Postglacial Landscape Evolution of Northeastern Lower Michigan, Interpreted from Soils and Sediments

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In this study, we used spatial data on soils, near-surface stratigraphy, and paleotopography to reinterpret part of the Late Pleistocene history of northeastern (NE) lower Michigan. We determined the relationships between various soil series and their likely sedimentary environments. Maps of these soil series for two counties in NE lower Michigan were then prepared within a geographic information system (GIS) to interpret the spatial patterns of the sedimentary environments on the paleolandscape which had been "downwarped" within a GIS to account for isostatic rebound. Our primary finding centers on the origin and distribution of clayey, lacustrine sediments in the region. These clays are found in swales between drumlins and on ground moraines. They occur, however, at elevations up to 60 m above any previously known paleolake. Although it is widely known that low-lying, clay-dominated areas near the Lake Huron and Lake Michigan basins were inundated by paleolakes in the Late Pleistocene, thick deposits of lacustrine sediments between drumlins in the *high interior* of this region suggest that it, too, was periodically submerged between 11,200 and 13,000 yrs B.P. Additionally, the crests of these drumlins are covered with 50–100 cm of sediment that appears to have been water-worked at some time in the past, overlying a denser, less altered till. We argue that a previously unknown lake, or series of interconnected lakes, existed across the uplands of this landscape. Stratified silts and clays were deposited beneath this water body, which was ponded between the Port Huron moraine to the south and an advancing, stagnant, or retreating ice margin to the north and east, and may have discharged to the south across a low section of the moraine. Our findings underscore the complex interactions among ice sheets, meltwater, and preexisting landscapes during final deglaciation, and should assist those who seek to understand and explain modern soil and biotic patterns on those landscapes. We hope that our preliminary findings facilitate further hypothesis generation and testing regarding this lake(s), this landscape, and their coevolution. *Key Words: glacial geomorphology, soil geography, paleolakes, lacustrine clays, paleoenvironmental reconstruction, GIS, Digital Evaluation Models.*

Understanding the relationship between soils and their parent materials can provide important information about paleolandscapes and the geomorphic processes that shaped them. Glacial processes during the Late Pleistocene have dramatically affected most of the Great Lakes region (Mickelson et al. 1983; Attig et al. 1989). Because these landscapes have generally been subjected to soil-forming processes for less than 16,000 years, the impact of pedogenesis on the sediments has been minimal, allowing correlations between soil series and their respective sedimentologic system(s).

In this study, centered on northeastern (NE) lower Michigan, we provide new evidence from sediments, soils, and landforms that supports the hypothesis that a longstanding paleolake or series of paleolakes once covered this landscape to levels much higher than previously recognized. We use this information to add, incrementally,

Annals of the Association of American Geographers, 90(3), 2000, p. 443–466

Published by Blackwell Publishers, 350 Main Street, Malden, MA 02148, and 108 Cowley Road, Oxford, OX4 1JF, UK.

to the existing knowledge base on postglacial landscape evolution in the upper midwest. In so doing, we advance our understanding of landscape evolution in the northern Great Lakes region and bring to the fore the points that clayey sediments on uplands therein are quite widespread, yet poorly documented; further, information about the lake (or lakes) in which they formed remains extremely elusive. Our study falls short in that we do not propose *detailed* information or explanations for these sediments and the lake(s) that led to their formation. Rather, we draw this dilemma to the attention of the scientific community, do some preliminary mapping of the sediments, and propose some testable hypotheses as to their origins, in the hope that our work will be carried on by others and that it will foster additional hypothesis generation and testing.

Morphostratigraphic data on this region were first presented by Leverett and Taylor (1915), but very little work in the region has been done since (Bergquist 1942; Melhorn 1954; Burgis 1977). Late nineteenth- and early twentieth-century mapping of glacial landforms, as exemplified by the work of Frank Leverett and Frank Taylor in Michigan (Leverett 1899, 1913; Leverett and Taylor 1915) was done primarily on foot and horseback with aneroid barometer, base map, and field notebook as the primary field "tools" (Rieck and Winters 1981). Later, topographic maps and aerial photographs became standard field apparatuses, and researchers traveled in motorized vehicles. Our study is an example of how these traditional "tools," coupled with Digital Elevation Models (DEMs) and a GIS, can facilitate mapping and interpretation of geomorphological features. We use digital, spatial data (county-level soil maps and elevation data), not available to earlier researchers, to better understand the spatial distribution of various postglacial sedimentary environments. In so doing, we compile a new landform map for the region, derived from a combination of fieldwork and analysis of these spatial data.

Background

Late Pleistocene and Holocene History

Although lower Michigan has been repeatedly glaciated during the Pleistocene (Farrand 1995), comparatively little is known about its Late Pleistocene and Holocene history, when contrasted with neighboring states (Ruhe 1969; Willman and Frye 1970; Wright 1989). There are several possible reasons for this:

1. Michigan's geomorphic history is complex and incorporates a great variety of spatially and temporally interrelated processes (deglaciation, rapid climatic change, isostatic rebound, paleolakes, drainage reversals, complex interlobate processes) over a short timespan, specifically ca. 14,000 to 9,000 yrs B.P.
2. Michigan's Pleistocene stratigraphy is spatially discontinuous, unlike the till sheets of Indiana, Illinois, and Iowa. As a result, mapping of till and outwash facies is not easily accomplished, leading to substantial uncertainty regarding the extent of some glacial advances and their associated sediments.
3. Sedimentologic and dating misinterpretations have introduced confusion into the literature. Farrand et al. (1969), for example, assigned a combined Port Huron/Valders age to sandy red till overlying the Cheboygan bryophyte bed; this till has since been shown (cf. Larson et al. 1994) to be Valders (now termed Greatlakean) in age. Additionally, Burgis (1977) may have misinterpreted red lacustrine clays as till.

The terrain of northeastern lower Michigan owes most of its characteristics to subglacial and proglacial processes. By about 13,000 yrs B.P., the Port Huron readvance of the Laurentide ice sheet had extended to its maximal position in northern lower Michigan—the Port Huron moraine (Figures 1 and 2). Great thicknesses of outwash were deposited at and beyond this moraine (Blewett 1991; Blewett et al. 1993; Blewett and Winters 1995; Figure 1). Subglacial landforms such as drumlins and eskers were also formed at this time. Also, water was ponded in low-lying landscapes that bordered the Port Huron ice margin (Leverett 1939; Eschman and Karrow 1985; Figure 2).

During the meltback of the Port Huron ice (Two Creeks Interstade: 13,000 to ≈12,000 yrs B.P., see Figure 2), a series of short-lived proglacial lakes came into existence between the retreating ice margin and the uplands in the interior of the peninsula (Eschman and Karrow 1985). Some of the longer-lived lakes associated with the retreating Port Huron ice margin in the eastern lower peninsula include Lakes Warren and Wayne, and a lower lake, Grassmere. Burgis

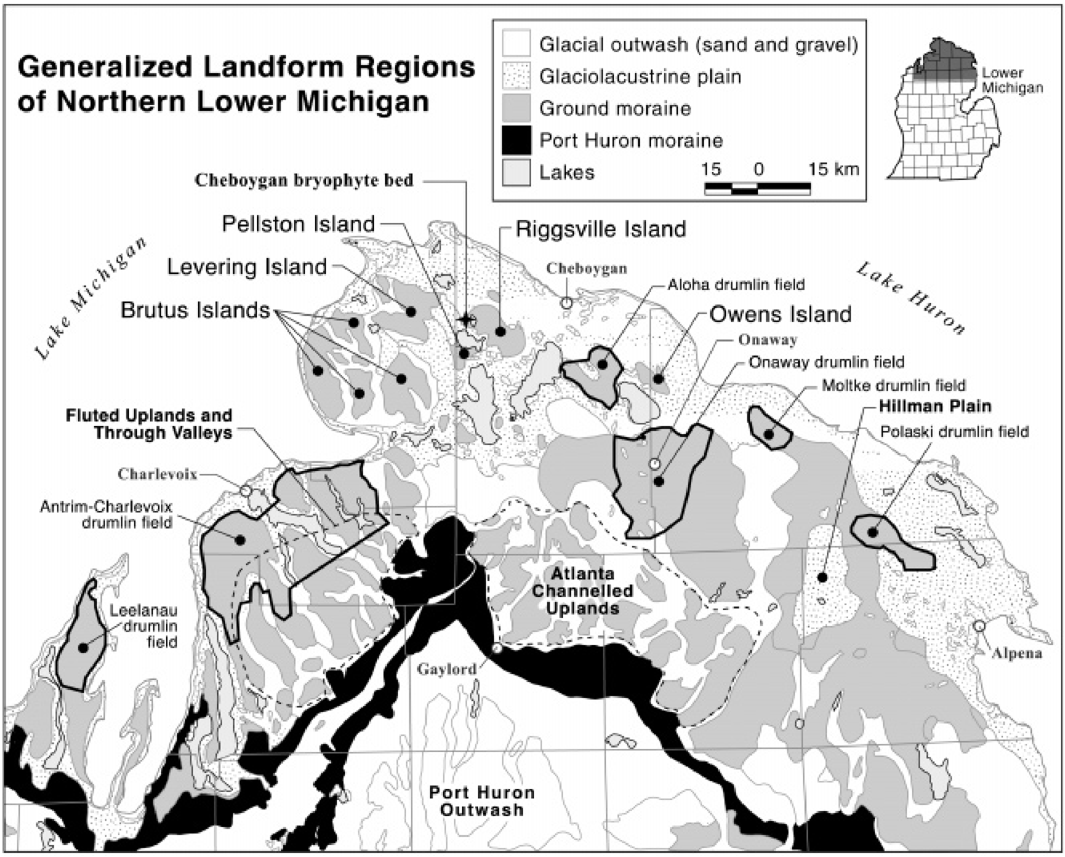

Figure 1. Generalized, regional landform map for extreme northern lower Michigan, with locations of major cities and rivers. Source: modified from Farrand and Bell (1982) and Larson et al. (1994).

(1977) believed that, in NE lower Michigan, the ice margin that held in Lake Grassmere was only a short distance north of the Port Huron moraine. Some of these proglacial waters had embayments within valleys of the Atlanta Channelled Uplands, which lie immediately northeast of the moraine (Figure 1). Burgis thought that red clay deposits in the Atlanta Channelled Uplands date to Grassmere, when water between the Port Huron moraine and the retreating ice margin was more-or-less stagnant. Continued glacial retreat uncovered an outlet for Lake Grassmere in what is today Sucker Creek, in Alcona County.

The ensuing glacial readvance, initially known as Valderan but since renamed Greatlakean, extended well into the Lake Michigan basin, advancing into eastern Wisconsin and western lower Michigan (Black 1970; Evenson et al. 1976; Maher and Mickelson 1996; Figure 2). The southern and eastern limits of this advance in northern lower Michigan and the Lake Huron basin are still unclear, primarily because it left no prominent end moraine and because the character and color of its drift (red versus brown) is in question (Melhorn 1954; Burgis 1977, Farrand 1995).

