine Creek where the outcrop contains at least three distinct subunits of Titusville Till separated by sand or sand and gravel beds between 1- and 1.5-meter thick. Statistical analysis of the three subunits shows that the Titusville Till III, the uppermost layer, is responsible for the large amount of variation in matrix texture of this till taken as a whole (table 3). Subunits I and II display nearly uniform matrix textures having relatively small standard deviations compared to subunit III. Generally, the standard deviation should increase as the number of samples increase (Davis, Parkman: detailed section description

Elevation of top of section: 332 meters (1,090 feet); height of section: 40 meters (131 feet) (modified from Totten, 1988)

Depth (meters)	Description
Pleistocene Series, Wisconsinan Stage	
Hiram Till	
0.00-0.86	10YR 3/3, dark-brown, loose, blocky, clayey, leached diamict.
Lavery Till	
0.86-1.27	10YR 3/3, dark-brown, firm, blocky, silty, unleached diamict.
Kent Till	
1.27-4.10	10YR 5/4, yellowish-brown, friable, sandy, partially leached diamict.
Pleistocene Series, Illinoian Stage	
Titusville Till	
4.10-5.00	10YR 5/4, yellowish-brown, large, angular blocks of Sharon sandstone in a sandy matrix.
5.00-7.65	2.5Y 5/3, light-olive-brown, sandy, very firm, unleached diamict having 2.5Y 6/8, olive-yellow, iron-stained fractures.
7.65-35.40	5Y 5/1, gray, sandy, very firm, unleached diamict containing sporadic sand lenses 5- to 25-centimeters thick.
35.40-36.20	2.5Y 4/4, olive-brown, friable, unleached sand.
36.20-38.00	5Y 4/1, dark-gray, sandy, very firm, pebbly, platy to irregularly blocky, unleached diamict having 2.5YR 4/6, red streaks.
38.00-40.00	Covered to level of the Grand River.

2002); if matrix-texture data are combined for the lower two subunits, standard deviations are still less than half of those of subunit III. The large variation in matrix texture in subunit III is suggestive of a superglacial melt-out till, whereas the smaller variations in the other two subunits may reflect their possible subglacial origin. Two fabrics measured 10 meters apart laterally in subunit II (fig. 29) have strength values (S_1) of 0.78 and 0.85 suggestive of deposition by lodgment.

The sequence of Titusville subunits may be interpreted in two ways. One interpretation is that there were multiple advances of Titusville ice during the Illinoian stage. Moran (1967) found five subunits of Titusville Till exposed in quarries and strip mines in Mahoning County 35 miles (56 km) southeast of Parkman. White and others (1969) also found multiple subunits of Titusville Till exposed in many strip mines in northwestern Pennsylvania. Moran (1967, 1971) proposed an alternative hypothesis involving the thrust stacking of till sheets. He noted that matrix textures and trends in feldspar contents were duplicated up section through subunits of the Titusville Till at many sections. Moran suggested that, as the basal layer of ice became stagnant, active ice was thrust over the stagnant layer. Each thrusted layer had its vertical distribution of matrix texture and feldspar content derived from active ice behind the terminus of the glacier. At some locations the thrusted till sheets were separated from each other by sands or sands and gravels, but at other locations there was no obvious break within the till. At the latter sections, discontinuities in feldspar trends were noted (Moran, 1971). Usually these trends were apparent in sections where the thickness of the Titusville Till was much greater than average. Because detailed sampling was not done at the Parkman and Swine Creek sections, and not all analyses were performed on all the samples, the trends found by Moran (1967, 1971) cannot be evaluated.

Provenance of the Titusville Till

Results of the laboratory analyses of samples from these

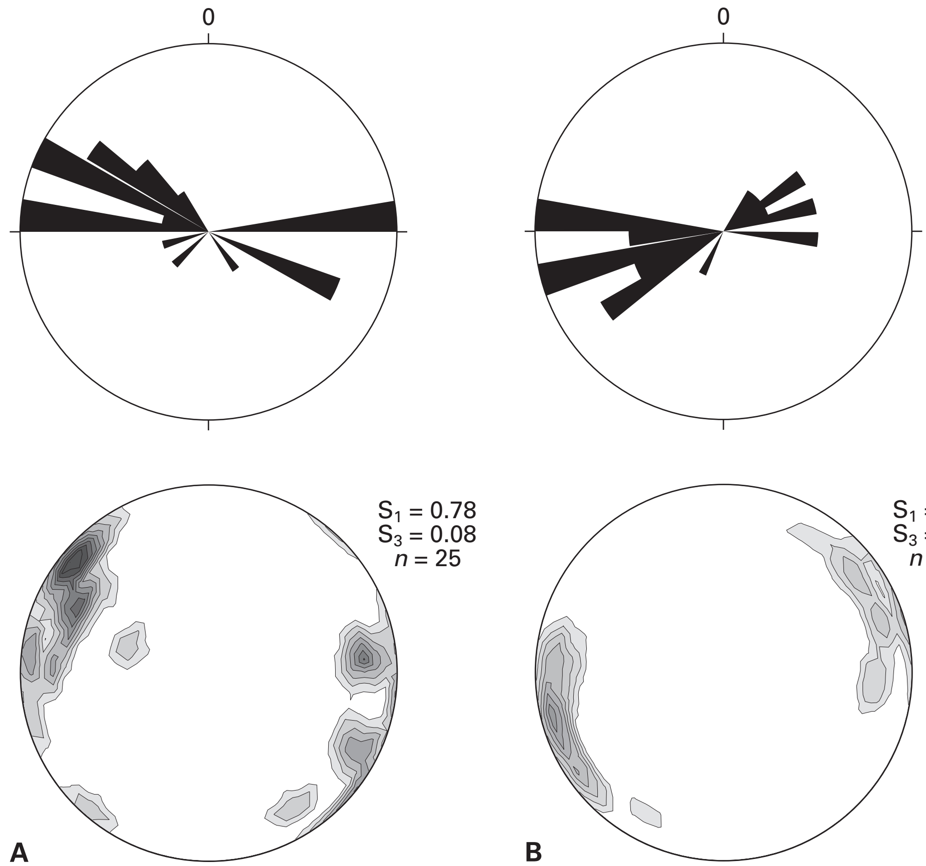


FIGURE 29.—Fabric data for the Titusville Till II at the Swine Creek section. **A**, site 1 rose diagram and stereonet. **B**, site 2 rose diagram and stereonet; this site is 33 feet (10 meters) south of site 1 and at the same elevation. Both indicate that the ice flowed from the west and that the tills may have been deposited by lodgment based on the strong alignment of clasts that generated large fabric-strength or S_1 values.

two sections can be used to interpret the provenance of the Titusville Till. The types of heavy minerals in the fine-sand fraction of Titusville Till are indicative of its source area. The garnet component is dominated by the purple variety of almandine, and garnet/epidote ratios are large (Matz, 1996). Amphibole consists largely of green hornblende, but samples also contain an average of 6% tremolite. The abundance of clinopyroxene is greater than that of orthopyroxene (Matz, 1996). The types of garnet and amphibole indicate an input from metamorphic rocks of the almandine-amphibolite facies, which is the most common grade of metamorphism in the Grenville Province (Gwyn and Dreimanis, 1979). These data suggest that the Titusville Till had a provenance in the Madroc-Arnprior area of the eastern Grenville subprovince northeast of the Grand River lobe.

Other laboratory analyses of the Titusville Till point to extralocal influences on the composition of the Titusville Till. Its fine-carbonate mineralogy, composed of 3 to 4% total carbonate and dominated by dolomite, varies little across northeastern and north-central Ohio (Szabo and Totten, 1995). It is difficult to assess if this unit ever had significant amounts of carbonate entrained along its flow path or if its original composition was diluted by interaction with local bedrock of the Allegheny Plateaus. The clay mineralogy of the Titusville Till may be a regional indicator of its dilution by Pennsylvanian bedrock. The average DIs in table 3 are typical of those of the Titusville Till and its equivalents in northeastern Ohio (Szabo and Totten, 1995), and reflect incorporation of Pennsylvanian shales and underclays. Volpi and Szabo (1988) demonstrated that 60% of the variation in DIs in the Titusville Till could be explained by the clay mineralogy of the underlying bedrock in Columbiana County, southeast of the field trip area. Quartz/feldspar ratios (Q/F) are another measure of the influence of regional bedrock on the composition of the Illinoian tills on the Allegheny Plateaus. Gross and Moran (1971) demonstrated that Q/Fs of the Titusville Till increase southward towards the boundary of the Grand River lobe. This and a similar trend in sand content suggest that basal till was being diluted by incorporation of local sandstones, which form bedrock highs on the plateaus. Q/Fs at Parkman are higher than the average ratio of 14.3 published by Gross and Moran (1971), whereas those at Swine Creek (table 3) are somewhat lower than that average value.

Additionally, Q/Fs may be a strong indicator of the influence of nearby bedrock on the composition of the Titusville

Till. Large Q/Fs may suggest that sandstone is the predominant bedrock near these sections, especially at Parkman where the Q/Fs are significantly above the average values for the plateaus. The Q/F of the lowest till sample at Parkman is 29.1, over twice the regional average (Gross and Moran, 1971); the average value of the lowest subunit at Swine Creek is 12.8 (table 3). Ice overrode a Pennsylvanian bedrock high north of Parkman and may have entrained a large amount of sandstone clasts. Q/F values are less up section in Titusville subunits II and III at Swine Creek (table 3) although the number of samples within the subunits are limited.

The lithology of the 1-2-mm sand fraction may yield a similar interpretation of the influence of local bedrock. The average percentage of clastics at Parkman is statistically greater than that at Swine Creek. Because the average percentage of carbonates is greater at Swine Creek, there may have been less dilution by local rock types. Crystalline lithologies are nearly identical and reflect the crushing of far-traveled rocks transported englacially.

Direction of ice flow

The distribution of glacial deposits proposed by White (1960, 1961, 1971, 1982) assumes that Late Wisconsinan ice essentially flowed along the same flow lines as Illinoian ice. Cited evidence includes observations of Totten (1969) that recessional moraines found in north-central Ohio had cores of thick Illinoian tills. These were later classified as superposed moraines, in which a younger end moraine has been deposited on an older moraine (Mickelson and others, 1983). At this stop, we are on the western side of the Grand River lobe and the Illinoian ice should have flowed from the east toward the interlobate area in the upper Cuyahoga Valley to the west (White, 1982). However, fabric data (fig. 29) not only suggest that the Titusville Till was deposited by lodgment, but also indicates that local Illinoian ice flowed from west to east at Swine Creek. This questions the assumption by White (1982) and requires further research.

Kent Till

The Kent Till that overlies the Titusville Till at both sections was examined in detail at Swine Creek. The average matrix texture of the Kent Till contains more clay and less sand than the Titusville Till (table 3). Its fine-carbonate content, DI, and sand lithology are similar to those of the Titusville Till. The similarities in its fine-carbonate content and its proportions of heavy minerals to those of the Titusville Till (table 3) suggest that it also had a source area in the eastern Grenville subprovince.

