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STRATIGRAPHY OF TILL SHEETS IN PART OF NORTHEASTERN WISCONSIN

by

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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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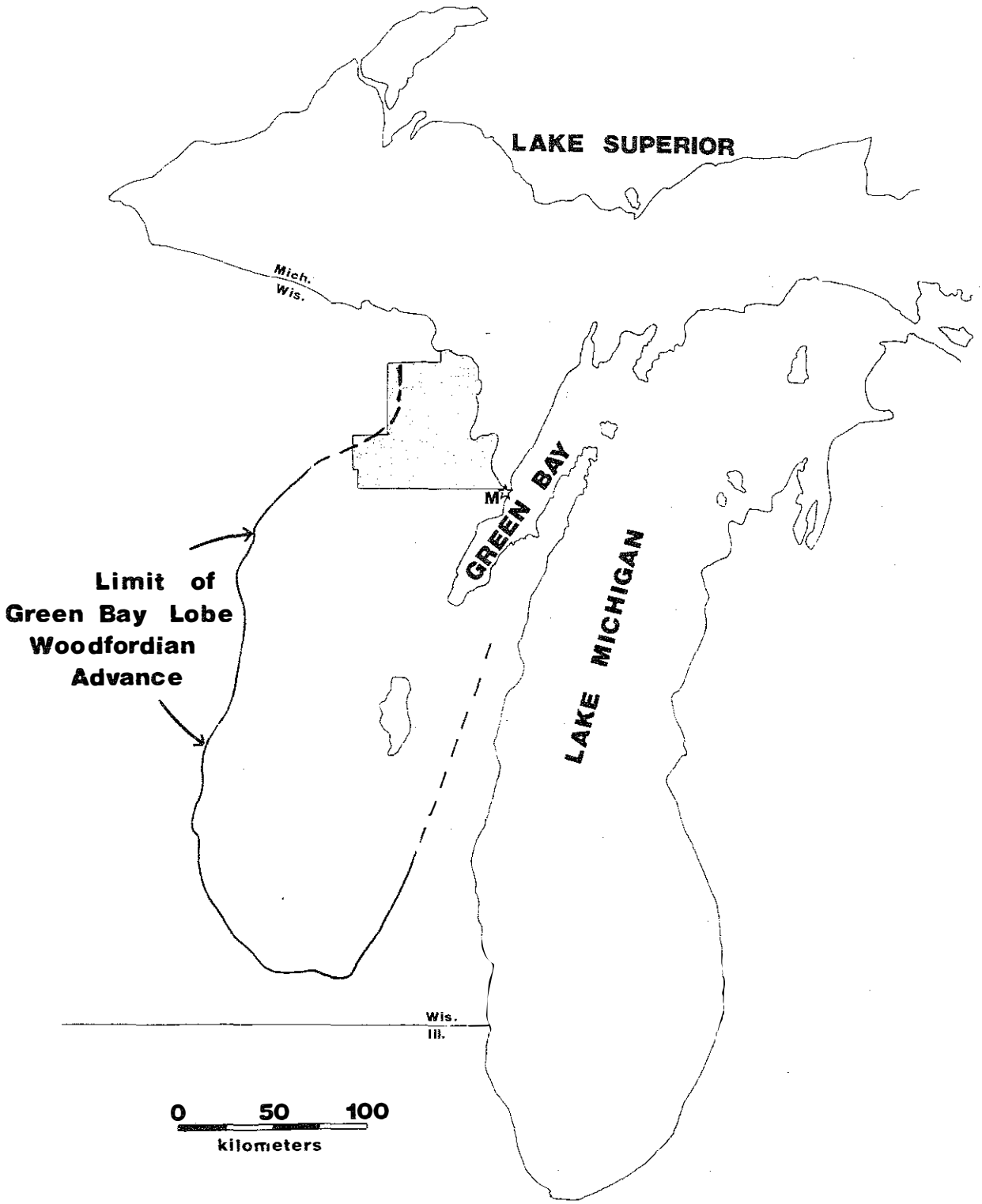

FIGURE 1.--Index map to area of investigation (stippled). The heavy line marks the outline of the Cary advance of the Green Bay Lobe. M is the City of Marinette, Wisconsin.