A till sheet of Greatlakean age occurs near Two Creeks, Wisconsin, where it overlies a buried forest radiocarbon dated at about 11,800 yrs B.P. (Broecker and Farrand 1963). In northern Michigan, near Cheboygan, sandy, reddish till overlies a buried bryophyte (moss) bed that is dated between 11,400 and 12,100 yrs B.P.; the till is therefore interpreted to be of Greatlakean age (Larson et al. 1994). This location, known as the "Cheboygan bryophyte bed" (Figure 1), provides the only definitive evidence of Greatlakean ice in the Lake Huron basin. In NE lower Michigan, Burgis (1977) identified isolated patches of a red, clayey deposit that crop out in

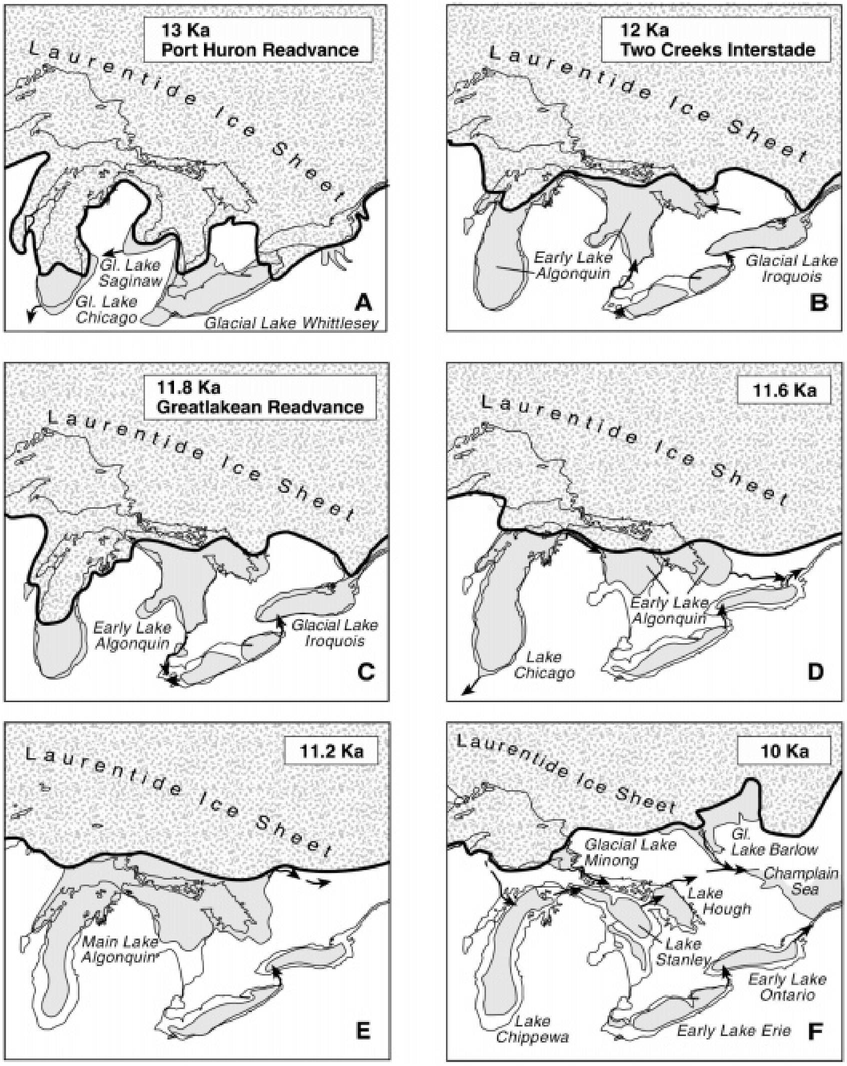

Figure 2. Geographic extent of some of the pertinent, major glacial lakes and ice-marginal position in the Great Lakes region. Source: after Eschman and Karrow (1985) and Hansel et al. (1985).

and on top of drumlins near Onaway, Michigan. She interpreted this sediment to be of Greatlakean age and named it the "Onaway till." Burgis (1977) therefore concluded that Greatlakean ice had advanced into NE lower Michigan, and she named it the "Onaway advance."

The Greatlakean advance has been credited with shaping many drumlin fields in northern Wisconsin and Michigan (Bergquist 1941, 1942; Burgis 1977), such as the Onaway field in northeastern lower Michigan (Fig. 1). These fields are important to this study because they have similar sediments and soils on the drumlin crests and sideslopes—Emmet and Onaway sandy loams and fine sandy loams (Schaetzl 1996; Table 1). Comparable soils and sediments on these drumlin crests are taken to indicate similar sedimentary environments during formation.

Most of the large proglacial lakes that existed before 11,500 yrs B.P. in southern Michigan occupied the southern end of the Lake Michigan or Erie basin, or Saginaw Bay (Eschman and Karrow 1985; Hansel et al. 1985; Larsen 1987; Hansel and Mickelson 1988, Figure 2). If they did extend into NE lower Michigan, they were probably short-lived and associated with a re-

Table 1. Thickness of the Upper, Fine Sandy Loam "Cap" in Drumlins of Some of the Major Fields in Northern Michigan

	Menominee Field	Antrim-Charlevoix Field	Onaway, Afton, and Aloha Fields	Polaski Field
Mean thickness of upper material (± st. dev.) (cm)	75.4 ± 26.4	101.8 ± 37.3	69.5[a]	31.0[a]
Number of observations	34 (all auger data)	51 (partly pit, partly auger data)	10 (all pit data)	3 (all pit data)

[a] Standard deviation not calculated due to small sample size. Data partially derived from unpublished research by Wesley Toland under the supervision of Schaetzl, in 1996.

treating ice margin (e.g., Lake Grassmere). For example, Melhorn (1954) postulated that soon after about 11,850 yrs B.P., the retreating Greatlakean ice margin was channeled into thin, weak tongues by preexisting valleys, and that red clay was deposited in proglacial, ponded water in proglacial lowlands (Melhorn 1954). Later, after the complete retreat of the Greatlakean ice sheet, the northern parts of the Lake Michigan-Huron basin became nearly ice-free (Hough 1966; Figure 2). The proglacial lakes in these basins now occupied high-water planes, because (1) ice covered a low-lying outlet in Canada, and (2) the land mass was isostatically depressed (Clark et al. 1994; Larsen 1994). At this time, (11,800–11,500 yrs B.P.), an "Early" phase of Lake Algonquin (Early Lake Algonquin) was established at an elevation[1] of 184 m (605 ft) (Karrow et al. 1975; Larsen 1987; Figures 2 and 3). Little is known about this lake because it was very short-lived, and evidence for it, either as shoreline features or as sediments, is scant (Hough 1963; Eschman and Karrow 1985).

At this same general time, evidence exists in southwestern Ontario for proglacial Lake Schomberg (Putnam and Chapman 1936). Near Schomberg, Ontario, over 1200 km^2 of silty clay, varved, lacustrine deposits drape over a drumlinized till plain; till knobs (drumlins) protrude out of the flat lake floor (Putnam and Chapman 1936; Chapman and Putnam 1984; Eschman and Karrow 1985). Lake Schomberg did not leave well-formed, continuous shorelines. Continued retreat of the ice margin at about 11,500 yrs B.P. exposed a low outlet in Ontario, either near Fenelon Falls or Kirkfield, allowing the Algonquin water plane to drop some 15–30 m; this brief low stand is referred to as the Kirkfield Phase of Lake Algonquin (Karrow et al. 1975; Larsen 1987). Eventually the lake level rose to 184 m—the level known as "Main Lake Algonquin" (Harrison 1972), and remained at or near this level for several centuries (Figure 3).

By 11,200 yrs B.P., the Greatlakean ice margin had exposed the Straits of Mackinac (Hansel et al. 1985). Hence, water in the Lake Superior and Michigan basins became confluent with water in the Huron basin, and Main Lake Algonquin expanded in area (Fullerton 1980; Futyma 1981; Figure 2). Main Lake Algonquin (hereafter referred to simply as Lake Algonquin) was identified from shoreline evidence in the late nineteenth and early twentieth-century by Spencer (1889) and Leverett and Taylor (1915). Although the exact date of the inception of this lake is questionable, the Main phase of Lake Algonquin had probably been established by 11,200 yrs B.P. (Figure 2).

Beginning at about 11,000 yrs B.P., large inflow pulses from Glacial Lake Agassiz, an immense proglacial lake north and west of Minnesota, entered Lake Algonquin via Lake Nipigon and the Lake Superior basin (Teller and Thorleifson 1983). Some of these discharges occurred as catastrophic outbursts (Teller 1985; Lewis and Anderson 1989; Colman et al. 1994). As new outflow channels were uncovered by the retreating ice sheet, discharges in excess of 100,000 $m^3\ s^{-1}$ might have flowed into Lake Algonquin, potentially and briefly raising lake levels some 20 m (Farrand and Drexler 1985).

As the ice margin continued to retreat across the isostatically depressed landscape, successively lower outlets were uncovered, forming a stepped series of post-Algonquin lakes (Hansel et al. 1985; Figure 3). Eschman and Karrow (1985: 89) concluded that the series of beaches below the Main level were cut in "just a few centuries."

At about 10,000 yrs B.P., continued retreat of the ice margin exposed some very low outlets near North Bay, Ontario, which opened into the St. Lawrence Valley (Hough 1955; Harrison

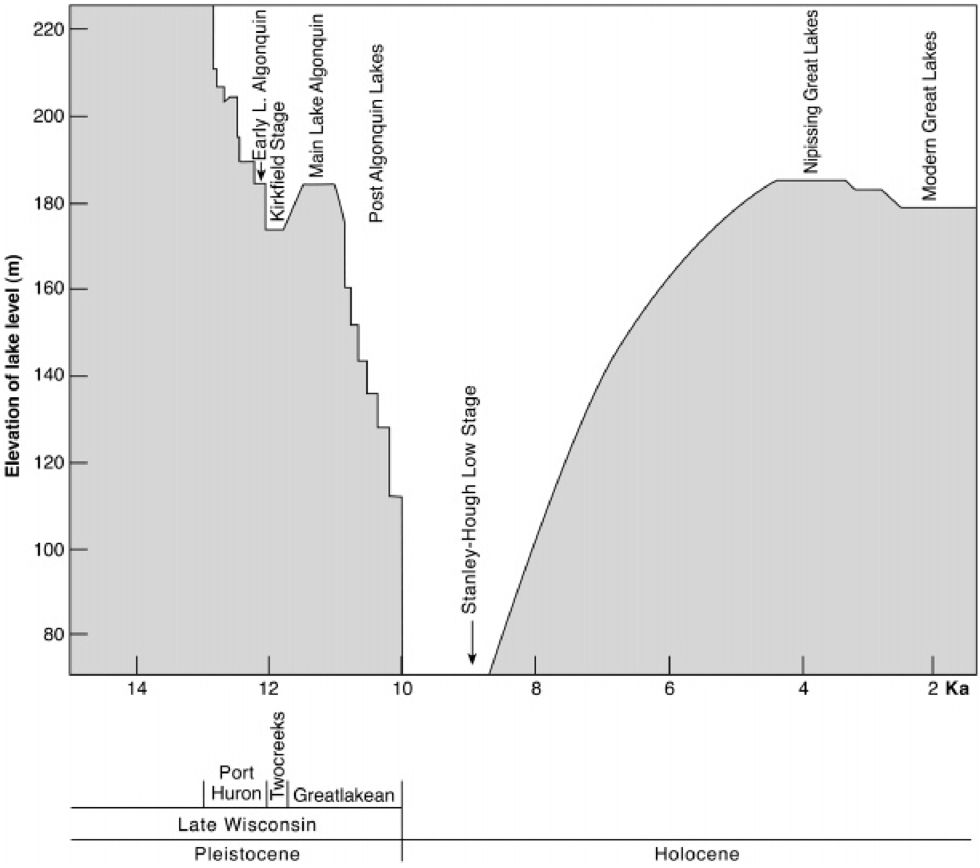

Figure 3. Lake phases and water levels in the Huron basin. Within the study area, modern elevations range from the Lake Huron coast (183 m) to high uplands that exceed 420 m. Source: after Eschman and Karrow (1985). See also Rea et al. (1994) for more detail.

1972; Lewis and Anderson 1989; Colman et al. 1994). Consequently, Lake Algonquin drained rapidly to a new, low level, more than 120 m below its Main level (Figures 2 and 3). This low stage is known as Stanley or Hough in the Huron basin and Chippewa in the Michigan basin (Hough 1955; Bader and Pranschke 1987).