Conclusion

The average thickness of the Titusville Till in the Grand River lobe is 6 meters (White, 1971). The two sections discussed at this stop expose much greater thicknesses of this unit. The Swine Creek section may represent a glacial environment in which thrust stacking was active, but the section would need to be sampled and analyzed in greater detail to determine if there was a repetition of textural and mineralogical parameters. The same is true of the Parkman section, which was only sampled at a gross scale. These two locations contain some of the thickest sections of Titusville Till measured in northeastern Ohio. The only other section having a similar thickness and geologic setting is a 19-meter-thick section of Mogadore Till in the valley of Mud Brook 5 miles (8 km) north of Akron, Ohio (Ryan, 1980). This section does display gross trends in Q/F similar to those of Moran (1967, 1971), but like the other two sections on this trip, it also needs further research to verify the model of Moran.

ROAD LOG: STOP 3 TO STOP 4

Turn left when leaving the parking lot at Swine Creek and follow Swine Creek Road (fig. 15) to Hayes Road and turn right (north). Follow the end moraine northward to the intersection of Hayes Road and Ohio Rte. 87. Turn left (west) onto Ohio Rte. 87 and proceed across the ground moraine of Kent Till deposited by the Grand River lobe on the upland. Go through Middlefield, cross the Cuyahoga River again, and climb onto the high bedrock knob occupied by Burton. Circumnavigate the town square in Burton in a counter-clockwise direction and continue due west on Ohio Rte. 87 to its intersection with Ohio Rte. 44. Nearing Ohio Rte. 44, the topography becomes hummocky, and is composed of kames and small bedrock knobs. Turn left (south) onto Ohio Rte. 44 at its intersection with Ohio Rte. 44, and in a short distance turn left onto the property of the Newbury Sand & Gravel Company, Stop 4.

STOP 4. NEWBURY SAND & GRAVEL COMPANY

by John P. Szabo

The Newbury Sand & Gravel Company is located southeast of the intersection of Ohio Rtes. 44 and 87 (fig. 30) in extreme northwestern Burton Township. The Newbury pit lies between the mapped limits of the Hiram and Lavery advances (fig. 31) near the northern extremity of the large area of ice-contact deposits between the Cuyahoga and Grand River lobes (fig. 10). Although the Hiram and Lavery Tills are found in this area, Totten (1988) suggests that Kent Till is abundant in the area. The sand and gravel pit occupies the flank of a buried valley that slopes to the east. Sandstone is exposed in an old pit along the western property line, but near the eastern boundary of the property, the pit operators are still able to dry mine the sand and gravel and also continue to dredge the main pit with a dragline (Mike Keazle, personal communication).

The soils in the area provide insight into the glacial stratigraphy. The Canfield soil is mapped over a sandstone high west of Ohio Rte. 44 (Williams and McCleary, 1982) and generally has been associated with sandy Kent or Mogadore Tills (White, 1982). The Ellsworth soil formed in clay-rich tills along the western part of the property at lower elevations than the Canfield soil on the bedrock high. This illustrates a common problem in mapping tills on the Allegheny Plateaus when using soil types as indicators of specific till units. Szabo and Angle (1983) demonstrated that glacially eroded sandstone highs had a tendency to dilute the

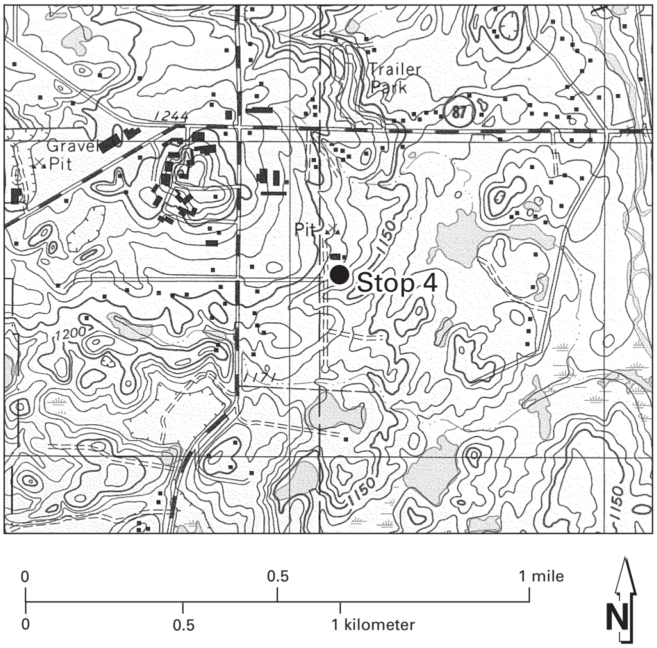


FIGURE 30.—Portion of the 1994 U.S. Geological Survey Burton, Ohio, 7.5-minute quadrangle showing the location of Stop 4, the Newbury Sand & Gravel Company, west of Burton in central Geauga County. Contour interval is 10 feet (slightly more than 3 meters).

textures of clay tills. This may be the case in the areas north and west of this stop because the Canfield soil appears to be anomalous in this area and more common beyond the Hiram boundary (Williams and McCleary, 1982). The Chili-Oshtemo soil complex develops in areas dominated by kames that once occupied the area of the pit and are still present to the south of this stop. The Bogart soil associated with outwash and the Canadice soil developed in lacustrine sediments are found at low elevations east of the pit.

Three sections were measured on the property of the Newbury Sand & Gravel Company. Section 1 was measured in an abandoned pit near the western edge of the property west of the office (fig. 32).

Laboratory analyses aid in determining the origin of the sediments in this section. The diamict is correlated with the Kent Till based on its sandy texture, averaging 38% sand, 40% silt, and 22% clay, and its small carbonate content dominated by dolomite (fig. 33). The clay minerals in the upper part of its weathering profile consist of vermiculite, degraded illite, illite-smectite intergrades, and minor amounts of smectite. The symmetry of the 1.0-nm illite peak increases with depth, and the 0.7-nm vermiculite peak becomes sharper. The apparently unweathered, lower 15 centimeters of diamict are somewhat problematic because of the abrupt change in color at its upper boundary. However, its texture and fine-carbonate contents are similar to those of the adjacent part of the diamict above. X-ray diffraction analysis of the dark-greenish-gray samples show well-organized illite and chlorite and a DI of 1.2 (fig. 33), typical of unweathered diamicts in northeastern Ohio. The thin, yellowish-brown sandy silt underlying the Kent Till contains no carbonate (fig. 33); its clay mineralogy consists of smectite and very degraded illite

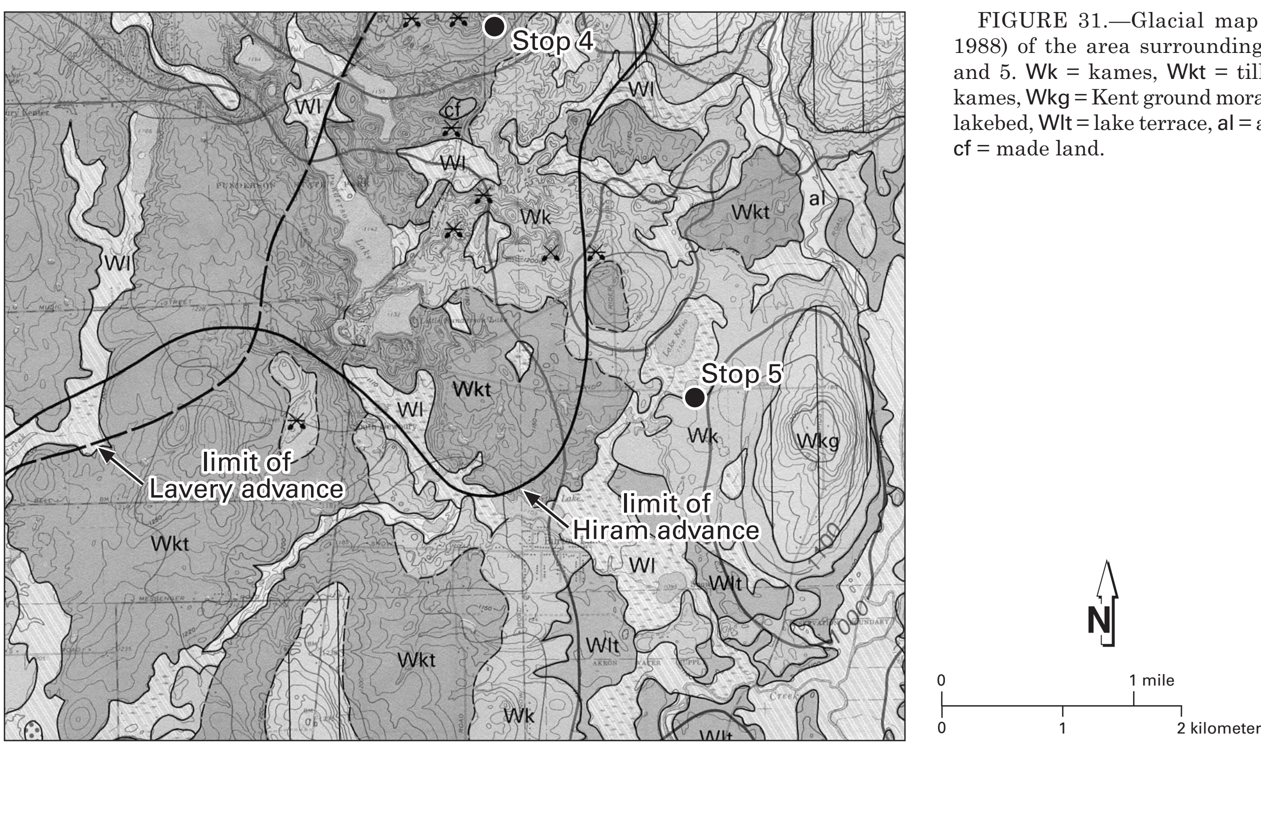


FIGURE 31.—Glacial map (Totten, 1988) of the area surrounding Stops 4 and 5. Wk = kames, Wkt = till covered kames, Wkg = Kent ground moraine, Wl = lakebed, Wlt = lake terrace, al = alluvium, cf = made land.

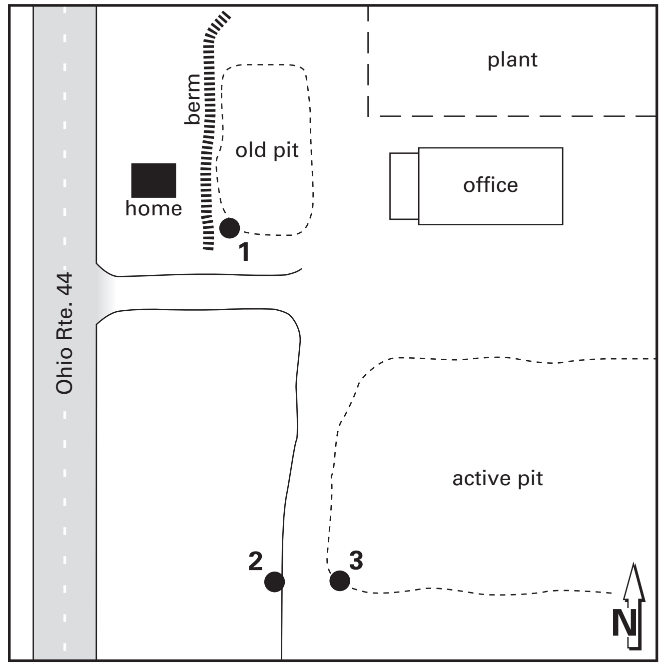


FIGURE 32.—Sketch map (not to scale) of the Newbury Sand & Gravel Company property showing relative locations of measured sections 1-3.

