LATE PLEISTOCENE ICE-FLOW DIRECTIONS AND THE AGE OF GLACIAL LANDSCAPES IN NORTHERN LOWER MICHIGAN

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Abstract: Lineation (alignment) of certain landscape features, most of which are glacigenic, and till-fabric data were mapped and used to indicate glacier flow directions in northern lower Michigan. I also reexamine the limit of the Greatlakean (ca. 11,850 ^{14}C yr B.P.) ice advance in northern Michigan. My study assumes that reddish-brown (7.5YR and redder) till in the region was deposited by the last ice advance, the Greatlakean, since this color till covers uplands immediately down ice from an established Greatlakean stratigraphic marker bed. Landscape linearity and till-fabric data within the reddish-brown till landscapes of northwestern lower Michigan both show strong northwest-southeast alignment, indicating that Greatlakean ice advanced out of the Lake Michigan basin. Earlier (Port Huron, ca. 13,000 ^{14}C yr B.P.) ice deposited brown till of 10YR hue, as evidenced at a borrow pit where reddish-brown Greatlakean till overlies brown drift. Thus, the "7.5YR and redder" vs 10YR hue limit is interpreted as the outer limit of the Greatlakean advance in northern lower Michigan. By mapping this limit only a few tens of km southeast of its only stratigraphically confirmed position at the Cheboygan bryophyte bed, I imply that Greatlakean ice did not advance as far into northeastern lower Michigan as others previously have suggested. Port Huron landforms in brown till show similar alignment and till fabrics to Greatlakean landforms in red till, suggesting that Port Huron ice in northern Michigan (also) advanced primarily out of the Lake Michigan basin. As it advanced from the northwest, flowlines and till fabrics suggest that the Port Huron ice gradually curved, eventually flowing north-to-south in northeastern lower Michigan, nearer the Saginaw Lobe. [Key words: glacial geology, drumlins, landscape fabric, Greatlakean advance, Port Huron advance, till fabric, glacial dynamics.]

INTRODUCTION

The terrain of northern lower Michigan, the focus of this study, owes most of its characteristics to glacigenic and glaciolacustrine processes operative since about 13,500 ^{14}C yr B.P. (Although the term "lower Michigan" is colloquial and not as geographically precise as others, such as "Southern Peninsula of Michigan," it has a deeply ingrained usage, and its meaning is unquestioned; thus, the more concise [former] term will be used in this paper.) At about that time, the Port Huron readvance of the Laurentide ice sheet spread into the region. Subsequently, the ice sheet stagnated at its margin and deposited glaciolfluvial sediments within large heads of outwash (Blewett, 1991; Blewett and Winters, 1995; Fig. 1). Radiometric data suggest that the Port Huron morainic system was deposited approximately 13,000 ±

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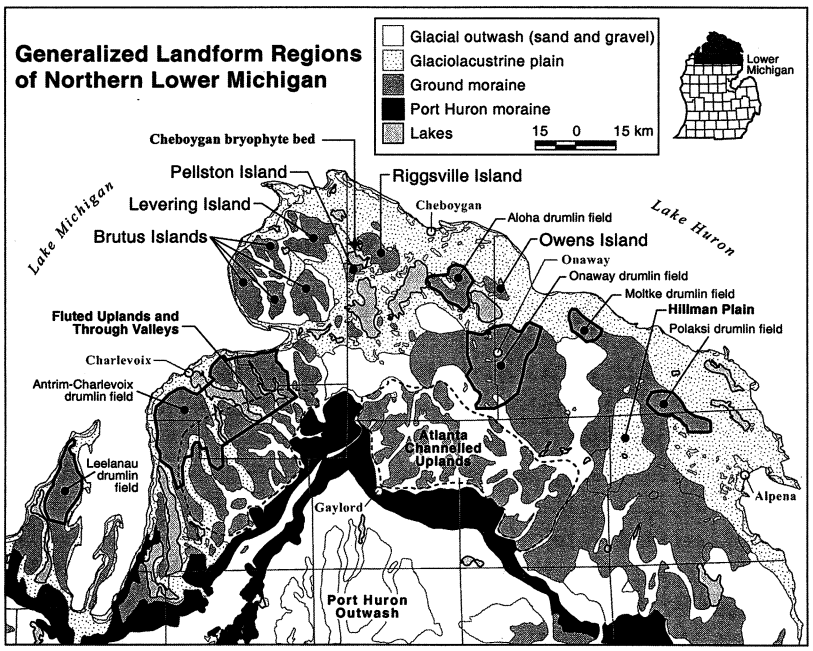

Fig. 1. Generalized landform regions of northern lower Michigan. After Burgis (1977), Farrand and Bell (1982), and Schaetzl et al. (2000). The location of the Cheboygan bryophyte bed (near the top-center of the peninsula) is noted with a star.