Research Problem

Burgis (1977) assumed that the Greatlakean advance left behind little till (Melhorn 1954). She saw a NE lower Michigan landscape which had pink-brown till on the uplands and isolated patches of red sediment in the swales. She then interpreted the latter as remnants of Greatlakean till (1977: 91, 141). She observed that this "red clayey till . . . exists as a . . . thin patchy veneer in a few isolated flat areas in the drumlinoid region," while the drumlins adjacent to this red clay are formed in brown till (1977: 91). We will argue in this paper that, because this "till" is reddish in color, clayey in texture, and occurs beneath low-lying, flat areas, it is an interdrumlin lacustrine sediment.

The uncertainty regarding the types and origins of surficial deposits in northeastern lower Michigan, in part, prompted this study of near-surface stratigraphy and soils. In light of the background materials discussed immediately above, two general research questions will be investigated:

1. What is the nature (stratigraphic, sedimentologic, and geographic) of the surficial deposits in and near the drumlinized areas in NE lower Michigan, and how do they spatially relate to each other?

2. What do these deposits suggest about late Pleistocene landscape evolution and glacial and paleolake dynamics?

Study Area, Sediments, and Soils

Soil and sedimentologic data in this study derive primarily from Presque Isle and Cheboygan Counties in NE lower Michigan, although data on topography and hydrology from the two adjoining counties to the south (Alpena and Montmorency) are also included. Our emphasis is on sediments in and near drumlin fields in NE lower Michigan (Figure 1). The Onaway field represents the largest drumlin swarm in the NE lower peninsula (Bergquist 1942; Burgis 1977; Schaetzl 1996; Figures 1 and 4). The till within the drumlins is dominantly gravelly and "flaggy" sandy loam in texture. Emmet soils dominate the drumlins where the till is loamy sand or sandy loam in texture; Onaway soils are mapped where the upper sediments are slightly finer-textured (fine sandy loam or loam). Schaetzl (1996) showed that most of the soils in the Onaway drumlins are formed in two distinct parent materials: a substratum of dense, platy till that contains abundant coarse fragments and coarser sands, and an upper material that has fewer coarse fragments and abundant fine and very fine sands. At the interface between these two materials, a stone line or stone zone is occasionally present. In the Onaway field and in many others, reddish brown, stratified, clayey and silty deposits often occur in the swales between the drumlins.

Methods

Field and Laboratory

Thirty-one pits were excavated by backhoe, 23 on drumlin sideslopes or crests and eight in

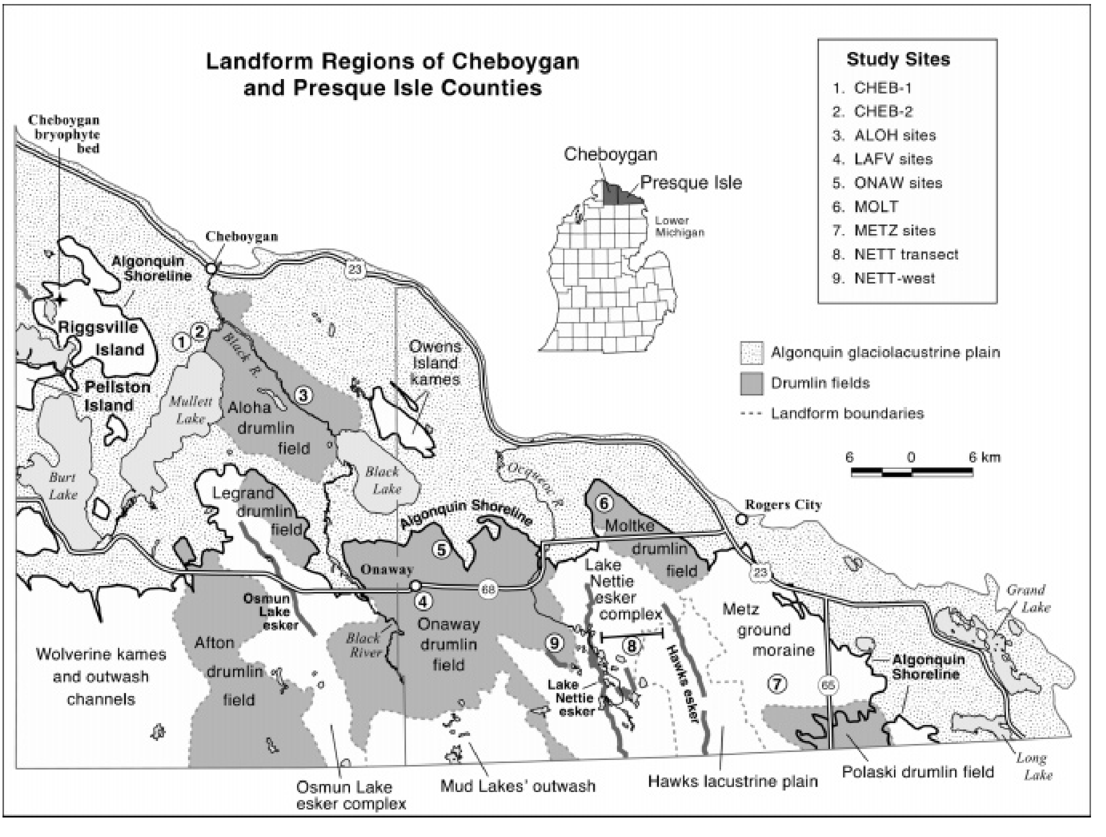

Figure 4. Landform regions of Presque Isle and Cheboygan Counties. Study sites, using names discussed in the text, are shown. The Main Algonquin shoreline is shown as a thick, dark line. Source: modified from Burgis (1977).

swales between drumlins or on the Algonquin lake plain. The two-m-deep pits were sited on representative landscape positions using county soil (Tardy 1991; Knapp 1993) and geomorphic (Burgis 1977) maps. Exact locations for excavation were based on interpretations of samples taken by hand auger. Within each pit, a representative soil pedon was sampled by horizon (Soil Survey Division Staff 1993). Deep samples were occasionally gathered by augering into the bottom of the pit. At other sites, samples were retrieved by bucket auger only, and labeled as to horizon type and depth.

All samples were transported to the Geomorphology Laboratory at Michigan State University, air-dried, and passed through 8, 4, and 2 mm sieves, taking special care not to crush coarse fragments. Standard particle-size analysis was performed by pipette (Sheldrick 1984). The clay mineralogy of selected samples was determined by X-ray diffraction (XRD) on a Philips XRG 3100 diffraction unit. We used four treatments: Mg-saturation, followed by glycolation, and K-saturation, followed by heating to 550°C (Moore and Reynolds 1989). The samples were scanned with CuKα radiation (35 kV, 20mA) from 3° to 14° 2θ. Results were reported as relative (high, medium, low, absent) amounts of kaolinite, micas, chlorite, and a vermiculite-smectite mineral.

Terrain Modeling

Using the TOPOGRID command in ARC/INFO 7.1, a DEM of the study area was generated from contour and hydrology data. Ten-m contour data were obtained from the U.S. Geological Survey (USGS) 1:100,000-scale digital line graphs (USGS 1999). Since manmade features such as dams have altered the flow of the modern hydrology network, a dataset representing the stream/lake network ca. 1800 across the study area was obtained from the Michigan Natural Features Inventory (Comer et al. 1995). Once converted into ARC/INFO format, the hydrology network and contour data were entered into the TOPOGRID command. Using an interpolation method, the TOPOGRID command generated a hydrologically correct DEM from elevation and stream data (ESRI 1999). The horizontal resolution (pixel size) of the output DEM is 30 m.

Although the DEM generated above depicts the modern terrain, it does not properly model elevations of the paleolandscape due to the isostatic rebound that has occurred within the study area (Leverett and Taylor 1915; Larsen 1987). To examine the Late Pleistocene landscape, we generated a second DEM from contours representing the amount of isostatic rebound the study area incurred. These rebound contours were created by digitizing lines between known points of uplift in the study area, located along the Lake Algonquin shoreline. Since the amount of isostatic rebound increases roughly from southwest to northeast (Futyma 1981), the second DEM, generated from the contours of isostatic rebound, is “wedge shaped.” The wedge-shaped rebound DEM values were then subtracted from the first DEM, thereby lowering the elevation values to their original heights ca. 11,200 B.P., when the ice is assumed to have last retreated from the study area.

We used this isostatically adjusted terrain model to simulate interior drainage basins ca. 11,200 yrs B.P. After calculating the surface water flow direction using ARC/INFO, we used the BASIN function to delineate basins. The BASIN function estimates drainage basin extent by identifying ridgelines dividing regions of flow. The lowest point along the rim of each basin, or pour point, was identified to estimate maximum standing water heights (if any) in each basin. We then subtracted the terrain elevation values found within each basin, based on the isostatically adjusted DEM, from the standing water height for each basin to determine potential ponded water depths. For example, in a basin, with a maximum standing water height of 300 m, a point at 250 m of elevation would have been under 50 ft of standing water. All areas containing negative elevation values remained above water and were disregarded. A second isostatically adjusted DEM was generated from USGS 1:24,000-scale, 30-m resolution, DEM data (USGS 1999). Basins and standing water depths were regenerated from this second data set, for the southern half of the study area, to validate the results.

Soils data, compiled by the U.S. Department of Agriculture (USDA), were converted into ARCINFO coverages and rasterized with the IDGSARC and POLYGRID commands, respectively. The digital data for Presque Isle County were originally digitized according to Soil Survey Geographic (SSURGO) database standards. Because the USDA did not rigorously check the soil data from Cheboygan County, it contains sliver polygons, edge-matching errors, and some missing data. Based on descriptions in Knapp (1993) and Tardy (1991), as well as our field observations, most of the soil series in the two counties were placed into a category that best describes the geomorphic or glacial environment under which its parent material was deposited (Table 2). This soil-sediment pairing allowed us to use soils data as surrogates for sedimentary environments. Series that were so broadly described that their environment of deposition was unclear, and those with more than one type of environment of deposition, were not included.

Results and Discussion

Landforms and Sediments of the Study Area

Our goal in this section is to demonstrate that lacustrine clays on various landscapes in NE lower Michigan document the existence of a previously unknown paleolake (or lakes). Our supportive data include the following:

1. Broad, flat landscapes on the fringes of the study area, which were covered by Glacial Lake Algonquin, are floored with thick (>10 m) deposits of lacustrine clay; some of these "flats" are in turn overlain by small dunes.
2. Interdrumlin *swales*, rather than being concave in shape, are planar, and commonly are floored with 2–3+ m of stratified fine sands, silts, and/or clay, which appear to have been deposited subaqueously.
3. On drumlinized *uplands*, soils with lithologic discontinuities (two parent materials) suggest that the drumlins were subjected to at least two different types of depositional environments. The upper sediment on the drumlin crests may have been subaqueously deposited (or at least subaqueously impacted), while the core of the drumlins is glacial till.

In the sections below, we provide field and lab data that substantiate these observations.

Subaqueously Deposited Sediments on Lake Plains and Low-Lying Drumlin Fields. Most of the landscapes on the northern fringes of the study area are the wave-beveled and clay-infilled plains of Lake Algonquin and its lower successors (Figures 1 and 4). This flat landscape is bordered on its south and west by a conspicuous wave-cut bench, the "Algonquin bluff" (Melhorn 1954), which unquestionably delimits the extent of Lake Algonquin. At sites where a conspicuous bluff is not present, we used our rebound DEM to delimit the Algonquin shoreline.