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)

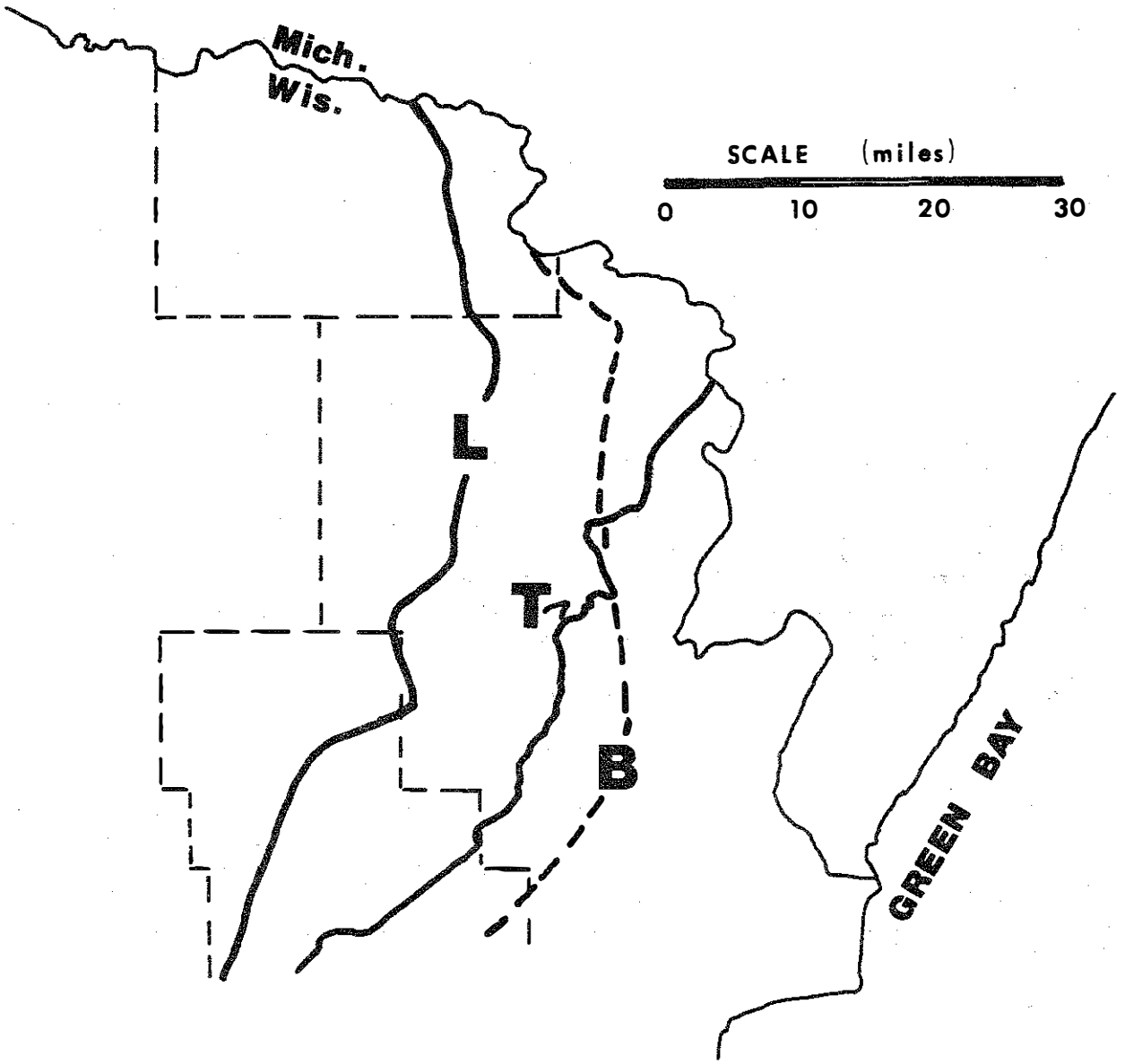

FIGURE 2.--Red till boundaries from Leverett, Thwaites, and Black. L = Leverett's (1929) limit of red drift in eastern Wisconsin. T = Thwaites' (1943) limit of the Valders advance. B = Black's (1966) Valderan border (from Black, 1974, fig. 23).

