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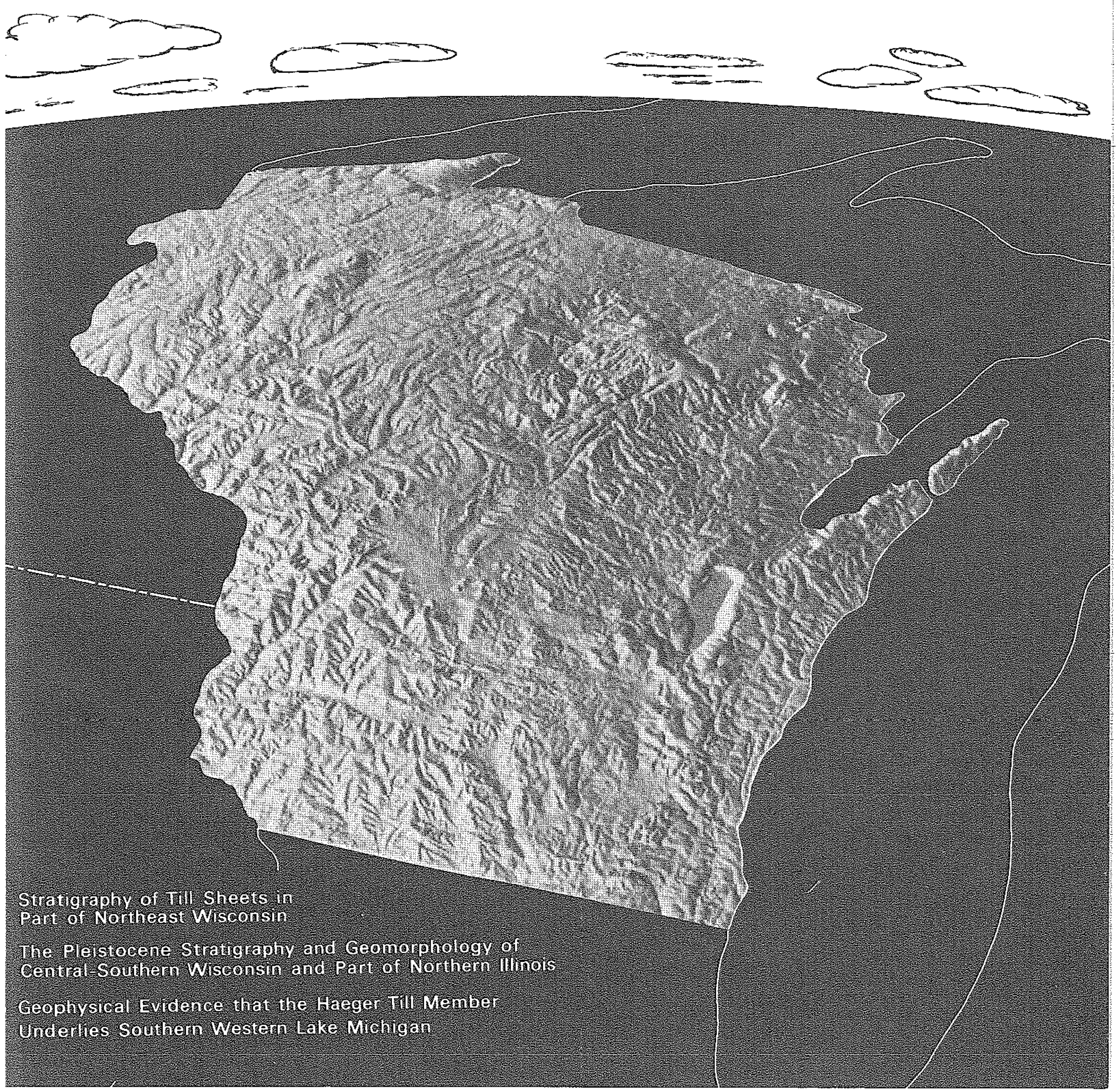

Stratigraphy of Till Sheets in Part of Northeast Wisconsin

The Pleistocene Stratigraphy and Geomorphology of Central-Southern Wisconsin and Part of Northern Illinois

Geophysical Evidence that the Haeger Till Member Underlies Southern Western Lake Michigan

Cover: An oblique photograph of a plastic raised relief map of Wisconsin by Hans J. Stolle a graduate student in the Geography Department, University of Wisconsin - Madison.

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by

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GEOPHYSICAL EVIDENCE THAT THE HAEGER TILL MEMBER UNDERLIES SOUTHERN WESTERN LAKE MICHIGAN

by

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PREFACE

"Geoscience Wisconsin" is a serial that addresses itself to the geology of Wisconsin--geology in the broadest sense to include rocks and rocks as related to soils, water, climate, environment, and so forth. It is intended to present timely information from knowledgeable sources and make it accessible with minimal time in review and production to the benefit of private citizens, government, scientists, and industry.

Manuscripts are invited from scientists in academic, government, and industrial fields. Once a manuscript has been reviewed and accepted, the authors will submit a revised copy of the paper, and the Geological and Natural History Survey will publish the paper as funds permit, distribute copies at nominal cost, and maintain the publication as a part of the Survey list of publications. This will help to insure that results of research are not lost in the archival systems of large libraries, or lost in the musty drawers of an open-file.

The three papers in this issue address Pleistocene geology in the northeastern and southeastern parts of Wisconsin. Carol McCartney describes the till stratigraphy in the Marinette County area and provides petrographic information for distinguishing the various units. Carl Fricke and Thomas Johnson discuss various till units in Rock and Walworth Counties and correlate those units with units in northern Illinois. Carol Welkie and Robert Meyer present the results of an off-shore geophysical survey north of Racine in which till stratigraphy was identified and correlated to land-based studies. Terminology has been reviewed and is in accord with present usage by the Wisconsin Geological and Natural History Survey.

We encourage submission of manuscripts relating to Wisconsin geology. Special consideration will be given papers which deal with timely topics, present new ideas, and have regional or statewide implications.

Wisconsin Geological and Natural
History Survey

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STRATIGRAPHY OF TILL SHEETS IN PART OF NORTHEASTERN WISCONSIN

by

M. Carol McCartney[1]

ABSTRACT

Four till units at the surface in northeastern Wisconsin were deposited during Late Wisconsinan time. The younger three units, which are members of an unnamed formation, can be distinguished from each other and from the oldest unit on tbe basis of stratigraphic position and texture, color, and depth of carbonate leaching. The Mapleview Member, which contains brown, sandy loam till, is overlain by the Silver Cliff Member. This unit contains till that is a dull reddish brown sandy loam which is slightly siltier than the till of the Mapleview. The Kirby Lake Member contains fine-grained till (less than 50 percent sand), which overlies the Silver Cliff Member, and it is dull to dark reddish brown. The Kirby Lake is overlain by the Middle Inlet Member that contains till that is dull reddish brown to dull brown, sandy loam. The Silver Cliff Member is probably time correlative with one of the outer red till units of the Port Huron advance in the Lake Michigan Lobe. The Kirby Lake is likely to also be a Port Huron deposit, and the Middle Inlet Member was probably deposited after 11,500 B.P.

INTRODUCTION

This paper presents the results of an investigation of the till stratigraphy in northeastern Wisconsin (fig. 1). Till sheets of this area are Late Wisconsin deposits of the Green Bay Lobe. This study was prompted by a reinterpretation of the stratigraphic relationships and late-glacial history of the Lake Michigan basin. It has been demonstrated (Acomb, 1978; Evenson and others, 1976; Lineback and others, 1974; Farrand, 1970; Farrand and others, 1969) that there are several Late Wisconsin red till units deposited by ice of the Lake Michigan Lobe. These red tills are interpreted as deposits of minor readvances of generally receding ice. Presumably, the adjacent Green Bay Lobe was responding similarly, if not synchronously, to the general climatic warming. The presence of several red till units in the Green Bay Lobe deposits, rather than a single, very extensive unit, supports this hypothesis.

The stratigraphic relationships and areal distributions of three Late Wisconsin red till units of the northern Green Bay Lobe are described in this report. Table 1 summarizes the relationship among event and lithostratigraphic terms for the northern Green Bay Lobe. The till sheets are distinguished from each other and from the underlying till on the basis of grain size, color, and relative stratigraphic position. Tentative correlations of these units to those of the Lake Michigan Lobe and implications to late-glacial history are also discussed.

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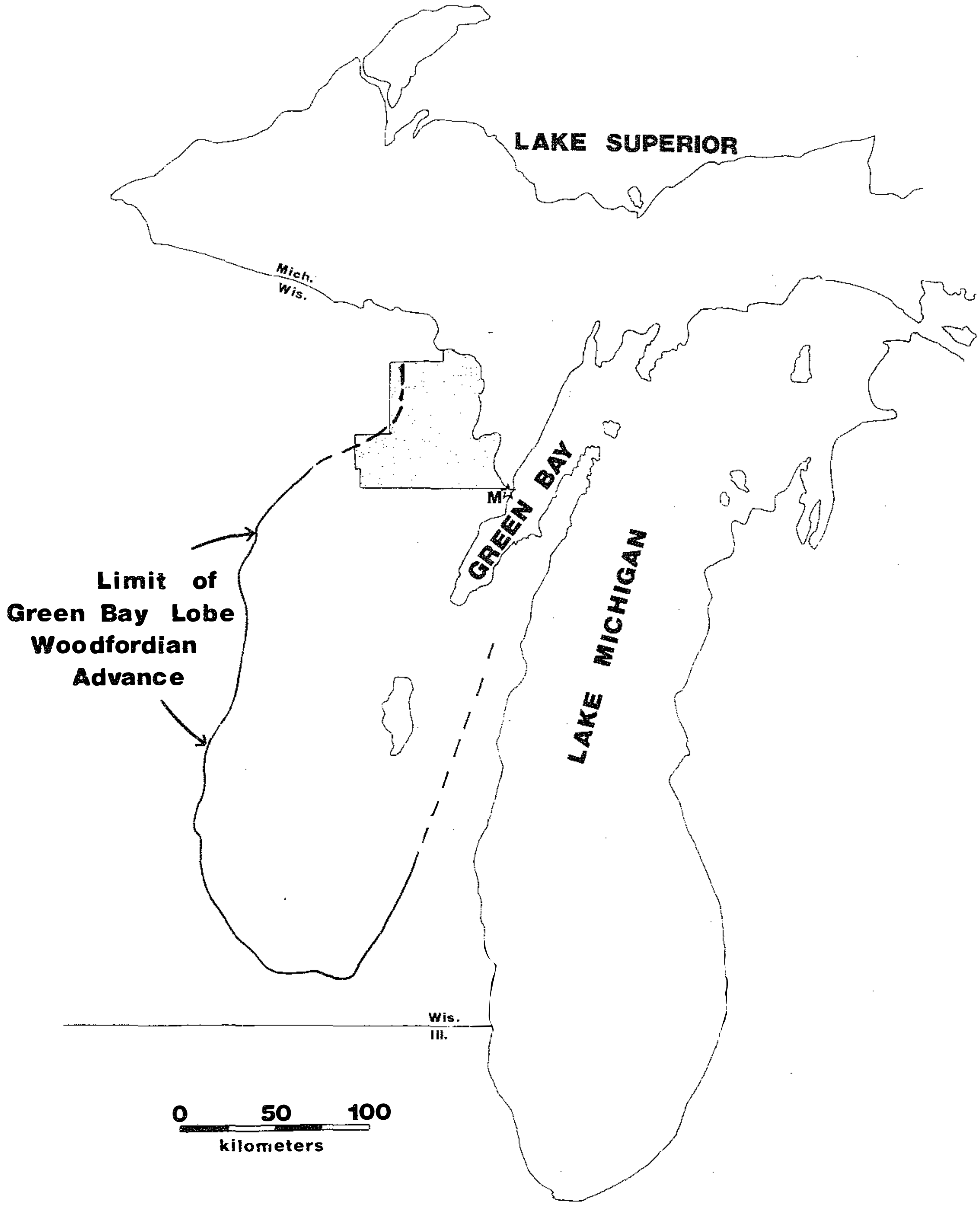

FIGURE 1.--Index map to area of investigation (stippled). The heavy line marks the outline of the Cary advance of the Green Bay Lobe. M is the City of Marinette, Wisconsin.

DESCRIPTION OF THE AREA

This investigation was carried out in the parts of Marinette and Oconto Counties north of an east-west line through the city of Marinette. The area is mostly underlain by Precambrian igneous and metamorphic rock (Martin, 1932). The southeastern quarter of the area is underlain by Paleozoic sedimentary rock, principally sandstone and dolomite, which dips gently to the southeast (Thwaites, 1943). Regional slope is to the southeast, toward Green Bay, and particularly in the eastern half of the area, bedrock is near the surface. The major feature in the bedrock surface is the upper Marquette Valley, a buried valley in the Cambrian sandstone, which begins in southern Marinette and northern Oconto Counties and crosses the state to the southeast (Stewart, 1976).

The direction of ice movement varied in this area during the Late Wisconsin but was generally from the southeast. This direction is recorded in glacial striae, drumlins, and eskers (Thwaites, 1943). A change in the regional direction of ice flow was associated with the latest advance into the area. Numerous drumlins, particularly in the drumlin fields of the upper peninsula of Michigan, indicate ice movement from northeast to southwest. Although the change in direction of flow is clearly associated with the last advance into the area, the flow directions of the advances between the Cary and the Denmark advance are uncertain. The ice-marginal features of these advances are perpendicular to the regional slope, which suggests that the ice was flowing out of the bay or from the southeast. In the lower peninsula of Michigan, a change in ice-directional features is the only clear evidence of an advance after the Port Huron (Burges, 1977). It is likely that the change in ice-flow direction in Wisconsin also occurred after the Port Huron advances.

HISTORICAL BACKGROUND

Northeastern Wisconsin was largely left unstudied by the early workers in the glacial geology of the state. The area is well behind the edge of the ice margins traced by Chamberlin (1883) and is north and east of the area described by Weidman (1907) when he defined and named the Langlade Lobe in north-central Wisconsin. Leverett (1929) sketched a red drift boundary in northeastern Wisconsin (fig. 2), correlating it with the border of Port Huron deposits of lower Michigan, but when Thwaites (1943) mapped the area he correlated post-Cary advance red till in the Green Bay Lobe with the Valders till. Thwaites drew the limit of the "Valderan" (interpreted as post-Two Creeks forest) advance at the western edge of red till throughout northeastern Wisconsin but reported difficulty tracing it across Marinette County (p. 137). Black (1966, 1976), primarily using flow-direction indicators, also traced a "Valderan" border across this area.

Figure 2 illustrates the red till boundaries of Leverett (1929), Thwaites (1943), and Black (1976). It is clear that these boundaries do not coincide in the northeastern corner of the state. The lack of agreement is due, in part, to the reconnaissance level of these investigations in this region, but the major cause of the disagreement is the presence of several till sheets that have formerly been mapped as one unit. Although several red till units have been previously reported in the deposits of the Green Bay Lobe (Black, 1966, 1974; Janke, 1962; Piette, 1963), the pre-Twocreekan red till has been

TABLE 1.--Relationships among event and lithostratigraphic terms for the northern Green Bay Lobe

Years B.P.	Events	Approximate age of lithostratigraphic units
10,000	Denmark	
		Middle Inlet
11,000		
12,000		Kirby Lake
	Port Huron	Silver Cliff
13,000		
14,000	Cary	Mapleview
15,000		
16,000		
17,000		
18,000		
19,000		
20,000		
21,000		
22,000		

considered Cary or older. The existence of more than one post-Cary till sheet in Wisconsin was not accepted by Thwaites (1943), Thwaites and Bertrand (1957), or Black (1966, 1974, 1976).

The stratigraphic framework upon which earlier workers based their interpretations of the red till of the Green Bay Lobe was developed east of the Green Bay lowland. Changes have been made in that framework in the form of revisions of time-stratigraphic and rock-stratigraphic nomenclature and reinterpretations of late-glacial climatic history (Evenson and others, 1976; Acomb, 1978; Acomb and others, 1982; McCartney and Mickelson, 1982). The development of these changes in the stratigraphy of the Lake Michigan Lobe, particularly as it pertains to the deposits of northeastern Wisconsin, is briefly reviewed here. Evenson (1973) provides a thorough history of this topic for the deposits of the Lake Michigan basin.

Recent work on stratigraphic relationships in the Lake Michigan basin (Evenson, 1973; Evenson and Mickelson, 1974; Lineback, and others, 1976; Acomb, 1978; Acomb and others, 1982) has shown that there is not just one post-Cary red till sheet, as thought by workers in the area since Alden (1918), but that there are several. One of these units, the Two Rivers Member, is stratigraphically above the Two Creeks horizon, and Acomb (1978)

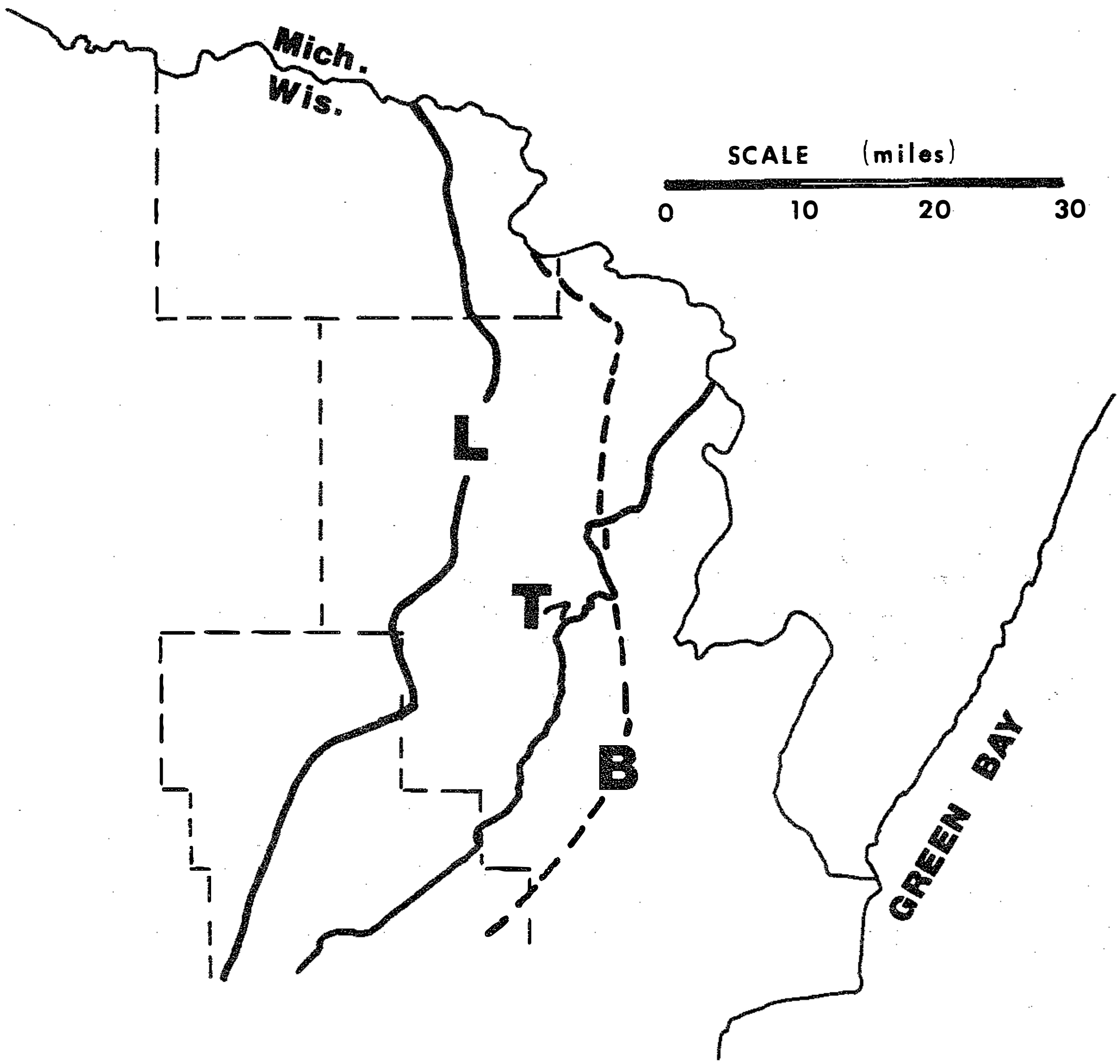

FIGURE 2.--Red till boundaries from Leverett, Thwaites, and Black. L = Leverett's (1929) limit of red drift in eastern Wisconsin. T = Thwaites' (1943) limit of the Valders advance. B = Black's (1966) Valderan border (from Black, 1974, fig. 23).

reported three red till units stratigraphically below this forest bed. These lower tills are presumed to be Port Huron deposits. Evenson (1973) argued, based on geomorphic evidence, that the upper till unit at the Valders Quarry is stratigraphically below the Two Creeks Bed near Two Rivers. Acomb (1978) traced the areal and stratigraphic extent of the Valers till and argued that it is stratigraphically below the Two Rivers unit, although it does not occur in the type section of the Valderan at Two Creeks. Evenson and others (1976) suggested replacing the time-term Valderan with Greatlakean to minimize the confusion that could result when the same rock and time terms are used for different ages.