Most of the Algonquin surface contains thick deposits of lacustrine clays, which are veneered with sand of varying thickness (Figure 5). The sands probably indicate wave shoaling during coastal emergence as the lake levels fell (Smith 1982: 197). Our first research site, CHEB-1 (Figure 4), is representative of many areas on the Algonquin surface. It has a thin layer of sand over stratified, lacustrine clay. Melhorn (1954: 110) noted that, between Rogers City and Cheboygan, sands almost invariably overlie red clays. Site CHEB-2 (Figure 4) is also located on the broad, flat lake floor, near the Black/Cheboygan River system, where the sands are sufficiently thin that clayey deposits are within 1 m of the surface. At this site, 59 cm of silts and very fine sands overlie stratified and (at depth) varved, reddish brown (5YR 5/4) silty clays (Figure 6, Appendix). The calcareous, clayey sediments are more than 5 m thick, and of glaciolacustrine origin. These sites provide a context within which to view and interpret other stratified red clays in the study area.

Our research sites (ALOH) in the low-lying Aloha drumlin field (Figures 1 and 4) were also covered by Lake Algonquin to depths exceeding 25 m. The NW-SE trending drumlins of the Aloha field are small, low features, partly because of >3 m infillings of stratified clays in the interdrumlin swales (Figure 7). The interdrumlin clays here are red and stratified—similar to those at CHEB-2 (Appendix). ALOH-S is an auger site in a swale between two drumlins; ALOH-UP is an upland soil pit site on the adjacent drumlin (Figure 4). The stratigraphy at the Aloha field illustrates that thick deposits of lacustrine clay can be deposited onto a preexisting drumlin field, in swales only. Analogs exist elsewhere for clayey infillings between drumlins; in all cases, the clays are subaqueous deposits. In Maine, stratified silts and clays of the Presumpscot formation were laid down by marine submergence of a deglaciated landscape (Stuiver and Borns 1975; Smith 1982; Thompson and Borns 1985). In Ontario, about 3 m of varved clays, deposited beneath paleo-Lake Schomberg, occupy swales between drumlins (Chapman and

Table 2. Sedimentological Characteristics and Geomorphic Groupings of Some of the Soil Series in This Study

Geomorphic/Sedimentologic Grouping	Soil Series Typical of That Grouping	Taxonomic Family of Soil Series
Shallow to bedrock	Bonduel	Fine-loamy, mixed Aquic Eutroboralfs
	Fairport	Fine-loamy, mixed Typic Eutroboralfs
	Hessel	Coarse-loamy, mixed, calcareous, frigid Typic Epiaquolls
	Ruse	Loamy, mixed, frigid Lithic Endoaquolls
	Summerville	Loamy, mixed, frigid Lithic Eutrochrepts
Ice-contact stratified drift and glacial outwash	Rubicon	Sandy, mixed, frigid Entic Haplorthods
	Wallace	Sandy, mixed, frigid, ortstein Typic Durorthods
	Dawson	Sandy or sandy-skeletal, mixed, dysic Terric Borosaprists
	Grayling	Mixed, frigid Typic Udipsamments
	Mancelona	Sandy, mixed, frigid Alfic Haplorthods
	Tawas	Sandy or sandy-skeletal, mixed, euic Terric Borosaprists
	Wheatley	Mixed, frigid Mollic Psammaquents
Eolian sand	Deer Park	Mixed, frigid Spodic Udipsamments
	Rousseau	Sandy, mixed, frigid Entic Haplorthods
Sand over lacustrine clay and silt	Allendale (eolian sand)	Sandy over clayey, mixed, semiactive, frigid Alfic Epiaquods
	Melita (outwash sand)	Sandy, mixed, frigid Alfic Haplorthods
	Pinconning (outwash sand)	Sandy over clayey, mixed, nonacid, frigid Mollic Epiaquents
Lacustrine clay and silt	Bowers	Fine, mixed, semiactive Glossaquic Eutroboralfs
	Cathro	Loamy, mixed, euic Terric Borosaprists
	Hettinger	Fine-loamy, mixed, nonacid, frigid Mollic Epiaquepts
	Nunica	Fine-silty, mixed Eutric Glossoboralfs
	Charity	Fine-silty, mixed, calcareous, frigid Typic Epiaquolls
	Ontonagon	Very-fine, mixed Glossic Eutroboralfs
	Rudyard	Very-fine, mixed Aquic Eutroboralfs
Lacustrine very fine sand and silt	Alcona	Coarse-loamy, mixed, active, frigid Alfic Haplorthods
	Burleigh	Sandy over loamy, mixed, nonacid, frigid Mollic Endoaquents
	Glawe	Coarse-silty, mixed, calcareous, frigid Typic Endoaquolls
	Grace	Coarse-silty, mixed Oxyaquic Eutroboralfs
	Moltke	Coarse-silty, mixed Glossaquic Eutroboralfs
	Brimley	Fine-loamy, mixed, frigid Argic Endoaquods
Calcareous, loamy till on uplands	Cheboygan	Coarse-loamy, mixed, frigid Alfic Haplorthods
	Onaway	Fine-loamy, mixed Typic Eutroboralfs
	Emmet	Coarse-loamy, mixed Typic Eutroboralfs
	Omena	Coarse-loamy, mixed Typic Eutroboralfs
	Krakow	Loamy-skeletal, mixed Typic Eutroboralfs
Reddish, clay loam till	Nester	Fine, mixed, semiactive Oxyaquic Eutroboralfs
Loamy till in swales between drumlins and on lains	Alstad	Fine-loamy, mixed Glossaquic Eutroboralfs
	Brevort	Sandy over loamy, mixed, nonacid, frigid Mollic Endoaquents
	Hagensville	Coarse-loamy, mixed Aquic Haploborolls
Sand over till in swales between drumlins and on lains	Iosco	Sandy over loamy, mixed, frigid Argic Endoaquods
	Ogemaw	Sandy over loamy, mixed, frigid, ortstein Aquentic Haplorthods
	Riggsville	Coarse-loamy, mixed, frigid Alfic Epiaquods
Offshore spits	Esau	Sandy-skeletal, mixed, frigid Aquic Udorthents
	Nadeau	Coarse-loamy, mixed Typic Eutroboralfs

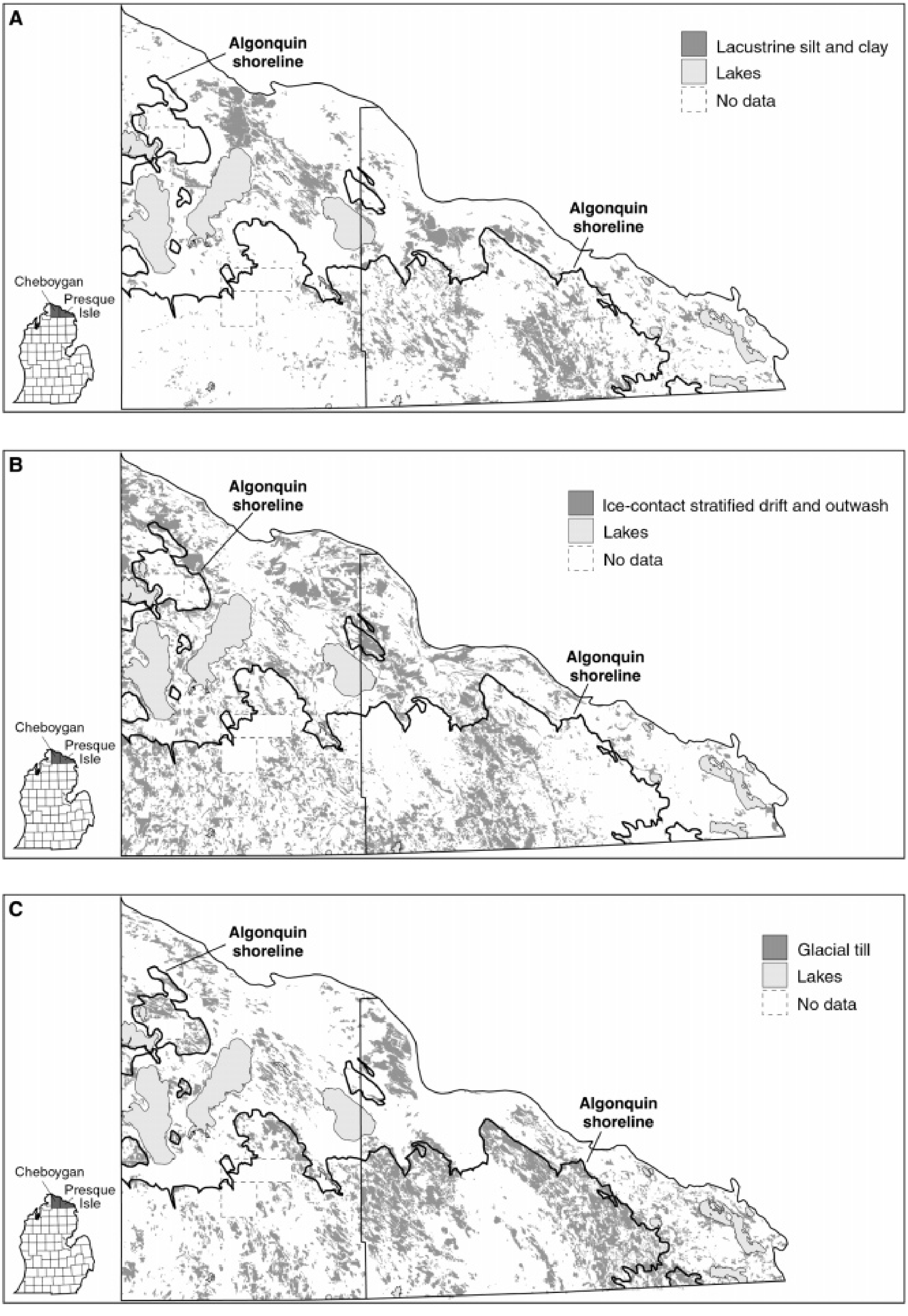

Figure 5. Distribution of the major surficial sediments of Presque Isle and Cheboygan Counties, as interpreted from soils data. Edge matching of soil map sheets in Cheboygan County creates apparent disjunctions in the soil polygons, but does little to affect the overall patterns. The shoreline of Main Lake Algonquin is shown on the lacustrine silt and clay map. Black "boxes" represent areas where data are lacking or of low quality.

Figure 6. Stratified and weakly varved, clayey sediments near Cheboygan, at site CHEB-1. Knife handle and blade are shown for scale.

Putnam 1984). Stalker (1960) described till landscapes with water-laid sediments in the swales in Alberta. In each instance, the contact between the infilled clays and the upland sediments is vertically and horizontally abrupt (Thompson 1982), as it is in the Aloha field.

The lacustrine clays in the Aloha field onlap the till that cores the drumlins. The crests and sideslopes of the drumlins may lack the clay drape because current and wave action were too intense, i.e., the overlying water was shallower. Sedimentological evidence of wave-working of the sediments on drumlin *crests* includes an upper sediment "cap" (Schaetzl 1996). This upper material (i.e., the cap) is less dense, has fewer coarse fragments and coarse sand, is slightly redder than is the dense platy till below, and is almost ubiquitous across the field (Schaetzl 1996). It is usually less than 2 m in thickness.

Parts of the Polaski drumlin field, in the SE part of the study area (Figures 1 and 4), were only shallowly (<3 m of water) inundated by Lake Algonquin. This field lacks the interdrumlin clays found in the Aloha field, but has the same stratigraphy on the drumlin crests. Sites within the Polaski field provide even stronger evidence than at Aloha for the distinctive two-storied nature of the sediments on drumlin crests (Schaetzl 1998). Sedimentologic conditions at Polaski were obviously not conducive to deposition of clay, perhaps because the lake was not as deep or as sheltered from waves driven by the strong easterly winds that dominated Glacial Lake Algonquin (Krist and Schaetzl nd). Sheltering of the Aloha field by Owens Island and its long spit that trails off to the northwest may have created a calm, almost bay-like, "settling environment" there.