Newbury Sand & Gravel Company: detailed description of section 1

Elevation of top of section at mounded overburden: 381 meters (1250 feet) (measured section begins below 3.35 meters of mounded overburden; height of measured section: 3.75 meters (12.3 feet))

Depth (meters)	Description
Pleistocene Series, Wisconsinan Stage	
Kent Till	
0.00-0.65	10YR 5/8, yellowish-brown, friable, platy, leached sandy diamict having 10YR 3/6, dark-yellowish-brown mottles and 10YR 2/1 black Mn staining.
0.65-2.50	10YR 5/3, brown, friable, platy, leached diamict having 5YR 5/8, yellowish-red and 5Y 5/2, olive-gray mottles and containing rotten mafic crystalline pebbles. Diamict has a weak reaction to HCl at 2.0 meters and is separated from the unit below by a weak stone line.
2.50-3.10	2.5Y 5/4, light-olive-brown, firm, platy, diamict having a weak reaction to HCl.
3.10-3.27	5GY 4/1, dark-greenish-gray, slightly plastic to firm, platy, calcareous diamict. Possible gleyed horizon overlying a 2-centimeter thick, 10YR 6/4 dark-yellowish-brown, plastic, platy leached clay silt.
Pre-Wisconsinan? Stage	
3.27-3.45	10YR 6/4, dark-yellowish-brown, friable, platy, weakly calcareous sandy silt.
3.45-3.70	10YR 4/4, dark-yellowish-brown, loose, calcareous sand and fine gravel containing weathered crystalline pebbles.
Pennsylvanian System	
Pottsville Group	
3.70-4.00	10YR 6/4, dark-yellowish-brown, loose, noncalcareous weathered sandstone containing pockets of angular sand grains.

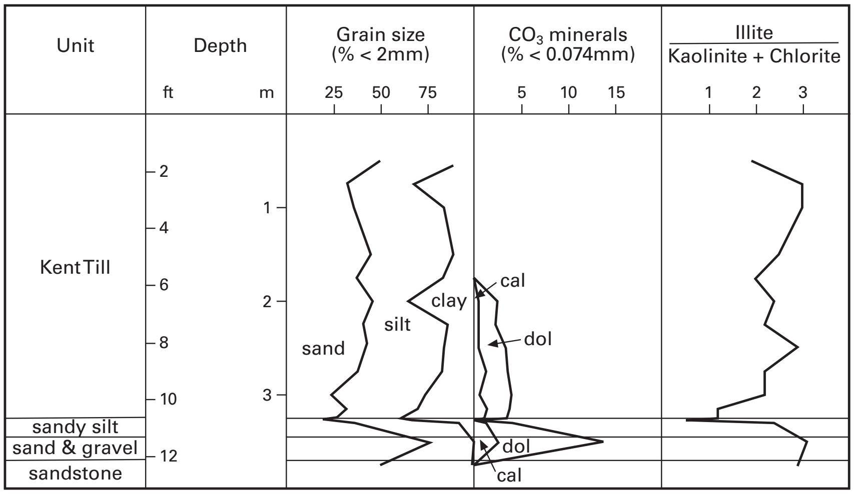


FIGURE 33.—Laboratory analyses of section 1 at Stop 4, Newbury Sand & Gravel Company.

resulting in a DI of 0.5. This may represent a period of weathering or oxidation from groundwater flow. The fine-carbonate content of the sand and gravel overlying the sandstone is dominated by dolomite (fig. 33), and its clay minerals are better organized that those of the overlying sandy silt. If the extremely weathered sandy silt represents an interval of surficial weathering or a period of extended ground water flow, the sand and gravel may be Illinoian in age.

The next two sections were measured south of section 1 (fig. 32); section 2 was described and sampled in a road cut, whereas section 3 was measured in the corner of the active pit. The lower part of section 2 was matched to the top of section 3 resulting in a combined section description and plot of laboratory data (fig. 34).

The sparsely pebbly diamict in the upper 3.75 meters of the combined section grades from dark yellowish-brown through dark-brown to dark-grayish-brown. Its consistency varies from plastic to firm, and its structure ranges from

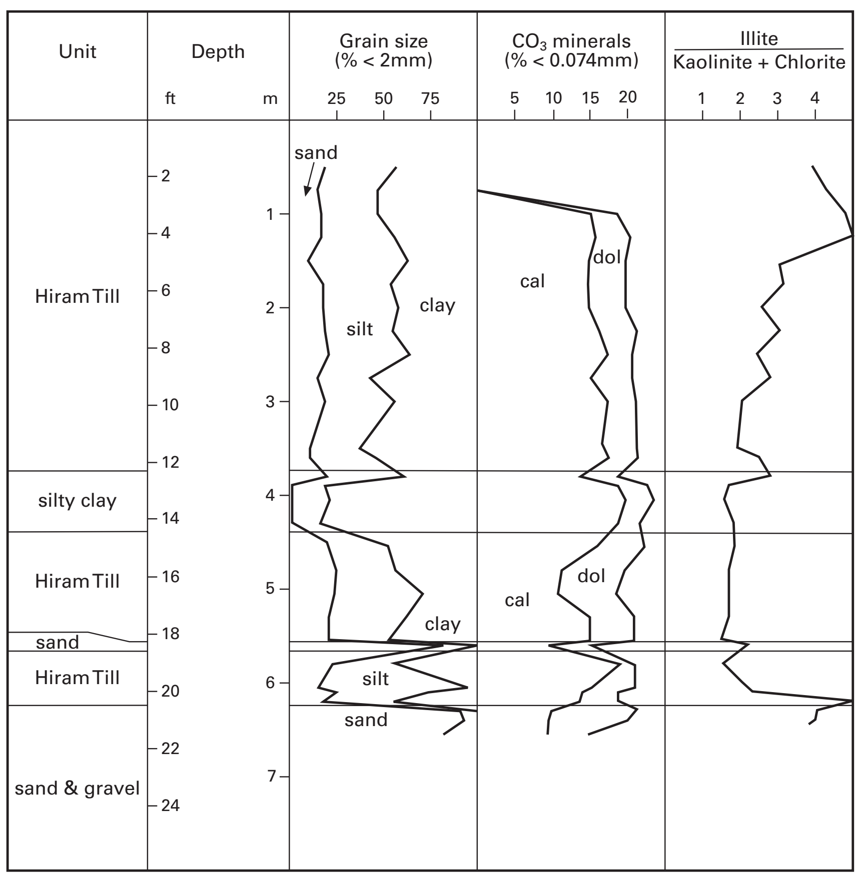


FIGURE 34.—Laboratory analyses of combined sections 2 and 3 at Stop 4, Newbury Sand & Gravel Company

Newbury Sand & Gravel: detailed description of sections 2 & 3

Elevation of top of section 2 along west side of road: 372 meters (1,220 feet); height of section: 8.75 meters (28.7 feet) (section 3 is offset 8 meters to the east to the SW corner of the main pit and begins below 1.3 meters of overburden forming a ridge between the road and the pit)

Depth (meters)	Description
Pleistocene Series, Wisconsinan Stage	
Hiram Till	
0.00-0.21	10YR 3/4, dark-yellowish-brown, friable, blocky, leached diamict having sparse pebbles.
0.21-0.70	2.5Y 4/4, olive-brown, plastic, blocky, leached diamict having 10YR 2/1 black Mn staining and few pebbles.
0.70-1.00	10YR 4/3, dark-brown, plastic, blocky, leached diamict containing few pebbles and having 10YR 6/2, light-brownish-gray silt and carbonate coatings along fractures.
1.00-2.60	10YR 4/3, dark-brown, firm, block to prismatic, calcareous diamict having 10YR 6/2, light-brownish-gray silt and moderately effervescent carbonate coatings along fractures and containing few pebbles.
2.60-2.90	10YR 3/3, dark-brown, firm, platy, calcareous diamict having 10YR 2/1, black Mn staining and 7.5YR 6/8, reddish-yellow mottles in addition to 10YR 6/2, light-grayish-brown silt and carbonate coatings along fractures.
2.90-3.50	10YR 4/2, dark-grayish-brown, firm, platy, moderately pebbly, calcareous diamict having 7.5YR 6/8, reddish-yellow mottles.
The following is from section 3.	
3.50-3.75	5Y 4/4, olive-brown, friable, prismatic, calcareous diamict having few pebbles.
3.75-4.40	10YR 4/2, dark-grayish-brown, friable, platy, mildly calcareous, silty clay having 2.5Y 5/4, light-olive-brown staining along fractures and containing very few pebbles. Upper 4 centimeters are more silty than the remainder of the unit.
4.40-5.55	10YR 4/2, dark-grayish-brown, friable, platy, moderately pebbly, mildly calcareous diamict having 2.5Y 5/4, light-olive-brown staining along fractures.
5.55-5.65	10YR 4/2, dark-grayish-brown, loose, medium- to coarse-grained sand bed dipping NW.
5.65-6.05	10YR 4/2, dark-grayish-brown, plastic, platy, moderately pebbly diamict having a mild sustained reaction with HCl.
6.05-6.25	2.5Y 5/6, light-olive-brown, very firm, strongly platy, mildly calcareous diamict containing few small pebbles. Upper 2 centimeters are weakly cemented with iron oxides.
6.25-6.55	10YR 4/6, dark-yellowish-brown, loose sand gravel.
6.55-8.75	2.5Y 5/6, light-olive-brown, loose sand and gravel; some sand grains are cemented to gravel clasts by calcite.

blocky near the surface to platy at depth. Below its nearly 1-meter depth of leaching, brownish-gray carbonate coatings occur along major vertical fractures and are a dominant feature of this diamict. Mn staining and reddish-yellow mottles are common in its lower part. The average matrix texture of the diamict is 16% sand, 36% silt, and 47% clay; its fine-carbonate content is dominated by calcite (fig. 34), averaging 15.9%. The plot of DI with depth (fig. 34) follows the ideal weathering profile for clay minerals described by Willman and others (1966).

The lower part of the diamict was traced eastward across the haul road to the active pit where section 3 was measured. Sixty-five centimeters of dark grayish-brown, platy, calcareous silty clay underlie the diamict (fig. 34). Pebbles and granules are scarce in this silty clay, and it averages 1% sand, 18% silt, 81% clay, 18.1% calcite, and 4.7% dolomite. Illite and chlorite are well organized having an average DI equal to 1.7. Another platy, calcareous diamict underlying the silty clay is 1.65-meter thick. This diamict resembles the upper diamict but is more firm and pebbly than upper unit. Fractures within the diamict are stained light-olive-brown, and a 10-centimeter-thick bed of medium- to coarse-grained sand dips to the northwest within the unit. This lower diamict has an average texture of 22% sand, 38% silt, and 40% clay and contains an average of 14.0% calcite and 5.7% dolomite. Its DI averages 1.7 and contains well-organized illite and chlorite except in the sand layer in which the DI increases to 2.2. The lowest 20 centimeters of the diamict is light-olive-brown, very firm, and cemented with iron oxides. Total carbonate decreases in this part of the diamict, and the DI increases to 5.5 in the lowest sample (fig. 34) as chlorite has been altered to vermiculite.

Yellowish-brown to light-olive-brown, loose sand and gravel underlie the diamict sequence. The dolomite content of the matrix of the sand and gravel is greater than that of the overlying diamicts. Because sand grains are cemented by secondary carbonates to gravel clasts, it is difficult to determine how much of the fine-carbonate content is primary in origin. An average DI of 4.0 for the sand and gravel is expected for such a permeable deposit in which dissolved oxygen in ground water can oxidize clay minerals in the matrix of the gravel.