A major result of the work by Evenson and others (1976) is that "the Two Creeks and Valders episodes no longer can be viewed as outstanding events of Lake Michigan Lobe history" (p. 417). Instead of one major readvance of the ice, the red till sheets represent minor readvances of generally receding ice. The retreat preceding the advances of the ice that deposited red till is now thought to be a significant event of the Lake Michigan Lobe. This retreat has long been recognized in the eastern Great Lakes (Evenson and Dreimanis, 1976). Further, the ice retreat before growth of the Two Creeks forest and subsequent readvance are now considered to be of minor significance. This is consistent with the "compelling evidence that late-glacial pollen fluctuations indicated progressive deglaciation with no major reversals in the northward movement of plant communities" (Evenson and others, 1976).

Acomb (1978) suggested that the extent and number of layers of the red till in the Lake Michigan lowland indicate that the Lake Michigan Lobe was an ice stream that drained the continental ice sheet. The rapid ice margin fluctuations during the limited period of deposition of the red tills require ice flow velocities typical of ice streams.

METHODS

Field Methods

Field work for this study was carried out primarily in July and August of 1978, but some reconnaissance was done in the summer of 1977. Because the area is large, about 4,060 square km, field investigations concentrated on till and till stratigraphy. No attempt was made to map or correlate the extensive outwash and the lacustrine deposits of the area that were earlier mapped by Thwaites (1943).

Most of the field investigation involved examination of roadcuts and pits but the information obtained from surface exposures was augmented by drilling to depths up to 20 m. Samples of about 750 g of unweathered till were taken for laboratory analyses. Because the layers of till are thin, some samples were taken from so near the top of the unit that carbonates were leached. All samples with less than 1 percent calcite in the less-than-0.063-mm fraction were assumed to be leached and were not included in the data analyses.

Laboratory Methods

Grain size was determined on the less-than-2-mm fraction by hydrometer and sieve analysis (Royce, 1970). Carbonate content of the less-than-0.063-mm fraction was determined by analysis with the Chittick gasometric apparatus (Dreimanis, 1962). The amount of carbonate in the 1-to-2-mm fraction was determined by weight difference before and after digestion in formic acid. Formic acid was used to minimize the error that would result from hydrochloric-acid digestion of sulfide minerals. Heavy minerals were separated from the 0.13 to 0.25-mm fraction using bromoform (specific gravity 2.85), and the carbonate content was determined by acid digestion of the fractions. Proportions of plagioclase, potash feldspar, and quartz were determined by mounting, staining, and counting as described by Gross and Moran (1970). Colors of moist samples were recorded in the laboratory under controlled lighting conditions.

RESULTS

Introduction

Four till sheets were deposited by the Green Bay Lobe in this area during the last glaciation. They are the Mapleview (Simpkins and others, 1978), the Silver Cliff, the Kirby Lake, and the Middle Inlet. The latter three units are formally defined and named in Mickelson, and others (in preparation). These tills can be distinguished in the field on the basis of stratigraphic position, texture, color, and depth of carbonate leaching. However, there generally are greater lithologic differences within these units than between them (see table 2).

The differences among the four till units reflect differences in underlying bedrock lithologies. The Mapleview is considered to be deposited during the Cary advance and the other three till sheets, which are stratigraphically above the Mapleview, are thought to have been deposited by Port Huron and Denmark advances. The Silver Cliff and the underlying Mapleview both contain sandy loam, but the Silver Cliff till is slightly siltier and lighter in color than the Mapleview. The Silver Cliff is overlain by the Kirby Lake Member which contains finer-grained and usually redder till than the other units. The Kirby Lake underlies the Middle Inlet Member. The till in this unit is very similar to that in the Silver Cliff Member and is best distinguished from it by stratigraphic position. Where the Kirby Lake Member, which is over the Silver Cliff and under the Middle Inlet, is not present, the two units may be differentiated by depth of carbonate leaching. The Silver Cliff till is more deeply leached of carbonate than the Middle Inlet till.

Figure 3 is a map showing the surface distribution of the till sheets in northeastern Wisconsin. The dashed line is the western edge of deposits of the Green Bay Lobe. Boundaries of the till units were drawn along the ice-marginal features, such as end moraines or outwash fans beyond which that till was not found. These till boundaries correspond with some of the geomorphic features mapped and named by Thwaites (1943). Figure 4 is a map of the named features in the study area.

The entire Pleistocene section appears to thin to the east in this area. The individual till members also thin to the east, in the up-ice direction, and as a result the thin, younger till sheets commonly rest directly on bedrock, particularly in the southeastern corner of the area. Because of this, and because relief is generally low in the area, no cuts have been found that contain all four till units. There are, however, several sites at which two or three units have been found. These localities are listed and briefly described in table 3. All of the red till units have been found overlying the next older till in at least one locality.

TABLE 2.--Summary statistics for lithologic data from northeastern Wisconsin till sheets.

	Mapleview	Silver Cliff	Kirby Lake	Middle Inlet
% sand (2-0.0625 mm)	78 (8, 32)	61 (6, 33)	36 (14, 33)	64 (9, 54)
% silt (0.0625-0.002 mm)	19 (7, 32)	32 (5, 33)	47 (10, 33)	28 (8, 54)
% clay (<0.002 mm)	4 (2, 32)	7 (3, 33)	17 (9, 33)	8 (3, 54)
% carbonate (0.13-0.25 mm)	5 (6, 2)	9 (4, 11)	14 (5, 21)	13 (5, 28)
% carbonate (1-2 mm)	24 (32, 2)	39 (13, 11)	44 (14, 21)	32 (12, 28)
% carbonate (<0.063 mm)	32 (1, 2)	27 (7, 11)	31 (8, 21)	32 (7, 128)
% dolomite (<0.063 mm)	26 (4, 2)	22 (5, 11)	24 (6, 21)	26 (7, 28)
% calcite (<0.063 mm)	5 (3, 2)	5 (4, 11)	7 (4, 21)	6 (4, 28)
% heavy minerals	3 (1, 28)	3 (1, 33)	3 (1, 21)	3 (1, 28)
% plagioclase	28 (9, 32)	23 (8, 33)	22 (7, 33)	21 (7, 54)
% potash feldspar	7 (5, 32)	10 (6, 33)	11 (5, 33)	12 (6, 54)
% quartz	65 (9, 32)	67 (9, 33)	67 (7, 33)	67 (7, 54)

The values for the first nine parameters are mean weight percentages. Numbers in parentheses are standard deviations and number of samples, respectively. The last three parameters are percentages of counted grains (plagioclase, potash feldspar, quartz) in the light minerals of the 0.13-to-0.25-mm fraction.

Mapleview Member

The Mapleview till is commonly the oldest till unit found in northeastern Wisconsin. Doubtless, there are some protected sites in the study area where the Mapleview overlies older tills that are mapped to the west (Stewart and Mickelson, 1976), but the older units do not crop out in this area. The Mapleview is at the surface from the outer moraine in Langlade County to the

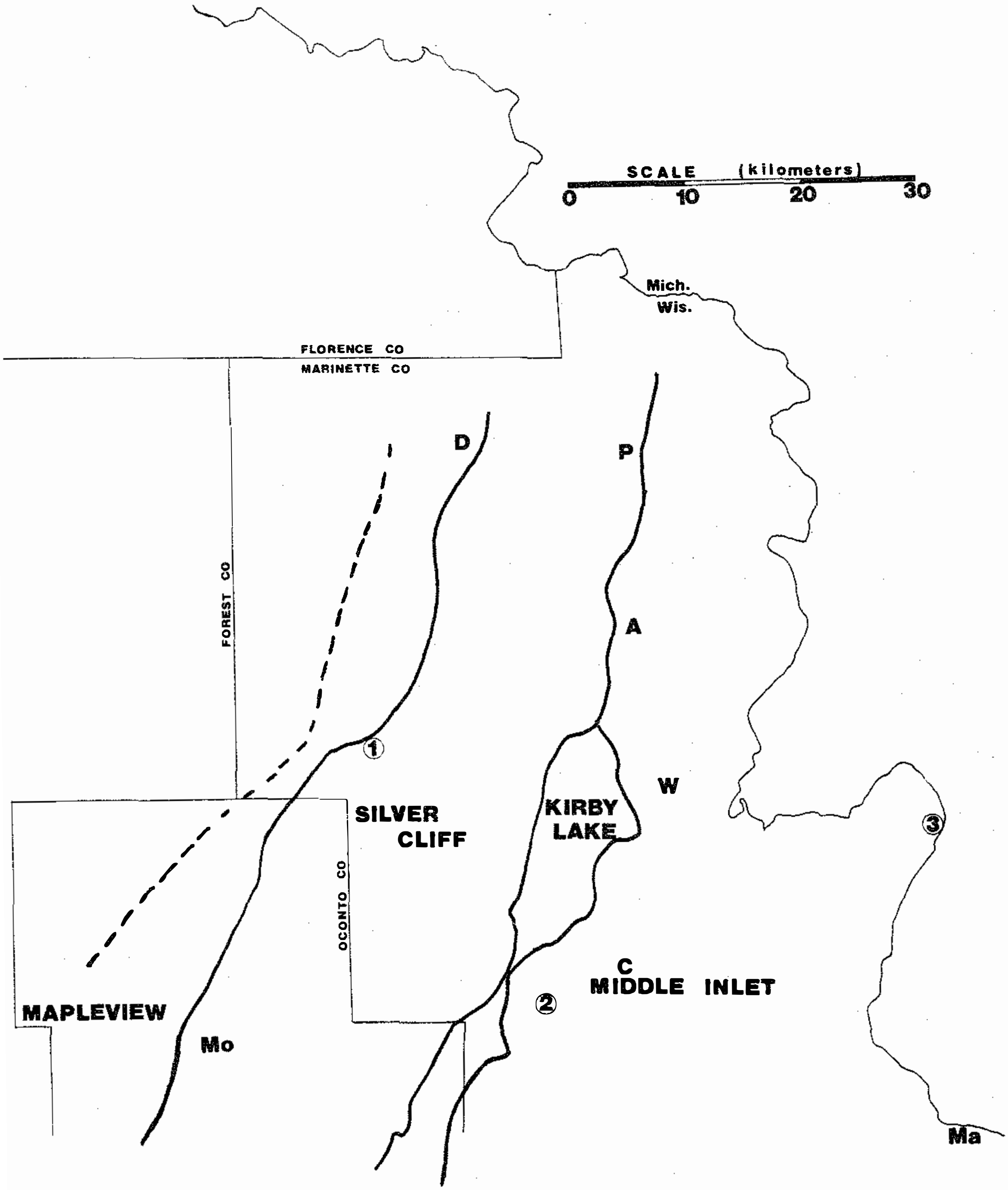

FIGURE 3.--Surface distribution of the till sheets in northeastern Wisconsin. Dashed line is the western edge of deposits of the Green Bay Lobe. City of Marinette = Ma. Towns are marked as follows: Mo = Mountain, C = Crivitz, W = Wausaukee, A = Amberg, P = Pembine, D = Dunbar. Type localities are marked as follows: 1 = Silver Cliff till, 2 = Kirby Lake till, 3 = Middle Inlet till.

Mountain moraine in Oconto and Marinette Counties (Simpkins and others, 1978). Beyond the Mountain moraine, to the east, the Mapleview crops out in a few places, but is generally covered by younger units or is absent.

Mapleview till is a loamy sand and averages, in Marinette and Oconto Counties, 78 percent sand, 19 percent silt, and 3 percent clay (in the less-than-2-mm fraction). In Langlade County, the till averages 83 percent sand, 13 percent silt, and 4 percent clay (Simpkins and others, 1978). The triangular diagram in figure 5 shows the distribution of sand, silt, clay percentages in till of the Mapleview Member as well as the tills that overlie it. The area plotted and the averages for Marinette and Oconto Counties represent 32 samples of Mapleview till.

The moist color of Mapleview till is sometimes dull reddish brown (5YR 5/4), but it is more commonly brown (7.5YR 4/4 to 4/6) and can usually be distinguished from the younger tills in the area by this brown, rather than reddish, color.

Silver Cliff Member

The Mapleview Member is overlain by the Silver Cliff which is named for the township of Silver Cliff in western Marinette County. At the surface, this till sheet is thin and discontinuous. It extends eastward from the eastern moraine of the Mountain system to glacial Lake Oconto in the south and to the eastern Athelstane moraine in the north (fig. 4). Beyond those eastern boundaries, it is usually buried by the Kirby Lake and/or the Middle Inlet units (fig. 3). The very limited till exposures in the western Mountain moraine (fig. 4) contained Mapleview, not Silver Cliff, till. Thus, the boundary of the red tills has been drawn east of this moraine.

The till of the Silver Cliff Member is a sandy loam that is slightly finer-grained (siltier) than that of the underlying Mapleview Member (fig. 5). Average sand/silt/clay percentages of the Silver Cliff till are 61/32/7 percent. These averages and the grain-size distribution in this till unit in figure 5 are from thirty-three samples from Marinette and Oconto Counties.

Silver Cliff till is generally dull reddish brown when moist (5YR 4/4 to 5/4). The carbonate content of eleven samples of this till is 39 percent in the 1-to-2-mm fraction (standard deviation = 13 percent), 27 percent in the less-than-0.063-mm fraction (standard deviation = 7 percent) and 9 percent in the 0.13-to-0.35-mm fraction (standard deviation = 4 percent) (table 2). Carbonates are leached to a depth of about 1 to 1.5 m in this till.

This unit is thin and poorly exposed. It generally overlies stratified sand and silt, but in the town of Mountain, it lies directly on bedrock. It is overlain by silty, stratified sand or gravel.

The type locality for the Silver Cliff Member is a road cut on the north side of Eagle River Road at NE¼NW¼NW¼ sec. 16, T. 34 N., R. 18 E. in Marinette County. The section, which is about 1.3 km north and east of the junction of Eagle River Road and Camp 10 Road, is in the eastern Mountain moraine of Thwaites (1943). The type section contains Silver Cliff till over poorly sorted sand which may be Mapleview ablation till. A sample from near the top of the cut directly across the road contained 61 percent sand, 31 percent silt, and 7 percent clay.

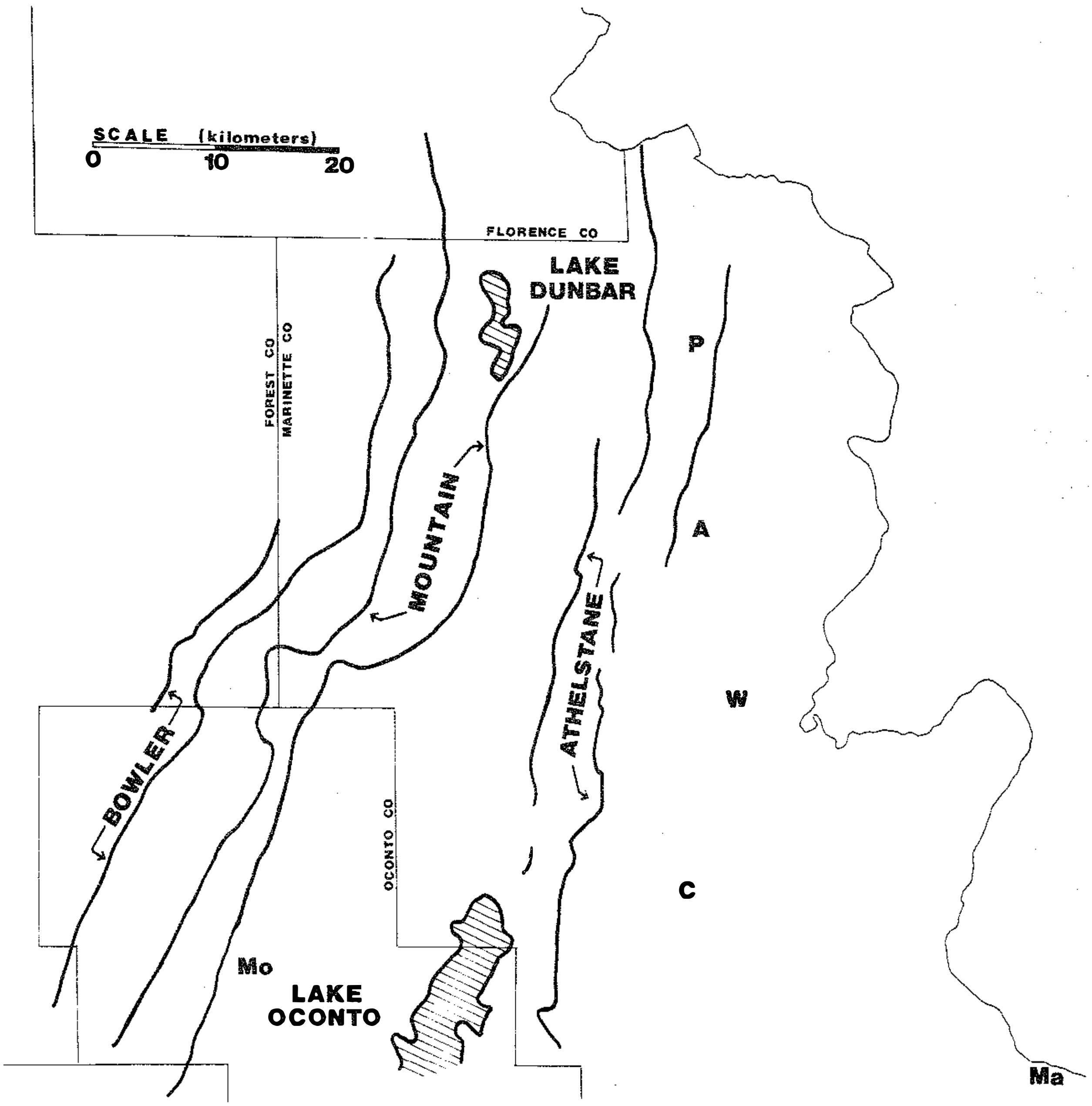

FIGURE 4.--Geomorphic features mapped and named by Thwaites (1943). Linear features are end moraines, striped areas are glacial lakes. City of Marinette = Ma. Towns are marked as follows: Mo = Mountain, C = Crivitz, W = Wausaukee, A = Amberg, P = Pembine.

TABLE 3.--List of localities of superposed till units

Locality	Upper Till	Separating Unit	Lower Till
SW, SW, SE, sec. 14, T. 33 N., R. 19 E.	Silver Cliff 0-0.7 (54-34-12)	Fine sand + clay 0.7-2	Mapleview 2-4 (79-15-6)
NE, NW, SE, sec. 27, T. 32 N., R. 19 E.	Kirby Lake 0-0.7 (19-57-24)	gray sand	Silver Cliff 1-4 (53-41-6)
*SE, SE, SW, sec. 22, T. 31 N., R. 18 E.	Kirby Lake 0-1.5 (30-50-20)	none	Silver Cliff 1.5-3 (56-34-10)
SW, SW, NE, sec. 25, T. 32 N., R. 19 E.	Middle Inlet 2-3.5 (65-29-6)	none	Kirby Lake 3.5-4.3 (29-62-9)
SW, SW, NW, sec. 27, T. 35 N., R. 21 E.	Middle Inlet (81-15-4)	silty sand	Kirby Lake (15-46-39)
*SW, SE, NW, sec. 1, T. 36 N., R. 20 E.	Middle Inlet 0-4.5 (80-1703)	sand/silt/gravel 4.5-20.5	Silver Cliff 20.5-21.3 (59-39-2)
*NW, SW, NE, sec. 36, T. 37 N., R. 21 E.	Middle Inlet 0-3.7 (57-25-18)	silt and till (?) 3.7-7.7	Kirby Lake 7.7-12 (47-29-24)
*NW, NE, NE, sec. 1, T. 32 N., R. 21 E.	Middle Inlet 0-10 (56-34-10)	none	Kirby Lake 10-12 (20-60-20)

Shows approximate depths (in meters) from the top of the cut or, if marked by *, from the top of an auger hole. Sand-silt-clay percentages are in parentheses.

Exposures with both the Silver Cliff and Mapleview are rare, but one such locality has been found. It is a roadcut 8 km west of Middle Inlet (SW¼SW¼SW¼ sec. 14, T. 33 N., R. 19 E.) that is 4 to 5 m high. In the upper 0.6 m of the cut is the dull reddish brown, sandy loam till of the Silver Cliff Members (sand/silt/clay = 54/34/12 percent). This unit overlies a dull reddish brown, loamy sand (sand/silt/clay = 79/15/6 percent) that is Mapleview till.