300 ^{14}C yr B.P. (Warner and Barnett, 1986; Blewett et al., 1993). At that time, subglacial landforms such as drumlins and eskers, which formed more-or-less parallel to ice-flow direction, also were being formed. The next major advance in the region occurred about 11,850 ^{14}C yr B.P., and has been termed the Valders or Greatlakean (Melhorn, 1954; Evenson et al., 1976). Confusion exists regarding the interaction between these two advances: their direction of advance, their outermost limits, the till they deposited, and the landforms they created. In this paper, I examine regional trends in the linearity of landforms that mostly have direct glacial origins and use those data to infer ice-flow direction. I also use till color and till-fabric data to suggest a general outer margin for the Greatlakean ice. Consequently, these findings suggest that some landscapes in northern lower Michigan are in fact older than previously interpreted.

LATE PLEISTOCENE GLACIAL HISTORY

The Port Huron glacial advance was widespread throughout the upper Great Lakes region (Blewett, 1991). Its ice-marginal landforms are wide and rolling, with a high, conspicuously steep proximal face (often more than 100 m above the till plain behind it); its distal surface is usually gently sloping and underlain by thick outwash (Leverett and Taylor, 1915). An examination of the Port Huron deposits in

northwestern lower Michigan by Blewett and Winters (1995) concluded that the latter phases of this advance were characterized by widespread stagnation and rapid melting. Although Port Huron landforms have been less studied in northeastern lower Michigan, similar morphology suggests that the Port Huron ice eventually stagnated here as well (Burgis, 1977; Blewett, 1991; Schaetzl et al., 2000). Large, flat-floored, anastomosing valleys occur proximal to the "moraine" in northwestern and northeastern lower Michigan. Burgis referred to this landscape in the latter (northeastern) area as the "Atlanta Channeled Uplands" (Fig. 1). In northwestern lower Michigan, Blewett (1990) labeled this landscape the "Fluted Uplands and Through Valleys" but did not study it per se. Some of these landforms, in fact, may be meltwater-fed tunnel valleys. When viewed in conjunction with large thicknesses of ice-marginal outwash and morphosequences, the valleys suggest that broad tracts of the outermost Port Huron ice were stagnant and melting rapidly, immediately after its maximum advance.

Following the Port Huron, another readvance occurred, initially known as Valderan but later Greatlakean (Black, 1970; Evenson et al., 1976; Clayton and Moran, 1982; Maher and Mickelson, 1996). This advance is now referred to as the Two Rivers Phase (Johnson et al., 1997). The Greatlakean advance extended far into the Lake Michigan basin (Broecker and Farrand, 1963) and into eastern Wisconsin and western lower Michigan (McCartney and Mickelson, 1982); it also covered parts of northern lower Michigan. The southern and eastern limits of this advance in northern lower Michigan, however, are still unclear and subject to debate (Fig. 2), primarily because it left no prominent or at least no continuous end moraine, and also because the character and color of its drift (red vs. brown) has been questioned (Melhorn, 1954; Burgis, 1977; Farrand, 1995). The Greatlakean advance was likely rapid and if so, given its up-ice connections to a large lake basin with abundant subglacial water, and possible subsequent stagnation, it may have been moving as a form of ice stream that was partially steered through the Straits of Mackinac (Patterson, 1997).

The type section for the Greatlakean substage is near Two Creeks, Wisconsin, where the Two Rivers diamicton overlies a buried forest radiocarbon dated at about 11,800 ^{14}C yr B.P. (Broecker and Farrand, 1963; Black, 1970). More important to this study, however, is a site in northern Michigan known as the Cheboygan bryophyte bed (Fig. 1). This site contains sandy, reddish-brown till overlying a bryophyte (moss) bed recently redated between 11,400 and 12,100 ^{14}C yr B.P.; therefore, the till is interpreted to be Greatlakean (Larson et al., 1994). The Cheboygan bryophyte bed is important stratigraphically because it provides the only definitive evidence of, and stratigraphic and radiometric control on, Greatlakean ice in the Lake Huron basin.