Sediments within the Onaway Drumlin Field. Although the sedimentology and stratigraphy of the Onaway drumlin field are quite similar to that of the Aloha field, it is situated well above the highest Algonquin level. The Onaway field is topographically as high as the Moltke field to its east, but is more extensive in area. Data from nine (upland) pedons on Onaway drumlins show that Onaway and Emmet soils, formed in sandy loam or loamy sand till, dominate the crests and sideslopes of the drumlins (Schaetzl 1996). The same soils and the same near-surface stratigraphy (i.e., the fine sandy loam "cap") are found on the crests of the Aloha and Polaski drumlins (Table 1). Swales between the Onaway drumlins usually contain 2–4 m of silty clay or silty clay loam lacustrine sediments, with a thin (<50 cm) fine sandy loam "cap" (Table 1). Thicknesses of the interdrumlin clays are usually greater at Aloha, perhaps because it was submerged for a longer period of time.

Stratigraphic data are presented for the LAFV site, which is representative of an Onaway drumlin and its associated silty clay loam sediments in the swale (Figures 4 and 8). The interdrumlin clays are remarkably similar to those at CHEB-1 and -2, and at ALOH-S—all sites that were inundated by Glacial Lake Algonquin (Appendix).

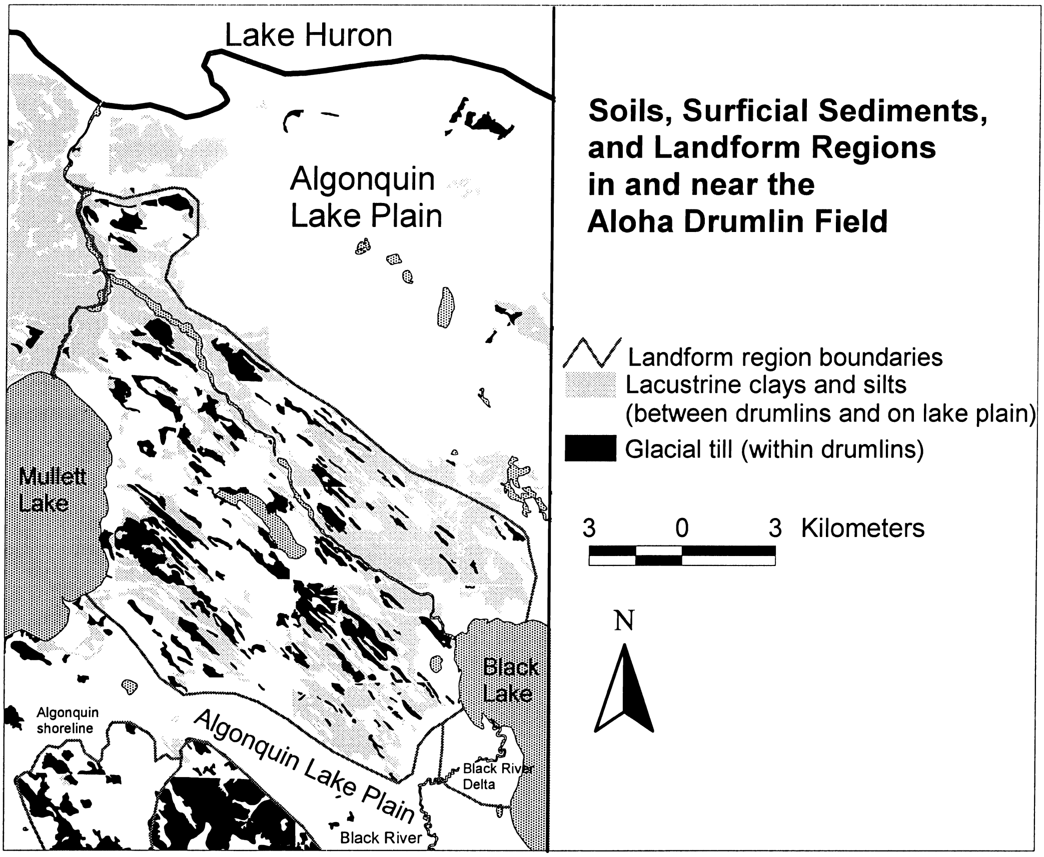

Figure 7. Soils and sediments in the vicinity of the Aloha drumlin field, near Aloha, Michigan, in eastern Cheboygan County. Landform boundaries, as depicted in Figure 4, are shown.

Within the center of the swale (site LAFV-S1) are clayey sediments with excellent stratification, resembling rhythmites of 3–10 mm in thickness, arguing strongly for a lacustrine origin. Deep augering through these sediments revealed sandy loam till below, with a gravelly zone at the interface. Comparable facies relationships occur within the Presumpscot formation in Maine, a marine clay (Thompson 1982). Site LAFV-S3 contains thicker deposits of fine sands over the same stratified clays (Figure 8).

Soils in the flat swales between Onaway drumlins often contain 30–50 cm of loam or fine sandy loam sediments over the lacustrine clay below. This upper zone also contains more fine sand and silt than do the clays below (Appendix). Site ONAW-S, in a swale between two Onaway drumlins, has sedimentology and pedology similar to LAFV-S1 (Figure 4, Appendix). Here, silt loam and fine sandy loam sediments overlie thick deposits of lacustrine clay (Appendix). We attribute the increased amounts of silts and fine sands in the uppermost few dm to one or more possible processes: (1) eolian activity (small dunes are occasionally present on these "flats"), (2) slopewash, either modern or at any time since the lake drained, and/or (3) shallow-water deposition during paleolake drainage.

As at other drumlin sites that have lacustrine clay in the swales (e.g., ALOH), upland pedons (e.g., ONAW-UP) show evidence for a sediment "cap" and a near-surface lithologic discontinuity (Appendix). Dense till of gravelly sandy loam texture is overlain by surficial sediment that contains fewer coarse fragments and finer sands (Schaetzl 1998). The contact between the two is often marked by a concentration of stones and gravel (Schaetzl 1996). We suggest that this upper material, which is usually 30–150 cm in thickness, is a water- and wave-worked equiva-

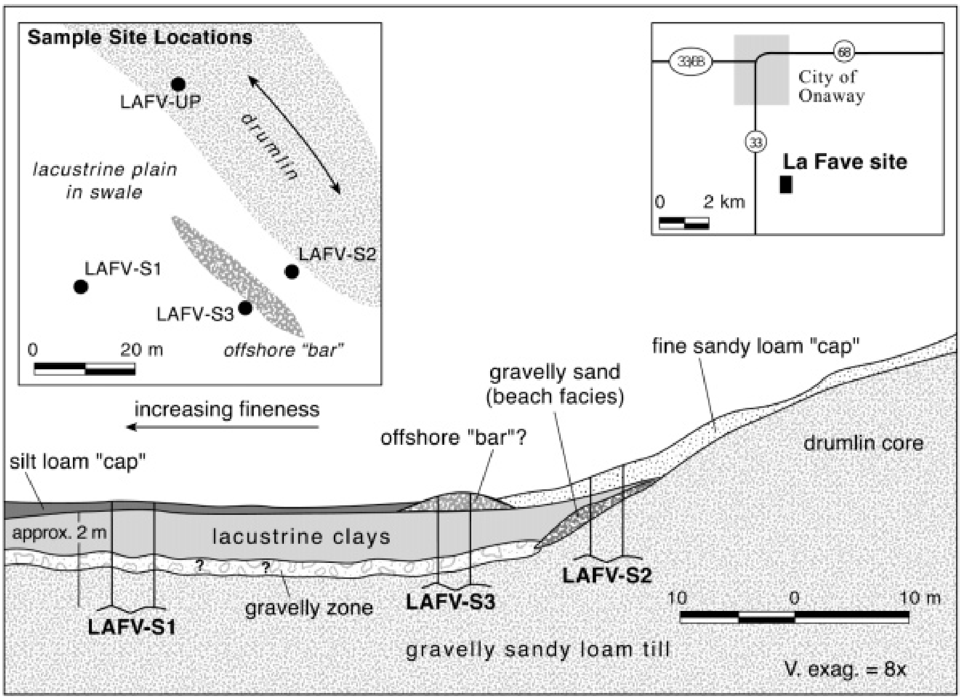

Figure 8. Stratigraphic and pedologic cross section through the LAFV sites, in the Onaway drumlin field: NW 1/4, NE 1/4, Sec. 29, T34N, R2E.

lent of the lower till. Similar material is found on the tops of drumlins that were definitively submerged (Aloha, Polaski). Thus, we suggest that overlying water on the drumlinized landscapes deposited clays in the swales and formed discrete, sedimentological "caps" on drumlin crests. The necessary elements of a scenario under which such a cap could have been formed—a fairly static lake level followed by rapid drainage, leaving no opportunity for the waning waters to rework the sediments or to dissect the clay in the swales—are entirely plausible if one can envision a proglacial lake or lakes in this region.

Sediments within the Moltke Drumlin Field. Drumlin crests within the Moltke field are more than 50 m higher than the Lake Algonquin plain. Despite this, the soils and sediments of the Moltke drumlin field show indications that the field *was* under water in the past. Swales between drumlins are usually floored with a thin mantle of sand (slopewash?) over stratified silty clay or silty clay loam deposits (Knapp 1993; Appendix). Although we only have detailed stratigraphic/soils data from drumlin crests in the Moltke field, reconnaissance data indicate that the sediments in swales are similar to the reddish brown clays in the Onaway field. Soils on drumlinized uplands in the Moltke field have formed in sandy loam or loamy sand tills (Schaetzl 1996; Appendix). A research site in the crest of one of the Moltke drumlins (MOLT; Figure 4) showed sedimentology typical of drumlins elsewhere: fine sand contents decrease below a subtle lithologic discontinuity, while coarse sands increase with depth (Appendix). We used similar upland and "swale" stratigraphy to infer that standing water had covered the field at some time in the past; a similar scenario is suggested for the Moltke drumlins.

Evidence from Nearby Landscapes

The Lake Nettie Esker Complex. Two large areas of ice-contact, glaciofluvial deposits exist in the study area, all of which contain NNW-SSE trending eskers. The first, located south of the Aloha drumlin field, is the Osmun Lake Esker Complex (Figure 4). The specific origin of this large area of sand, with little gravel, is unclear. The second area lies in eastern Presque Isle and northeastern Montmorency Counties; Burgis (1977) named this large area of sand, gravel, eskers, kames, and kettle lakes the "Lake Nettie Esker Complex" (Figure 4). Both areas clearly indicate ice stagnation, and were well above the waters of Lake Algonquin.

The Hillman Plain and Metz Ground Moraine. The Hillman Plain lies to the south of the Lake Nettie Esker Complex. It is a flat landscape dominated by reddish, stratified clays, and extends north as the Metz Ground Moraine (Figure 1). Burgis (1977) suggested that southeasterly-flowing meltwater ponded on the Hillman Plain. Reconnaissance fieldwork and detailed soil mapping by Williams in that area suggests that, near Hillman, thick (>10 m), reddish brown, stratified clayey sediments cover large tracts of land. On the Metz Ground Moraine, the clays do exist, but are not as thick, and thus many till "knobs" protrude form beneath the clay infillings (see below). Burgis (1977: 202) suspected that the Hillman Plain clays were deposited beneath a large lake, formed as ice locally stagnated. Melhorn (1954) noted that large areas of Montmorency County, on the west side of the esker complex, are floored with outwash sand which in turn overlies thick deposits of red lacustrine clay.

Our soil pit on the Hillman Plain (site HILL) contained thick, rhythmic, silt loam and clayey deposits (Appendix). It lacked the fine sand cap so common on lacustrine clays that occur between drumlins, perhaps because no upland sites were nearby to contribute such sediments. The C horizon here was a 5YR 6/3 (light reddish brown) silty clay loam—a color and texture that are extremely similar to lacustrine clays elsewhere (Appendix). Sites at HILL and CHEB demonstrate that lacustrine clays of very similar composition and mineralogy exist at the two extreme ends (near Cheboygan and Hillman) of the study area, and point to a common source (Appendix). All are high in kaolinite and micas, with minor amounts of 2:1 minerals, and little chlorite. Similar data obtained for interdrumlin clays in the Onaway field (Appendix) point to the interconnectedness and large size of the lake or lakes that may have covered the study area, within which these clays were deposited.