Kirby Lake Member

The Kirby Lake Member overlies the Silver Cliff and is found at the surface from the east shore of Glacial Lake Oconto to the western Athelstane moraine (fig. 4) in southern Marinette County, within the northern extent of the Marquette Valley (Stewart, 1976). The Kirby Lake till sheet is thin and

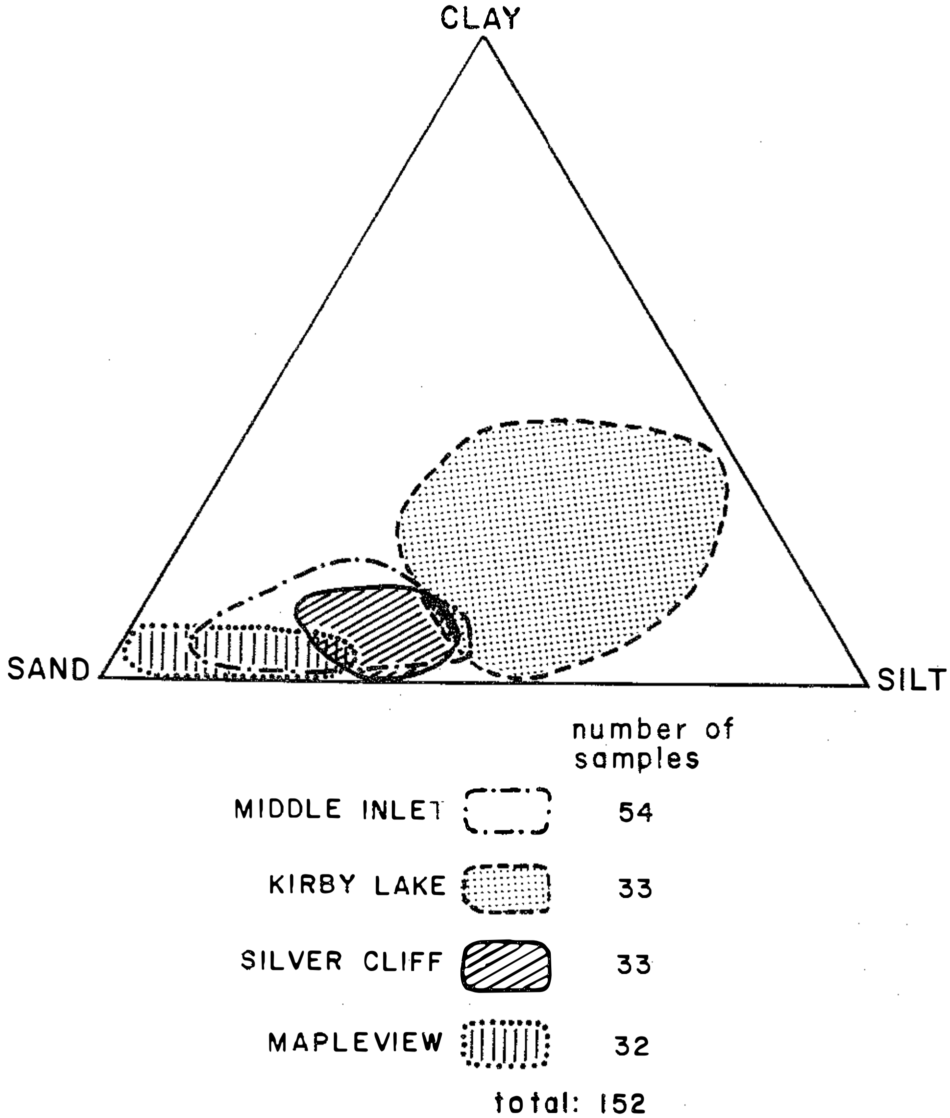

FIGURE 5.--Triangular diagram showing sand/silt/clay percentages of the four tills in northeastern Wisconsin.

patchy in this area and overlain, to the east, by the Middle Inlet till unit. The Kirby Lake Member is named for Kirby Lake, a lake 9 km west of Crivitz, Marinette County.

The Kirby Lake till sheet has the most variable grain-size distribution of the northeastern Wisconsin tills (fig. 5). The average for thirty three samples is 36 percent sand, 47 percent silt, and 17 percent clay, with standard deviations of 14, 10, and 105 percent, respectively, in the less-than-2-mm fraction. There are two possible reasons for the variability of this till unit: (1) this very thin till sheet may have some of the underlying sand incorporated into it, or (2) the till may have two phases, one more silty and one more clayey, which have not yet been separated, or both. Neither phase has more than 50 percent sand and the Kirby Lake is distinguished by this characteristic.

Kirby Lake till is commonly dull reddish brown (2.5YR 4/4 and 5YR 5/4 to 5/3), but infrequently it is dark reddish brown (5YR 3/6) or dull orange (7.5YR 6/4). It is generally darker in color and finer grained than both the underlying and overlying till units. The carbonate content of 21 samples of Kirby Lake till averages 44 percent in the 1- to 2-mm fraction (standard deviation = 14 percent), 30 percent in the less-than-0.063-mm fraction (standard deviation = 7 percent), and 14 percent in the 0.13-to-0.25-mm fraction (standard deviation = 5 percent).

The type section of the Kirby Lake Member described by McCartney (1979) is a road cut at the NE¼NW¼SE¼ sec. 27, T. 32 N., R. 19 E. on the south side of County Highway W in Marinette County. Kirby Lake till is near the top of the west end of the cut and it overlies sand, which in turn overlies Silver Cliff till. A sample of Kirby Lake till from the top of this cut contains 19 percent sand, 57 percent silt and 24 percent clay. Kirby Lake till is overlain by Middle Inlet till, which is very thin at this locality. An alternate type section is being considered (Mickelson, and others, in preparation).

Middle Inlet Member

The Middle Inlet member is named for the township of Middle Inlet in eastern Marinette County. This unit overlies the Kirby Lake Member and is the uppermost till sheet in the area. The Middle Inlet covers the eastern third of the area (fig. 4) from the eastern Athelstane moraine in the north and from a discontinuous ice-contact margin in the south. The till sheet is thin over bedrock in the southeastern corner of the area and generally 1- to 3-m thick in outcrop.

Middle Inlet till is a sandy loam which averages (for 54 samples) 64 percent sand, 28 percent silt, and 8 percent clay, in the less-than-2-mm fraction, in Marinette and Oconto Counties. Moist colors of this till are dull brown (7.5YR 5/3 to 5/4) or, more commonly, dull reddish brown (5YR 5/3 to 5/4). The average carbonate content in 28 samples is 32 percent in the 1-to-2-mm fraction (standard deviation = 12 percent), 32 percent in the less-than-0.063-mm fraction (standard deviation = 7 percent) and 13 percent in the 0.12-to-0.25-mm fraction (standard deviation = 5 percent). Carbonates are leached to a depth of less than 15 cm in this till.

The type section of the Middle Inlet Member is a road cut on the north side of Grand Rapids road at NE¼NW¼SE¼ sec. 8, T. 33 N., R. 23 E. This cut, which is about 4 m high, contains Middle Inlet till throughout. Augering showed Middle Inlet till overlying Kirby Lake till at two localities (table 2).

DISCUSSION

The four tills in northeastern Wisconsin represent a major ice advance and three less extensive readvances during the Late Wisconsin. The Mapleview Member is associated with the Cary Outer moraine in Langlade County (Simpkins and others, 1978) and deposits of this age have been long accepted as indicative of a major advance. Evidence that the later tills represent readvances is both stratigraphic and geomorphic. The fact that the tills are found superposed in outcrops rules out the possibility that the red tills are actually one very variable till. Where the tills have been found overlying each other, the contacts between them are sharp, not gradational, and their lithologies are distinct. Figure 6 illustrates the grain-size differences among the four tills in northeastern Wisconsin. Differences among the upper three tills are clearly not gradational. These tills also differ in depth of carbonate leaching and color. Where the relative stratigraphic position is unknown, the tills can be distinguished on the basis of grain size, color, and depth of leaching.

The geomorphic evidence also points to interpreting the red tills of northeastern Wisconsin as readvance deposits. The western edges of these tills are all associated with ice-marginal features, usually end moraines. Thwaites (1943) believed these moraines are recessional features of the Cary ice, but Black (1966, 1976) disagreed and he drew the western edge of the red till along constructional ice marginal features. Clearly, those moraines which have separate tills associated with them are margins of at least minor readvances. They may have earlier been recessional moraines of the Cary advance which were overrun by the later advances.

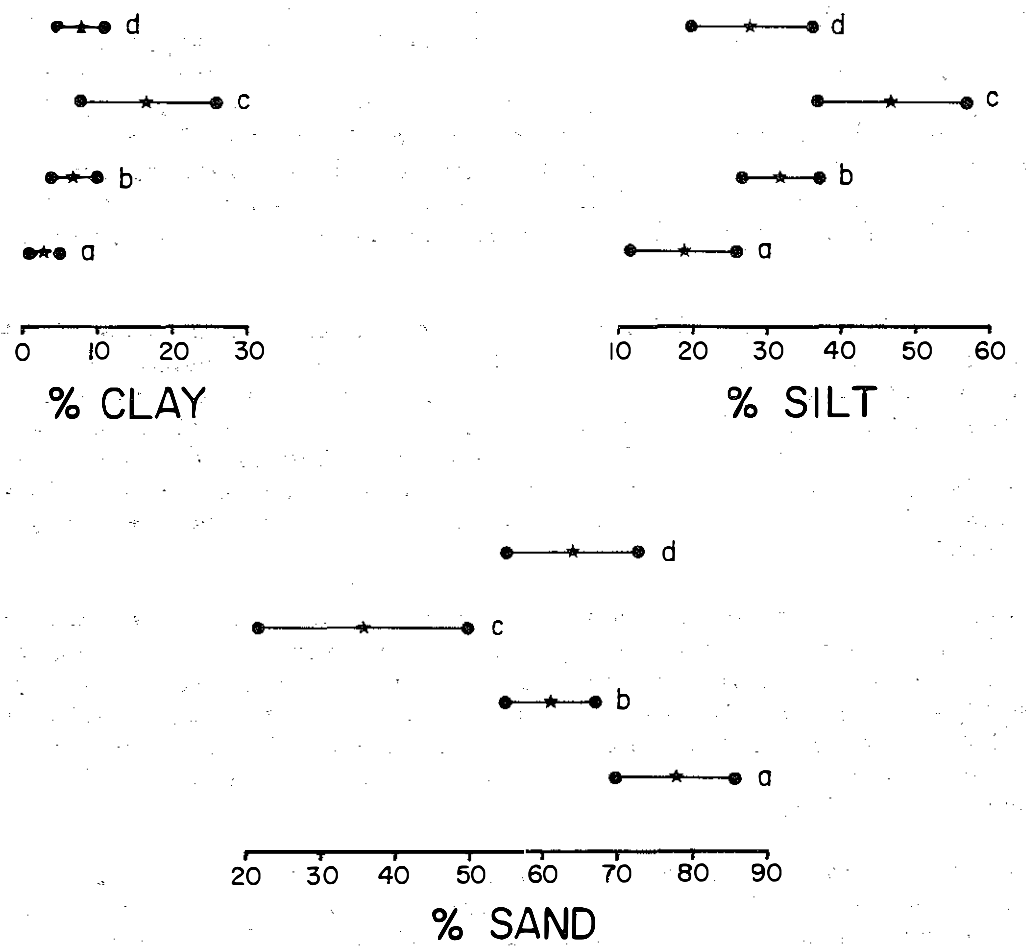

FIGURE 6.--Means and standard deviations of the % clay, % silt, and % sand of the four till sheets in northeastern Wisconsin illustrated in stratigraphic position: a = Mapleview Member, b = Silver Cliff Member, c = Kirby Lake Member, d = Middle Inlet Member. Stars are plotted on the mean percentile and the dots are plotted one standard deviation from the mean.

The distance of retreat between the readvances is unknown but the finer texture and redder color of the younger tills are presumably from incorporated lake sediment. The ice retreated far enough into the basin to allow development of a lake which was the source of that sediment.

The moraines associated with the post-Cary tills are semi-continuous throughout the Green Bay Lobe, and if traced across the western limb of the lobe, they mark advance boundaries as indicated in figure 7. The western boundaries of these tills have been traced outside the study area to the south (McCartney and Mickelson, 1982). The western edge of the Silver Cliff till approximately coincides with Leverett's (1929) red till limit throughout the lobe, and south of the study area it is nearly coincident with the edge of the red till that has been mapped in approximately the same position (see figure 2) by workers since Thwaites (1943). The western limit of the Kirby Lake is very nearly the Valders limit of Thwaites (1943). The edge of the Middle Inlet till outlines, in the northern half of the Green Bay Lobe, the distinctly different northeast to southwest trending ice-directional features. In the southern half of the lobe, the edge of the till is drawn approximately along the Athelstane Moraine (Thwaites, 1943). East of this moraine, particularly between Appleton and Green Bay, a red till is reported to overlie a Twocreekan horizon (Black, 1976), and at more than one locality, the Twocreekan horizon separates two red tills (Piette, 1963; Stewart, 1976). This boundary is west of Twocreekan radiocarbon dates from materials in or under till and is east of Twocreekan dated material that is unburied by till as reported by Black (1976).

Leverett's (1929) red till limit continues to the north along the Watersmeet moraine in the upper peninsula of Michigan. This boundary may be time-correlative with the edge of the Silver Cliff till. It includes an area of fine-grained red till in Florence County which is likely till deposited by the Langlade Lobe. The edge of the Kirby Lake till is buried in the northern half of the study area (fig. 4) and thus cannot be traced to the north. The limit of the Middle Inlet till may be the equivalent of Leverett's Marenisco morainic ridge (1929).

Tentative correlations are here suggested between the Green Bay and Lake Michigan Lobe deposits, based solely upon the position of end moraines (fig. 7). The southern boundaries of the Silver Cliff and the Kirby Lake correlate with the edge of the pre-Twocreekan red till units of the Lake Michigan basin that are Port Huron deposits. The edge of the Middle Inlet corresponds to the edge of the post-Twocreekan (Denmark phase) tills of the Lake Michigan Lobe (Acomb and others, 1982).

In northeastern Wisconsin, the term Valderan has been used to define the edge of the red till and has been considered equivalent to the edge of the post-Twocreekan ice advance. In the Lake Michigan basin, the equivalence of these two boundaries has been disproved, and the term Valders has been confined to the youngest Port Huron red till of the Lake Michigan Lobe (Acomb, 1978). My evidence shows that the term Valders should also be rejected for tills of the Green Bay Lobe. Acomb (1978; Acomb, Mickelson, and Evenson, 1982) mapped three red till sheets older than the post-Twocreekan Two Rivers. The Silver Cliff or Kirby Lake Members are possible time-correlatives of the pre-Twocreekan Valders till, but these units are undoubtedly lithologically different from the Valders because the bedrock traversed by the two lobes differs. On that basis, the separate rock-stratigraphic nomenclature proposed

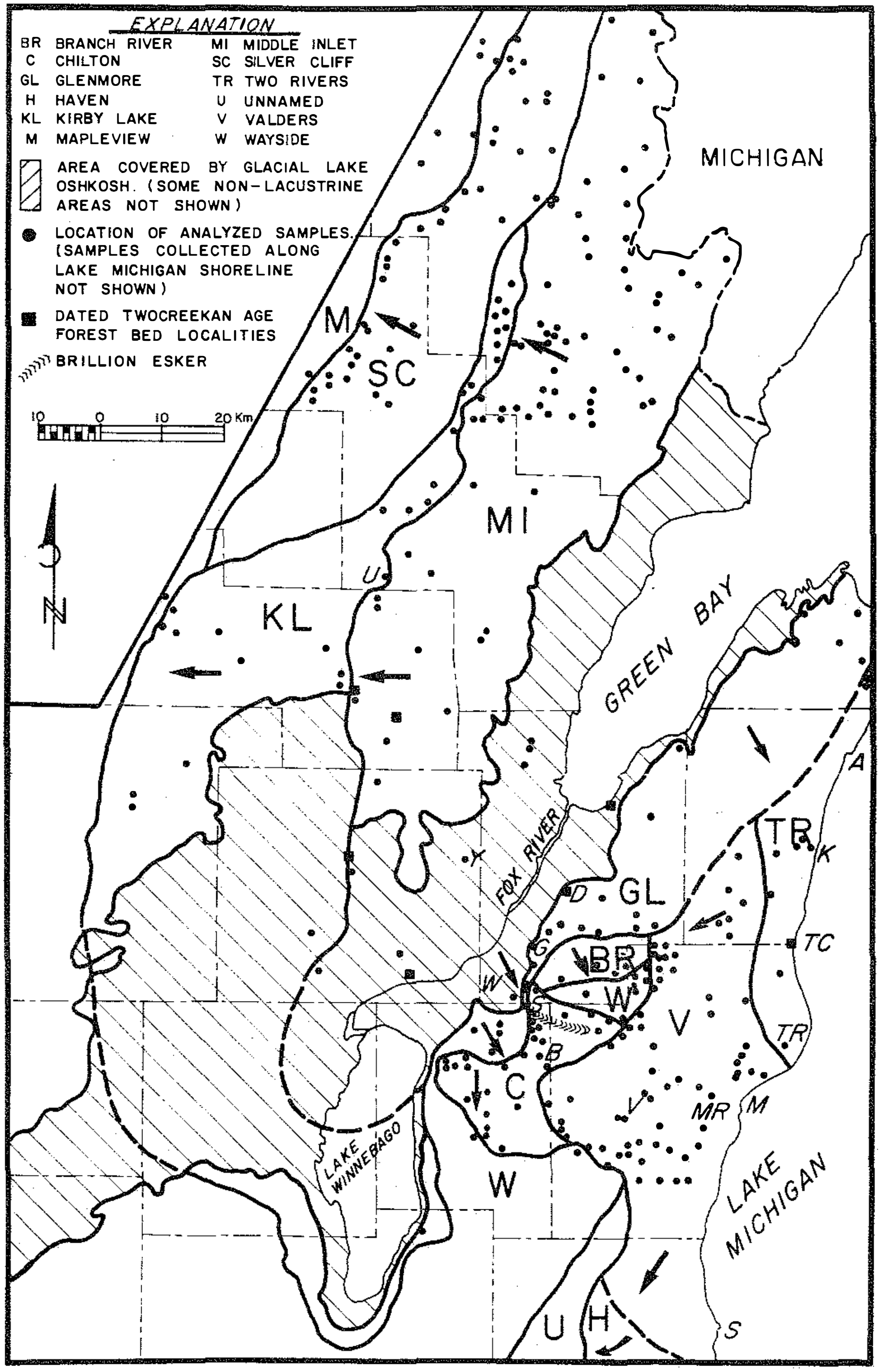

FIGURE 7.--Distribution of tills in the Green Bay Lobe and adjacent Lake Michigan Lobe in eastern Wisconsin. Large letters are till units, italic letters are locations (D=DePere, B=Brillion, V=Valders, TC=Two Creeks), arrows indicate ice-flow direction.

here is necessary for the Green Bay Lobe. Correlations of the lithostratigraphic units of the Green Bay Lobe with those of the Lake Michigan Lobe are, at this time, tentative.

The correlations proposed here are based on a single criterion, that is, the position of the end moraines associated with each till sheet. These correlations are therefore preliminary. However, these till sheets have been traced to the south and into the interlobate area. Correlations between the Green Bay and Lake Michigan Lobes are presented by McCartney and Mickelson (1982). It is possible that the advances of these two lobes are not strictly correlative. Perhaps their deposits overlap. It is clear, however, that the two lobes were responding similarly to general climatic warming in the Late Wisconsin. In both the Lake Michigan Lobe and the Green Bay Lobe, major Cary advances were followed by less extensive readvances. In the Lake Michigan Lobe, the distance each advance extends out of the basin becomes progressively shorter through time (Evenson and others, 1976; Acomb, 1978). The same relationship holds for the northwestern limb of the Green Bay Lobe (fig. 7) but to the south the Kirby Lake Member extends further than the underlying Silver Cliff. The ice margin of the Green Bay Lobe was generally behaving in the same manner as was that of the Lake Michigan Lobe. That is, it was making minor readvances while generally retreating in response to the climatic amelioration of the Late Wisconsin (Evenson and others, 1976).

CONCLUSIONS

1. There are four till sheets in northeastern Wisconsin, three of which are post-Cary in age.

2. The post-Cary units differ from the Cary till (the Mapleview Member) and from each other in grain size, color, and depth of carbonate leaching, and are distinguished as separate stratigraphic units by their superposition.

3. These three till units, from the lowest to the highest in stratigraphic position, are named the Silver Cliff, the Kirby Lake, and the Middle Inlet Members of the Kewaunee Formation (Mickelson and others, in press).

4. The till units of northeastern Wisconsin are deposits of an ice sheet that advanced progressively less far out of the basin through time, suggesting a gradual climatic warming.

5. The post-Cary tills are associated with end moraines that are semicontinuous throughout the Green Bay Lobe. These end moraines appear to correlate with the dated advances of the Lake Michigan Lobe as follows: the western edge of the Silver Cliff and Kirby Lake tills with the Port Huron deposits and the edge of the Middle Inlet with the Denmark Advance.

Further field work is required to (1) test if the end moraines associated with these tills continue to mark their western extents south of the study area, and (2) to test, in the interlobate area, the correlations proposed here between the Green Bay and the Lake Michigan Lobes.

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THE PLEISTOCENE STRATIGRAPHY AND GEOMORPHOLOGY OF CENTRAL-SOUTHERN WISCONSIN AND PART OF NORTHERN ILLINOIS[1]

by

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ABSTRACT

In south-central Wisconsin and north-central Illinois six mappable till units have been differentiated. The differentiation is based on texture, clay mineralogy, soil profiles, gross lithology, and areal field mapping. Two till units of Woodfordian age, the Tiskilwa and Haeger Members, can be traced from northern Illinois into southern Wisconsin near Lake Geneva in Walworth County. The Marengo Moraine and the Darien-West Chicago Moraine, which are associated with the Tiskilwa and Haeger Members respectively, can also be correlated across the state line. Four pre-Woodfordian units are present west and south of the prominent Woodfordian Johnstown and Darien Moraines. The Capron Member is correlated with its equivalent in northern Illinois. The Clinton Member which is overlain by a remnant paleosol and which was formerly thought to correlate with the Argyle Till Member in Illinois, is shown to overlie the Allens Grove Member, the Wisconsin equivalent of the Argyle Till Member. The Clinton Member, Allens Grove Member, and the underlying Foxhollow Member are newly recognized and described lithostratigraphic units. The Foxhollow Member, found only in the subsurface, is the lowermost till recognized in southern Wisconsin and correlates with a yet unnamed unit in northern Illinois.