Both the Port Huron and Greatlakean advances have been credited with shaping many drumlin fields and landforms in northern Wisconsin and Michigan (Bergquist, 1941, 1942; Melhorn, 1954; Lotan and Shetron, 1968; Burgis, 1977; Rindfleisch and Schaetzl, 2001). Most drumlins inside the Port Huron moraine trend in a northwest-southeast or a north-northwest–south-southeast direction, whether they are in the Lake Michigan or Lake Huron basin (Fig. 3).

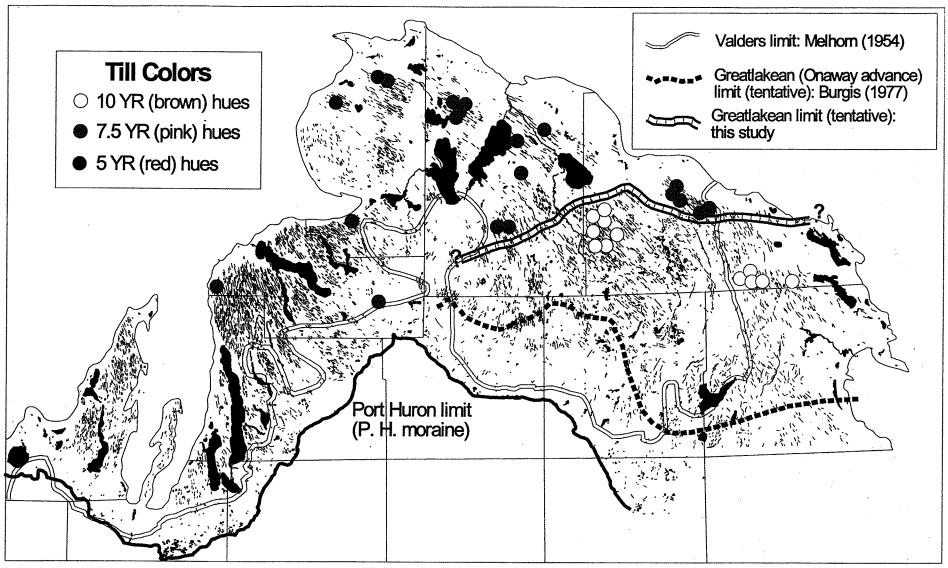

Fig. 2. Landscape linearity, (uppermost) till colors, and inferred (general) Greatlakean limits in northern lower Michigan. County boundaries are shown.

CONNECTIONS TO THE LITERATURE

The Pleistocene history of northern lower Michigan remains poorly understood. However, new field and mapping methods are now available which could improve interpretation and help resolve the deglaciation history of northern lower Michigan. Possible misinterpretations exist in the older literature for several reasons: (1) the uppermost glacigenic sediments are not laterally continuous and differ in color and texture across short distances; (2) the depositional environments of some of the sediments may have been misinterpreted (Burgis, 1977); and (3) early work at the Cheboygan bryophyte bed (e.g., Farrand et al., 1969) misinterpreted the uppermost reddish-brown till as Port Huron-to-Greatlakean in age (cf. Larson et al., 1994). Given this confusion, a review of the pertinent literature seems warranted.

Melhorn (1954), the first to study the tills and landforms of northern Michigan in detail, considered Port Huron till to be brown and Greatlakean (then termed "Valders") till to be red or pink. In northwestern lower Michigan he observed drumlins cored with brown till. Some drumlins, and the Port Huron moraine in places, had a veneer of reddish-brown till, which he also interpreted to be Greatlakean/Valderan. In short, Melhorn used till color (i.e., the red-brown till limit) to map the southern extent of the Greatlakean ice in Michigan (Fig. 2).