Immediately east of the Lake Nettie Esker Complex is the low-relief Metz Ground Moraine (Burgis 1977; Figure 4 and 9). The Metz Ground Moraine has NNW-SSE linearity; low drumlins and flutes can occasionally be observed. Although most of the Metz Ground Moraine lies 20–30 m above the level of Lake Algonquin, it shows evidence for extensive areas of ponded water. Soil and stratigraphic data here are remarkably similar to those obtained at nearby drumlin fields; lacustrine sediments in flat swales overlie till. At a swale landscape position (site METZ-S; Figure 4), we observed about 85 cm of stratified, reddish brown (5YR 5/4), silty clay loam sediments overlying sandy loam till (Appendix). Texturally and mineralogically, the clays here are nearly identical to those on the Hillman Plain, the Algonquin lake plain, and within the swales between Onaway drumlins (Appendix). A pit in the crest of a drumlin

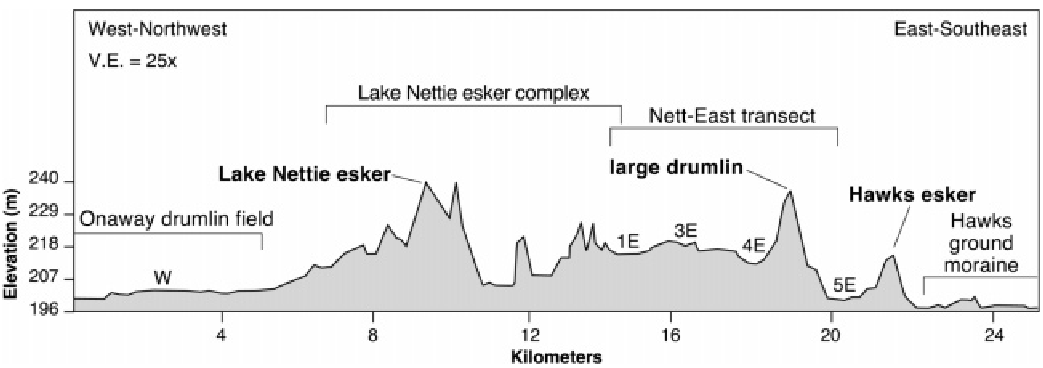

Figure 9. Generalized topographic profile across the Lake Nettie Esker Complex and adjoining landscapes to its east and west: from section 30, T34N, R3E to section 15, T33N, R5E, Presque Isle County, a distance of 25 km. Approximate locations of bucket auger sample sites (W = NETT-west, 1E = NETT-1 east, 3E = NETT-3 east, 5E = NETT-5 east and 5a east) and landform types are shown.

about a km to the east (site METZ-UP; Figure 4) provided data on upland sediments here. As was the case at previous drumlin sites, the soil contained a lithologic discontinuity (Appendix), evidenced by increases in coarser sand fractions and gravel contents, along with decreases in fine sand contents in the lower material, with depth (Schaetzl 1996, 1998). We therefore conclude that water from a paleolake or lakes must have covered the Metz Ground Moraine, as it also did the Onaway and Moltke drumlin fields, and that this water was probably contiguous with a larger expanse to its south, on the Hillman Plain.

We hypothesized that the higher esker complex may at one time, have, formed a shore zone for the water body that covered the Metz Ground Moraine. To test this hypothesis, we examined the sediments and stratigraphy on the Metz Ground Moraine where it abuts the east side of the Lake Nettie Esker, and at one site west of the esker. On the east side of the esker, we sampled soils by bucket auger, along a 5-km transect (named NETT) out onto the Metz Ground Moraine (Figure 4). Our transect, shown in Figure 4 and diagrammatically illustrated in Figure 9, contains sites labeled NETT-1 east (closest to the Lake Nettie Esker) through NETT-5a east. NETT-west was a pit site, located in a dune on the west side of the esker. Here, dune sand overlies lake clays. On the immediate eastern and western margins of the esker, the surficial sands become finer, and gravels are rarely observed. Several km from the esker, however, shallow, thick (>5 m) deposits of lacustrine clays occur. They are overlain by 20–80 cm of fine sand. Some of these sands have destabilized and migrated across this landscape as low dunes. Finally, at sites farther from the esker, and on the Metz Ground Moraine, overlying sand is absent and the clays are subaerially exposed in swales between low ridges. Because the "cover sand" on the lacustrine flats gets both finer and thinner as distance from the esker increases (Appendix), we believe that the source of the sand was the esker itself, and that eolian activity deposited much of the sand after a large lake, that once covered the area, drained.

What We Hypothesize about a Previously Unreported Lake (or Lakes)

The presence of many hectares of stratified, sometimes varved, silts and clays that generally lack coarse sands and gravels, within landscapes that are topographically higher than Lake Algonquin, definitively points to a high-standing water body in the region at some time in the past. The "upland clays" are remarkably similar, mineralogically and texturally, to lacustrine sediments on the Algonquin Plain and the Aloha drumlin field, both of which were submerged for several hundred years (Table 3, Appendix).

Since this area was covered by the Port Huron readvance, any such high-standing lake must postdate its retreat (13,000 yrs B.P.). By 11,200 yrs B.P., the Laurentide ice sheet had retreated from the Straits of Mackinac, allowing waters in the Lake Superior, Huron, and Michigan basins to become confluent, initiating the Main phase of Glacial Lake Algonquin. After this time, positioning a long-standing and extensive lake or lakes in the study area, above the level of the Port Huron and Chicago outlets, would have been impossible. Thus, this water body is temporally constrained between 11,200 and 13,000 yrs B.P.

Figure 10 illustrates the elevations of soil mapping units in the two counties that are developed on lacustrine clay, or in sand overlying clay. About 42 percent of the lacustrine clay mapping units are below the level of Lake Algonquin and are probably directly associated with that lake (i.e., on the Algonquin Plain). Most of the clays, however, are much higher (Figure 10); more than a quarter lie between 200 and 216 m, and were thus far above that level. A few small clay mapping units—"perched" at elevations above 230 m—are isolated to the west of the Black River, in the headwaters of some small valleys that originate in the Atlanta Channelled Uplands (Figure 1). They may have formed during an episode of ponding that was probably disjunct from the main lake or lakes in eastern Presque Isle County. The highest clayey deposits *east* of the Black River valley are at ≈230 ± 10 m, still nearly 50 m above Lake Algonquin.

Before it can be definitively stated that the upland clays predate Lake Algonquin, it must be demonstrated that they could not have originated from inflows from Glacial Lake Agassiz that entered Lake Algonquin (Teller and Thorleifson 1983; Drexler et al. 1983). After about 11,200 yrs B.P., the Straits had become ice-free, and Lake Algonquin received inflows from Lake Agassiz in Canada. If some of these discharges were catastrophic in nature, as has been suggested

Table 3. Clay Mineral Data for Lacustrine Clay Deposits and Tills at Various Research Sites throughout the Study Area[a]

Research Site	Kaolinite	Micas	Vermiculite-Smectite	Chlorite
Lacustrine clay sites				
Onaway field				
LAFV-S	****	***	***	—
ONAW-S	*****	****	***	**
Hillman plain				
HILL	****	****	***	**
Metz ground moraine				
METZ-S	****	***	****	**
Lake Nettie esker transect				
farthest west				
NETT-west	****	*****	***	**
NETT-3	*****	****	****	**
NETT-5	*****	*****	***	**
farthest east				
Upland drumlin sites				
Aloha field				
upper material	*****	*****	*****	*
lower material	****	*****	****	*
Onaway field (LAFV)				
upper material	*****	*****	*****	*
lower material	***	***	***	**
Polaski field				
upper material	*****	*****	*****	*
lower material	****	*****	**	***

[a] Relative amounts of each clay mineral are presented: ***** = very abundant, **** = abundant, *** = common, ** = rare, * = extremely rare, — = undetected.

(Teller 1985; Colman et al. 1994), the level of Lake Algonquin could have temporarily risen by several m. Pools of silt- and clay-laden water, then, could have been left behind on uplands, and upland clays could have remained as evidence.

We examined this scenario by modeling a flood of about 230 m on the isostatically depressed landscape, followed by immediate drainage. If the upland clays were simply remnant deposits from remnant Agassiz "flood pools," clayey soils should spatially correspond to basins of interior drainage on the modern landscape. The results of this simulation show that only about 8 percent of the upland clay deposits occur within basins of internal drainage. Even if we assume that drainage net integration during the past 11,200 years has caused some potential "paleo-pools" to now appear as through-draining lowlands, it surely cannot account for the vast number of sites that would *not* have held ephemeral pools, *and* for the fact that Lake Algonquin would have had to have risen almost 50 m to flood this landscape. We conclude that the upland clays were deposited under a more-or-less static water body or bodies that existed between 13,000 and 11,200 yrs B.P.

Leverett and Taylor (1915: 315) discussed reddish, laminated clays in *northwestern* lower Michigan, where they occur at elevations as high as 268 m and are often overlain by sand or red/pink till. They concluded that these lacustrine clays were closely associated with water ponded in front of either an advancing or a waning ice sheet. Melhorn (1954) felt that, as tongues of Valders (Greatlakean) ice were channeled into preexisting valleys, deposition of red clay occurred beneath proglacially ponded water in lowlands. In southern Ohio, an Early Pleistocene glaciation blocked a prominent drainageway, resulting in the deposition of great thicknesses of lacustrine silts in various proglacial lakes (Bonnett et al. 1991). Thus, analogs exist to support the hypothesis that ice blockage(s) could have caused proglacial ponding in northeastern lower Michigan.

Further evidence in support of submergence comes from drumlins themselves. Drumlins,

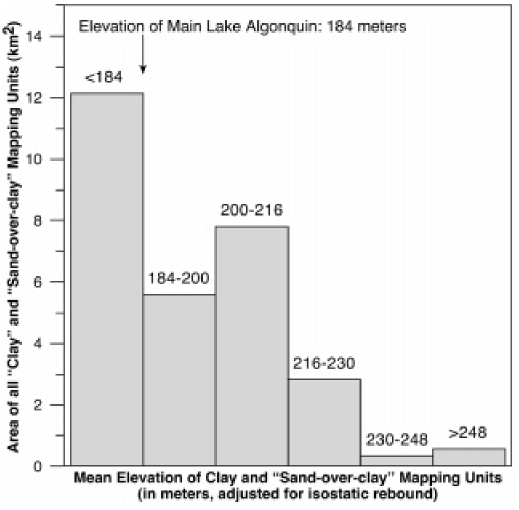

Figure 10. Histogram showing the elevations of all the soil mapping units in Presque Isle and Cheboygan Counties that have as their presumed origin lacustrine clay, or eolian or outwash sand *overlying* clay. In all cases, the elevation of the *mean* point within the mapping unit is taken as the value for the unit. Where more than one similar mapping unit abut, the "joined" unit is counted only once, and elevation of the highest point within the joined unit is used in the histogram.

whether in the Aloha, Onaway, or Moltke field, or on the Metz Ground Moraine, have dense, platy till at depth, with a stone line/zone at about 50–100 cm (ALOH-UP; Appendix). This type of near-surface stratigraphy is usually lacking in the Afton drumlin field, west of the Black River (Figure 1), where we also have not observed clays in swale positions. We suggest that the uppermost sediment on the drumlin crests, once thought to be till (Schaetzl 1996), has been subaqueously modified. Burgis (1977) provided data to indicate that some of the drumlins in this region have a thin cap of till overlying a lower till unit with a different fabric orientation. In all cases, however, the discontinuity she reports between these two deposits is much deeper (>1.4 m) than the one we report (Appendix). Thus, if there are two till units in the drumlins proper, it is only the uppermost one that has been modified by lacustrine processes. Melhorn's (1954: 120) description of the Aloha drumlins, which at one time were submerged by Lake Algonquin, stated that the lake "winnowed out the finer material and sorted and stratified the coarser till" and that this washing action "deposited a layer of sand on their tops." Beaver (1966) studied landscapes similar to those in Northeastern lower Michigan and concluded that the soils, typical of the uplands in eastern Wisconsin, had formed in two distinct parent materials, with a stone line often marking the discontinuity. The lower material, which was often very stony, was assumed to be till; the genesis of upper material was not clear. The above evidence suggests that the thin (60–120 cm) veneer of sediment on the uplands in the drumlinized landscapes of northern Michigan has a different sedimentologic history than does the dense till below (Schaetzl 1996). It is not a till sheet because it is not continuous across the landscape. Data on particle roundness in the upper and lower materials in these drumlins indicated that sand grains from the upper material are typically more spherical and compact in shape (Schaetzl 1998)—subtle properties that could have been imparted subaqueously. We conclude that the upper material is a water-worked sediment.