INTRODUCTION

Early studies by Chamberlin (1877, 1878, 1883, 1894), Leverett (1899), and Alden (1904, 1918) in southern Wisconsin and northern Illinois formed the basis for classification of glacial deposits in the Midwest. Chamberlin (1883) recognized that the glacial deposits near Lake Michigan were less weathered than those farther west. He assigned the older, more visibly weathered deposits to the First Glacial Epoch and the younger, less severely weath-

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1 This manuscript was prepared while lithostratigraphic nomenclature and convention were evolving. The text has been changed to be consistent with present usage but the figures and table have not. All named units labelled "till" should be considered "Members" in Wisconsin and "Till Members" in Illinois--Editor

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ered material to the Second Glacial Epoch. The Second Glacial Epoch was renamed the East Wisconsin by Chamberlin in 1894, and this name was changed to the Wisconsin Glacial Stage by Leverett in 1899. Alden (1904, 1918) extended Chamberlin's work by mapping glacial deposits in greater detail in central, southern and eastern Wisconsin.

This study focuses upon a part of southern Wisconsin originally mapped by Chamberlin (1883), Alden (1904, 1918), and Bleuer (1970, 1971). It was undertaken because mapping of glacial deposits and stratigraphic correlations were not made, or did not match well at the Wisconsin-Illinois state line (fig. 1). When Alden (1904, 1918) mapped southeastern Wisconsin, he proposed that the Delavan Sublobe of the Lake Michigan Glacial Lobe flowed southward and southeastward depositing the Genoa, Darien, and Elkhorn Moraines (fig. 2). In northern Illinois, detailed studies of glacial deposits established the existence of the West Chicago Moraine (Willman and Frye, 1970), which, although supposedly deposited by the same ice advance, could not be correlated with any of Alden's moraines in Wisconsin (fig. 2). Recognizing this discrepancy, Leighton and Ekblaw (1932), Thwaites (1937), Leighton and Willman (1953), and Thwaites (1956) suggested that, contrary to Alden's mapping, the West Chicago Moraine of northern Illinois was continuous with the western portions of the Darien Moraine (figs. 3 and 4). However, except for some work by Black (1958) these studies have been based more on inference than on field evidence.

Bleuer (1970, 1971) mapped the older glacial materials to the west and correlated them, for the most part, with stratigraphic units previously mapped in northern Illinois. He suggested that the Capron Member, which contains the surface till on the Capron Ridge in Illinois, continues northward into Wisconsin. The sandy-loam surface till between the Capron Ridge and the Sugar River in Wisconsin was correlated with the Argyle Till Member of north-central Illinois. However, there was no detailed sampling program to thoroughly document these correlations. Bleuer also encountered several problems with these correlations, finding that the physical characteristics of the presumed Argyle till in Wisconsin did not match well with those of the surficial Argyle Till Member in northern Illinois. A summary of correlations of units in this area is given in table 1.

PLEISTOCENE STRATIGRAPHY

In Illinois, the pre-Woodfordian (Altonian) age materials are grouped into one rock-stratigraphic unit called the Winnebago Formation (Kempton and Hackett, 1968; Willman and Frye, 1970) (fig. 5). The Winnebago Formation consists of till, silt, peat, and outwash reaching at least 120 m in thickness in northeastern Illinois. It is comprised of three members; from oldest to youngest they are the Argyle Till Member, the Plano Silt Member, and the Capron Till Member. The Farmdalian substage, which separates the Altonian from the Woodfordian Substage, is represented by the Robein Silt. Deposits of the Woodfordian Substage are included in the Wedron Formation and consists of till, outwash, silt, and peat. In northeastern Illinois, the Wedron Formation contains six till members, which are the Esmond, Tiskilwa, Malden, Yorkville, Haeger, and Wadsworth till Members (fig. 4).

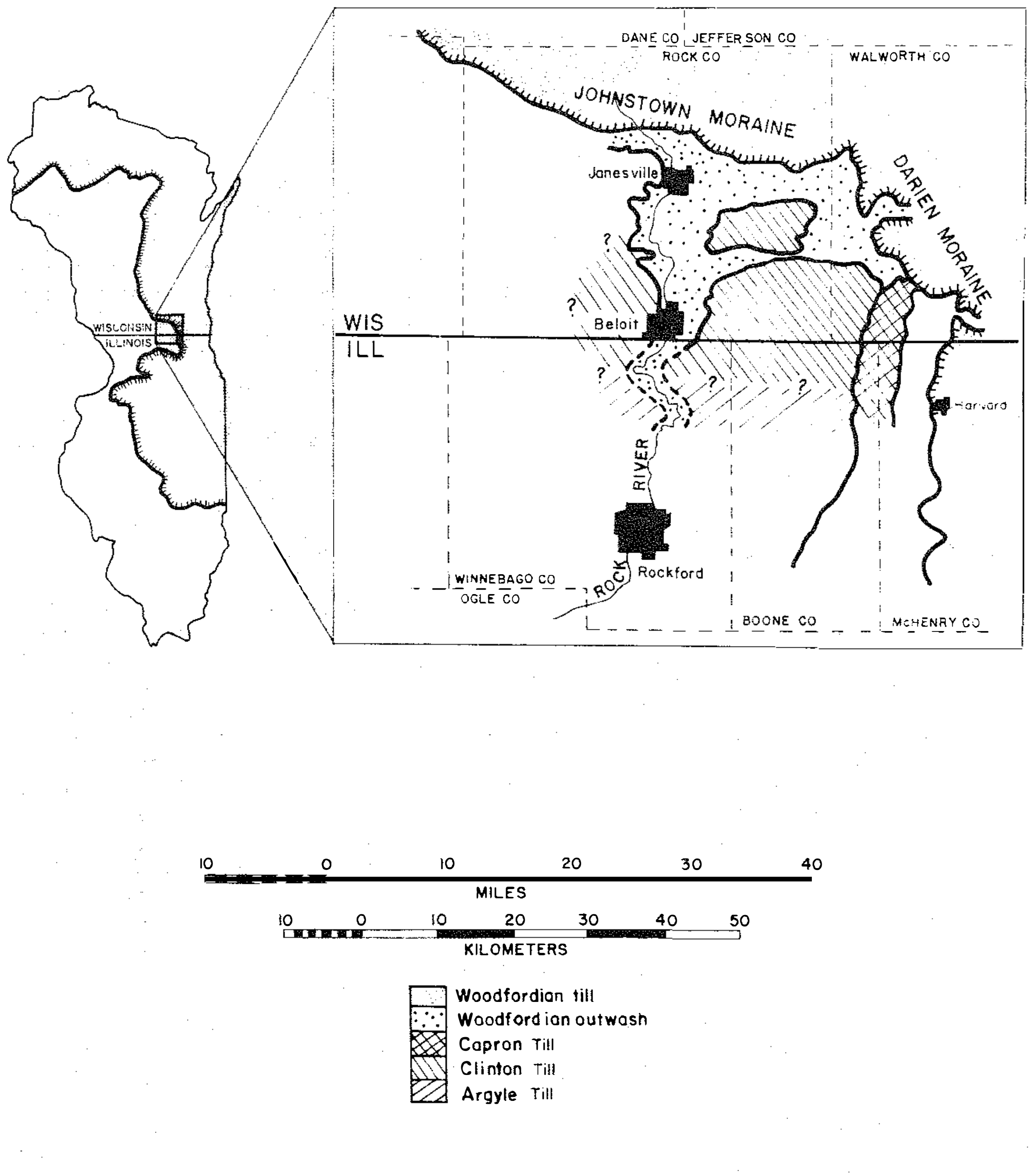

FIGURE 1.--Location of the study area, major physiographic features, and distribution of surficial units. Present Woodfordian till boundary corresponds closely to Chamberlin's boundary of the second glacial epoch. (Adapted from Chamberlin, 1883; Alden, 1904, 1918; Willman and Frye, 1970; Bleuer, 1970).

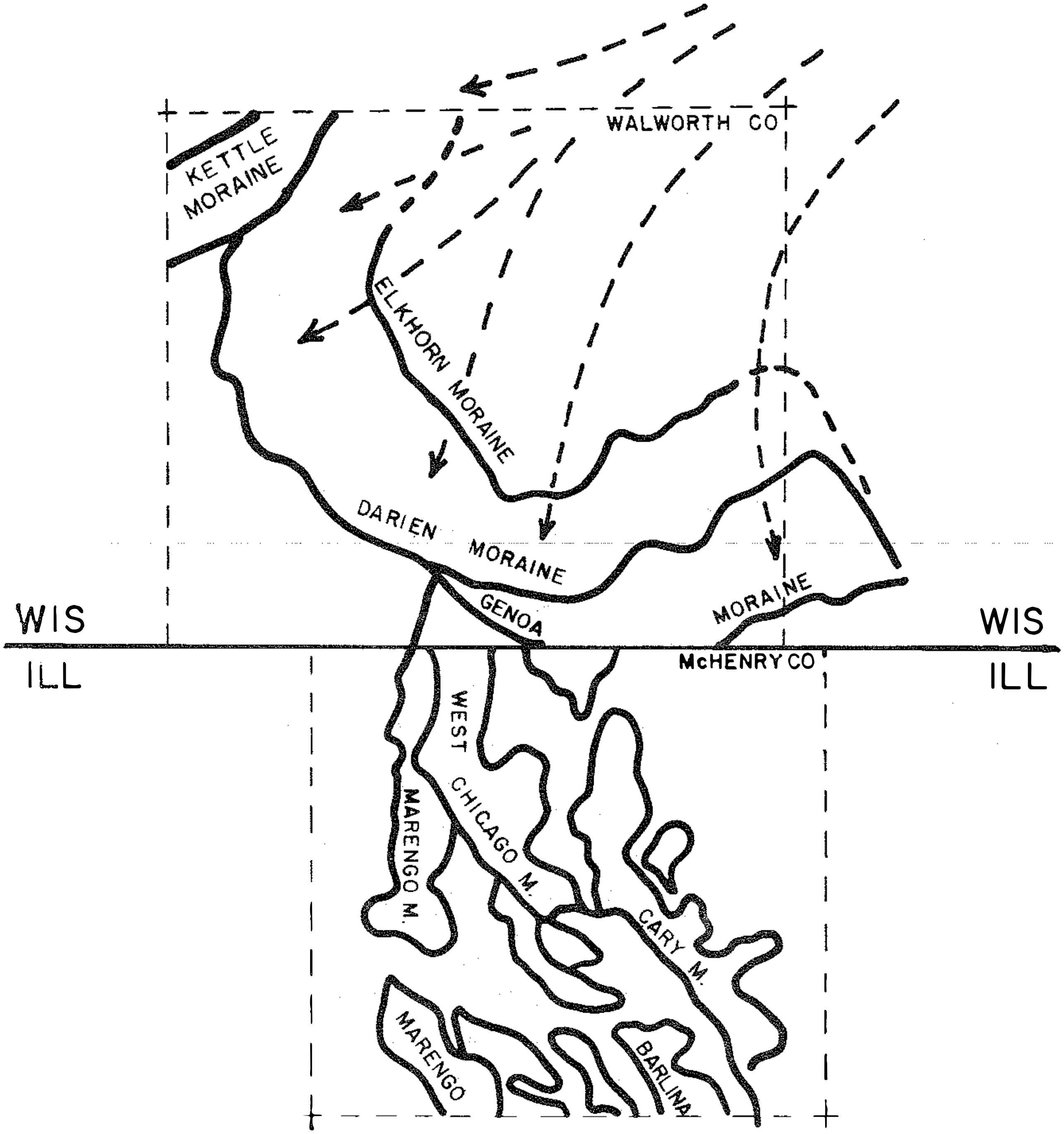

FIGURE 2.--Generalization of the Woodfordian moraines as mapped by Alden (1904) in Walworth County, Wisconsin and by Willman and Frye (1970) in McHenry County, Illinois.

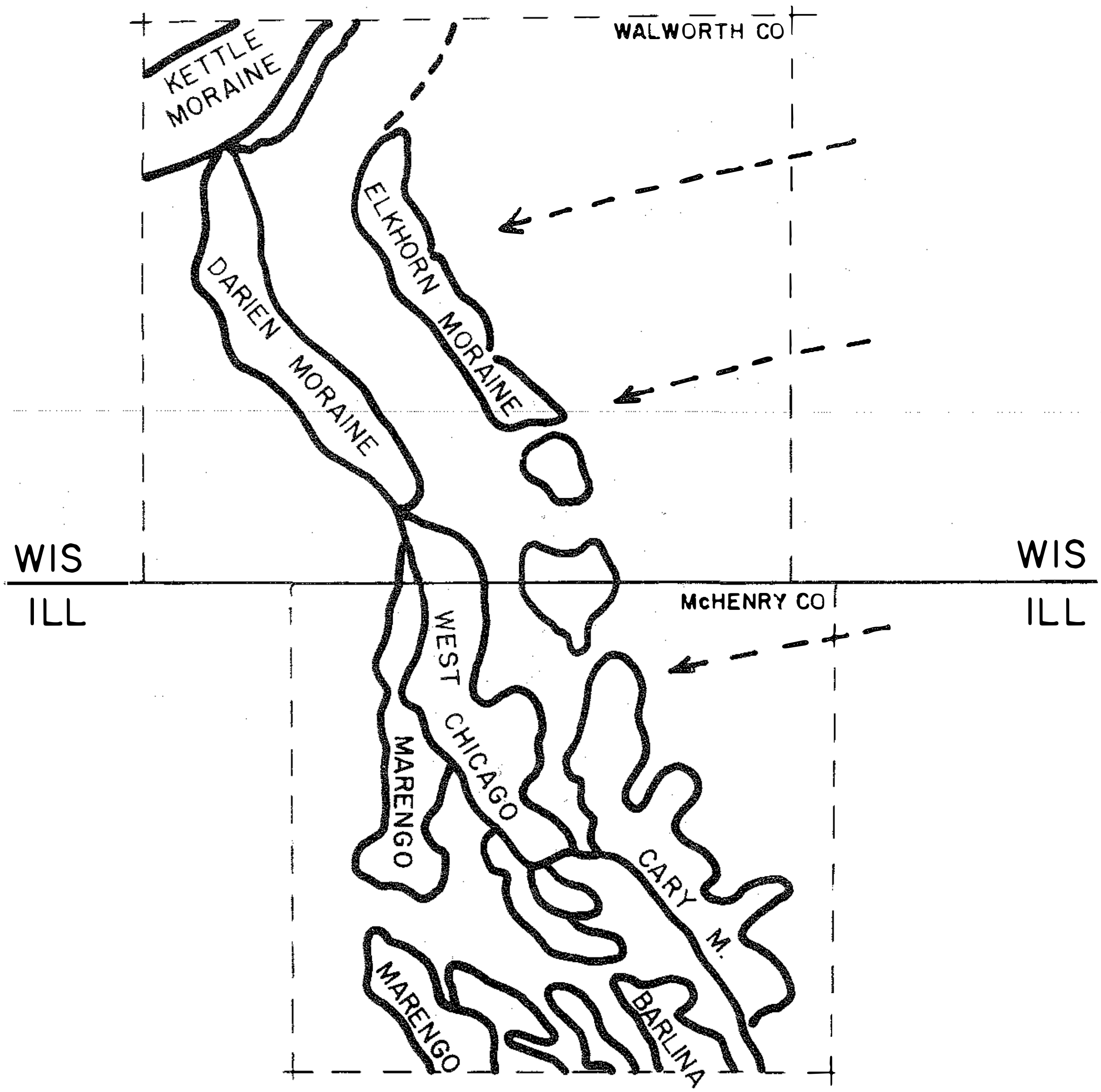

FIGURE 3.--Correlation of the Woodfordian moraines of Walworth County, Wisconsin and with those of McHenry County, Illinois.

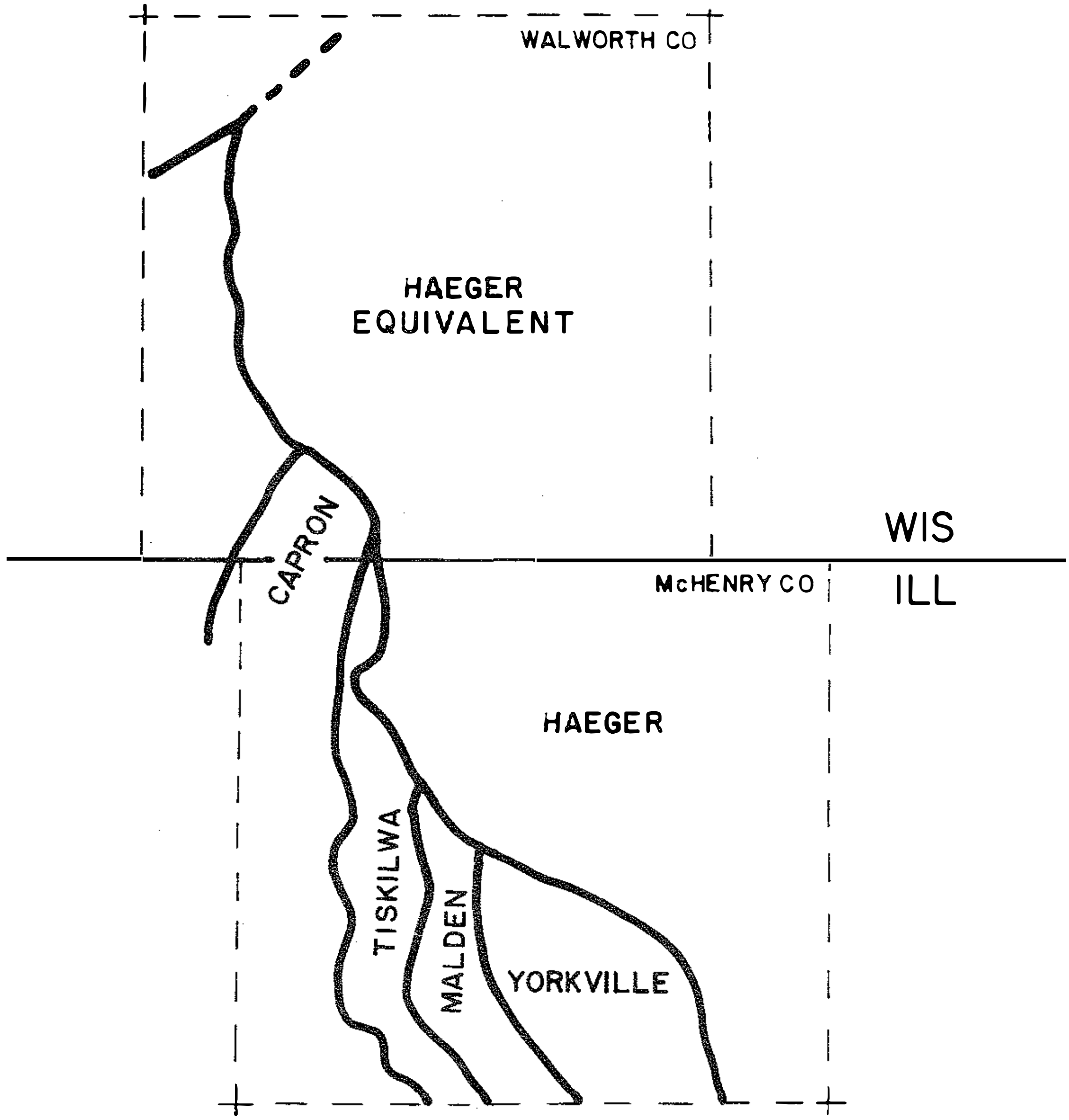

FIGURE 4.--Correlation and distribution of units in Walworth County, Wisconsin and McHenry County, Illinois.