Burgis (1977) next studied the glacial geology of the region, and made some interpretations that we now know to be inconsistent with subsequent research findings:

(1) Believing that the Farrand et al. (1969) interpretation of the bryophyte bed was correct, the reddish-brown drift above the bryophyte bed was assumed to have

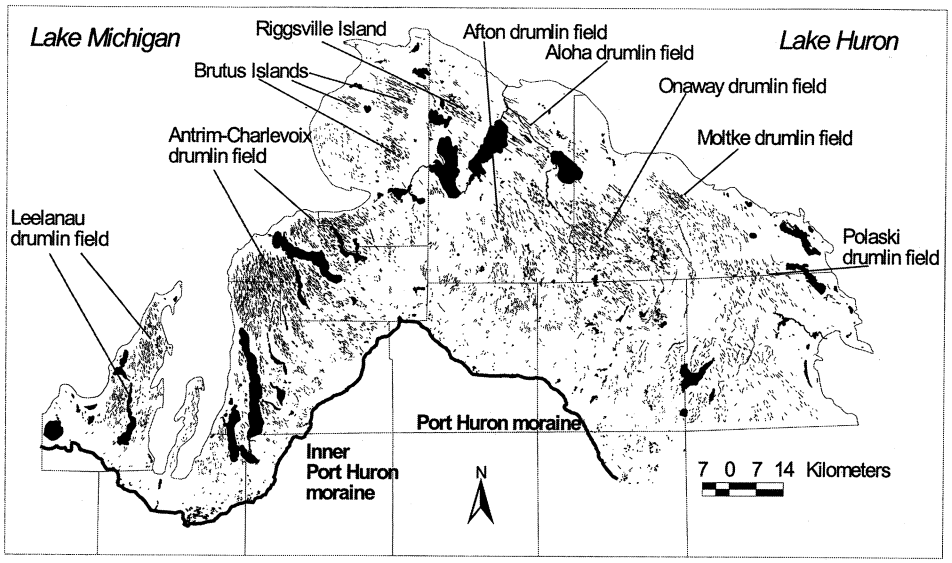

Fig. 3. Landscape linearity in northern lower Michigan showing major drumlin fields and landform regions.

been deposited by ice that initially advanced across the site during the Port Huron advance. As follows, the underlying (brown) drift had to predate the Port Huron advance. However, Larson et al. (1994) later established that the till above the bryophyte bed is Greatlakean, indicating that the preexisting brown (10YR hue) till in the region predates the Greatlakean, and by inference is probably Port Huron in age.

(2) Not finding much reddish-colored drift in the Onaway drumlins (Fig. 1), southeast of the bryophyte bed, Burgis (1977) concluded that the Greatlakean advance was primarily erosional in nature, carving out drumlinoid forms from preexisting, brown till landscape.

(3) At sites, especially in the Onaway drumlin field, red clayey sediments may have been misinterpreted as till (Burgis, 1977). Burgis noted 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 from brown till (p. 91). However, new data indicate that these red clayey deposits occur only as infillings within swales, and are stratified and almost devoid of coarse fragments (Schaetzl et al., 2000). Based on these observations, Schaetzl et al. concluded that Burgis's "Onaway till" is, in fact, lacustrine clay formed within an ice-marginal lake or series of lakes.

(4) Burgis (1977) also supported the notion that the Port Huron ice advanced into northeastern lower Michigan from the northeast, perpendicular to its end moraine there, forming a landscape (and leaving behind tills) with a northeast-southwest fabric (Fig. 1). If true, the Port Huron advance in northeastern lower Michigan would have been a major readvance out of the Lake Huron basin (referred to as the

"northwestern sublobe"). Further, she based her conclusions on till fabrics from a few drumlins in northeastern lower Michigan, which show a northeast-southwest trend at depth with a weak northwest-southeast pattern nearer the surface. However, the fabrics were all seemingly from one till unit. To explain this, Burgis suggested that Port Huron ice advanced into northeastern lower Michigan from the northeast, leaving behind till with a northeast-southwest fabric. Next, the Greatlakean ice was hypothesized to have advanced into the region from the northwest, reorienting the landscape/landforms and creating new (northwest-southeast) till fabrics in the uppermost few meters of the same till (Burgis, 1977). This reworked till, with its northwest-southeast fabric near to the surface, was Burgis's primary evidence for the advance of Greatlakean ice in this part of the state. Consequently, Burgis concluded that the northwest-southeast trending drumlins in northeastern lower Michigan were formed primarily by reworking and eroding older tills, rather than by construction from new drift.

In sum, Burgis (1977) interpreted this trend as consistent with deposition by a Port Huron ice sheet advancing to the Port Huron moraine from the northeast, followed by reorientation of the upper few meters of till by a Greatlakean ice sheet coming from the northwest. Thus, in northeastern lower Michigan, the existence of northwest-southeast trending drumlins have been taken as the primary evidence of a post-Port Huron readvance that advanced into the region from the northwest.