This combined section illustrates some of the common problems associated with the mapping of Late Wisconsinan tills on the Allegheny Plateaus. Correlation with the established stratigraphy of White (1982) is problematic because both the Hiram and Lavery Tills have nearly identical characteristics. In eastern Portage County, these two units are separated by the Windham Sand, a cover sand of possible eolian origin (Winslow and White, 1966). In Geauga County, Totten (1988) presents nearly identical descriptions for these units except that the thickness of the plates differs in these two tills. The implication is that the Hiram Till is so thin that its contact with the Lavery Till is obscured by the soil profile. This is implied in many county reports for northeastern Ohio. Both White (1982) and Totten (1988) admit that the contact between these units is a till-on-till contact that may be difficult to differentiate.

Does the stratigraphy of sections 2 and 3 represent two glacial advances or one? At the combined section it may be possible that two different diamicts are present, the stratigraphic break being at the silty clay between the upper and lower diamicts (fig. 34). There is a significant statistical difference ($P \leq 0,05$) in the sand and dolomite contents of the upper and lower diamicts. The lowest 60 centimeters of the lower diamict is quite variable in texture and has a declining calcite content (fig. 34). This may be the result of overriding of sand and gravel and possibly silt beds that are exposed in the pit wall above the sand and gravel north of section 3. The combined section also may represent deposition during a single glacier advance over sand and gravel, followed by melt out. The silty clay between the upper and lower diamicts may have been deposited during subglacial melt out, followed by superglacial melt out as the glacier downwasted near its limit of advance.

The latter hypothesis may be the preferred model for this site, but was the sequence deposited during the Lavery or Hiram glaciation? The large fine-carbonate contents, dominated by calcite, add to the enigma because they appear to be anomalous when compared to the average laboratory values for Hiram and Lavery Tills on the Allegheny Plateaus (table 2). Typical values for fine-carbonate contents of Late Wisconsinan tills are illustrated by data from the borehole at Pond Brook (fig. 20). The data in table 2 may be biased because thick, unweathered exposures of the Hiram and Lavery Tills are rare on the plateaus. The carbonate-coated near-vertical fractures are common in these units at many places on the plateaus. Clay mineralogy is of little value because this is the only section on the plateaus where unweathered Late Wisconsinan till has been analyzed, and it yielded values similar to those of any other till derived from pre-Pennsylvanian rocks (Szabo and Fernandez, 1984).

The fine-carbonate contents of the diamicts of this section are similar to those of surficial diamicts and lacustrine deposits in the wetlands of White Pine Bog (Stop 5, fig. 31). If the lacustrine deposits were derived from the last ice sheet in the area, then they would be associated with the Hiram advance. The mapped limit of the Hiram advance extends southeastward towards the lacustrine deposits of White Pine Bog (fig. 31). The Newbury Sand & Gravel Company lies beyond the mapped limit of the Lavery advance and within 0.6 miles (1 km) of the Hiram limit (fig. 31). Thus, the diamicts exposed at the sand and gravel company are correlated with the Hiram advance. Additional support for this correlation is provided by Totten (1988), who found as much as 6 meters of Hiram Till over Kent Till just north of Punderson Lake northwest of this stop. He also mapped Hiram Till over Kent Till in the now reclaimed pit of the Teague Sand & Gravel Company on Ohio Rte. 87 in Newbury Township west of Ohio Rte. 44. Hiram Till also overlies Kent Till in the pit of the Haueter Sand & Gravel Company immediately south of this stop (Totten, 1988).

ROAD LOG: STOP 4 TO STOP 5

When leaving Stop 4, turn left (south) onto Ohio Rte. 44 (Fig. 15) and pass through the kame and kettle topography associated with the land around Punderson State Park. There are many abandoned and some reclaimed sand and gravel pits around the park. On the east side of Ohio Rte. 44 before Little Punderson Lake is a large gravel pit of the Haueter Sand & Gravel Company. They have removed whole kames from nearly a 250-acre (100-hectare) area and have created a large pit that extends into Illinoian gravels in the fill of a buried valley that is a tributary to a much larger buried valley that is crossed by Hotchkiss Road between Rider Road and Rapids Road (fig. 15). The Ohio Drilling Company (1971) explored for water resources using a seismic survey along Hotchkiss Road, and also drilled some test wells for pumping tests. They lost circulation in several test wells and had to add a large amount of drilling mud to stabilize some holes. Their cross section (fig. 35) shows extensive sand and gravel deposits in the buried valley. Various types of sediments ranging from diamicts to sands and gravels of kames overlie the valley fill. Travel past Little Punderson Lake and turn left (east) onto Pond Road. Follow Pond Road past its intersection with Hotchkiss Road and continue past its intersection with Rider Road (fig. 15) to Stop 5.

STOP 5. WHITE PINE BOG

by John P. Szabo and Valerie Keinath

The White Pine Bog Forest Nature Preserve in Geauga County, Ohio (figs. 10, 36), is located adjacent to La Due Reservoir, part of the water supply system for the city of Akron. Both the outflow from the reservoir and that from the preserve drain into the upper Cuyahoga River to supply the reservoir at Lake Rockwell. A preliminary site-specific hydrologic analysis was done to gain a rudimentary understanding of the hydrology of the preserve and the possible hydrologic connections between the surface and groundwater systems.

Background

Paleozoic rocks underlie the White Pine Bog Forest Nature Preserve. The topographic high east of the preserve is underlain by Pennsylvanian sandstone; whereas the rocks beneath the preserve consist of shales and siltstones deposited during the Mississippian period. The first advance of the late Wisconsinan deposited loamy Kent Till and kames composed of outwash throughout much of the area (White, 1982). Totten (1988) mapped the limit of the Hiram advance across the northwest corner of the preserve (fig. 31). Much of the glacial topography may be inherited from the Kent advance; deposits of the later advance are thin and overlie Kent outwash deposits. Large pieces of ice were detached from the Hiram ice margin and were buried in the outwash. When these blocks of ice melted, they became kettle lakes such as Lake Kelso and Snow Lake (fig. 36). The lakes were reduced in size as their margins filled with bog sediments. The white pines of the preserve are relict, remaining from the pine period in Ohio that existed about 10,000 years ago (Ogden, 1966).

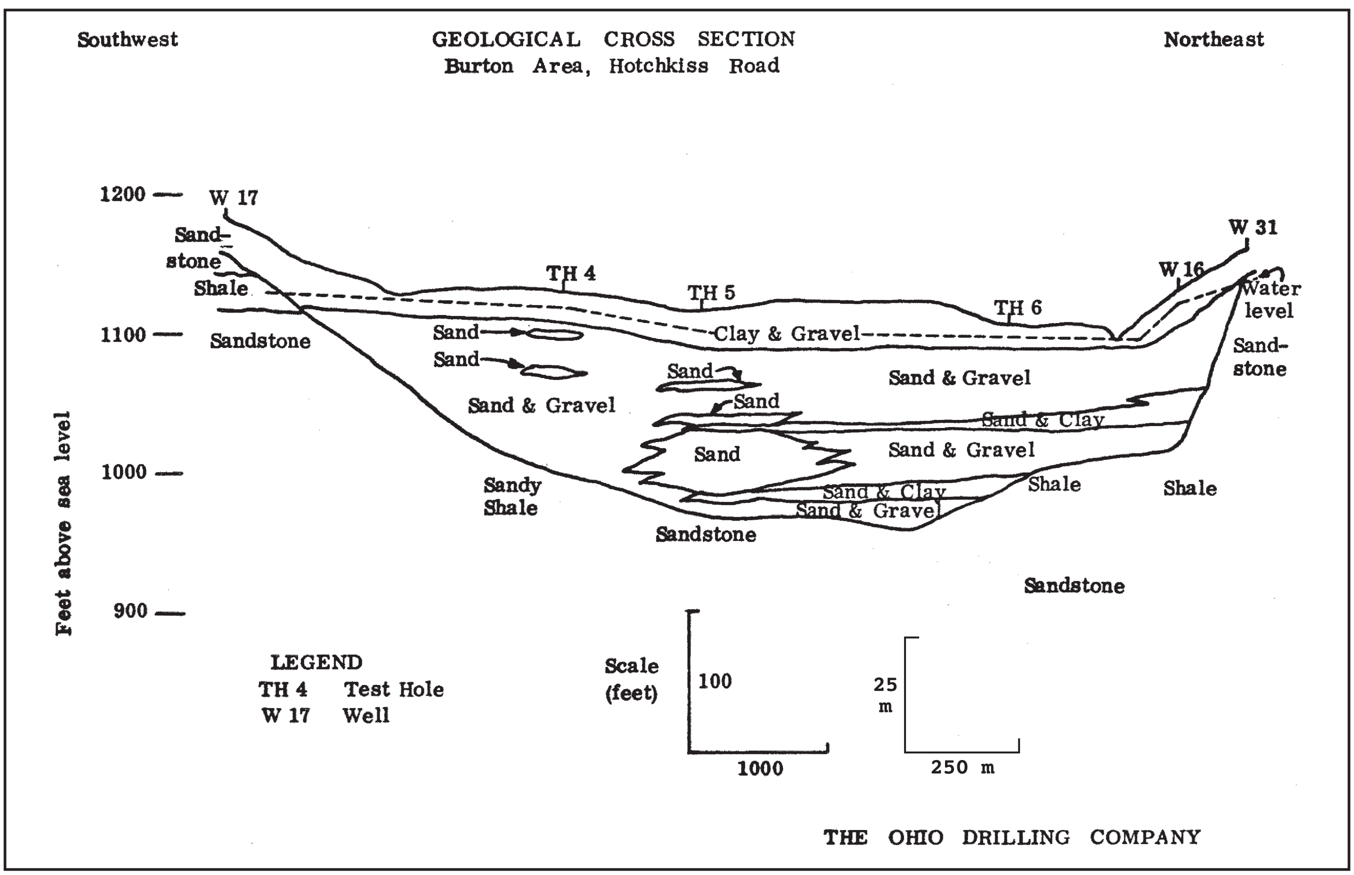


FIGURE 35.—Cross section constructed from seismic and well-log data along Hotchkiss Road (fig. 15) showing the variable nature of the fill of the buried valley (modified from Ohio Drilling Company, 1971).