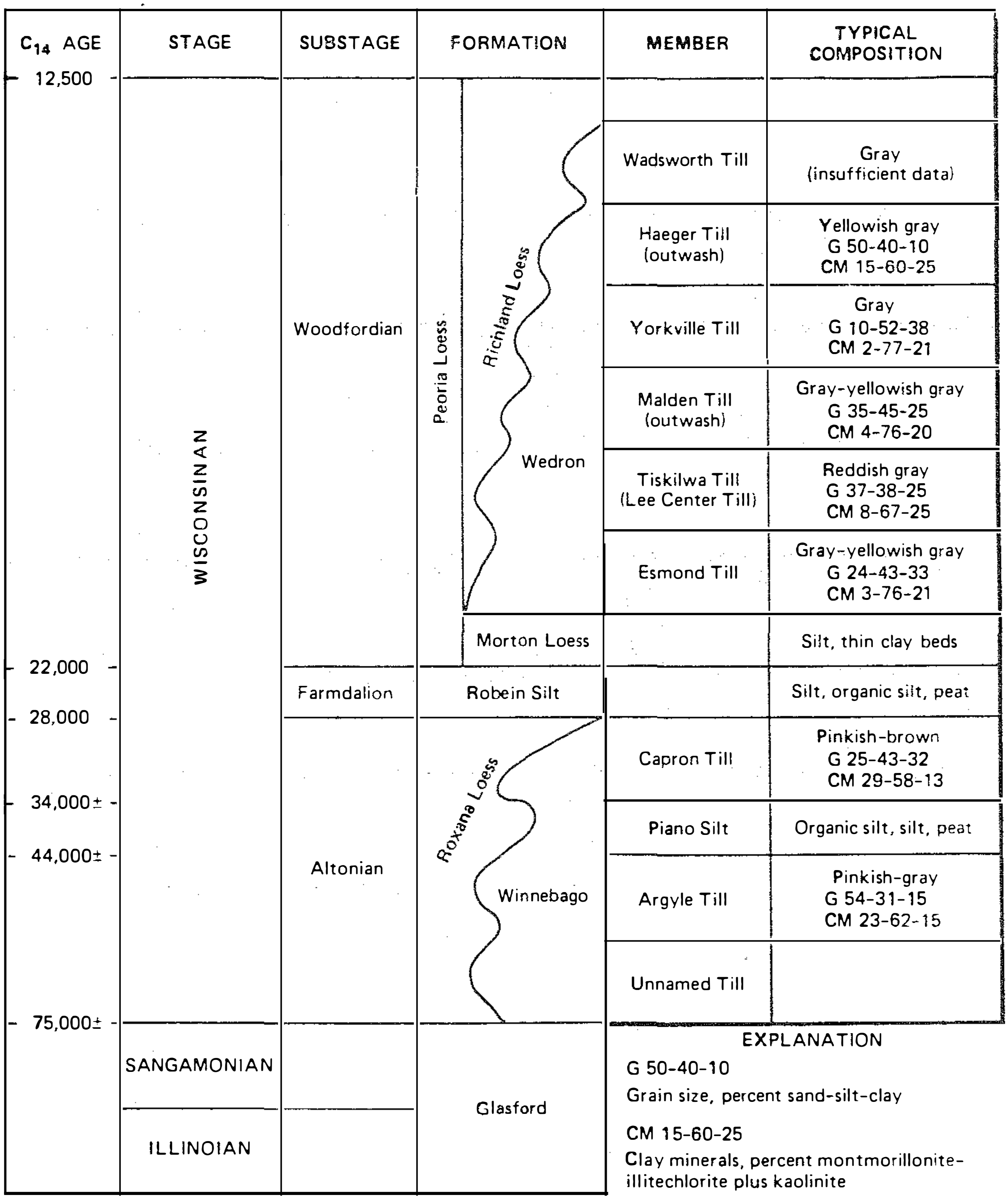

FIGURE 5.--Classification of Plesistocene stratigraphic units in northeastern Illinois with radiocarbon age and typical properties of the tills. (From Kempton and Gross, 1970).

TABLE 1.--Glacial stratigraphy in south-central Wisconsin as used by Bleuer (1970, 1971), as redefiend here, and as correlated with the stratigraphy in northern Illinois.

ILLINOIS	WISCONSIN	WISCONSIN
(Willman, 1975)	(Bleuer, 1971)	(This report)
Capron Till	Capron Till	Capron Till
unnamed till	Argyle Till	Clinton Till
Argyle Till	Janesville till	Allens Grove Till
unnamed till		Foxhollow Till

WOODFORDIAN GLACIAL GEOLOGY

The Tiskilwa Member

The early Woodfordian Tiskilwa Member, named from its type section near Tiskilwa, Illinois (Willman and Frye, 1970), consists of pink, silty-sand to sandy-silt till. The Tiskilwa Till Member in Illinois composes the prominent Marengo Moraine, a north trending feature characterized by rolling topography. Less than 2 km north of the Wisconsin-Illinois state line the Marengo Moraine is overlapped by outwash and the Wisconsin equivalent of the younger Haeger till Member of the Darien Moraine (fig. 4). Large channels filled with valley-train outwash deposits cut through the Marengo Moraine and contribute to the abrupt disappearance of the moraine north of the state line.

The Tiskilwa Member in Wisconsin is exposed at the surface or beneath a veneer of the younger, surficial Haeger Till Member equivalent in south-central Walworth County, Wisconsin. In this area, the oxidized Tiskilwa till is characterized by a light brown color (7.5YR 6/4); where unoxidized, the color is dark reddish gray (5YR 4/2). Grain-size analyses of 35 samples averaged 39 percent sand, 39 percent silt, and 22 percent clay.

The rolling topography of this unit is evident at the surface even where it has been covered by younger till and outwash. The overlying equivalent to the Haeger Till Member is very thin and locally absent; landforms composed of the Haeger till equivalent are limited to locally irregular morainic deposits.

The Equivalent of the Haeger Till Member in Wisconsin

The sandy, gravelly till within and behind the Darien and West Chicago Moraines correlates with the late Woodfordian Haeger Till Member in Illinois, named for Haeger's Bend in McHenry County, Illinois (Willman and Frye, 1970). The equivalent of the Haeger Till Member in Walworth County, Wisconsin is highly variable in thickness and character. The till is generally thin (less than 8 m), sandy and gravelly and varies from brown (10YR 5/4) to light brown (7.5YR 6/4) in color. There appear to be several phases within the Wisconsin equivalent of the Haeger Till Member distinguishable by local differences in texture and color. These differences are probably the result of local changes in source material or glacial regime. Although its clay mineralogy is similar to that of the underlying Tiskilwa Member, the Haeger equivalent is generally much coarser and less pink. In the Darien Moraine, the till is sandy, gravelly, reddish-brown to yellowish-brown and contains about 65 percent sand, 27 percent silt, and 8 percent clay; it is interbedded with deposits of sand and gravel. Behind the Darien Moraine, the till is generally less than 3.3 m thick and is commonly absent. The surface till behind the moraine contains an average of about 54 percent sand, 36 percent silt, and 10 percent clay and is well exposed in gravel pits near Lake Geneva where it overlies a thick outwash unit. In some areas the ice overrode substantial amounts of outwash that contributed sand and gravel to the till. Where the ice overrode the Tiskilwa Member, the drift acquired more fines and a reddish color.

Near the state line in Wisconsin, the Darien Moraine consists largely of sand and gravel with some gravelly, sandy, reddish brown till. East of the moraine, the underlying Tiskilwa Member is covered by a thin, discontinous, sandy, gravelly till with approximately 51 percent sand, 39 percent silt, and 10 percent clay virtually identical in character to the Haeger Till Member of the West Chicago Moraine in Illinois.

In summary, stratigraphic correlations based on field mapping and laboratory data confirm the continuity of the Darien Moraine in Wisconsin with its equivalent in Illinois, the West Chicago Moraine (fig. 3). Till units in both the Marengo and Darien Moraines in Wisconsin also are continuous across the state line and correlate with the Tiskilwa and Haeger Till Members in Illinois (fig. 4).

PRE-WOODFORDIAN GLACIAL GEOLOGY

The only major study west of the Woodfordian moraines in southern Wisconsin since Alden (1918) was made by Bleuer (1970, 1971). Bleuer mapped the pre-Woodfordian glacial materials in southern Wisconsin, but he did not directly trace the units across the state line into Illinois with a detailed sampling program.

Bleuer (1970, 1971) equated the surficial till between the Capron Ridge and the Sugar River south and west of the Woodfordian moraines with the Argyle till Member in northern Illinois. He encountered several problems with this correlation. The physical characteristics of the surficial till in his area of mapping did not match well with those of the surficial Argyle Till Member in northern Illinois. Bleuer (1970) noted that the typical pinkish or salmon color (7.5YR 6/4) of the Argyle Till in Illinois was not necessarily characteristic of the surficial till in south-central Wisconsin.

Textural analyses performed on 125 samples from numerous localities indicated that the surficial till in southern Wisconsin is significantly sandier than the surficial till in northern Illinois. The surficial till in Wisconsin averages 61 percent sand, 27 percent silt, and 12 percent clay, whereas the Argyle Till Member in Illinois averages 53 percent sand, 35 percent silt, and 12 percent clay. On the basis of shale pebbles and clay mineral data, Frye and others (1969, p. 6) suggested that the surficial Argyle till in northern Illinois was deposited by the Green Bay Lobe from the northeast. However, drumlinoid forms, till distribution, and Silurian dolomite pebbles in the till of central-southern Wisconsin support the suggestion that the Argyle till was deposited by the Lake Michigan Lobe as it advanced from the east (Bleuer, 1971).

Texture, clay mineralogy, color, and pebble lithology served as a basis for distinguishing and classifying pre-Woodfordian units in this study (table 2). Heavy mineral and carbonate content were found by Bleuer (1970) not to be useful in making stratigraphic correlations.

Closely spaced sampling and traverses across the state line were used to help solve correlation problems in portions of the area of older till outside the Woodfordian moraines. As a result, a new stratigraphic framework was established that contains the newly named surficial Clinton Member overlying at least two other units, the Allens Grove Member and the Foxhollow Member. While the Argyle till was previously thought to continue north as a surficial till, from Illinois into southern Wisconsin, it can now be shown that the Clinton Member overlies the Allens Grove Member and that the Allens Grove Member found in the subsurface in southern Wisconsin is instead the stratigraphic equivalent of the Argyle Till Member of Illinois. The third unit, the Foxhollow Member, underlies the Allens Grove Member and represents a previously unrecognized stratigraphic unit.

Foxhollow Member

The Foxhollow Member, a new lithostratigraphic unit, is stratigraphically the oldest and lowermost till unit recognized in the study area. Where sampled, this unoxidized, gray, clayey silt till averages 44 percent sand, 37 percent silt, and 19 percent clay. It generally contains a larger number of pebbles and cobbles than any of the other pre-Woodfordian tills in the study area and ranges in color from silver to brownish gray to purplish gray. The Foxhollow Member differs from the other pre-Woodfordian age tills in this area by its lower ratio of light-to-dark-colored dolomite in the 1 to 2 mm (coarse sand) size fraction (less than 0.8:1); whereas the Allens Grove Member typically has a ratio between 0.8:1 and 1.3:1, and the Clinton Member typically has a ratio greater than 1.3:1. Of all the tills in southern Wisconsin, the Foxhollow contains the smallest average amount of illite. X-ray diffraction analyses of the less-than 2 micron clay fraction indicated large amounts of calcite and dolomite and consistently more dolomite than calcite.

In some places, the sand-sized fraction of the Foxhollow till contains small quantities of wood, but no significant amounts could be retrieved. This is the only till known to contain wood in this area outside of the Capron Ridge and the Woodfordian moraines. One of the best sample localities at which wood fragments were found in the Foxhollow till was a test hole drilled approximately 5 km east of Beloit on the east side of a country road, north of old Wisconsin highway 15 in the center of the NE¼SE¼NE¼ sec. 33, T. 1 N., R 13 E. Alden (1918, p. 140) also reported finding organic material at a number of localities in the area.

The Foxhollow Member generally occurs in the subsurface and typically is confined to preglacial or early glacial bedrock valleys where it was protected from erosion during later glacial events. Consequently, the Foxhollow Member is almost totally defined from subsurface sampling.

Allens Grove Member

The Allens Grove Member, which overlies the Foxhollow Member, is named for the village of Allens Grove in Walworth County, Wisconsin. Its type section is on the west side of a borrow pit along State Highway 15 in the

TABLE 2.--Compositional summary of the Pre-Woodfordian tills in Central-southern Wisconsin. Amounts shown are averages, except where noted.

UNIT	TYPICAL COMPOSITION			
	G^{H}_{L}	C	R	N
Capron Till, sandy phase	41^{44}_{37}-35^{36}_{33}-24^{27}_{23}	28-61-11	—	3
Capron Till, silty phase	27^{31}_{24}-38^{40}_{36}-35^{40}_{29}	28-61-11	—	2
Clinton Till	61^{69}_{57}-27^{34}_{15}-12^{29}_{24}	26-60-14 45-45-10	>1.3:1	85
Allens Grove Till	53^{56}_{47}-35^{43}_{27}-12^{22}_{3}	26-61-13 39-47-14	0.8-1.3	40
Foxhollow Till	44^{48}_{39} 37^{46}_{24} 19^{32}_{9}	28-53-19	<0.8:1	22

G = Grain size, percent sand (2-.062mm), silt (.062-.004mm), clay (<.004mm)
H= Highest value, L=Lowest value

C= Clay minerals, percent montmorillonite-illite-chlorite plus kaolinite

R= Ratio of light colored to dark colored dolomite sand grains

N= Number of samples analyzed

NW¼SE¼SW¼ sec. 32, T. 2 N., R. 15 E., 0.8 km east of Allens Grove and approximately 4 km west of the Capron Ridge.

At the Allens Grove type section, a sequence of 11 samples were collected from the outcrop face and from the subsurface using a power auger (fig. 6). At the top of the section below 1 m of loess is 0.6 m of a yellowish-red (5YR 4/6 to 4/8), weathered, truncated B horizon formed on 8 m of Clinton till. A 1 m thick bed of sand separates the Clinton Member into two parts that are lithologically the same. A second sand and gravel layer 1.5 m thick, and 6.4 m below the top of the section separates the Clinton till from the underlying Allens Grove till. The stratified layer contains coarse gravel and cobbles; some reach 11 cm in diameter. The till of the Allens Grove Member is hard, very well compacted, and is brown and light brown to yellowish and light yellowish brown (7.5YR 5/4 to 6/4 to 10YR 5/4 to 6/4) in color. The amount of compaction in the Allens Grove till here, as well as several roadcuts west of sampling location 663 and east of Turtle Creek, may be the result of incorporation and compaction within or beneath glacial ice.

The base of the Allens Grove Member is not exposed. A nearby auger hole penetrated another 2 m of Allens Grove Member before encountering a 14 m section of gray, lacustrine silt. Beneath the silt is a firm, compact, gray (5YR 5/1) till identified as Foxhollow.

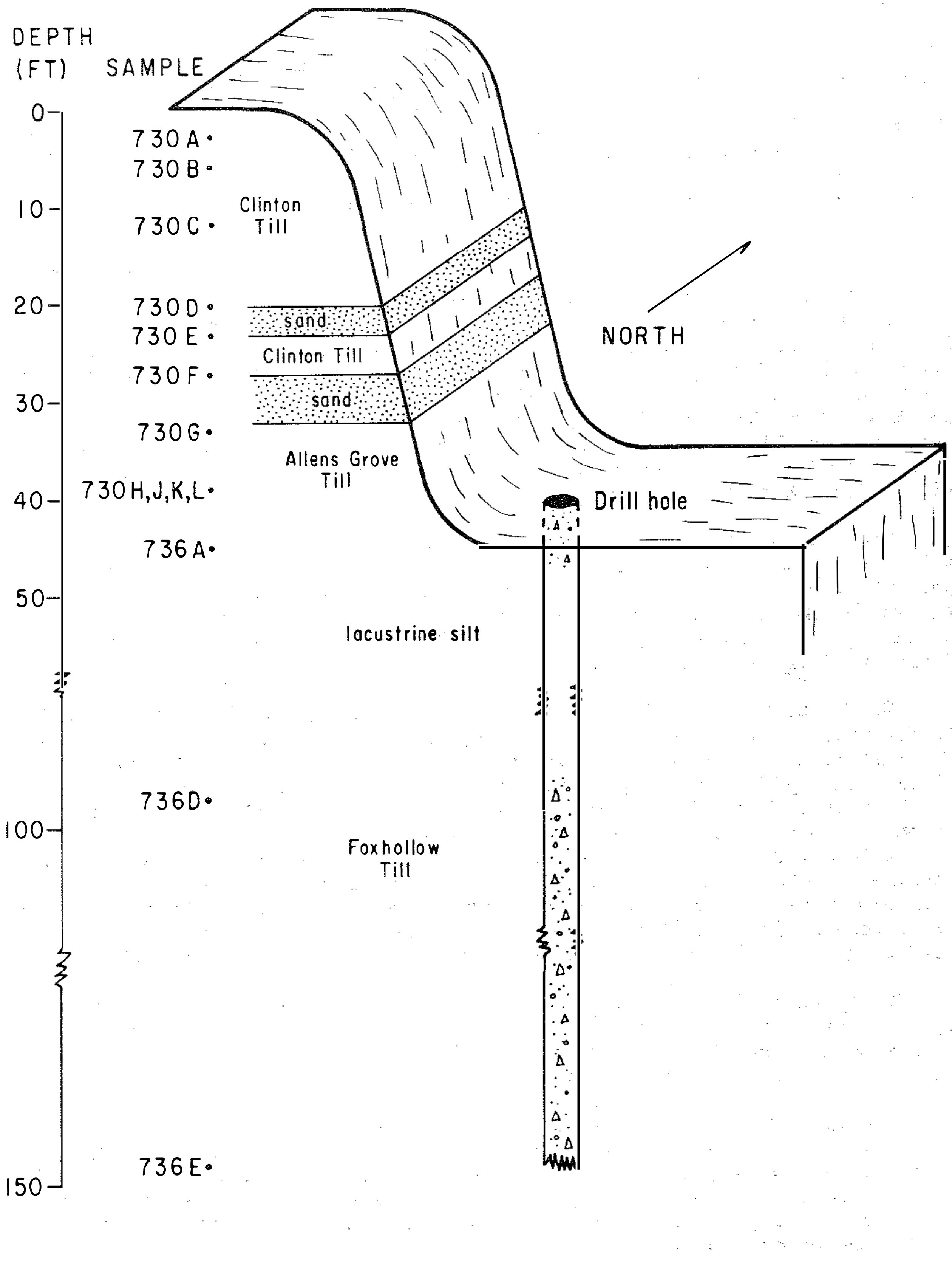

FIGURE 6.--Diagrammatic sketch of the Allens Grove Member type section (NW¼SE¼SW¼ sec. 32, T. 2 N., R. 15 E., Walworth County, Wisconsin).

The texture, clay mineralogy, ratio of light to dark colored sand-sized dolomite, and stratigraphic position support correlation of the Allens Grove Member in Wisconsin with the Argyle Till in Illinois. Samples of the Argyle till, at the Cherry Valley Section, (SE¼SE¼SW¼ sec. 30, T. 44 N., R. 3 E., Boone County, Illinois), an important reference section of the Illinois Geological Survey as well as a stop made on the 1965 INQUA field trip (Frye and Willman, 1965) near Rockford, Illinois, have a texture, clay mineralogy, and ratio of light-to-dark-sand-size dolomite similar to that of the Allens Grove till. For additional evidence supporting this correlation, see section entitled Wisconsin-Illinois Stratigraphic Correlations.

Clinton Member

With the possible exception of an area west of Janesville, the surficial Clinton Member extends throughout nearly all the rolling upland areas west of the Capron Ridge and the Woodfordian Moraines within the study area. The sandy, pebbly, light yellowish brown (10YR 6/4) Clinton Member is named from its type section in a roadcut and adjacent drillhole along the Beloit-Milwaukee Road (State Highway 15), 3.3 km northeast of Clinton, Wisconsin. Formerly correlated by Bleuer (1971) with the Argyle Member, the Clinton Member can be demonstrated to be a separate, distinct unit stratigraphically above the Allens Grove Member and below the Capron Member.

The clay of the Clinton Member is mineralogically similar to that of the Allens Grove and Capron Members; it averages 26 percent montmorillonite, 60 percent illite, and 14 percent chlorite plus kaolinite. However, the Clinton Member is distinguished by a sand-silt-clay content averaging 61 percent, 27 percent, 12 percent and by a light-to-dark dolomite ratio in the sand-sized fraction of greater than 1.3:1 (table 2).

The Clinton till in some places has a pinkish cast similar to that of the Argyle till. Its chroma varies with lighting condition and moisture content. The pinkish cast may be due to incorporation of material from the underlying Allens Grove till, as is indicated by very small inclusions of pink clay in the Clinton till matrix. However, the sandy, buff-colored Galena-Platteville Dolomite beneath much of the area probably had a great influence on forming the composition of the Clinton till. In several pits dug for bridge pilings along Wisconsin Highway 15 near Clinton, large amounts of sandy, weathered Galena-Platteville dolomite were found beneath the Clinton Member. As ice which deposited the Clinton till moved over the dolomite and sand, much of the weathering material could have been incorporated into the Clinton till matrix.

Weathering of the Clinton till has produced a paleosolic B horizon that persists beneath the loess on the flatter uplands. Removed from the steeper slopes by erosion, this paleosol may still exist along the footslopes of hills beneath loess and colluvial deposits.

The upper 6.7 m of the Clinton Member is exposed in the face of the road cut at its type section and was sampled at approximately 0.3 m intervals. The lower 8.2 m were explored by using a power auger. The sandy, buff-colored Clinton Member is overlain by 1.8 m of loess (fig. 7). The loess is an oxidized, light yellowish-brown (10YR 6/4) silt, is noncalcareous throughout, and has no observable bedding.