METHODS

At several upland sites on drumlin crests in northern lower Michigan, the orientation of 50 elongate (greater than 2:1 long:short axis ratio) clasts from within till were determined. I did not detect evidence for stacked tills of different color at any of the fabric sites—that is, all the fabric sites are in uniform till units. However, it should be noted that most drumlins in the region show evidence of a subtle lithologic (but not color) discontinuity at from 35- to 125-cm depth (Schaetzl, 1996, 1998). Because the origin of the upper material remains unclear (Schaetzl, 1996; Schaetzl et al., 2000) and because near-surface stones have been subject to surficial processes that could have realigned the coarse fragments (e.g., wave-working beneath a proglacial lake, bioturbation, surface creep, permafrost), till fabrics from the upper 1.2 m must be viewed with caution. I emphasize that this subtle, near-surface discontinuity is not considered to be glacigenic. Till fabrics were plotted with StereoNet software, version 3.01 (©Per Ivar Steinsund, University of Tromsø, Norway).

Second, a mosaic of Digital Raster Graphic (DRG) topographic maps (1:24,000 and 1:25,000) was compiled for areas inside the Port Huron moraine. The DRGs were displayed in the GIS package ArcView™, and the crests of all "lineated," constructional landforms (usually eskers, drumlins, flutes, or linear hills on fluted till plain) were digitized "on-screen." Linear features below the level of Lake Algonquin, one of the highest and longest-lived proglacial lakes in the region (Larsen, 1987), usually offshore bars or spits, were not marked.

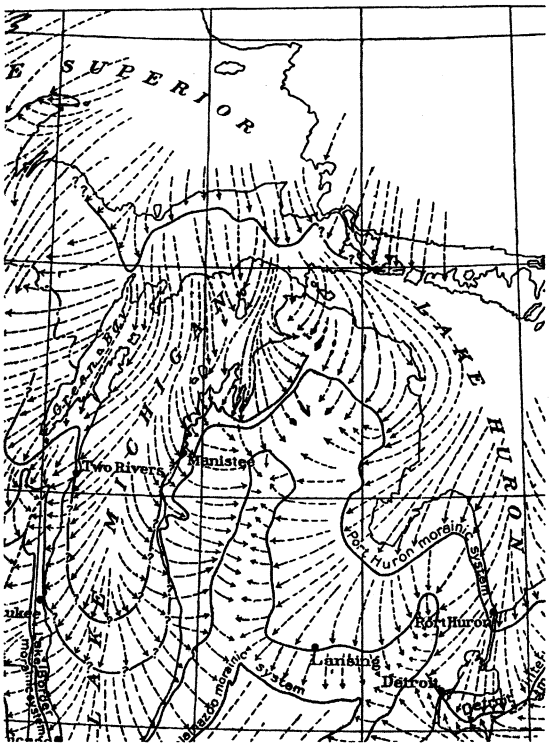

Fig. 4. Ice-flow reconstruction for northern lower Michigan, based on Plate V in Leverett and Taylor (1915).

RESULTS

Previous research has suggested the following:

(1) Port Huron ice in northeastern lower Michigan moved from the northeast to the southwest. This conclusion is based on data from deep till fabrics within glacial landforms that lie within the Port Huron boundary in northeastern lower Michigan, assumed to be Port Huron in age. Fabrics in some of these landforms trend northeast-southwest (Burgis, 1977). This conclusion forces the Port Huron readvance (of the northwestern sublobe) to be dominantly from the Lake Huron basin—in general agreement with Leverett and Taylor's (1915) interpretations of the landscape (Fig. 4).

(2) The many northwest-southeast trending drumlins in northeastern lower Michigan were later sculpted into Port Huron drift by a Greatlakean ice sheet moving across the region from the northwest to the southeast. Greatlakean ice deposited little till; instead it reworked existing till and reoriented the fabric of that till (Burgis, 1977).

However, the data presented here suggest that both the Port Huron and the Greatlakean advances moved into the region from the northwest. I find no evidence

to support a dramatic "shift" in ice-flow directions (and hence, source regions) during the late Pleistocene.