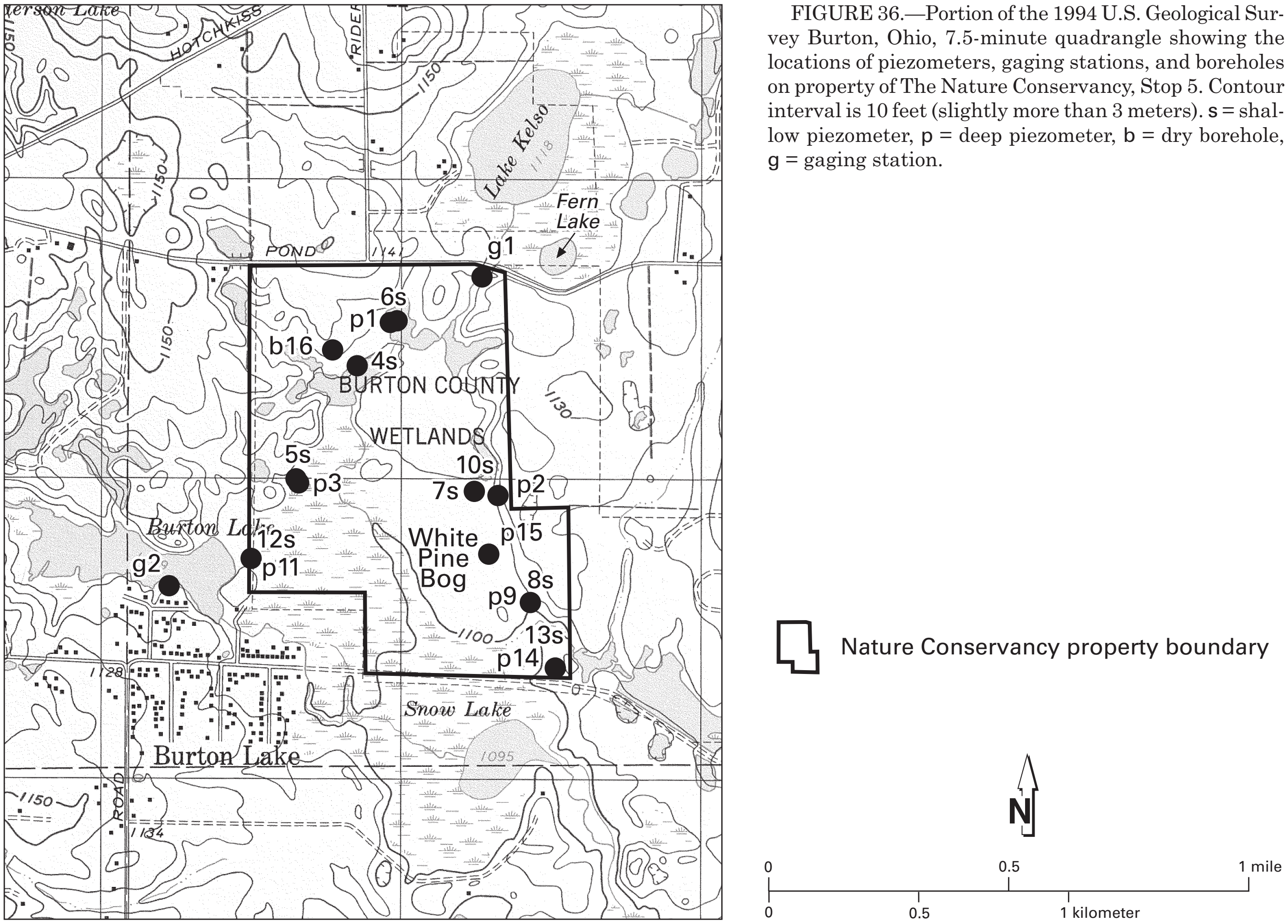


FIGURE 36.—Portion of the 1994 U.S. Geological Survey Burton, Ohio, 7.5-minute quadrangle showing the locations of piezometers, gaging stations, and boreholes on property of The Nature Conservancy, Stop 5. Contour interval is 10 feet (slightly more than 3 meters). s = shallow piezometer, p = deep piezometer, b = dry borehole, g = gaging station.

General hydrology

The surface hydrology surrounding the preserve can be partitioned into three parts. Approximately 75% of the surface drainage is directed into the wetlands of the preserve via the Punderson Lake-Burton Lake system. Punderson Lake serves as a natural sink, trapping sediments and possibly retaining any pollutants from the upper part of the drainage basin. Agricultural runoff from the farms northwest of the preserve flows into Burton Lake (fig. 36). We have observed that the artificial ponds within the western part of the preserve also trap sediment from runoff from these farms. The northeastern part of the drainage basin contributes about 15% of the overall surface drainage. Locally, permeable sands and gravels underlie this area (fig. 36) and overland flow appears to be limited. The remainder of the runoff (10%) into the wetlands is from the area south of Snow Lake. Upper slopes in this area are underlain by vegetated sand and gravel deposits, whereas lower slopes are underlain by clay. The wetlands surrounding Lake Kelso (fig. 36) are another potential source of inflow into the preserve. However, this inflow is through an artificially constructed ditch connected by culverts to Lake Kelso wetlands.

Groundwater is withdrawn in Geauga County from both bedrock and unconsolidated aquifers (Walker, 1978). Sandstones and conglomerates of the Pennsylvanian Pottsville Group are the rock aquifers that underlie much of Geauga County. The outwash sands and gravels found in kames and buried bedrock valleys have the largest potential groundwater yields in the county. Walker (1978) suggests that a yield in excess of 31 L/sec can be pumped from the buried valley beneath the wetlands. More recent GIS-based mapping by the Ohio Division of Water (2000) estimates potential yields between 6 and 31 L/sec for the buried valley aquifer. Pumping test data from the buried valley north of Lake Kelso suggests that the sand and gravel aquifer is capable of yielding that amount of water (Ohio Drilling Co., 1971).

Glacial stratigraphy

Samples taken during piezometer installation and from other borings permit reconstruction of a generalized sequence of glacial sediments found in the preserve (fig. 37). The oldest deposit consists of the loamy, weakly calcareous diamict that correlates with the Kent Till and underlies much of the northwest part of the preserve. Samples of

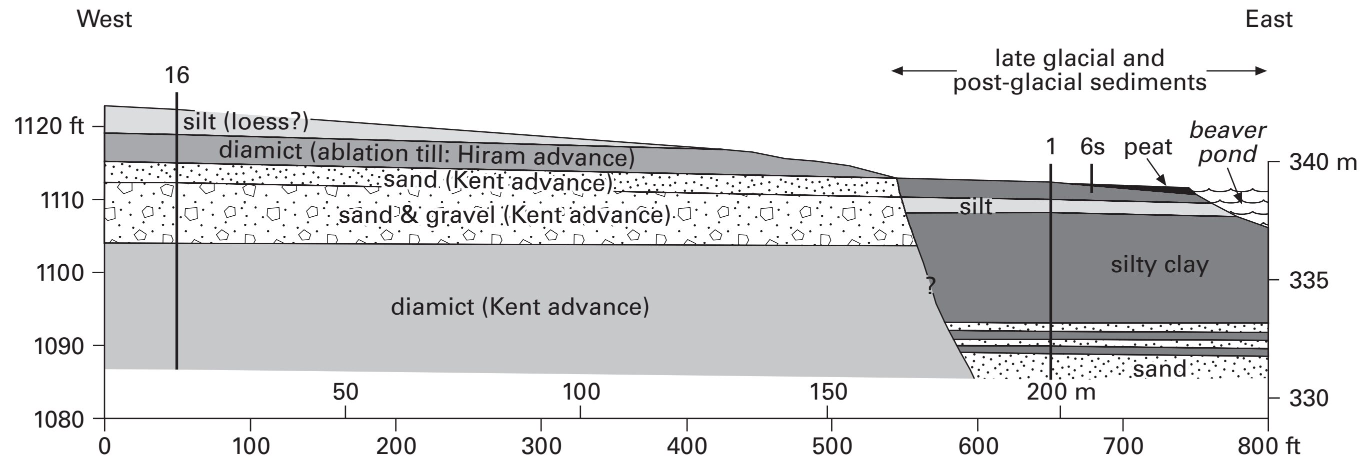


FIGURE 37.—Cross section (vertical exaggeration 5:1) representing glacial stratigraphy in the northwest part of Nature Conservancy property. A diamict of a late Wisconsinan advance overlies Kent sand and gravel. The wetlands sequence truncates the older glacial deposits.

Kent Till taken from boring 16 (fig. 36) averaged 40% sand, 33% silt, and 27% clay; fine carbonate was dominated by dolomite and contained an average total carbonate of 6.1%. Clastic rock types dominate the coarse-sand lithology of these samples that also average 11% carbonate and 27% crystalline clasts. Kent Till crops out or lies just beneath the surface on lower slopes surrounding parts of the wetlands and was used to construct the dams for artificial ponds built to attract waterfowl. The Kent Till is overlain by loose sand and gravel, fining upward into sand, associated with wastage of ice. Its fine-carbonate content is similar to that of the Kent Till. Less than one meter of dark brown, calcareous, clayey Hiram or Lavery Till overlie the sand and is capped by up to a meter of brown friable silt (loess?). The clay-rich till contains nearly 13% fine carbonate, most of which is calcite. On the eastern side of the preserve the clay-rich till is missing and the surficial deposits consist predominantly of sand and gravel.

Meltwater may have eroded away Kent deposits in the central part of the preserve where calcareous lacustrine deposits derived from the later ice advance are present. Most piezometers terminate in coarse gray sand or fine gray gravel at depths ranging from 2.5 to 9 meters. Interbedded gray fine sand, silt, and clayey silts overlie the sand and gravel. These are generally very calcareous, and their fine-carbonate fraction contains up to 22% total carbonate. The sequence fines upward into plastic, calcareous, gray clay containing black blebs of iron monosulfide. At some locations the clay is overlain by brown fibrous peat; at others a layer of marl containing mollusk shells separates the clay from the peat. The peat and marl are the thickest on the east side of the preserve where they occur beneath the white pine forest (fig. 38). The marl is missing from the west side of the wetland.

The sequence of deposition of sediments underlying the wetlands of the preserve suggests that a meltwater stream from melting Hiram or Lavery ice deposited sand and gravel in the upper part of a buried valley under the wetland. During retreat of the Hiram ice, a large ice block calved from the ice and lodged in the meltwater channel. Meltwater may have continued to flow around the block but eventually the flow began to decrease depositing finer sands and silts. Eventually, the meltwater flow found other outlets and possibly water ponded around the ice block as part of Lake Grove, a large lake (fig. 31) created by damming of the upper Cuyahoga River farther south (Totten, 1988). The lake may have existed sufficiently long enough for waves to erode a shoreline into the older sediments. Evidence for this is the 6-meter- to 9-meter-wide flat area that surrounds the wetlands. During this time, clays from the surrounding uplands were transported into the lake and slowly settled to the bottom. As the lake became more isolated, biological activity and the influx of carbonate-bearing surface and ground waters caused deposition of marl. Alternating layers of marl and peat show that regional climatic changes affected the lake as it slowly began to fill in with sediment and peat. Mollusk shells in the alternating marl and peat sequence are from species that lived in the area during the last 10,000 years. The area occupied by open water was reduced as peat formed along the margins until only Snow Lake, the present lake, remained. At some locations a thin layer of fine gravel occurs in the upper part of the peat; this may represent increased erosion after clear-cutting of the native forest during settlement of the area.