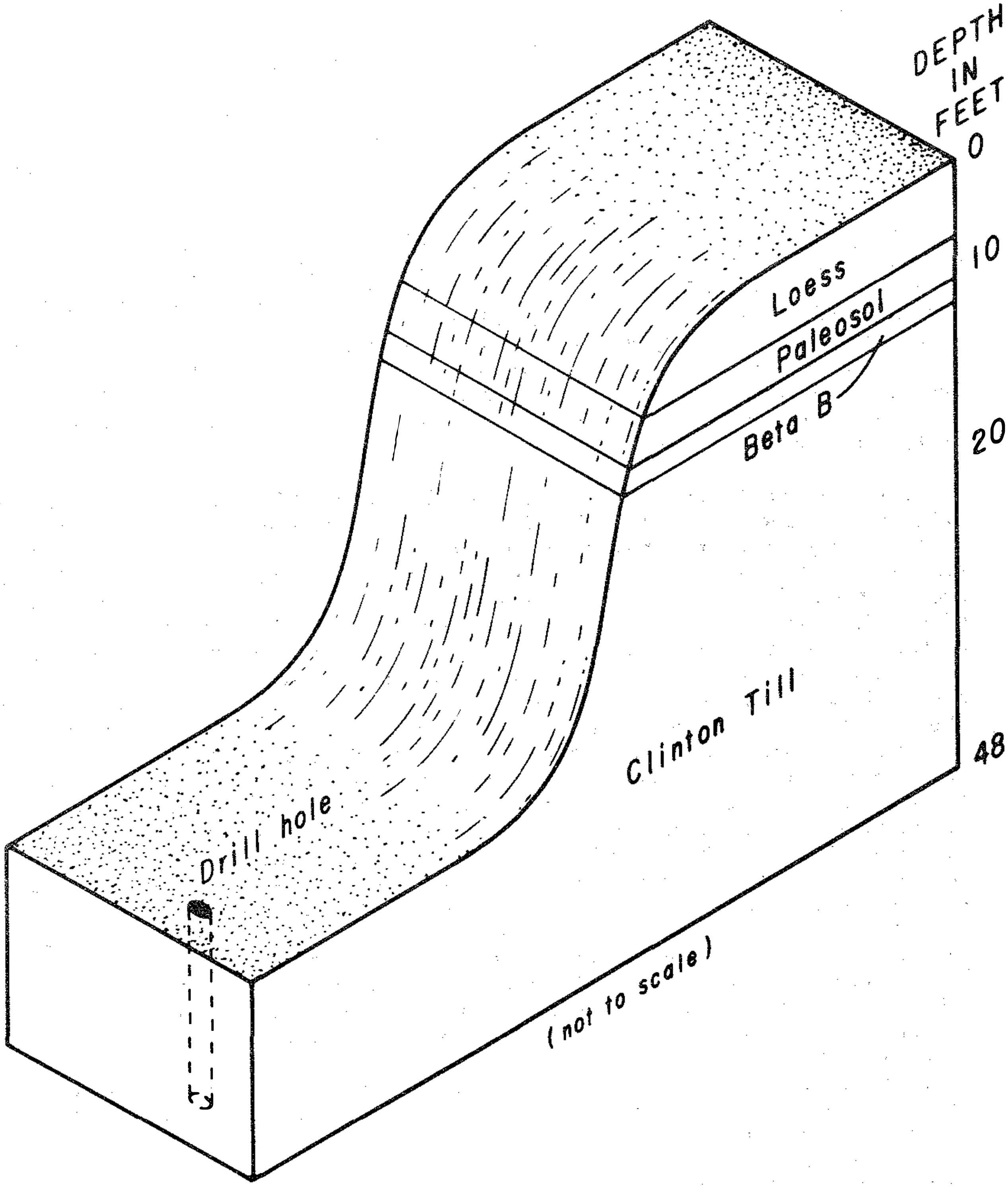

FIGURE 7.--Diagrammatic sketch of the Clinton Member type section. (NW¼SW¼ sec. 3, T. 1 N., R. 14 E., Rock County, Wisconsin).

In composite profile from the type section of the Clinton Member (fig. 8), an illuviated B2t horizon occurs below the A1 horizon in the loess. A significant decrease in silt with a reciprocal increase in sand 1.8 to 2.1 m below the top of the section marks the contact between the loess and the Clinton till. Except for a sample from the basal portion of the Clinton till at a depth of 13.1 m which contained slightly less sand, eleven samples between 2.7 m and 11.6 m depth contained nearly the same amount of sand. Apparently the upper part of the underlying Foxhollow Member was incorporated into the base of Clinton Member when the former was overridden by the advancing ice sheet.

In situ weathering of the Clinton till before the deposition of the Peoria Loess produced a reddish-brown to light-reddish-brown (5YR 4/4 to 6/4) B horizon in the upper 1.7 m of the Clinton Member. Clay-percentage data indicate that illuviation also took place in the B horizon as well as in the brown (7.5YR 4/4) beta B, a zone developed immediately below the Bt horizons.[5] There is an overall gradual increase in clay content upward from the unweathered till through both the beta B and B horizons. The profile is leached to the base of the beta B horizon. No soil structure is evident in the highly weathered, sandy paleosol.

Clay minerals in the less-than-2 micron fraction of 8 samples in the Clinton type section were analyzed by X-ray diffraction (fig. 9). Representative X-ray patterns from various parts of the type section are shown in figure 9. The presence of dolomite, calcite, chlorite, and montmorillonite are represented by sharp, well-defined peaks in sample 17. In the lower parts of the Clinton Member in its type section, both dolomite and calcite are present in relatively large amounts. The calcite peak decreases in intensity from sample 17 up to sample U. Calcite has been leached from the profile in sample P, while dolomite still remains. In samples M and H, which are from the beta B and the B horizons respectively, both calcite and dolomite were removed by weathering. Flattening and reduction of the chlorite plus kaolinite peak and the illite peaks upwards through the profile are concomitant with a broadening of the montmorillonite and mixed layer peak (near 5.4° 2Θ). The third-order (003) chlorite peak, a very sensitive indicator of weathering (Willman, Glass and Frye, 1963; Glass, 1976, oral communication), decreases in intensity and clarity upward through the profile as the influence of surficial weathering increases. The persistence of an artifact chlorite (001) peak at 6.1° 2Θ in sample H, the paleosol (fig. 9), may be due to aluminum integrades (Glass, 1976, oral communication), vermiculite, or both. Chlorite should have been removed by weathering at this point. The X-ray pattern of sample H exhibits characteristics of the most severe weathering and represents a horizon for which calculations of clay-mineral percentages are impractical. Illite and chlorite peaks in this sample are much smaller, and peaks reflecting montmorillonite and mixed-layer clay minerals (near 5.4° 2Θ) are larger. The location of the peak near 5.4° 2Θ instead of at 5.1° 2Θ suggests that the expandable clay may have had a chlorite parent material (Glass, 1976, oral communication).

5 In calcareous sediment, a secondary zone of clay accumulation occurs in the leached zone directly above the contact with the underlying calcareous sediment. Both clay and organic matter, which gives the beta B its characteristic brown color, accumulated here as the result of (1) a change in porosity and permeability, and (2) a change from leached to calcareous material (Bartelli and Odell, 1960).

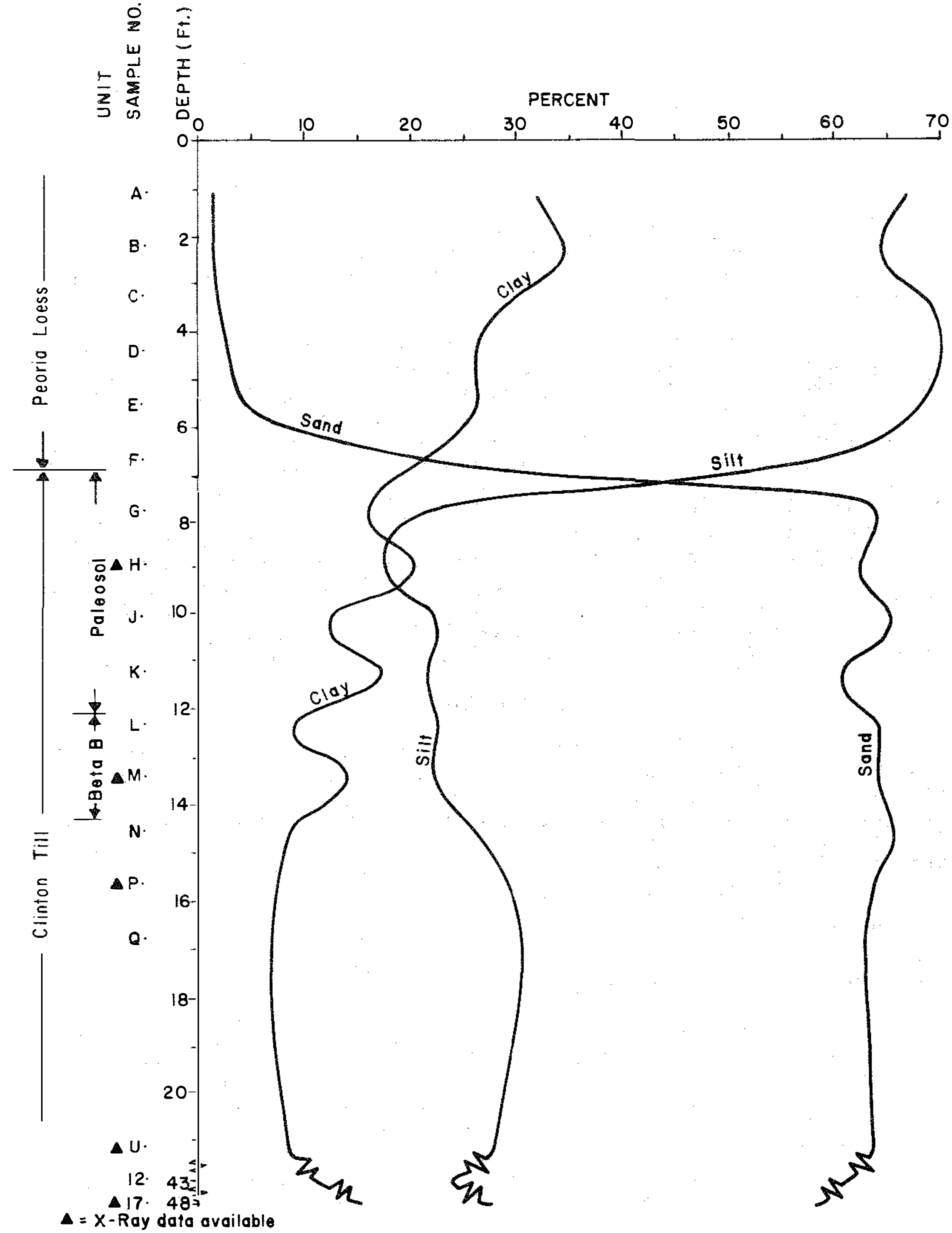

FIGURE 8.--Grain-size distribution in samples from the Clinton Member type section and stratigraphic positions of samples selected for x-ray analysis.

Effects of weathering on a profile can also be observed by changes in the diffraction intensity (DI) ratio (William, Glass, and Frye, 1963). The DI ratio is a comparison of the glycolated 10 nm illite peak with the glycolated 7.2 nm kaolinite plus chlorite peak. Kaolinite is a stable mineral and any change in the DI ratio is the result of a change in the amount of chlorite or illite. Chlorite is the first mineral affected by the weathering process and the DI ratio increases accordingly. With sufficient continued weathering, the illite begins to alter and the DI ratio drops. Alteration of illite in Woodfordian till has not been observed, whereas alteration of illite extends into the B2 horizon in Altonian age tills (Willman, Glass, and Frye, 1963). In the Clinton Till profile, the DI ratio increases upward through sample U and then decreases from sample U through sample H. This change at sample U represents alteration of illite below the paleosolic B horizon and supports the conclusion that a great degree of weathering has occurred in the upper part of the Clinton Till.

At the base of the type section for the Clinton Member a second till unit represented by sample 21 (fig. 9) contrasts sharply with the overlying Clinton Member. The Clinton till, with sand percentage in the upper 50s and 60s overlies a till with a sand content of 43.5 percent (sample 21). The X-ray patterns for sample 21 also exhibit a smaller ratio of calcite-to-dolomite than overlying samples, suggesting that it correlates with the Foxhollow Member, although more data are needed to support this conclusion. In the Vermiculite Index (VI)[6], a weathering index that is used to compare the glycolated 10 nm illite peak to the glycolated 14 nm chlorite peak, there is a break between samples 17 and 21. The VI is less than 50 in the upper sample (17) and larger than 145 in the lower sample (21). This difference, along with the less intense 5.4 nm peak in sample 17, and the broad 5.4 nm peak in sample 21, substantiates the stratigraphic boundary determined from the textural break and suggests correlation of this unit with the Foxhollow Member.

Capron Member

Overlying the Clinton Member and overriden by the Woodfordian glacier that formed the Darien Moraine near Lake Geneva, Wisconsin, is a small ridge of red clayey till that trends southward into Illinois. The till composing this ridge was correctly correlated by Bleuer (1970, 1971) with the Capron Till Member of the Capron Ridge in Illinois. Woodfordian outwash from the Lake Michigan Lobe marks the eastern surficial border of the till and the occurrence of the distinctly sandier Clinton Member defines its western limit.

The Illinois State Geological Survey recognizes a silty phase and a sandy phase in the Capron Till Member (Frye and others, 1969). Both phases have been observed in the Capron Ridge in Wisconsin, although in places the difference in texture is often less than that reported in the Capron Ridge in Illinois. Several samples collected by Bleuer (1970) from the Capron Ridge had compositions intermediate between the two phases. One Illinois boring (Northeastern Illinois Planning Commission test hole NPC-12, in the NE¼NE¼ sec. 7, T. 40 N., R. 6 E. Kane Co.; open-file report at the Illinois State Geological Survey) contains till with sand percentages grading upward from 20

[6] The VI measures the ratio of the peak heights of the 10 nm and the 14 nm peak. The $>$ or $<$ sign signifies whether the 14 nm peak is greater than ($>$) or less than ($<$) the 10 nm peak. The numerical value is a relative size indicator and is unitless.

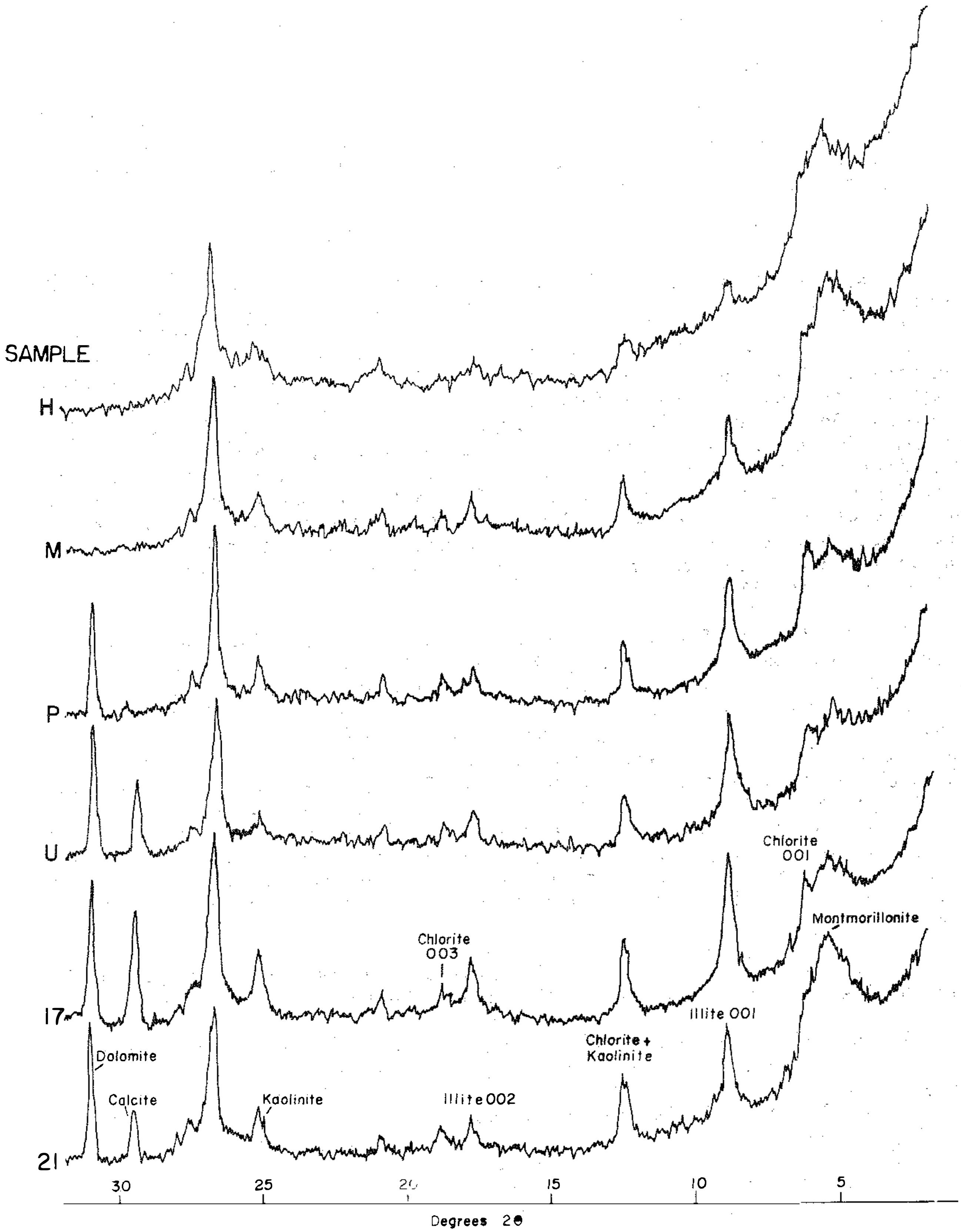

FIGURE 9.--X-ray diffraction patterns of glycolated samples from the Clinton Member type section.

to 36 percent over a vertical distance of 5 m. At all sites sampled during this study, the sandier unit of the Capron equivalent lies above the siltier one. The lower part of the Capron till sheet may contain finer material derived from the underlying sediment or the upper part may represent ablation till. In adjacent Winnebago County, Illinois, incorporation of pre-existing material into younger deposits by glacial ice resulted in overlying material acquiring some of the characteristics of the overridden deposit (Kempton and Gross, 1970, p. 68). Examples of this in Winnebago County include the Esmond Till Member, which acquired some of the characteristics of the underlying Argyle Till Member, and the Malden Till Member which incorporated some of the underlying Tiskilwa Till Member.

WISCONSIN-ILLINOIS STRATIGRAPHIC CORRELATIONS

Except by inference, very little work has been completed to base glacial stratigraphic correlations between Wisconsin and Illinois. In this study, correlations were established by tracing the stratigraphic units from one state to the other. The relationship of the Argyle, Clinton, and Capron Members is shown on a cross section extending from a point about 4.8 km southeast of Hunter in Boone County, Illinois, to a point near the northeast corner of Boone County (fig. 10). A profile of the Beaverton Section (ILL 5 on fig. 10), described in detail by Frye and others, (1969) which has the Farmdale soil developed in the Argyle till, and the Northeastern Illinois Planning Commission's cored test hole NPC-1 on the Capron Ridge, are included on the cross section (fig. 10). Part of this cross section, as evidenced by the great thickness of unconsolidated deposits in test hole NPC-1, lies over the Troy bedrock valley. The total depth of NPC-1, although not fully presented here, is 144 m.

The NPC-1 core (fig. 11) contains the most complete sequence of stratigraphic units. Beneath the surficial Peoria Loess lies the sandy phase of the Capron Till Member which, in turn, overlies the sandy, yellow-brown Clinton Member. A layer of silty sand and gravel outwash separates the Clinton Member from the pink to gray-brown Argyle Member below. Beneath the Argyle is a less sandy till (T1) characterized by a sand percentage in the low to upper 40s. Although the stratigraphic position of till T1 supports its correlation with the Foxhollow Till, the consistently higher illite content of T1 does not. Below till T1 is a thick outwash sequence. Under the outwash is a till designated T2, which possibly corresponds with the Sterling Till of Illinoian age. Still lower in the section is a massive lacustrine deposit underlain by another till (T3) which may correlate with the Ogle Till, also of Illinoian age.

The Capron Till mantles the Clinton Member to the western margin of the Capron Ridge. West of that margin the Clinton Member is at the surface.