Till and Landscape Fabrics

Although there is some variability in the till-fabric data, as is expected (Andrews and King, 1968; Young, 1969), the fabrics determined for northern lower Michigan agree surprisingly well with general and local landscape fabric (including the orientation of major and subtle landform features; e.g., a drumlin swarm would have strong fabric, while a pitted outwash plain may have a nearly random fabric), whether the fabrics are from brown or red till (Fig. 5). Landscape and till fabrics typically trend from northwest to southeast in the extreme northern part of the lower peninsula and gradually curve into a north-northwest–south-southeast direction. Burgis (1977) reported on drumlins in northeastern lower Michigan that had till fabrics with a northeast-southwest trend at depth (>3 m) and a northwest-southeast trend nearer the surface. She then concluded that the drumlins had inherited the deep, northeast-southwest fabric from southwestwardly moving Port Huron ice and that a weak Greatlakean advance, from the northwest, had simply reoriented the clasts in the upper few meters of the preexisting till into a northwest-southeast alignment. In her Figure 14, Burgis showed two such "stacked fabrics" for the Moltke drumlin field; only one of these clearly shows a fabric "shift" as described earlier. Contrary to previous findings, the data reported herein and presented in Figure 5 do not support the conclusion that till fabrics at depth are dissimilar from those nearer the surface. Rather, I found only one site where till fabric changes markedly with depth (marked "A" on Fig. 5).

One of my till-fabric sites also was sampled by Burgis (1977) and used by her to support the hypothesis of a directional ice shift. My data from that site indicate both the shallow and the deep till fabrics (marked "B" on Fig. 5) show remarkably similar fabrics at 110 and 500 cm. Although there is evidence for a near-surface lithologic discontinuity in some of the upland drumlins in this area (Schaetzl, 1998), the till colors above and below this discontinuity remain similar—that is, the upper material is not a distinctly different till.

An additional line of evidence for repeated ice advances from the same general direction (i.e., the northwest) comes from the coastlines of northwestern and northeastern lower Michigan (Fig. 1). Glacial drift is thin (Rieck and Winters, 1993), and the underlying bedrock geology is similar along both coasts (Dorr and Eschman, 1970). Furthermore, dips of the sedimentary beds are roughly perpendicular to the coastlines along both the northwestern and northeastern shores. Despite these similarities, the coast of northeastern lower Michigan is dramatically different in outline from that of northwestern lower Michigan. The former has few large indentations and trends rather smoothly from northwest to southeast, whereas northwestern lower Michigan is replete with large embayments, deeply scoured "finger" lakes, and strong, high headlands. These patterns suggest that recent ice advances moved into both areas from the northwest, forming a comparatively smoother shoreline for the northeastern lower peninsula and, at the same time, scouring out large bays (either directly via scour or indirectly via ice-marginal tunnel valleys) into the north-