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

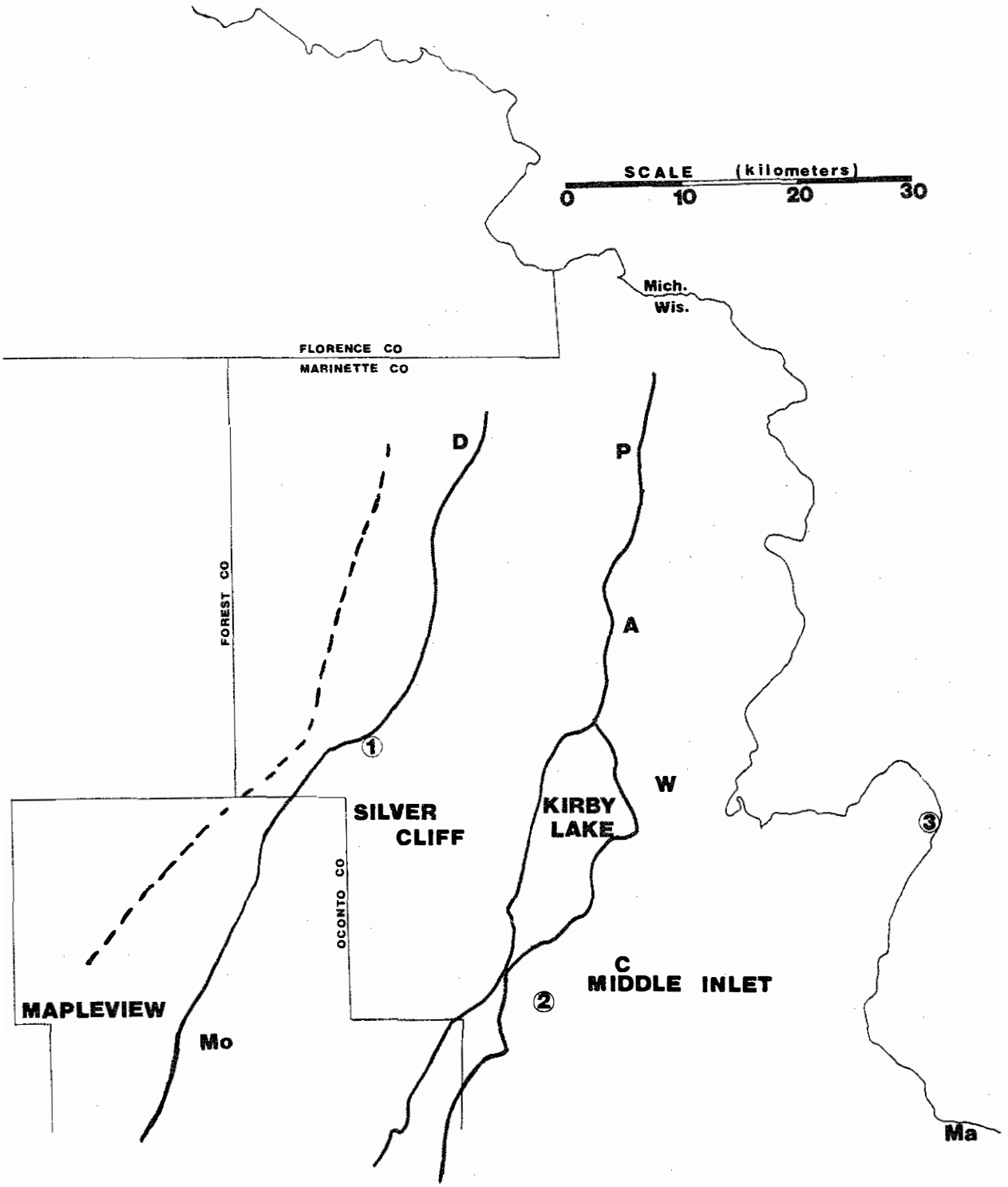

FIGURE 3.--Surface distribution of the till sheets in northeastern Wisconsin. Dashed line is the western edge of deposits of the Green Bay Lobe. City of Marinette = Ma. Towns are marked as follows: Mo = Mountain, C = Crivitz, W = Wausaukee, A = Amberg, P = Pembine, D = Dunbar. Type localities are marked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