Hydrogeologic settings

A conceptual model of groundwater and surface flow that supports the wetlands of the preserve is based on hydrologic and stratigraphic data. Three hydrogeologic settings are common in parts of the wetland. The first setting (hydrogeologic setting 1, figs. 38, 39) consists of the wetland sequence abutting older sands and gravels of the kames on the eastern side of the wetland. There are two variations of this setting; the first (hydrogeologic setting 1A, fig. 38) shows a complete wetland sequence beginning with peat on the surface underlain by marl, silty clay, and coarse sand. Piezometer p15 penetrates the entire sequence, whereas

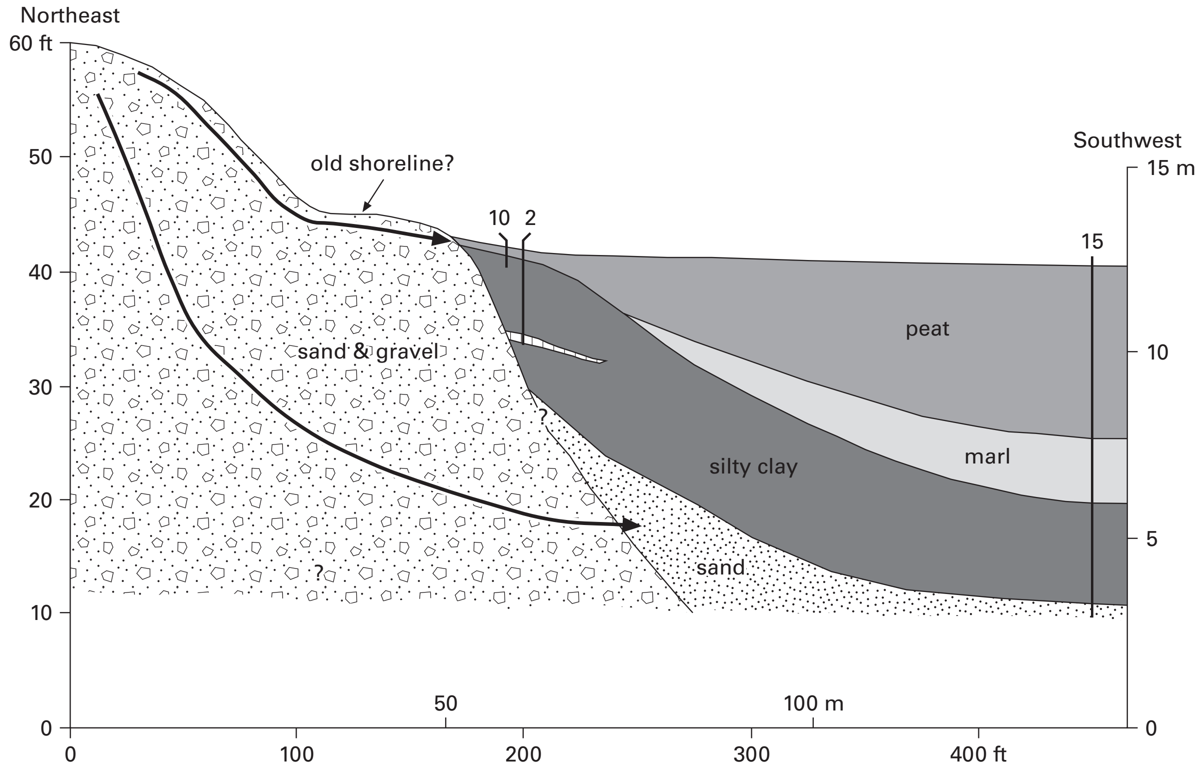


FIGURE 38.—Hydrogeologic setting 1A (vertical exaggeration 5:1) representing glacial stratigraphy in the northestern part of Nature Conservancy property. Runoff and shallow groundwater flow recharges the peat, whereas the shallow artesian aquifer is recharged by sand and gravel of the uplands.

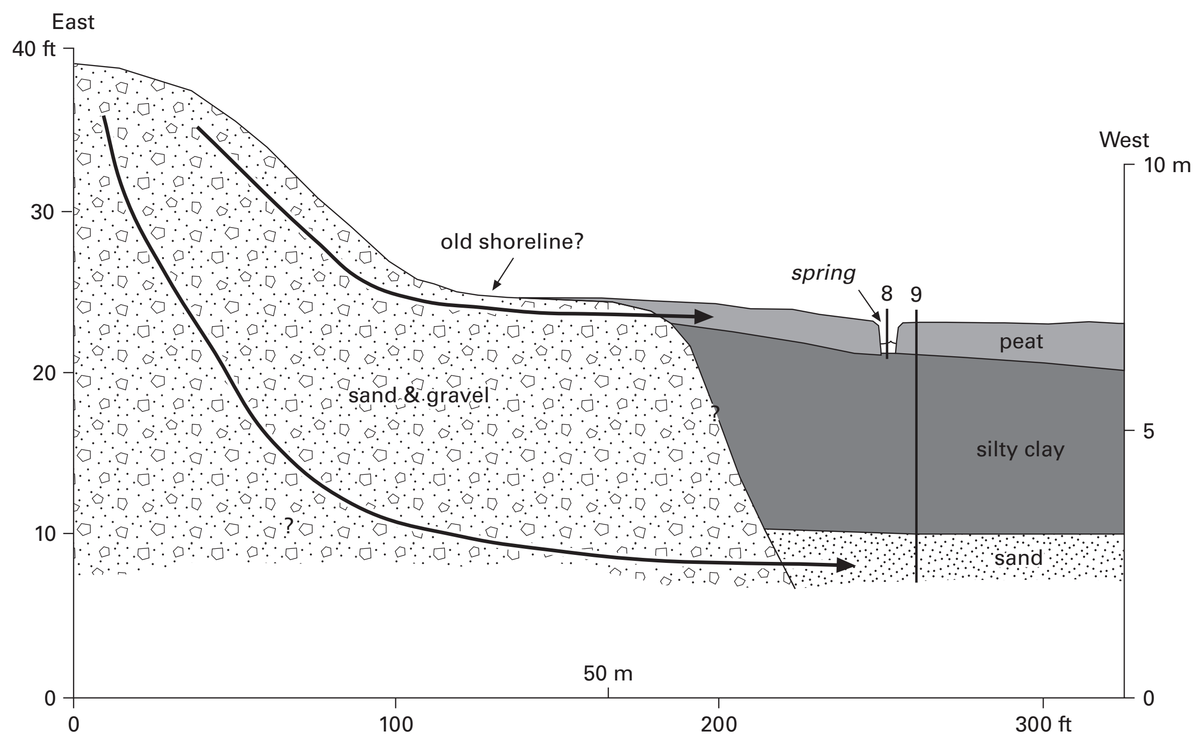


FIGURE 39.—Hydrogeologic setting 1B (vertical exaggeration 5:1) representing glacial stratigraphy in the southeastern part of Nature Conservancy property. Springs discharge water at the contact of the peat and the underlying silty clay.

piezometer p2 terminates in a sand layer of possible limited extent that is recharged from the sand and gravel of the upland. The saturated peat on this location receives water largely from runoff and shallow groundwater flow from the uplands. Excessive runoff collects at the base of the slope, making the relatively flat area at its base wet after intense rains. We suspect that the coarse sand of the wetland sequence is recharged by infiltration through the sand and gravel of the eastern upland.

The second variation of the first setting (hydrogeologic setting 1B, fig. 39) is found to the south. Here, the marl is missing from the wetland sequence, and there is a spring at the contact between the silty clay and the peat. We suspect that shallow groundwater flow and runoff supply water to the spring. When the geochemistry of the spring was first analyzed, nitrate levels were low. A ten-fold nitrate increase was detected during the fall sampling period. The source of nitrate may have been the liquid fertilizer applied to the large leased field east of the preserve (fig. 36). These data can be used to trace groundwater flow and to calculate the flow rate. Although we do not know when the nitrate first appeared in the spring, the estimated groundwater velocity may be as high as 1 meter/day, suggestive of sand and gravel (Freeze and Cherry, 1979). Runoff and shallow groundwater flow may recharge the peat during intense rainfalls.

The second setting (hydrogeologic setting 2, fig. 40) is found in the southwest corner of the preserve where glacial diamicts crop out at the surface. These diamicts are relatively impermeable and were consequently used to construct dams throughout the preserve. Again the marl is missing in this area, and peat overlies silty clay that confines the underlying sand. In this setting the wetland is supplied with runoff from the surficial diamicts. The impermeable nature of soils developed in the diamicts causes the generation of runoff more quickly in this area than in the eastern areas underlain by sand and gravel.

In the third setting (hydrogeologic setting 3, fig. 41), sand and gravel are overlain by a thin layer of glacial diamict. This area is found in the west-central part of the preserve, where a large kame is veneered with a thin layer of diamict. This setting is also found in the northwestern part of the preserve; the marl is again missing from the wetland sequence and a silt layer overlies the confined sand (fig. 41). The diamict limits the amount of infiltration into the underlying sands and gravels where it is present. The diamict may be missing from intermittent stream valleys, and the sand and gravel may receive direct infiltration. Runoff and shallow groundwater flow may supply water to the peat of the wetlands.

Vegetational history

No cores for pollen analysis have been taken from White Pine Bog, but Gersbacher (1939) analyzed pollen from three cores taken from Fern Lake Bog immediately north of the boundary of The Nature Conservancy property (fig. 36). At the time of Gersbacher's study, Fern Lake was surrounded by swamp loosestrife, a narrow zone of leather leaf, and dense tamaracks; the western edge of White Pine Bog still

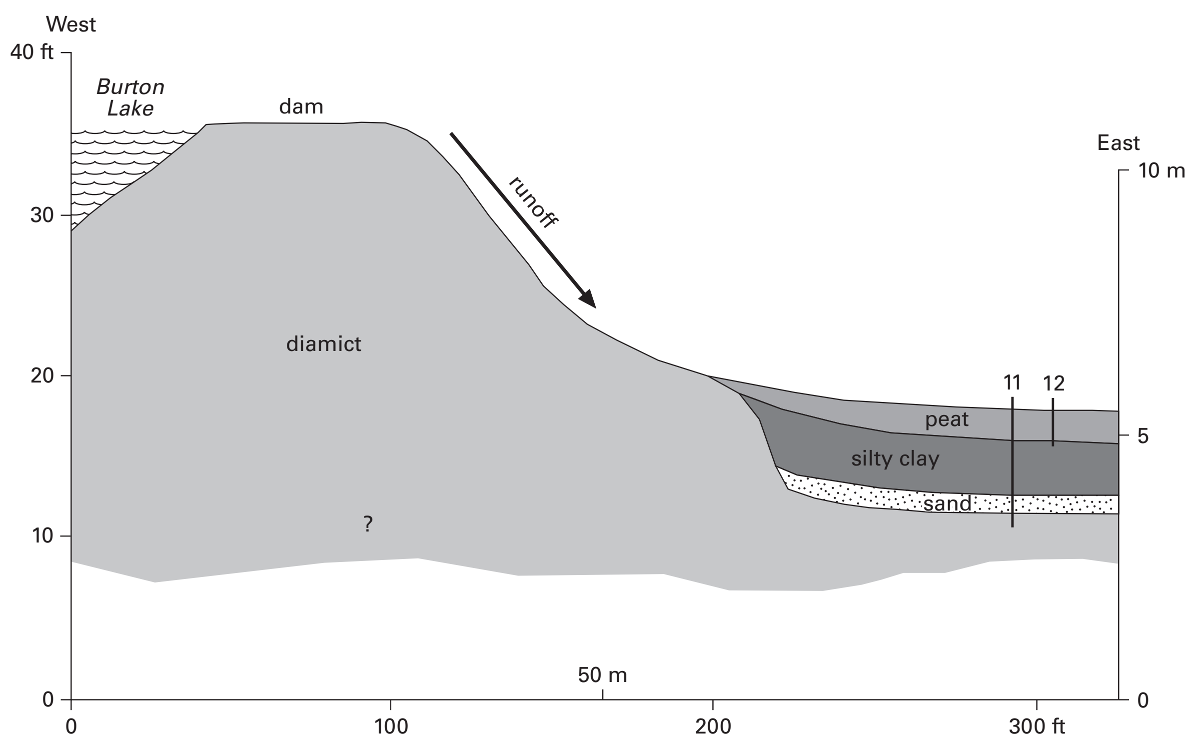


FIGURE 40.—Hydrogeologic setting 2 (vertical exaggeration 5:1) representing glacial stratigraphy in the southwestern part of Nature Conservancy property. Peat is recharged by runoff from low-permeability till in this part of the wetlands.