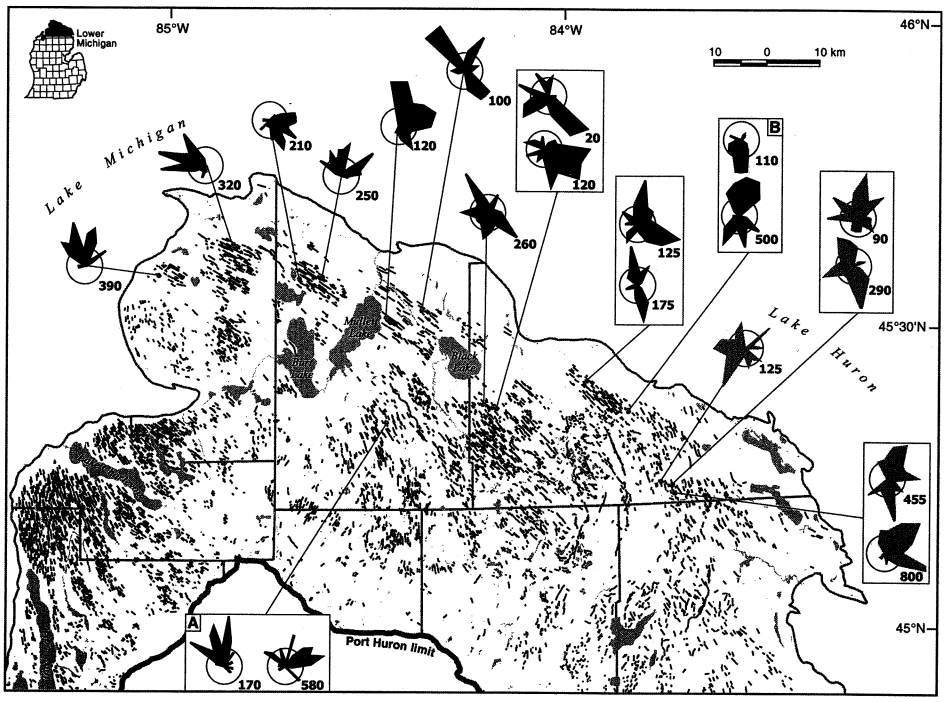

Fig. 5. Landscape linearity and till-fabric diagrams for the study area. Where more than one fabric was taken at a site, both fabric roses are set within a rectangle. Mean depth (cm) at which the sample was taken is listed next to the fabric rose. Gray areas are current lakes; the largest lakes are labeled. Gray "roses" were sampled from brown (10YR) till; black roses were sampled from reddish-brown or redder till.

western Michigan coast (Fig. 1). The formation of these coastline configurations is reconcilable with ice advances having come from the northwest. As a result, little geomorphic evidence for southwestwardly moving ice exists in northern lower Michigan, except for a narrow zone near the Port Huron moraine itself (Fig. 3). This finding diminishes the importance of the Lake Huron basin as a source for ice during the late Pleistocene, and reaffirms the importance of ice flow out of the lakes Michigan and Superior basins during this time period.

Greatlakean and Port Huron Tills

Clear radiometric and stratigraphic control for the Greatlakean advance exists at only one site in Michigan—the Cheboygan bryophyte bed (Fig. 1). Here, sandy reddish-brown (7.5YR hue) till overlies mosses and other organic remains that in turn overlie a brown diamicton. Organic sediments there generally date to around 11,850 ^{14}C yr B.P., which is in good agreement with dates from the Two Creeks forest bed in Wisconsin (Broecker and Farrand, 1963; Larson et al., 1994). Clearly this site was deglaciated ca. 12,000 ^{14}C yr B.P., at which time mosses and voles inhabited it. Shortly thereafter, Greatlakean ice overrode the site and buried it with a few

meters of reddish-brown till. The upper till at the site is sandy loam in texture, with some gravel, and is of a 7.5 YR hue (Munsell colors, moist).

The Cheboygan bryophyte bed is located on the northwestern edge of Riggsville Island—an upland that was not submerged by Glacial Lake Algonquin (Fig. 1). Till and landscape fabrics from Riggsville Island (one site is less than 2 km "down ice" from the bryophyte bed) clearly show that the ice was moving from the northwest to the southeast (Fig. 5). Flutes and drumlins on Riggsville Island also are unmistakable in this regard (Fig. 3). Up ice, to the west, on Brutus Island (Fig. 1), the till is more red (5YR hue; Fig. 2) and slightly more clay rich. To the southeast, in the presumed "down ice" direction, the till maintains a 7.5 YR Munsell hue (Fig. 2).

At an active gravel pit in the center of Riggsville Island, 2 to 5 m of reddish (7.5 YR), sandy loam till overlies a browner diamicton that is either 10 YR in hue or at the 7.5/10 YR "boundary." In places, reddish till overlies stratified sand and gravel in the pit. This stratigraphy is interpreted as reddish-brown Greatlakean till overlying "brown" Port Huron till. This conclusion is reinforced by the fact that the uppermost till is 10 YR (brown) in hue more than 50 km to the southeast on the Onaway and Polaski drumlin fields. These two drumlin fields are farther from the bryophyte bed than is the crest of Riggsville Island (Fig. 1), thus making it less likely that the Greatlakean ice (shown to have advanced into the region from the northwest; Fig. 2) could have advanced that far. Recall that only three firm dates exist for the location/timing of the Laurentide ice sheet in this region: at about 13,000 ^{14}C yr B.P., it was at its maximal Port Huron position; by about 11,850 ^{14}C yr B.P., it had retreated from and the readvanced across the Cheboygan bryophyte bed; and, by about 11,200 ^{14}C yr B.P., it had retreated from the Straits of Mackinac (Hansel et al., 1985).