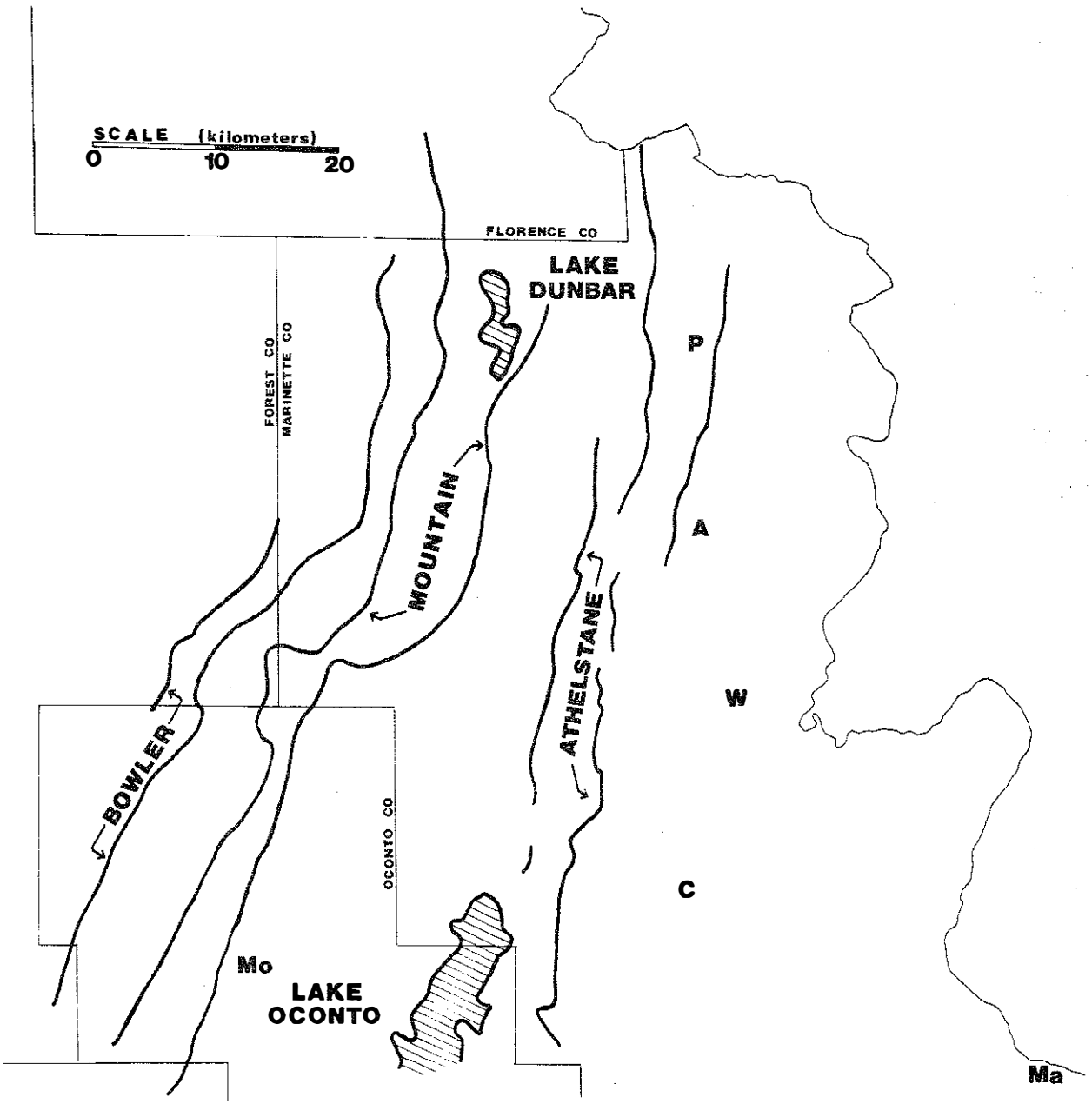

FIGURE 4.--Geomorphic features mapped and named by Thwaites (1943). Linear features are end moraines, striped areas are glacial lakes. City of Marinette = Ma. Towns are marked as follows: Mo = Mountain, C = Crivitz, W = Wausaukee, A = Amberg, P = Pembine.

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

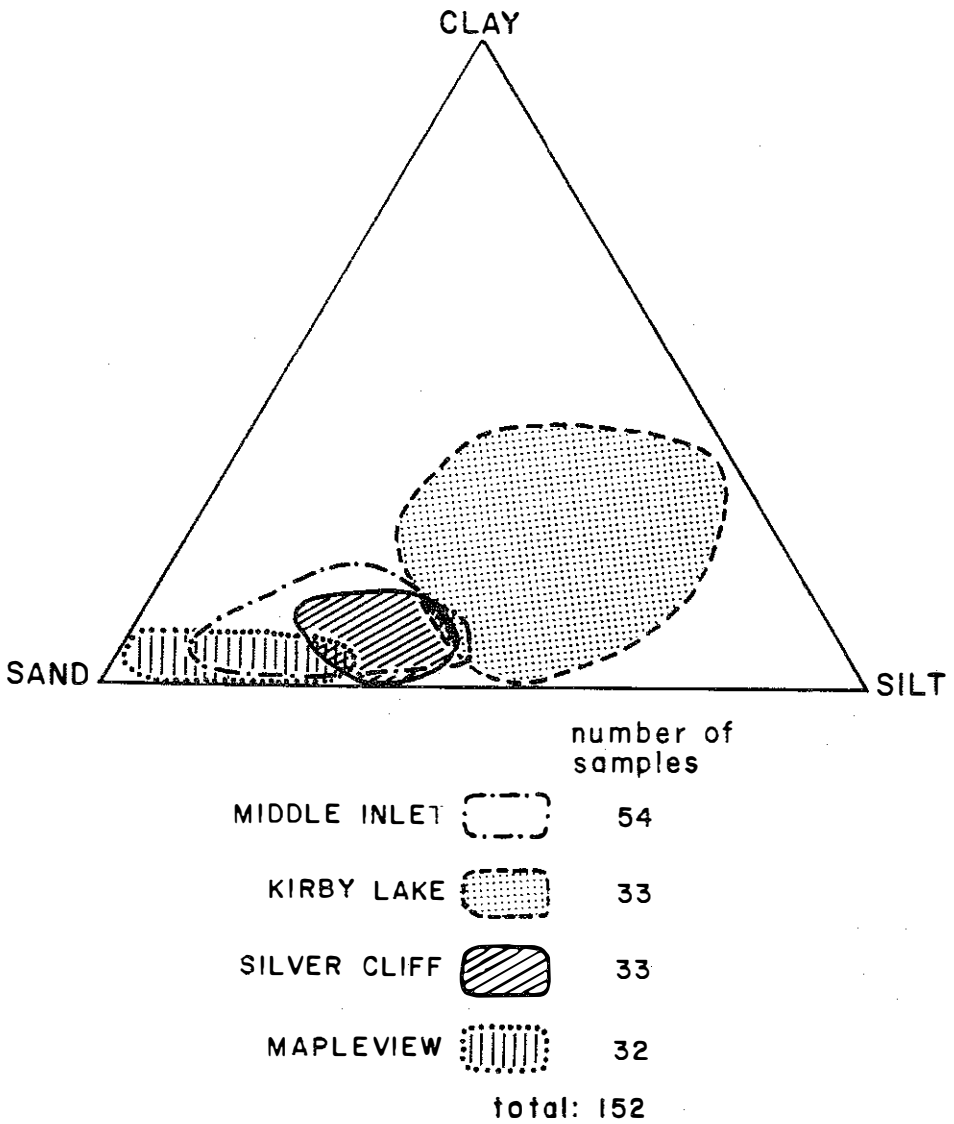

FIGURE 5.--Triangular diagram showing sand/silt/clay percentages of the four tills in northeastern Wisconsin.