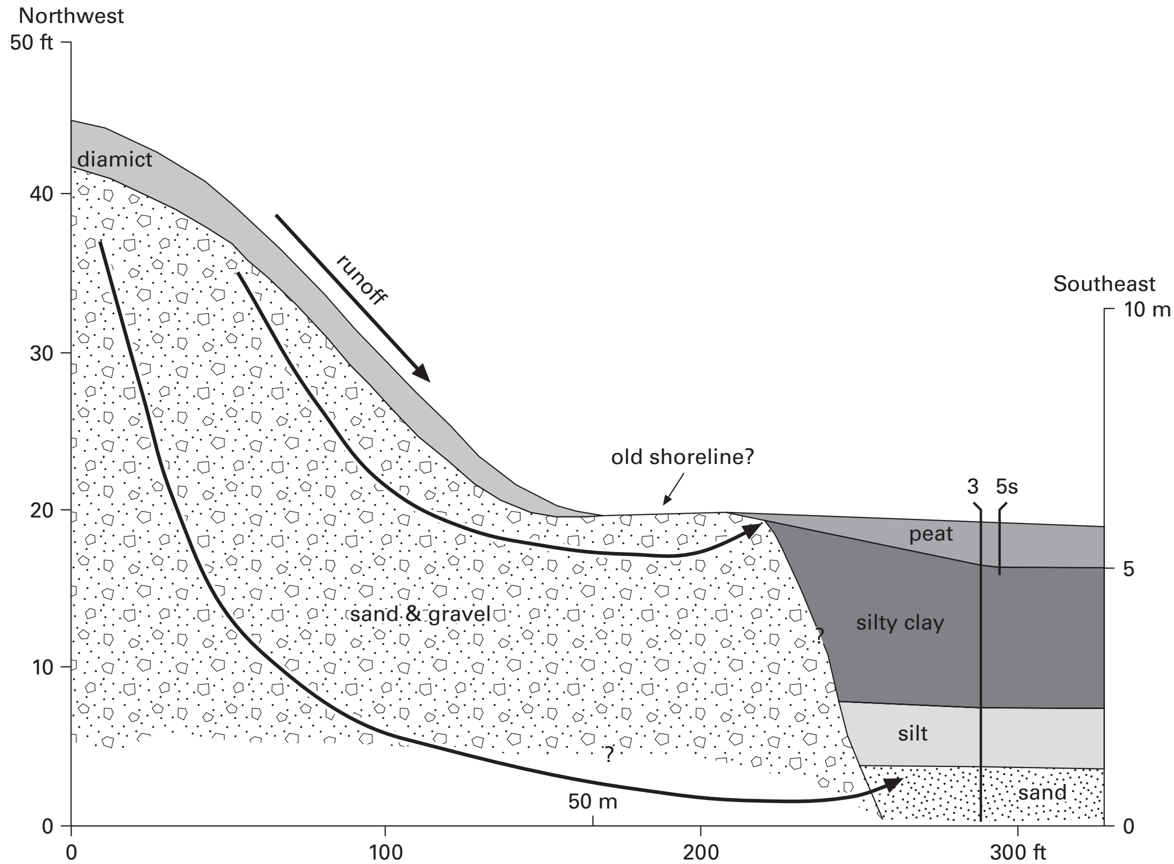


FIGURE 41.—Hydrogeologic setting 3 (vertical exaggeration 5:1) representing glacial stratigraphy in the northwest part of Nature Conservancy property. Till overlies sand and gravel. Peat is recharged by runoff and shallow groundwater discharge in this part of the wetlands.

has a substantial growth of tamaracks. Gersbacher (1939) collected samples from three borings, the deepest of which was 12.8 meters. The first boring was on the north side of the lake and penetrated 9.1 meters of peat and 3.7 meters of marl. The second boring on the east side penetrated 2.4 meters of peat, ending in a sandy forest peat; a third boring penetrated 4.9 meters of peat and 1.2 meters of marl. Almost no pollen was present in the marl; fir and spruce pollen reach maxima in the top of the marl (fig. 42) and decrease abruptly. It is likely that the fir pollen was misidentified because of its abnormally high percentage (Catherine Yansa, personal communication). What was identified as fir pollen may be actually spruce pollen; Shane (1980) found up to 75% spruce pollen in the lowest pollen zone at Battaglia Bog about 16 miles (25 km) south of Fern Lake. Pine is abundant at the transition zone between the marl and the olive ooze. Pine nearly disappears at the upper part of this transition zone where the forest type shifts from coniferous to deciduous. Oak and hickory pollen are dominant in the upper 8.5 meters of the core (fig. 42) and represent the presence of a mixed deciduous forest in the area during most of the Holocene (fig. 43). One unusual aspect of the pollen diagram is that pine increases and beech decreases in the upper 3 to 4 meters of the core (figs. 42, 43), whereas hemlock and larch remain uniform at 1% (Gersbacher, 1939). Thus, this simple study shows the transition from cool and moist to warm and moist during early post-glacial time.

The stratigraphy described by Gersbacher (1939) is somewhat similar to that found in a piston-core boring (p15) in a hydrologic study of White Pine Bog (fig. 36). The magnetic susceptibility, dry density, percent organic matter, and percent carbonate based on loss on ignition were measured at 10-centimeter intervals along the length of the core. The core terminated in dense, gray sand and gravel between 9.1 and 9.3 meters (fig. 44). Olive-gray to dark-olive-gray lacustrine clay containing black blebs of iron monosulfide, indicative of low-oxygen environments, spans the interval from 6.6 to 9.1 meters, has a high density, and contains small amounts of carbonate and organic matter. The clay is paramagnetic, having the largest magnetic susceptibility of all units in the core. Gray, diamagnetic, olive-brown marl dominated by snails and interbedded with dark-grayish-brown, organic-rich zones overlie the clay. Figure 44 illustrates the antithetic relation between carbonate and organic matter in this 2-meter-thick layer; when organic matter increases, carbonate content declines. This interbedded layer may be equivalent to the olive-ooze to marl transition zone found at Fern Lake and suggests that the local environment was

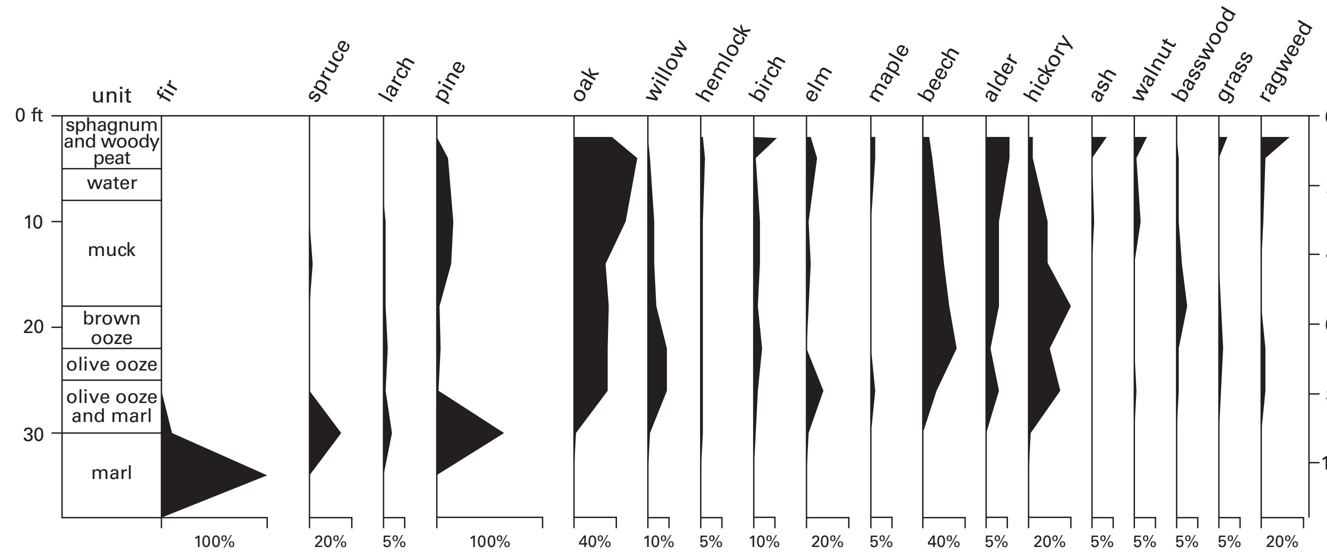


FIGURE 42.—Reconstructed pollen diagram for Fern Lake (Gersbacher, 1939) north of White Pine Bog (fig. 36).

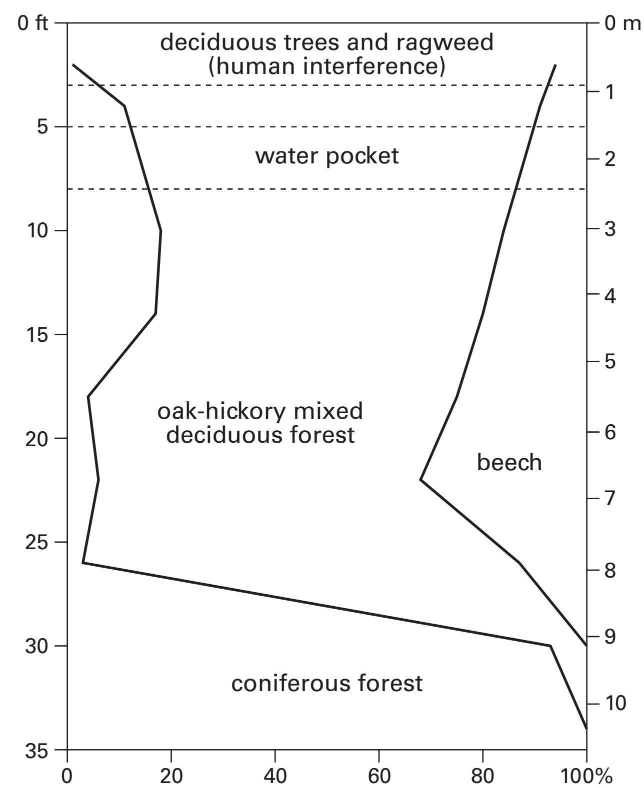


FIGURE 43.—Forest composition interpreted from the pollen record of Fern Lake (modified from Gersbacher, 1939).

in a state of flux. Local conditions were cycling between conditions that favored marl production and those that produced peat. The uppermost layer consists of 4.6 meters of saturated, diamagnetic, brown fibrous peat averaging 80% organic matter (fig. 44) and having occasional wood fragments. Could the resurgence of pine pollen in the Fern Lake cores be attributed to the stand of white pines that occupied White Pine Bog? Further research on the palynology of White Pine Bog is necessary to test the link between the two locations.