I assert that the red/brown till boundary may be a reasonable first approximation to the Greatlakean limit (Fig. 2), given that: (1) red till occurs at the surface up ice and immediately down ice (i.e., on Riggsville Island) from the bryophyte bed; (2) a few kilometers down ice from the bryophyte bed, there is evidence for red till overlying a brown diamict; and (3) still farther (>50 km) down ice the uppermost till is brown. The map in Figure 2 assumes that the Greatlakean ice was carrying reddish-brown till and that Port Huron drift was brown. Although the purpose of this study was not to sample hundreds of outcrops and thereby establish the exact red-brown drift boundary, the tentative Greatlakean limit I suggest is probably closer to reality than are the two preexisting attempts at mapping this extremely elusive glacial boundary. Nonetheless, it is possible that as the Greatlakean ice moved farther inland and away from the Lake Michigan basin, it incorporated more and more of the underlying brown drift into the ice sheet, such that along the northeastern coast of lower Michigan it was depositing drift that was more brown than red. If this is the case, then all of northern lower Michigan theoretically could have been covered by Greatlakean ice and surficial till deposits are simply a facies of red to brown from the northwest to the southeast. This hypothesis has yet to be tested.

The proposed outer limit of the Greatlakean advance has been drawn in Figure 2 so as to coincide with major topographic barriers. For example, I place the line at the northern edge of the Onaway drumlin field, assuming that the ice would not have climbed up onto this high plateau, and because till at the extreme northern

edge of this drumlin field is 10YR in hue. Similarly, the high uplands immediately south of the Afton drumlin field may have limited how far it could have advanced into this region as well. In theory, the ice margin could have been anywhere between the southeastern edge of Riggsville Island and the northern edges of the Moltke and Onaway drumlin fields. However, because this region is a low flat plain that was later inundated by Glacial Lake Algonquin, exposures of till are rare.

Finally, red, clayey sediment that occupies swales between drumlins just beyond the proposed Greatlakean limit, such as on the Onaway drumlin field (Schaetzl et al., 2000), may provide an additional clue to the location of the Greatlakean limit. These red, laminated lacustrine sediments may have been deposited in ice-marginal lakes associated with an advancing or stagnant Greatlakean ice sheet. Upland locations—shown on Figure 2 as having been covered by the Greatlakean advance—do not contain this sediment within swales, perhaps because they were covered by ice and not proglacial lake(s).

CONCLUSIONS

This study suggests a new limit for, and new dynamics of, the Greatlakean ice in northern lower Michigan. The maps and data presented herein hopefully will stimulate future researchers, much as Burgis's (1977) pioneering work has stimulated the present study. A proposed, simplified late Pleistocene chronology is summarized below:

(1) Port Huron ice advances into northern lower Michigan from the north and northwest. Deep bays and inlets are carved (or if previously present, they are deepened and widened) in northwestern lower Michigan. In northeastern lower Michigan, the ice flow "bends" to the southwest at marginal locations, possibly owing to pressures from the southwestwardly moving Saginaw lobe to its east. Drumlin fields and other landforms are formed in brown (10 YR hues) till.

(2) Stagnation of the Port Huron ice occurs. Heads of outwash develop at ice-marginal positions. Tunnel valleys and eskers form subglacially.

(3) Port Huron ice continues to melt, exposing much of northern lower Michigan to subaerial processes. Bryophytes begin growing at a swale on the northwest side of a hill, which is later named Riggsville Island.

(4) Greatlakean ice advances into northern lower Michigan from the northwest, following closely along the path provided by the Port Huron ice and its lineated landforms. Reddish-brown (7.5 and 5 YR hues) till is deposited above preexisting brown (10YR hue) drift, including the sandy loam, reddish-brown till on top of the bryophytes at the Cheboygan bryophyte bed. The ice margin stops at or north of the marginal position noted on Figure 2. Uplands, especially Brutus Island and Riggsville Island, and the Aloha and Moltke drumlin fields are (again?) sculpted with flutes and drumlins with a northwest-southeast orientation.

(5) Stagnation and melting occur. Proglacial lakes form. Red, clayey sediment is deposited in swales on high-standing drumlin fields (especially the Onaway field and ground moraine to its immediate southeast) that are immediately distal to the Greatlakean margin.

(6) The melting Greatlakean ice continues to contribute red sediment, resulting in the deposition of the Lake Michigan Formation on the floor of Lake Michigan (Larson et al., 1994).

These data indicate that Greatlakean can be considered a smaller but in many ways a similar successor to the Port Huron advance.

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