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 lithol-

ogies 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.

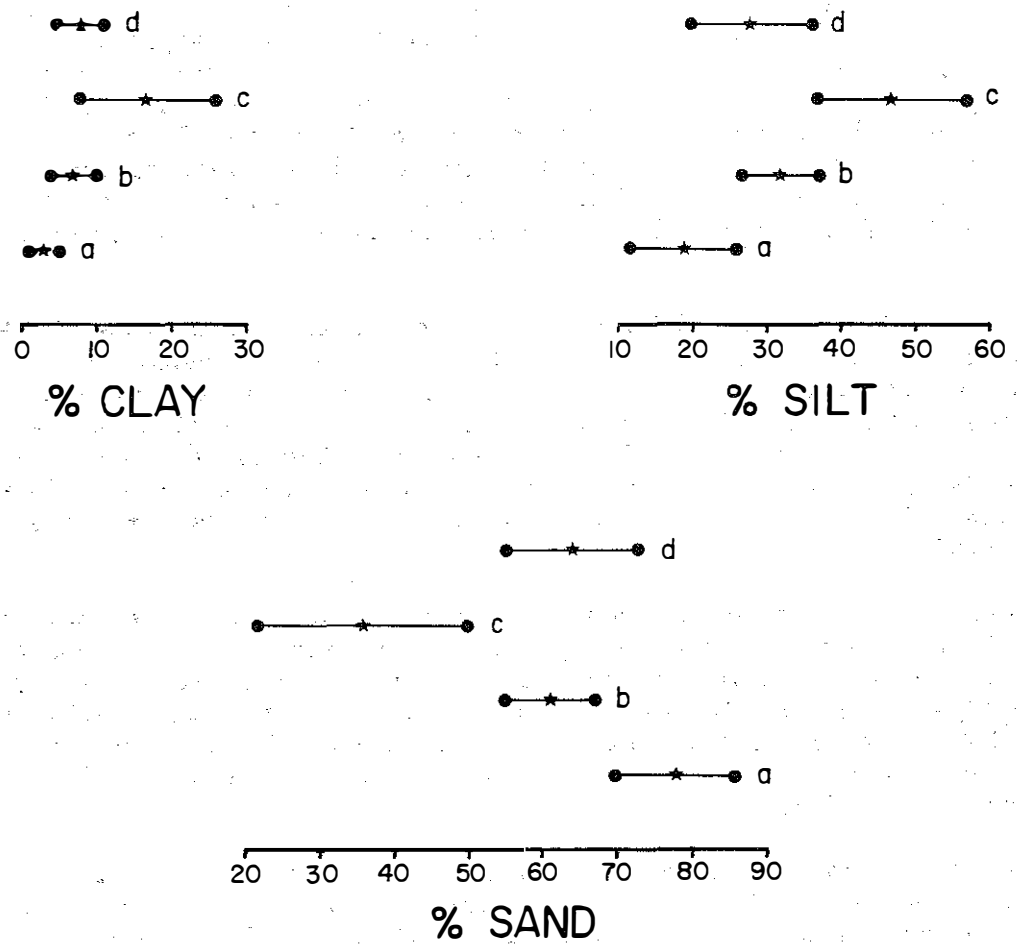

FIGURE 6.--Means and standard deviations of the % clay, % silt, and % sand of the four till sheets in northeastern Wisconsin illustrated in stratigraphic position: a = Mapleview Member, b = Silver Cliff Member, c = Kirby Lake Member, d = Middle Inlet Member. Stars are plotted on the mean percentile and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