In the Beaverton Section (ILL 5 fig. 11), the Clinton Till is absent and 1 m of Peoria Loess overlies 4.6 m of Argyle Till Member. Developed on the Argyle Till Member and below the loess is 0.6 m of Farmdale Soil (Frye and others, 1969). From field observations, the Farmdale Soil is visibly less developed than the paleosol on the Clinton till in Wisconsin. This may indicate that the Argyle till, at least at the Beaverton section, was not exposed to subaerial processes as long as the Clinton till or that a thin cover of Clinton till was removed from atop the Argyle till during the late Altonian

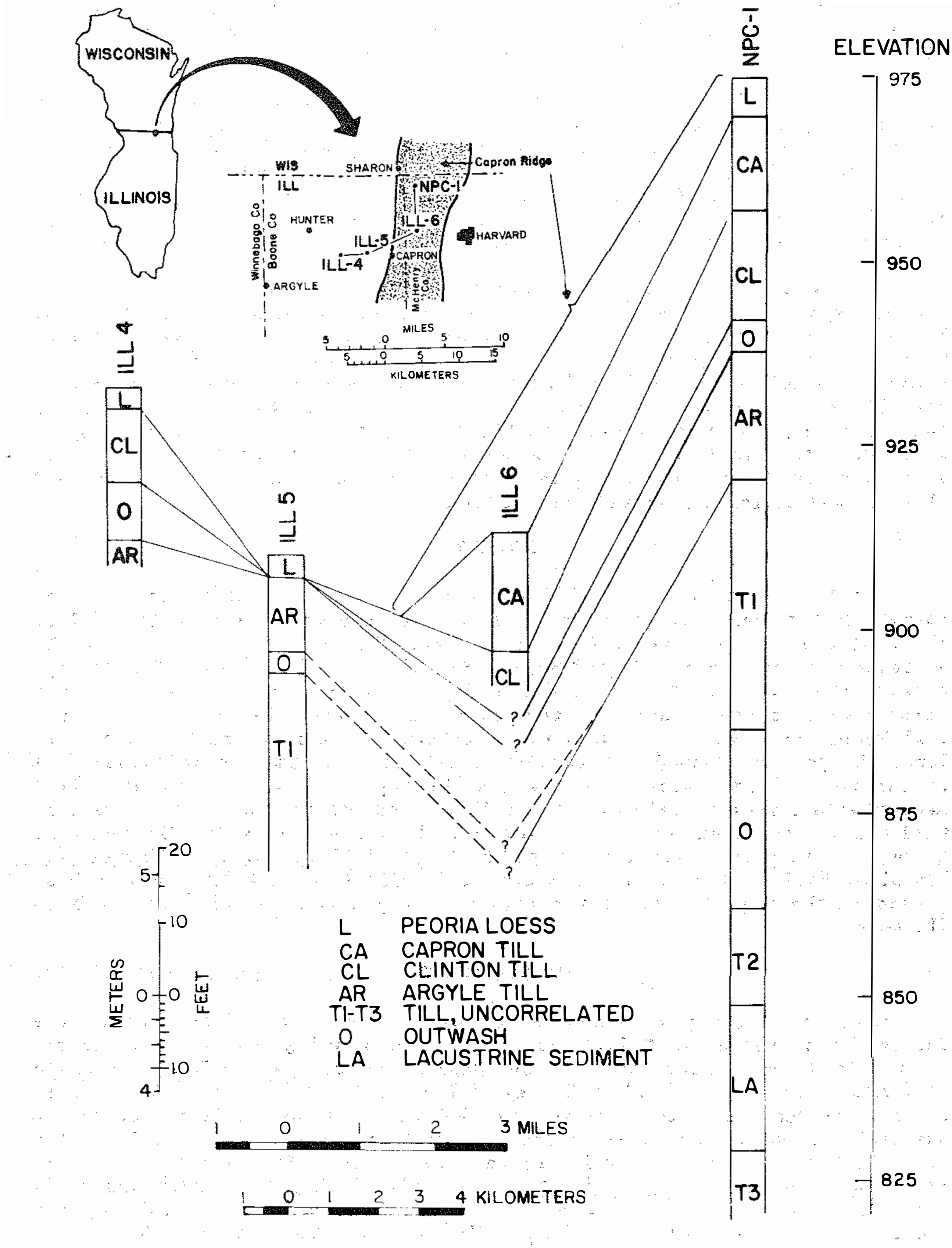

FIGURE 10.--Cross section across a part of northern Illinois showing the stratigraphic relations of glacial materials.

when the Capron till was deposited. The Argyle till is separated from till T1 below by a 1-m thick bed of sand and gravelly sand. The Argyle till is distinguished from T1 by differences in clay mineralogy and texture.

West of the Beaverton section, test hole ILL 4 contains sandy Clinton till resting on outwash that overlies the Argyle till. Separation of these tills was based partly on the difference in their grain size and the presence of an intervening outwash layer. Clay mineralogy also helps to distinguish these tills; not only do their DI ratios differ, but the difference in chlorite (003) peaks for the two tills indicates that the lower unit is much more severely weathered than the upper unit.

The cross section shown on figure 10 provides the basis for defining the stratigraphic relationships between the Clinton and Allens Grove Members. Instead of forming the surface till in both northern Illinois and southern Wisconsin, the Clinton Member overlies the Allens Grove (Argyle in Illinois) Member in southern Wisconsin and extends at least a short distance into northern Illinois. Although not presented here, additional data from test holes and outcrops in both Wisconsin and Illinois support these correlations and compliment the cross section (see Fricke, 1976). Further mapping needs to be done to better define the surficial extent of the Clinton Member in northern Illinois and define its westernmost margin.

SUMMARY

Six till units are included among the Pleistocene units that can be correlated between Illinois and Wisconsin. The Woodfordian age Haeger till of the West Chicago Moraine in Illinois is traceable into Wisconsin where the equivalent of the Haeger Till Member forms the Darien Moraine. The Marengo Moraine and the associated Tiskilwa Member are overlapped by the Darien Moraine a short distance north of the state line. Capron Ridge and the Capron Till Member extend from Illinois into southern Wisconsin where they are overlapped by younger outwash and the Darien Moraine. In the area of older till to the west of the Darien Moraine and the Capron Ridge, the Clinton Till Member with a remnant paleosol formed locally on its surface is the surficial till unit. The Allens Grove Till Member, which lies below the Clinton Till Member in Wisconsin, correlates with the Argyle Till Member in Illinois. The Foxhollow Till Member is the lowermost till unit recognized in southern Wisconsin in the sequence and correlates with a yet unnamed till in northern Illinois.

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GEOPHYSICAL EVIDENCE THAT THE HAEGER TILL MEMBER UNDERLIES SOUTHERN WESTERN LAKE MICHIGAN

by

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ABSTRACT

While developing methodology for underwater sand and gravel exploration (western Lake Michigan, 1976 to 1978), we collected evidence that a till unit which was not seen in previous geophysical investigations overlies the bedrock under the lake. Interpretation of the newly-detected till sheet was based upon data gathered by electrical resistivity and acoustic reflection profiling at Wind Point, north of Racine, Wisconsin. The till is postulated to be the Haeger, which crops out onshore in southern Wisconsin and northern Illinois. It is an older and more gravelly till than any previously reported under Lake Michigan.

INTRODUCTION

A major goal of the 1976 to 1978 Western Lake Michigan Sand and Gravel Assessment project sponsored by the University of Wisconsin Sea Grant Program was to test and apply promising geophysical methods for delineation of the lateral extent and thickness of possible offshore deposits of sand and gravel (Welkie, 1980). Six test sites along the western Lake Michigan shoreline were selected as promising for sand and gravel exploration based upon previous studies, or extrapolation of onshore geology to offshore shallow-water areas. Four geophysical methods (acoustic profiling, seismic refraction, electrical resistivity profiling, and resistivity sounding) were chosen on the basis of the following criteria: (1) previous successful application of the method; (2) applicability in shallow water where sand and gravel are likely to be exploited; (3) possibility of modification for rapid data acquisition and interpretation; and (4) ability to distinguish sand and gravel from other sediments. Methods were tested singly and in combination, and our interpretations were verified by obtaining samples at locations suggested by the geophysical data.

As a result, a more accurate assessment of offshore deposits was possible than by previous blind surficial sampling or coring programs, and interpretation of geologic structure was possible also at depths that could not be reached by sampling. Indeed, an estimate of sediment texture, compressional velocity, resistivity, and thickness could be obtained for geologic units between the lake floor and Paleozoic rock.

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As an auxiliary result of our investigations at a test site north of Racine at Wind Point, Wisconsin (fig. 1), a previously unreported till unit under the lake was inferred to overlie the Paleozoic rock. This interpretation was based on data collected by acoustic profiling followed by sampling, although the till unit itself could not be sampled because it did not crop out.

SUBSURFACE GEOLOGY AND GEOPHYSICS OF THE 1977 TEST SITE

Along the western shore of Lake Michigan, the Paleozoic rock (depth 0 to 100 m) is mostly reef and interreef dolomite of the Racine Formation, Niagaran Series, Silurian System (Alden, 1918). Exposures of dense reef rock, which contain a variety of invertebrate fossils, are known throughout the Silurian sequence and are present in Chicago, off Waukegan Harbor, and off Wind Point, (Alden, 1918).

Some of the major topographic relief on the Paleozoic rock surface was caused by preglacial stream erosion (Horberg, 1950). Ancient stream valleys were buried by glacial till of Wisconsin age (100,000 to 10,000 years B.P.) (Hough, 1958; Mickelson and others 1977a). Compressional velocity of about 1.7 km/s and electrical resistivity of about 100 ohm-metre of the tills are considerably lower than those of the bedrock (Woollard and Hanson, 1954). Therefore, we expected that the till-bedrock boundary would be definable on the basis of both seismic and resistivity methods.

Four major till units are exposed in a north to south sequence under the lake (fig. 1). These till units have been named under the lake by Lineback and others (1974), and numbered in bluff exposures by Mickelson and others (1977a). In their detailed study of till outcrops along the western shore of Lake Michigan, Mickelson and others (1977a) found that the major till units contained sub-units that were distinguishable because of lithology and inter-beddded lake sediment. From oldest (south) to youngest (north) their names and corresponding numbers are the Wadsworth Till Member (2), Shorewood Till Member (3A), Manitowoc Till Member (3C), and Two Rivers Member.

A still older till unit, known as the Haeger, crops out 40 km to the west of the present lake shore in northern Illinois and in southern Wisconsin. By projection, the Haeger should underlie the others under the lake, but geophysical evidence for this has been missing so far. Mickelson and others (1977a) have divided one equivalent of the Haeger Member into subunits 1A and 1B (fig. 2). The 1A till is coarse and sandy, containing over 40 percent sand, pebbles, cobbles and boulders. The 1B till is gray, is sandy and silty, and contains fewer cobbles, pebbles and boulders. At an outcrop, the thickness of the 1B unit was measured to be 2 to 3 m; the 1A unit was thicker, but its thickness is not yet determined.

The next-younger overlying till unit, the Wadsworth of Illinois (2A, 2B, and 2C of Mickelson and others 1977a), which extends southward to beyond the present lake basin (fig. 1), is more fine grained than the Haeger. The 2A and 2B subunits are similar lithologically, gray and clayey, containing greater than 70 percent illite in the clay fraction and more dolomite than calcite in the carbonate fraction (Lineback and others 1974). Occasional lenses of granular outwash are enclosed in the till (State of Illinois, 1958). The maximum known thickness of the Wadsworth under the lake is 18 m, found in the southwest corner (Lineback and others 1974).

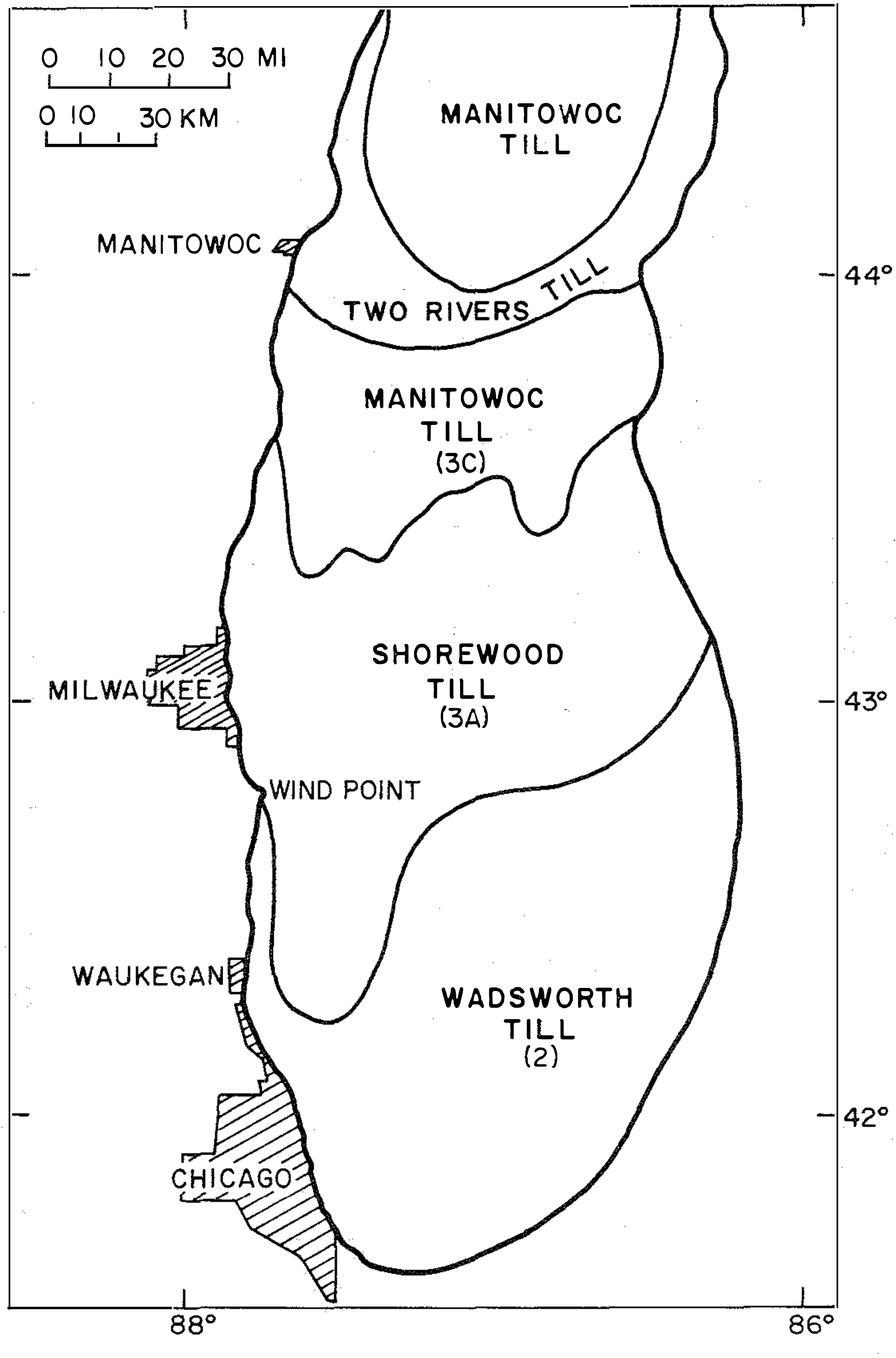


FIGURE 1.--Glacial tills underlying Lake Michigan. The location of the study site along the western shore north of Wind Point is indicated.

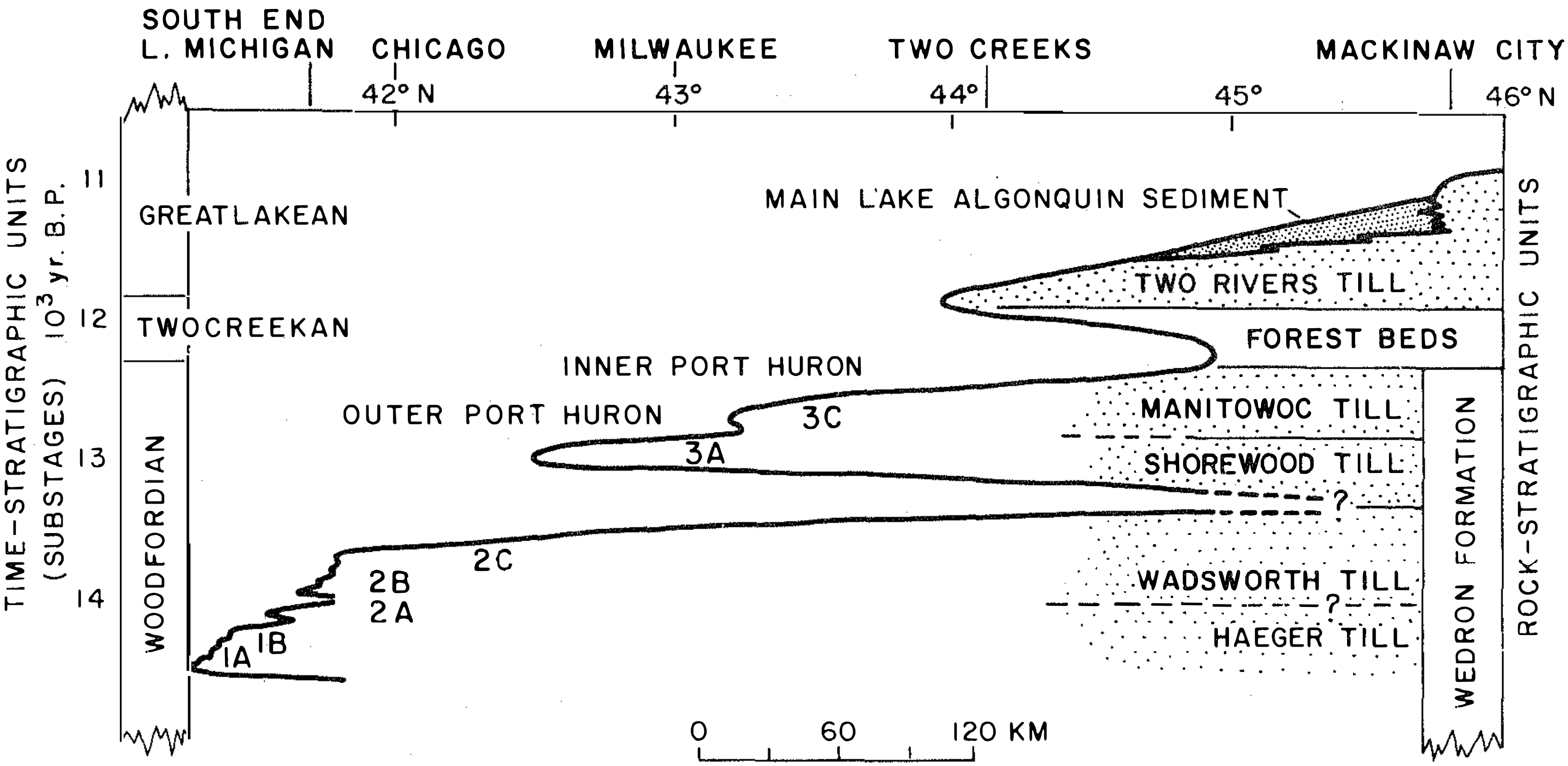


FIGURE 2.--Time-sequence, rockstratigraphic units, and extent of glacier ice in the Lake Michigan basin in Wisconsin time. The distances of advance are at the center of the lake and are somewhat less on the western shore. The numbered units are those used for till units found in the bluffs in Wisconsin by Mickelson and others (1977a). The terminology on the right is that used in Illinois for till units under the lake (Lineback and others 1974) except for the Two Rivers Member which has been formally named in Wisconsin.

Onshore and in the nearshore, the Shorewood Till member (3A) overlies the Wadsworth only as far south as Milwaukee, north of the study area; but it extends farther south under the center of the lake (fig. 1).

We expected that the units and subunits would be distinguishable geophysically by the nature of the interfaces between them. Three types of divisions between till units are possible. First, most of the units exposed onshore are separated physically from the others by a layer of lake sediment deposited during minor glacial retreats (D. Mickelson, oral communications). Second, gravel is commonly found on the top surfaces of till units (Flint, 1964). Finally, predecessors of the present lake are known to have receded after episodes of glaciation causing some till surfaces to be exposed to the air. Drying of the clay at the surface of the till should have occurred, and because the clay has low permeability, it should not quickly become saturated when covered again with water. The dry part of the till should provide yet another physical discontinuity (D. Mickelson, oral communication).

Because a difference in grain size, age, and history exists between the Wadsworth and the Haeger, some differences in seismic velocity, density, and resistivity are reasonable expectations. The fine-grained lake sediment, gravel, or dried clay that may exist between till units should provide reflective interfaces. A velocity contrast on the order of 1:2 between the Haeger and the Paleozoic rock could be expected.

SURFICIAL GEOLOGY OF WIND POINT

The offshore sediments north of Wind Point have not been examined previously in detail. An onshore surficial sediment map (fig. 3) (Alden, 1918) shows the locations of onshore sand, stratified clay, and gravel deposits that may extend into the offshore. North of Wind Point, onshore gravel deposits that have been mined intersect the shore. This sediment is thought to have been deposited along the shores of predecessors to the present lake (Alden, 1918).

METHODS

The instruments used in this study have been described in detail in a previous paper (Welkie and Meyer, 1982). A brief summary of methods follows.

The position of the boat was determined to within 5 m of its true position with a Motorola Miniranger II active radar system.

A Shipek sampler of 10 cubic centimeter capacity was used to obtain surficial samples. Locations of sample stations were selected from the acoustic profiles.

For acoustic profiling, the modified EDO Western Corporation Model 248A/TVG sonar transceiver used has been previously described (Lineback and others 1971; Nebrija, 1979). A streamlined depressor-body containing a transducer that transmitted pulses at 5 kHz was towed from the stern A-frame of the boat about 3 m below the surface and was decoupled from the vessel's pitch by elastic shock cords. A pulse length of 0.3 milliseconds (1 cycle) was used for greatest resolution. The maximum vertical resolution of the complete system is 0.5 milliseconds (determined by measurements from the records).

Electrical resistivity profiling was used in conjunction with acoustic reflection profiling (Nebrija, 1979). The Schlumberger configuration rather than the Wenner was used because the shorter separation of potential electrodes allows greater resolution along traverses (Bhattacharya and Patra, 1968; Dobrin, 1976). A surface-towed current electrode spacing (AB) of 120 m and potential-electrode spacing (MN) of 15 m were selected from the standard two-layer Schlumberger curves using the anticipated water depth and expected contrast in resistivity between the water and the sediments. The AB spacing used was approximately 10 times the water depth, and MN was 1/5 or less than the AB separation.

RESULTS

North of Wind Point, near Racine, the area where onshore gravel deposits appeared to extend offshore was examined by combining the techniques of acoustic and resistivity profiling and sampling (fig. 4).