Mollusk identifications

by Barry B. Miller and Michael J. S. Tevesz

Mollusk shells were picked from sections of a core from White Pine Bog and identified, as follows: Sediment samples were cut from indexed sections of the core, dried, and disaggregated; and mollusks were picked from these sediment samples using a binocular microscope, forceps, and a finely pointed brush. The mollusk taxa from the core are listed in table 4, following the nomenclature of Clarke (1981), as updated in cases by Turgeon and others (1988).

The mollusk taxa found in this core are species common in lakes in the eastern half of the northern United States. A study by Miller and others (2000) describes the relation of several of these taxa to ambient water chemistry. *Amnicola limosus, Marstonia decepta, Valvata tricarinata, Helisoma anceps, Physella gyrina,* and *Promenetus exacuous* are part of a relatively large group of species found to be associated with a narrow range of "normal" water chemistries, whereas species of *Fossaria* and *Pisidium,* as well as *Gyraulus deflectus*, constitute part of a smaller group associated with high alkalinity lakes. The water chemistry parameters associated with all of these taxa are available in Miller and others (2000), and additional information on using preserved mol-

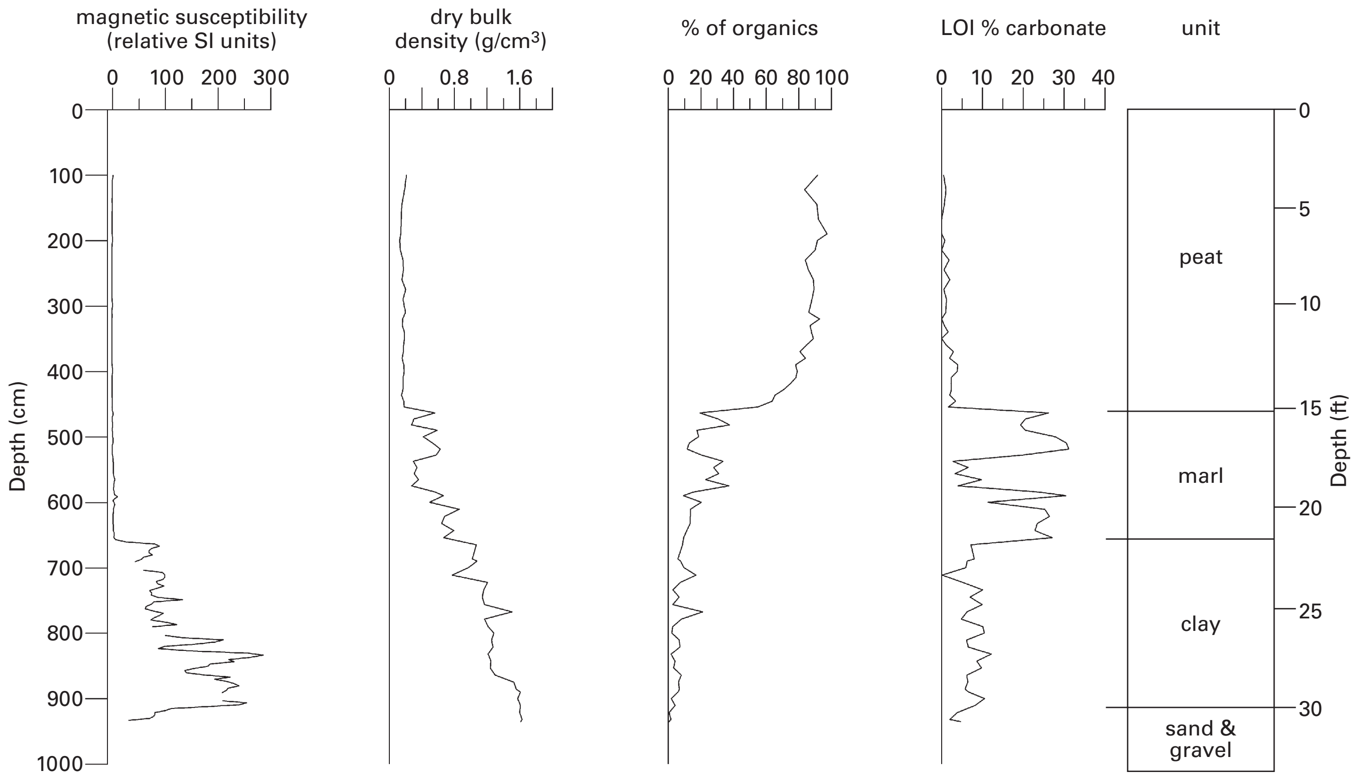


FIGURE 44.—Sediment properties of the core taken from p15 (fig. 36). Note the antithetical relation between percent organics and percent LOI (loss-on-ignition) carbonates (courtesy of Melisa Bishop).

Table 4.—*List of taxa found in the core from p15*

Prosobranch (gill-breathing) gastropods	Pulmonate (lung-breathing) gastropods	Pisidiid bivalves (fingernail and pill clams)
Amnicola limosus (Say, 1817)	*Carychium* sp.[1]	*Musculium* sp.
Marstonia decepta (Baker, 1928)	*Ferrissia* sp.	*Pisidium* sp.
Pomatiopsis lapidaria (Say, 1817)	*Fossaria* sp.	*Pisidium compressum* Prime, 1852
Valvata perdepressa Walker, 1906	*Helisoma anceps* (Menke, 1830)	
Valvata tricarinata (Say, 1817)	*Gyraulus deflectus* (Say, 1824)	
	Physella gyrina (Say, 1821)	
	Physella/Physa sp.	
	Promenetus exacuous (Say, 1821)	

[1]This is the only terrestrial species; the remainder are aquatic.

lusks to reconstruct the history of lacustrine environments is presented in Miller and Tevesz (2001). In this core, taxa from both groups occur together, perhaps suggesting that water chemistry fluctuations may have occurred during the time interval represented by the interbedded marl and organic layers in the White Pine Bog core and possibly the marl to olive-ooze transition at adjacent Fern Lake.

ROAD LOG: STOP 5 TO THE UNIVERSITY OF AKRON

The route to The University of Akron from Stop 5 follows Pond Road to Rapids Road. Turn right (south) at Rapids Road and proceed to U.S. Rte. 422 (fig. 15). Again turn right (west) onto U.S. Rte. 422 and cross La Due Reservoir, another impoundment to supply water to the city of Akron. The city owns 10,000 acres (4,050 hectares) in Geauga County. Continue westward towards Bainbridge where there is a transition from till-covered ice-contact topography to ground moraine of the Hiram advance of the Cuyahoga lobe. Before Ohio Rte. 91 in Solon, road cuts are covered by vegetation but vary in composition. Some cuts are in sandstone and shale, whereas others occur in glacial sediments. Any gullies or slope failures are soon remediated by the Ohio Department of Transportation. The Cochran Road exit leads to the

Glenwillow landfill sites in which most of the trash from the eastern suburbs of Cleveland resides. There are a few kames in the area and glacial deposits are over 30 meters thick. Past Cochran Road, follow the signs for I-271 south to Columbus; at its intersection with I-480, I-271 cuts through sandy tills of the Kent advance. These tills are pebbly and do not form gullies as easily as the younger clay-rich tills. North of Ohio Rte. 82, I-271 cuts across an upland in Mississippian shale covered by ground moraine. Just past the Ohio Rte. 82 interchange, exit to the right to join Ohio Rte. 8. Turn right (south) onto Ohio Rte. 8. Between this intersection and Graham Road, Ohio Rte. 8 follows a buried valley filled with Wisconsinan deposits. Much of the topography over the valley was formed by lacustrine deposition around kames and knobs of till (Wilson, 1991). The route from Graham Road to the university is the reverse of that at the beginning of this trip.

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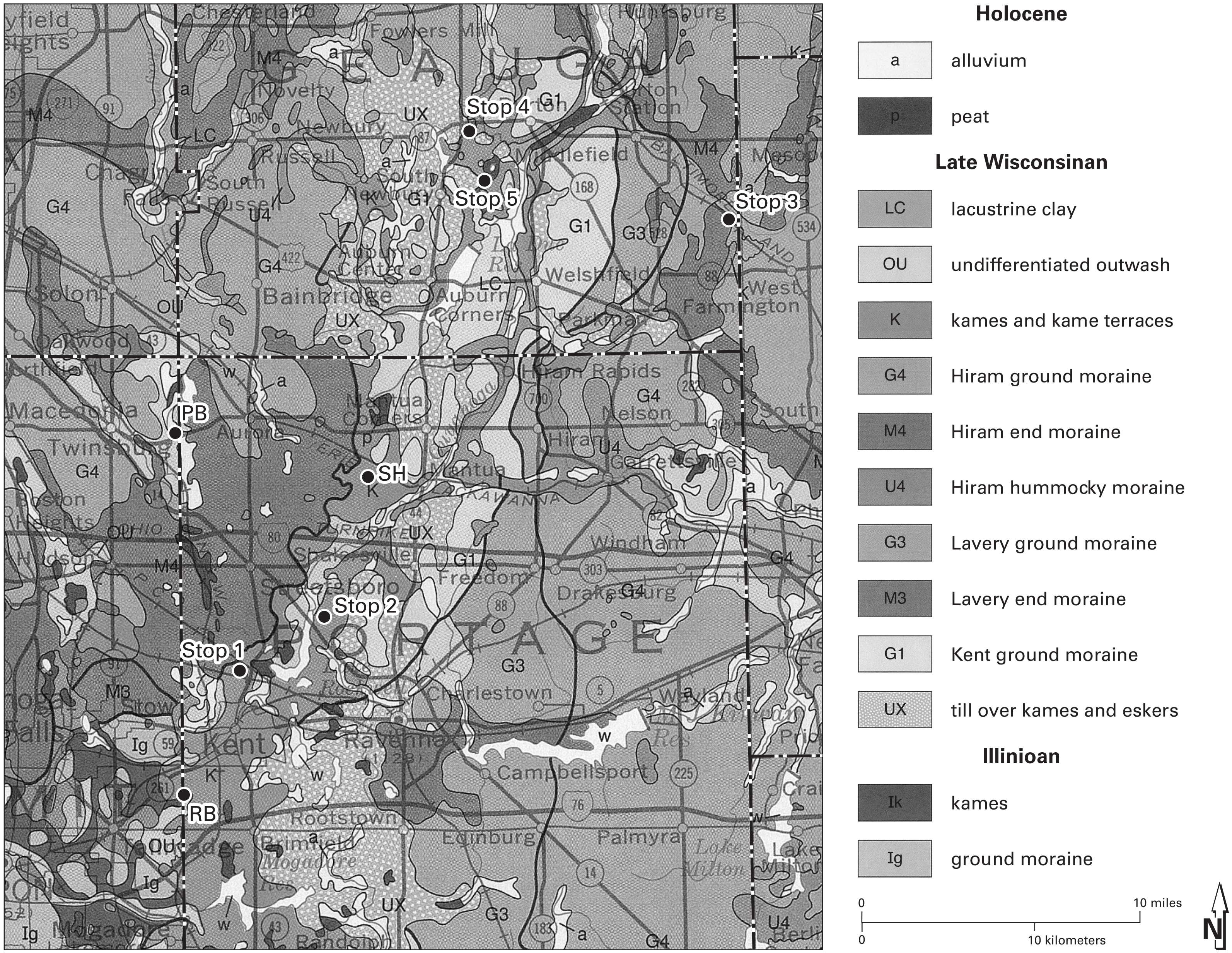

Portion of the glacial map of Ohio showing Stops 1-5, borings (RB and PB), and a measured section (SH) noted in the text.