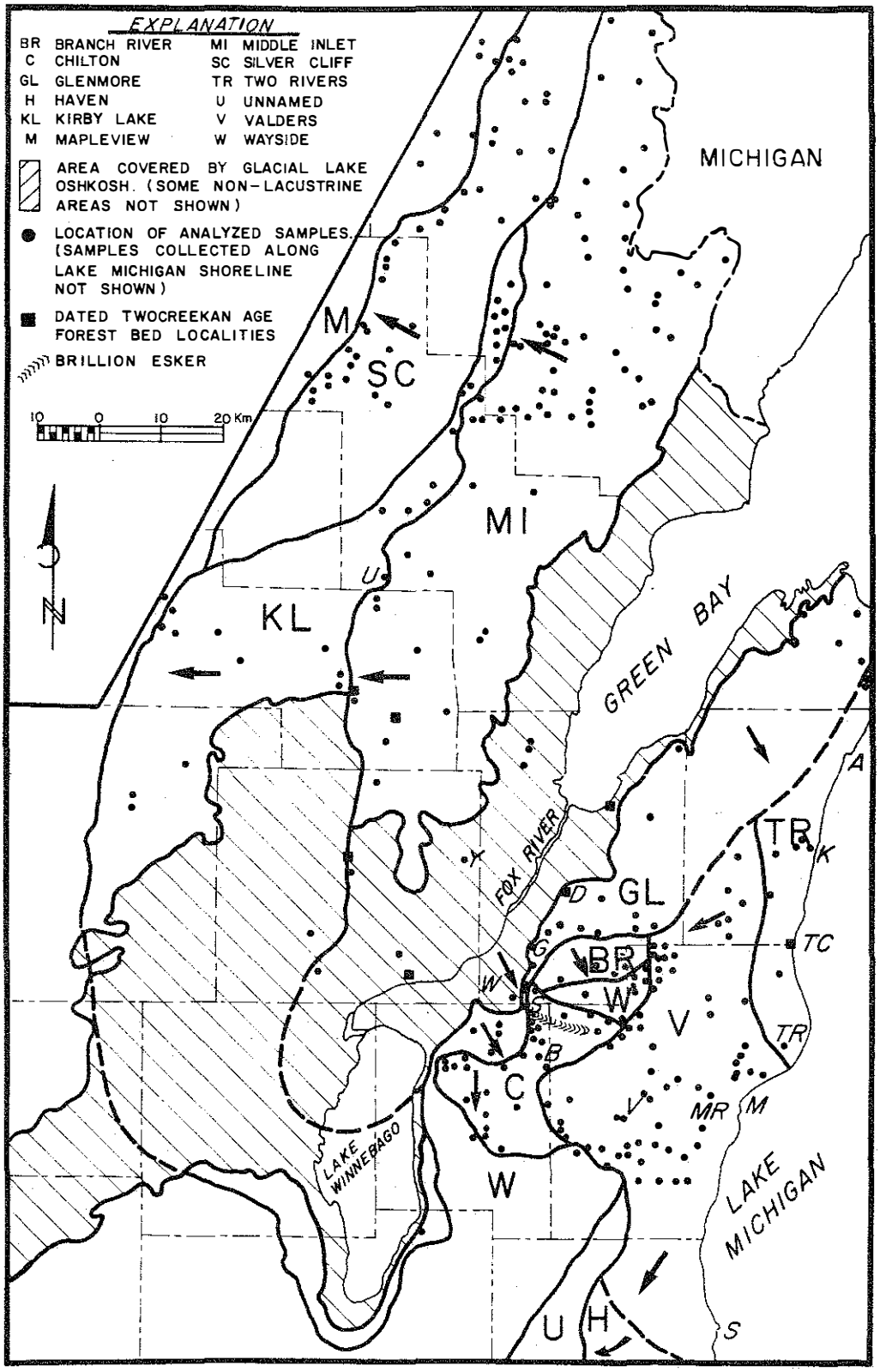

FIGURE 7.--Distribution of tills in the Green Bay Lobe and adjacent Lake Michigan Lobe in eastern Wisconsin. Large letters are till units, italic letters are locations (D=DePere, B=Brillion, V=Valders, TC=Two Creeks), arrows indicate ice-flow direction.

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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