The eastern-most acoustic profile measured perpendicular to the shore (C-D, figs. 5 and 6) shows humps 1 to 2 m high on the lake bottom that stop where a subsurface reflector begins to outcrop (fig. 6). Samples were not recoverable over the ridges, (sample stations 4 and 5, fig. 4), but hard clay was found on the sampling tool. Over the outcropping material, closer to shore, samples were also difficult to obtain (sample stations 1 to 3, fig. 4), but small amounts of sand were recovered. Because the sampling attempts suggested a hard bottom, erosion may be taking place here. Shore erosion rates are 3 m/yr at the northern part of Wind Point (Mickelson and others, 1977); therefore, offshore erosion is also likely here.

The material that outcrops close to shore is interpreted as dolomite because of its high resistivity (fig. 5). It is covered in places by sand which was probably derived from eroding onshore deposits.

The irregular-surface material that is truncated at the dolomite outcrop is probably till covered with gravel. The gravel possibly is a lag deposit resulting from removal of the fine-grained components of the lake sediment or the till. Clay was sampled here, so the gravel is probably thin or intermingled with the clay. A further indication that the gravel is thin or patchy is that acoustic penetration was achieved into the till. If the gravel was thick, penetration should not have been possible because most of the acoustic energy would have been returned as reflected energy. Subsurface reflectors indicate that there is layering within the till. Because three till units are expected here but at least five subsurface reflectors are seen, the till units appear to have been deposited in several episodes, as numbered by Mickelson and others (1977). By examining those places where the subsurface reflectors outcrop, connecting them between profiles, and projecting the trends to outcrops of known till units onshore, the subsurface reflectors can be identified and mapped (figs. 5 and 6).

Schneider and others (1977) have prepared a cross-section of the bluff stratigraphy along the shore to the north of Wind Point (from A to B, fig. 5). In the cross-section, a layer of lake sediment consisting mostly of silt and clay with some fine sand lies between till units 2A and 2B; one of the subsurface reflectors corresponds to this layer of lake sediment. Another of the subsurface reflectors can be mapped to where the 2B till outcrops onshore (b, fig. 5). All of the other reflectors can now be mapped by their spatial

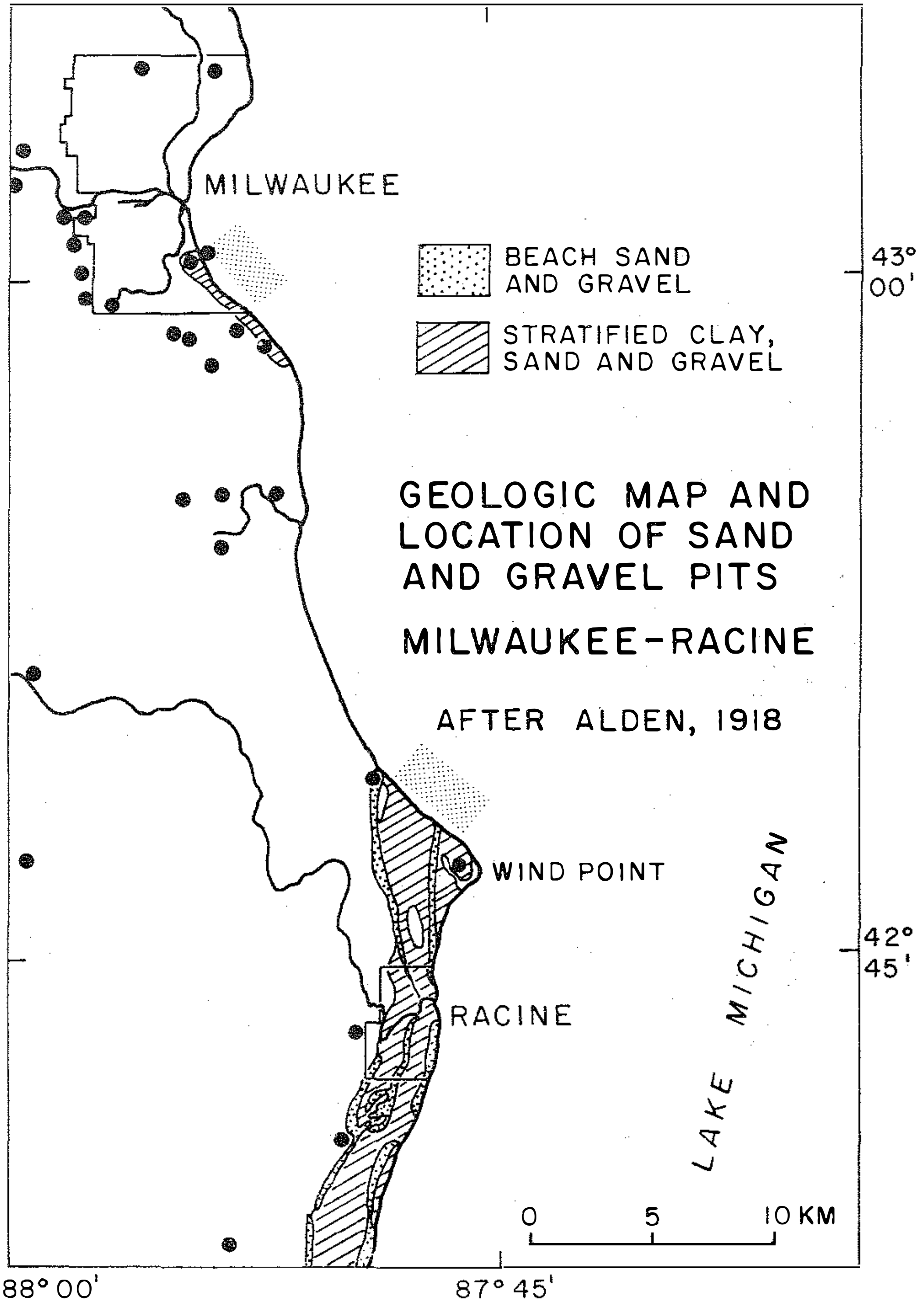


FIGURE 3.--Surficial sediment map in the vicinity of Milwaukee and Racine, Wisconsin, showing only the sandy and gravelly sediments nearshore. Locations of sand and gravel pits are indicated by black dots (Alden, 1918). The offshore areas examined in 1977 and 1978 are shaded. The southernmost area, north of Wind Point, is a subject of this paper.

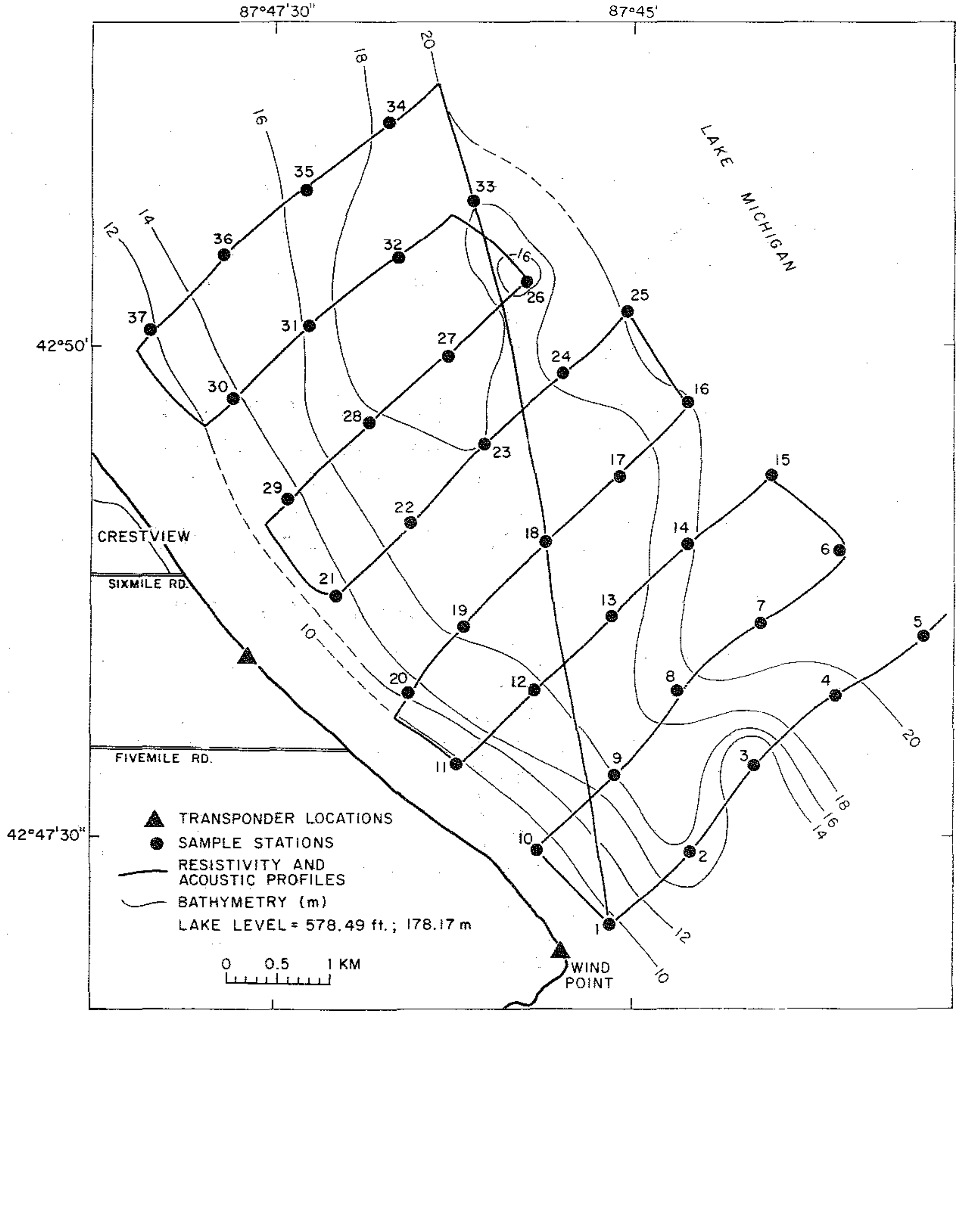


FIGURE 4.--Bathymetry based upon the 1977 acoustic profiles north of Wind Point. Sample station locations are also shown.

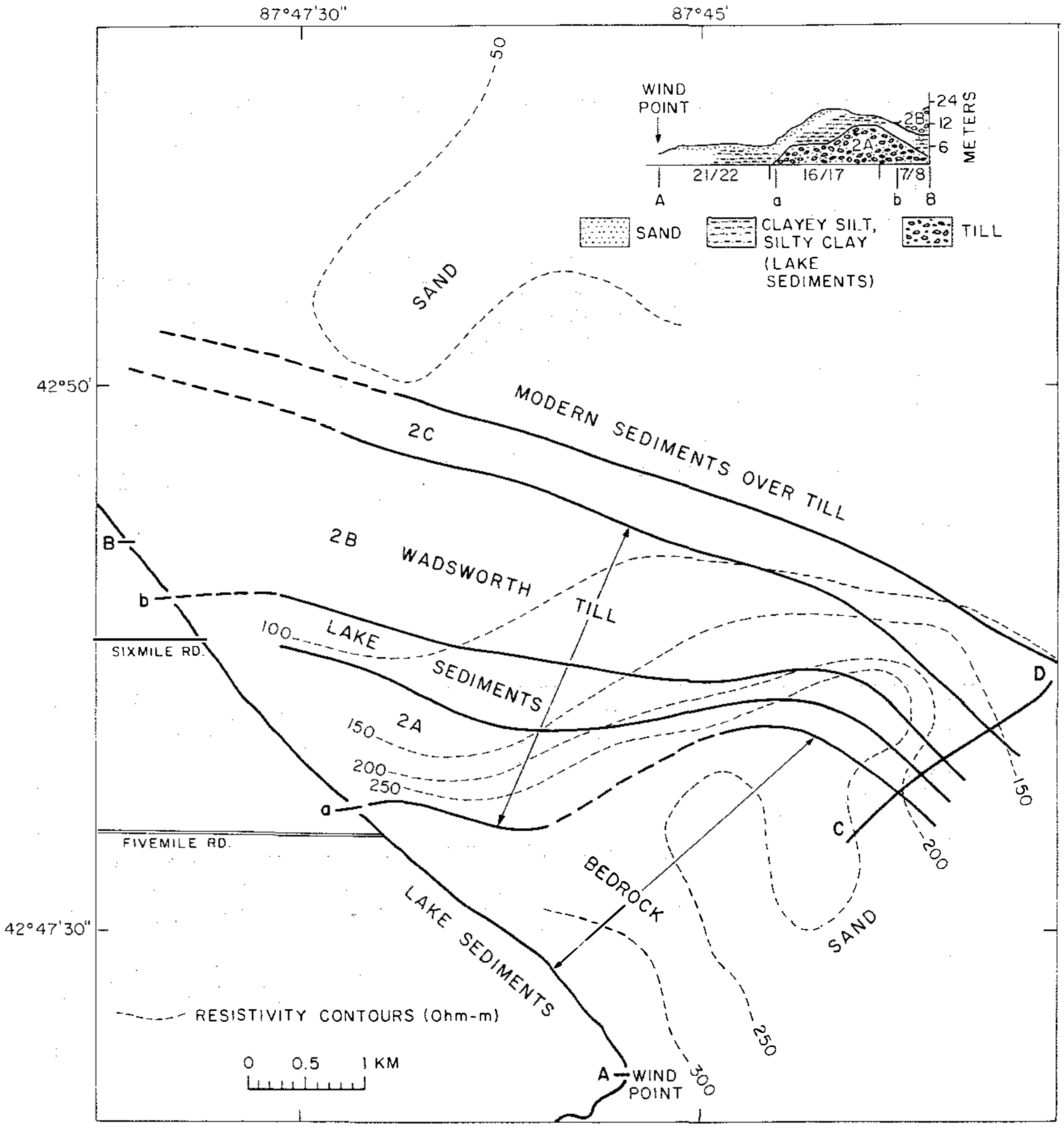
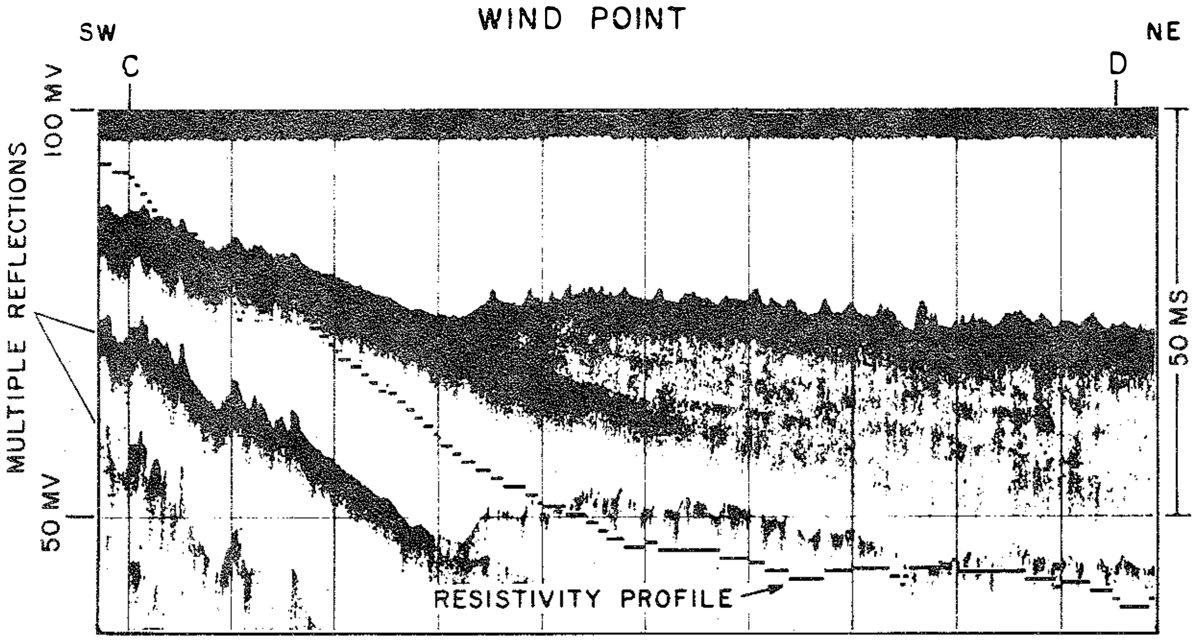


FIGURE 5.--Interpretation north of Wind Point. Because of erosion, till units are exposed on the lake floor and can be traced to shore, where they can be identified. A gravel lag overlies most of the area surveyed. High resistivity measured near Wind Point reflects the rock outcrop. Dotted lines are isoresistivity contours.



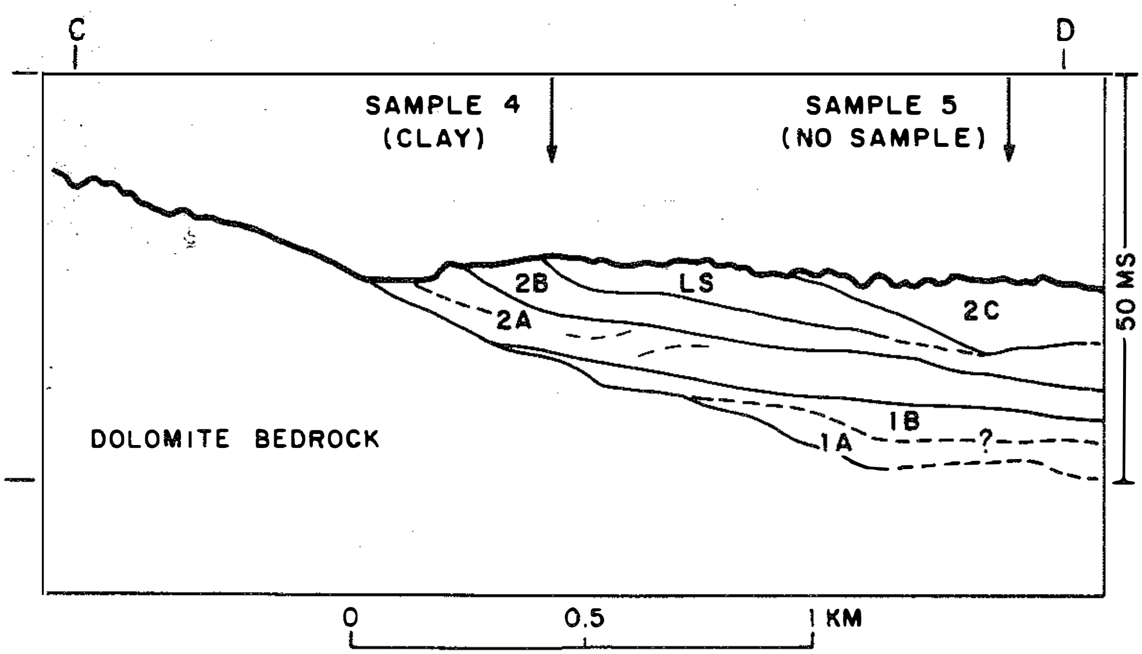


FIGURE 6.--Acoustic profile and interpretation along C-D of figure 5. The sub-units of till were identified by extrapolating to their outcrops in the nearshore bluffs except for till units 1A and 1B which do not outcrop, but lie roughly 7 m below the lake bottom at the location of sample 4.

relationships to the three reflectors that were tentatively identified. Thus, at least two other reflectors of acoustic energy lie under the Wadsworth Till Member (2A). These are most probably the two subunits of the Haeger Till Member. The Haeger Till Member does not outcrop on the lake bottom but is truncated at the dolomite outcrop (fig. 5). The layer of lake sediment pinches out about 3 km from shore (fig. 6).

The reconnaissance surficial sampling tool (Shipek) could not sample the till because the till did not outcrop. Vibratory coring should be able to provide positive identification of the till units. The Haeger Till Member, previously not sampled under the lake (Lineback and others 1974), can be cored most easily near the dolomite outcrop, where the overlying till units are thin. At its shallowest, the hypothesized Haeger lies 7 m below the lake bottom at a water depth of about 18 m.

Resistivity contours (fig. 5) indicate that the resistivity of the lake bottom is controlled by the shape of the Paleozoic rock surface, as expected, because the dolomite is much higher in resistivity than the till and is shallow. Near Wind Point, there is a small depression in the rock which is filled with sand. Sand was also sampled offshore northwest of Wind Point. Because mobile surficial sand at Waukegan has the same resistivity as the bottom water (Welkie and Meyer, 1982), sand at Wind Point probably also has a lower resistivity than the till and rock on which it lies. Another sand deposit at the tip of Wind Point could be responsible for the lower (than rock) resistivity values there.

The elevation of the rock where it outcrops on the lake floor is 160 m, consistent with the projected elevation of the rock surface predicted by Alden (1918).

SUMMARY

Offshore of Wind Point, erosion appears to be taking place. Identification of stratigraphic units exposed on the lake floor was possible by extrapolating to bluff deposits onshore. Two till layers underlying the Wadsworth Till Member were seen on the acoustic records. These layers may be two subunits of the Haeger Till Member. Coring would positively identify these units, and they may be cored most easily off Wind Point, where they lie only 7 m below the lake floor. North of Wind Point, the topography of the rock surface is manifested in the resistivity data because the rock is shallow and an order of magnitude higher in resistivity than the till.

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