Similar soils and near-surface stratigraphy in the major drumlin fields in the region (Figure 1; Table 1) support the hypothesis that they have all been submerged at one time in the past. Interdrumlin clays are not known to exist in the Polaski drumlin field, part of which was *shallowly* submerged by Lake Algonquin (Figures 1 and 4). This finding suggests that the Polaski drumlins were ice-covered when other, higher drumlin fields were under proglacial water, and that interdrumlin clays settle out only in comparatively deep water. Aloha, Polaski, Onaway, and Moltke drumlins, however, all exhibit similar upland stratigraphy. This observation, coupled with the interdrumlin clays in the latter three fields, suggests that the above-mentioned drumlin fields were covered by water for some time, and that wave action has created a fine sand or fine sandy loam mantle on them and deposited clays between them.

We examined, but did not field-test, various scenarios that could have created a lake with a water surface at about 260 m. To do so, we were forced to model an ice margin that blocked the major north- and east-flowing drainageways, specifically the Black, Ocqueoc, and Thunder Bay Rivers. This ice dam had to be positioned such that most of the upland, lacustrine clay units lie within its boundary. In so doing, the northern shore of one such ice-dam scenario coincided with either the Algonquin beach or the northern slope of some of the large upland ka-

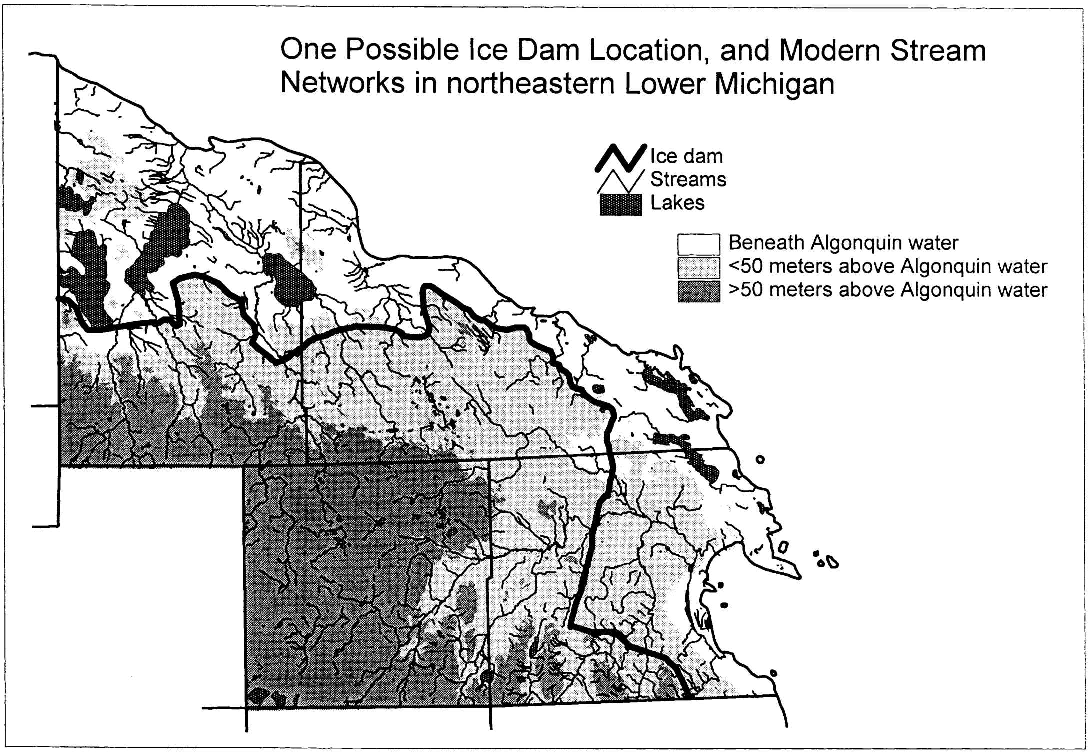

Figure 11. One possible location of an ice dam that could have formed the northern and eastern edges of a lake or lakes in the Late Pleistocene. High lands to the south and east (Atlanta Channelled Uplands and the Port Huron Moraine) would have formed the southern margins of such a lake.

mic masses (Figure 11). The southern and western edges of a lake formed by such an ice dam were ultimately walled in by the Port Huron moraine. On the inner margins of this moraine are the Atlanta Channelled Uplands, which consist on broad, flat valleys floored with various thicknesses of sand or lacustrine clay, between high uplands formed in till (Figures 1 and 11). Burgis (1977: 248) suggested that the Atlanta Channelled Uplands retained water, ponded between the Port Huron moraine and a retreating ice margin, during early Lake Grassmere time. The valleys within may have also functioned as outflow channels; and their steep-walled morphology does nothing to disprove this theory. Our working hypothesis, not yet field-tested, is that a lake or a series of interconnected lakes, deep enough to cover the main uplands in Northeastern lower Michigan, drained tortuously through the southern parts of the channeled uplands, and eventually exited through a col in the Port Huron moraine, perhaps near Flat Lake or via a more easterly path through the Wolf, Sucker, or Comstock Creek drainages. The "interconnnectedness" of these lakes in both space and time cannot be discounted, since inflows would have been quite variable, allowing for rapid rises in lake(s) level. We continue to work to ascertain the shorelines of such a lake, its temporal constraints, and its outlet(s).

Conclusions

Multiple lines of evidence support new interpretations of the Late Pleistocene history of northeastern lower Michigan. Soils and near-surface stratigraphic data reveal that a large body of water, or several interconnected bodies, was ponded across much of southern Presque Isle and northern Alpena Counties, shortly after 13,000 yrs B.P. Thick units of stratified, reddish brown (5YR 4/3) lacustrine clay in swales on even the highest drumlin fields and on ground moraines attest to the presence of standing water, probably walled in by ice dams on its north and east sides, while the Port Huron moraine formed a high upland to the south and east. The water probably drained to the south, though a col in the Port Huron moraine.

These findings illustrate the complexity of rapid deglaciation that occurred in the upper midwest in the Late Pleistocene, and highlight how little we actually know about immediate postglacial landscape evolution. Our study also suggests that ponded water and its associated sediments were much more common on the Late Pleistocene landscapes of the upper Great Lakes region than heretofore thought. Last, the study highlights the point that soils data, manipulated within a GIS, can potentially lead to new discoveries of geomorphic and paleoenvironmental significance.

Appendix. Textural Data for Soils and Sediments at Selected Research Sites Throughout the Study Area[a]

Research Site	Horizon	Sample Depth (cm)	Moist Color	USDA Texture Class[b]	Sand (%)	Silt (%)	Clay (%)	V. Coarse Sand (%)	Coarse Sand (%)	Medium Sand (%)	Fine Sand (%)	V. Fine Sand (%)
CHEB-2[c]	Ap	0–35	10YR 3/3	fsl	63.5	29.5	6.9	0.8	7.9	19.1	7.5	28.2
CHEB-2	Bs	35–51	7.5YR 5/8	fsl	65.8	26.6	7.6	1.2	7.7	17.1	7.3	32.5
CHEB-2	BC	51–59	7.5YR 5/4	sil	29.4	63.3	7.4	0.3	1.9	8.2	4.5	14.5
CHEB-2	2C1	59–86	7.5YR 5/4	sic	0.6	56.1	43.3	0	0.2	0.1	0.3	0
CHEB-2	2C2	86–113	5YR 5/4	sic	1.1	55.7	43.2	0.2	0.2	0.3	0.3	0.1
CHEB-2	2C3	113–140	5YR 5/4	sicl	0.6	62.0	37.4	0	0	0.2	0.2	0.2
CHEB-2	2C3	230–235	5YR 5/4	sic	0.5	57.1	42.4	0	0.2	0.1	0.1	0.1
CHEB-2	3C	370–385	5YR 4/3	c	0.8	29.1	70.1	0.1	0.3	0.2	0.1	0.1
CHEB-2	4C	400–410	10YR 6/4	sil	24.8	71.3	3.9	0	0.8	5.3	4.7	14.0
CHEB-2	5C	435–450	5YR 4/3	sic	0.6	47.2	52.2	0	0.1	0.1	0.2	0.2
ALOH-S	Ap	0–25	10YR 2/1	sl	75.4	10.6	14.0	0.3	10.5	50.0	10.8	3.9
ALOH-S	Bw	25–35	10YR 4/3	s	98.0	2.0	0	0.4	7.3	76.9	12.9	0.5
ALOH-S	C	35–73	2.5YR 4/4	ls	84.4	8.6	7.0	0.6	18.7	48.3	10.6	6.2
ALOH-S	2C1	73–110	7.5YR 4/4	sic	1.0	51.2	47.8	0	0.2	0.4	0.4	0.1
ALOH-S	2C2	110–150	5YR 4/3	sic	0.9	44.9	54.2	0.1	0	0.3	0.2	0.3
ALOH-S	2C3	170–175	5YR 4/3	sic	0.9	48.5	50.5	0	0.5	0.2	0.2	0.1
ALOH-S	2C4	220–230	5YR 5/4	sic	0.4	48.4	51.1	0	0.1	0.2	0.2	0
ALOH-S	2C5	300–315	5YR 4/3	sic	0.2	57.7	42.1	0	0.1	0	0	0.1
ALOH-UP	Ap	0–23	10YR 3/3	sl	69.3	23.0	7.7	3.3	7.2	28.2	24.9	6.7
ALOH-UP	Bs/E	23–31	7.5YR 4/6									
			10YR 5/4 (E)	sl	75.5	16.4	8.1	1.3	7.5	29.9	29.7	7.2
ALOH-UP	E/Bt	31–42	10YR 5/4 (E)									
			5YR 4/4	sl	74.8	16.1	9.1	1.9	6.9	30.3	28.7	7.0
ALOH-UP	Bt	42–56	5YR 4/4	sl	68.3	16.1	15.7	1.3	6.0	27.7	26.6	6.6
ALOH-UP	2C	56–130+	7.5YR 6/4	grsl	64.1	23.0	12.9	2.9	6.8	28.5	19.4	6.6
HILL[c]	C	135–200	5YR 6/3	sicl	7.1	58.8	34.1	0	0.2	1.1	2.2	3.6
NETT-1 east	Ap	0–12										
NETT-1 east	Bs1	12–44		lfs	83.1	14.4	2.5	0.4	0.3	4.0	40.1	38.3
NETT-1 east	Bs2	44–68		fs	89.5	4.3	6.2	0.9	2.0	11.0	46.7	28.8
NETT-1 east	BC	68–85		lfs	84.9	13.9	1.3	0	0	1.9	37.5	45.4
NETT-1 east	C1	85–109		lfs	80.0	19.1	0.9	0	0	1.7	29.1	49.3
NETT-1 east	C2	109–165		vfsl	56.2	40.5	3.3	0	0.1	0.1	3.7	52.3
NETT-1 east	C3	165–210		sil	30.0	58.5	11.5	0	0.1	1.0	5.5	23.5
NETT-1 east	2C1	210–290		sil	5.6	70.8	23.6	0.1	0	0.3	0.6	4.7
NETT-1 east	2C2	300–310		sil	6.5	73.4	20.1	0	0	0	0.7	5.8
NETT-3 east	A	0–20		l	30.2	49.1	20.8	0.4	0.7	7.1	12.3	9.7
NETT-3 east	C1	46–63		sil	6.3	74.0	19.7	0	0.3	2.0	2.8	1.2
NETT-3 east	C1	63–127		sicl	0.7	64.2	35.1	0	0	0.3	0.2	0.2
NETT-3 east	C2	127+		sic	0.2	57.8	42.0	0	0	0	0.2	0
NETT-5a east	A	0–3	no data	no data	—	—	—	—	—	—	—	—
NETT-5a east	Bw	3–30	10YR 4/3	s	87.1	12.9	0	0.2	1.8	34.1	35.9	15.2
NETT-5a east	Bt	30–37	7.5YR 3/4	fs	89.2	4.5	6.3	0	0.3	21.4	52.0	15.5
NETT-5a east	BC	37–80	10YR 4/4	fs	96.8	2.0	1.2	0.1	2.8	37.2	50.6	6.1
NETT-5a east	C	80–98	10YR 4/3	s	96.9	3.0	0.1	0.7	10.2	52.1	32.2	1.9
NETT-5a east	2Cg	98+	7.5YR 5/2	sic	55.9	42.5	0.1	0.2	0.9	0.4	0	
NETT-west	A	0–9	10YR 2/2	s	95.4	4.6	0.1	0.1	6.7	55.0	29.9	3.7
NETT-west	E	9–39	7.5YR 6/2	s	95.4	4.5	0.2	0.4	7.1	56.0	28.9	2.9
NETT-west	Bs	39–53	5YR 5/8	s	94.3	3.9	1.8	0.4	7.0	55.2	29.7	2.1
NETT-west	Bsm1	53–92	5YR 3/4	s	96.6	2.8	0.6	0	4.2	54.1	35.0	3.3

(*continued*)

Appendix (*Continued*)

Research Site	Horizon	Sample Depth (cm)	Moist Color	USDA Texture Class[b]	Sand (%)	Silt (%)	Clay (%)	V. Coarse Sand (%)	Coarse Sand (%)	Medium Sand (%)	Fine Sand (%)	V. Fine Sand (%)
NETT-west	Bsm2	92–115	7.5YR 4/6	s	96.9	2.6	0.5	0.2	4.9	54.2	34.1	3.5
NETT-west	BC	115–127	2.5YR 4/4	ls	85.5	2.8	11.7	0.1	4.6	42.3	34.4	4.1
NETT-west	2C	127–140	5YR 5/4	c	1.3	38.4	60.4	0.4	0.2	0.4	0.2	0.1
NETT-west	2C	190–200	5YR 4/3	c	1.3	37.7	60.9	0.2	0.3	0.5	0.3	0.1
NETT-west	2C	240–250	5YR 4/3	c	4.8	38.1	57.1	0.3	0.4	1.8	1.6	0.8
NETT-west	3C	270–290	2.5YR 4/4	sil	16.4	56.7	26.9	0.2	0.5	1.3	2.1	12.2
NETT-west	4C	290–300	7.5YR 5/4	sic	2.8	41.0	56.2	0.2	0.3	0.8	1.1	0.5
METZ-S[c]	C2	85+	5YR 5/4	sicl	0.2	60.9	38.9	0	0	0	0.1	0.1
METZ-UP	A	0–9	10YR 3/2	l	48.7	42.9	8.6	0.3	1.1	8.5	17.8	21.1
METZ-UP	E	9–28	10YR 4/2	l	49.6	46.1	4.2	0.2	0.5	8.5	18.7	21.6
METZ-UP	Bs	28–37	7.5YR 4/6	l	51.2	41.5	7.3	0	0.5	8.8	24.3	24.3
METZ-UP	E’	37–51	10YR 5/4	sl	67.1	23.0	9.9	0	0.6	8.9	27.6	27.6
METZ-UP	2Bt	51–68	5YR 4/6	cl	39.4	28.4	32.2	1.1	3.6	14.2	14.4	5.8
METZ-UP	2BC	68–109	10YR 5/3	sl	61.3	26.9	11.8	4.4	6.8	22.3	20.8	8.7
METZ-UP	2Cd	109–153+	10YR 5/3	sl	67.0	23.8	9.2	3.0	5.6	25.7	23.5	9.7
MOLT	E	0–20	7.5YR 4/2	ls	73.5	24.6	1.9	0.4	3.5	23.4	25.7	20.5
MOLT	Bs1	20–29	5YR 3/4	sl	65.2	24.5	10.3	0.9	2.9	19.5	22.3	19.9
MOLT	Bs2	29–49	7.5YR 4/6	sl	72.6	21.1	6.3	1.4	5.2	24.2	26.0	16.6
MOLT	E’	49–59	10YR 5/3	sl	75.0	20.0	5.1	1.3	5.9	28.6	30.1	9.1
MOLT	Bt/E’	59–86	7.5YR 4/4 (Bt) 7.5YR 5/4 (E’)	sl	72.5	16.0	11.5	1.6	5.6	27.5	26.6	12.1
MOLT	2BC	86–100	7.5YR 5/4	sl	70.0	20.5	9.5	2.7	7.5	28.7	23.9	8.3
MOLT	2Cd	100–145+	7.5YR 5/4	sl	69.2	21.9	8.9	3.6	8.2	28.3	22.5	8.4
LAFV-S1	Ap	0–27	10YR 4/3	l	39.4	46.1	14.5	0.2	1.3	10.7	9.7	17.6
LAFV-S1	2E/Bt	27–36	7.5YR 6/4 (E) 2.5YR 4/4 (Bt)	l	37.4	37.5	25.1	0.6	1.7	10.8	10.4	14.0
LAFV-S1	2Bt1	36–59	2.5YR 4/4	c	9.3	37.3	53.4	0.3	0.3	3.0	2.9	2.7
LAFV-S1	2Bt2	59–80	5YR 4/4	sic	0.4	40.2	59.4	0	0	0.1	0.1	0.2
LAFV-S1	2BC	80–101	5YR 4/4	sic	0.2	50.0	49.8	0	0.1	0	0	0.1
LAFV-S1	2C	101–160	5YR 4/4	sic	0.2	46.3	53.5	0	0	0	0	0.2
LAFV-S1	2C	160–175	5YR 4/4	sic	0.4	42.0	57.6	0	0.1	0	0.1	0.2
LAFV-S1	3C	198–215		fsl	52.7	34.4	13.0	2.3	6.6	20.3	13.5	10.0
LAFV-S2	Ap	0–19	10YR 3/3	l	49.8	37.5	12.7	0.3	2.5	17.2	14.1	15.8
LAFV-S2	Bw	19–25	7.5YR 5/6	l	47.1	44.1	8.8	0.4	2.4	17.2	12.9	14.2
LAFV-S2	2Bt/E	25–35	5YR 4/4 (Bt) 10YR 6/3 (E)	c	22.2	37.4	40.3	0.1	1.3	7.5	6.5	6.8
LAFV-S2	2Bt	35–67	5YR 4/4	c	1.2	39.3	59.5	0	0	0.4	0.4	0.4
LAFV-S2	3C	67–89	2.5YR 4/4	fsl	66.0	20.1	13.9	1.4	5.1	21.8	24.3	13.3
LAFV-S2	4C	89–121	10YR 5/4	s	88.8	7.9	3.3	1.8	4.7	30.7	38.1	13.4
LAFV-S2	5C	121–135	10YR 5/3	s	94.2	4.6	1.2	2.3	3.9	39.8	38.1	10.1
ONAW-S	A	0–21	10YR 3/1	sil	15.1	59.0	26.0	0.4	0.7	2.0	2.6	9.5
ONAW-S	Bw	21–31	10YR 5/4	sicl	12.1	60.8	27.1	0.2	0.7	1.7	2.1	7.4
ONAW-S	2Bg1	31–55	2.5Y 5/2	fsl	64.3	16.9	18.8	3.6	5.4	20.6	22.1	12.6
ONAW-S	2Bg2	55–87	2.5Y 5/2	sicl	16.9	54.1	28.9	0.2	0.5	1.6	1.8	12.9
ONAW-S	2BC	87–109	5YR 5/4	sil	20.2	55.0	24.8	0.2	1.3	5.7	4.7	8.4
ONAW-S	2C	109–125	2.5YR 5/4	c	24.4	27.1	48.5	0.6	2.0	7.8	8.9	5.1
ONAW-S	2C	160–165	2.5YR 5/4	c	5.2	35.5	59.3	0.4	0.4	1.4	1.6	1.4
ONAW-S	2C	190–205	2.5YR 5/4	c	7.7	33.6	58.7	0.5	0.8	2.6	2.4	1.5
ONAW-S	2C	235–245	2.5YR 5/4	c	11.3	32.4	56.3	0.4	0.6	2.9	4.6	2.9
ONAW-S	2C	250–260	2.5YR 5/4	c	8.8	32.1	59.2	0.3	1.2	3.9	2.2	1.1
ONAW-UP	A	0–21	10YR 2/2	l	49.6	41.3	9.1	1.7	5.6	17.9	14.3	11.1
ONAW-UP	Bs	21–39	7.5YR 4/6	sl	55.4	35.8	8.7	2.9	8.3	18.3	16.6	10.9
ONAW-UP	E	39–48	7.5YR 4/2	sl	61.4	29.4	9.2	3.4	7.2	21.9	18.9	11.5
ONAW-UP	Bt	48–70	5YR 3/4	scl	51.9	25.7	22.4	2.0	5.6	16.9	16.4	11.6
ONAW-UP	2C1	70–144	5YR 4/4	sl	53.9	31.9	14.2	4.2	6.9	17.8	15.7	11.4
ONAW-UP	2C2	144–164+	5YR 4/4	sl	57.0	31.3	11.7	5.0	7.7	18.3	16.8	11.7

[a] Listed in the approximate order discussed in the text.
[b] Texture classes and particle size divisions according to the Soil Survey Division Staff (1993). Abbreviations: s: sand, fs: fine sand, ls: loamy sand, lfs: loamy fine sand, cs: coarse sand, sl: sandy loam, fsl: fine sandy loam, vfsl: very fine sandy loam, grsl: gravelly sandy loam, l: loam, sil: silt loam, cl: clay loam, scl: silty clay loam, sic: silty clay, c: clay.
[c] Data are provided for only a subset of all sampled horizons and pedons, due to space limitations.

Acknowledgments

This study was supported by Grant SBR-9319967 from the National Science Foundation, Geography and Regional Science Program. We thank the many landowners who allowed research on their property: Camilla Algenstedt, Clyde Berry, Julia Brown, Don Butler, Duane Crawford, George Galbraith, Nicholas Heinrich, Larry Karsten, Joe LaFave, John Mason, John Milbocker, LeRoy Ormsbee, Richard Porter, Ed Quade, John Ricci, Ken Scott, Ned Vermilya, and Ray Winters. Bruce Knapp and other personnel from the USDA-NRCS helped locate some of the study sites. Carla Gregory (NRCS) kindly allowed me access to her office while in the field. Bill Blewett, Grahamme Larson, and Alan Arbogast kindly reviewed a previous version of the manuscript.

Note

1. All evaluations listed are above mean sea level.

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