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Late Wisconsinan Drift Stratigraphy
of the Saginaw and Lake Michigan Ice Lobes
in Southwestern Michigan

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George William Monaghan III

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of the requirements for

Masters degree in Geology

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LATE WISCONSINAN DRIFT STRATIGRAPHY
OF THE SAGINAW AND LAKE MICHIGAN ICE LOBES
IN SOUTHWESTERN MICHIGAN

By

George William Monaghan III

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ABSTRACT

Late Wisconsinan Drift Stratigraphy
of the Saginaw and Lake Michigan Ice Lobes in
Southwestern Michigan

By

George William Monaghan III

Three Lake Michigan Ice Lobe till units are exposed along the Lake Michigan shoreline in southwestern Michigan (Glenn Shores section). The lowermost (Glenn Shores), the middle (Ganges), and uppermost (Saugatuck) tills are each overlain by lacustrine deposits. All three tills are easily differentiated by 7A/10A X-ray diffraction peak height ratios of their clay-size fraction.

X-ray diffraction analyses performed on Lake Michigan Lobe till sampled from the Lake Border, Valparaiso, and Sturgis-Kalamazoo morainic systems suggest till from each correlates with the Saugatuck till at Glenn Shores, while till sampled from the Tekonsha Moraine and subsurface exposures correlates with the Ganges till at Glenn Shores. The occurrence of lake deposits between these tills at Glenn Shores implies a significant retreat of the Lake Michigan Lobe between the formation of the Tekonsha and the Sturgis-Kalamazoo moraines. Clay mineral analyses of Saginaw Lobe tills similarly suggest a significant retreat of the Saginaw Lobe between the Tekonsha and Kalamazoo moraines.

DEDICATION

To Heidi, for her patience with muddy boots
and long drives.

ACKNOWLEDGMENTS

I am indebted to the members of my committee, Drs. John T. Wilband and David T. Long, for all their help and guidance given during this research, although special thanks must go to my chairperson, Dr. Grahame J. Larson, for his assistance and advice, both personal and professional, given throughout my graduate tenure. I am grateful to the following organizations for providing the funding to support this research: U.S. Environmental Protection Agency; Tri-county Planning Commission; Michigan Department of Natural Resources, Ground Water Quality Division; and the Department of Geology, Michigan State University. I am also indebted to the United States Geological Survey, Coal Division for stipend support over the past few years.

I would like to thank Greg Gephart for his discussions, criticism, and help (as well as for stumbling over the Glenn Shores logs) and Steve Dworkin (for stumbling into the Bloomingdale pit). Thanks also go to Gordon Thompson for his dedication and countless hours of sample preparation and x-ray analyses. Although the ideas generated in this paper were derived from uncountable (sometimes painful) hours of discussion with Greg Gephart and Dr. Grahame Larson, I take the blame for any errors.

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INTRODUCTION

Although in regions bordering Michigan recent glacial geologic research has been directed towards a Pleistocene, particularly Wisconsinan, history based on drift stratigraphy, the Wisconsinan glacial history in Michigan remains based primarily on the morphology of end moraines first defined by Frank Leverett (Leverett and Taylor, 1915) during the early part of this century. The focus of this research is to establish lithologic criteria which can be used to differentiate and correlate till deposits in southwestern and south-central Michigan. The goal of such research is to set up a stratigraphic system and to relate these units to major flucuations of the Laurentide Ice Sheet. In order to establish such a stratigraphic system in Michigan, two ice lobes, the Lake Michigan and Saginaw lobes, were studied. This involved: 1) detailed mapping of geologic deposits, 2) locating and sampling tills in section, borings, and road-cuts, and, 3) analysis of the lithology of the till samples. Laboratory analysis focused primarily on differences in relative amounts of clay minerals found within the till samples.

This research has shown that the drift in southwestern and south-central Michigan can be differentiated based on unique clay mineralogies of each till sheet. Once the litho-stratigraphic units were established for the Lake Michigan and Saginaw lobes, broad correlations between stratigraphic systems established for the Lake

Michigan, Saginaw, and Huron-Erie ice lobes in other parts of the Great Lakes Region could be proposed. These correlations are based on morphologic relationships of drift deposits within areas where two adjacent lobes actually abutt. Kalamazoo County (Monaghan, et al., 1983) was chosen for detailed mapping since at least two time equivalent ice-edge positions associated with both the Lake Michigan and Saginaw lobes (the Kalamazoo moraines and Tekonsha moraines) occur with in the are. These relationships are critical because by tracing till sheets established for each lobe to these moraines, the stratigraphic systems of both lobes can be chronologically correlated with each other.

The paper is divided into three chapters. Chapter 1 outlines a proposed Late Wisconsinan drift stratigraphy for the Lake Michigan Lobe. Chapter 2, on the other hand, outlines a proposed drift stratigraphy of deposits associated with the Saginaw Lobe and also suggests correlations with other stratigraphic systems in the Great Lakes Region. Chapter 3 presents a detailed description of the drift deposits within Kalamazoo County as well as a summary of the deglaciation history of both the Lake Michigan and Saginaw ice lobes in southwestern and south-central Michigan.

Although the techniques employed for clay mineral analysis of till samples is briefly outlined in chapters 1 and 2, a more detailed description is pre nted in Appendix A. Appendix B contains lists of the raw clay mineral data for each sample analyzed. It also has compilations of the statistics used in this paper. Detailed descriptions of four sections containing buried or multiple till units discussed in chapter 1 are shown in Appendix C.

CHAPTER 1
LAKE MICHIGAN ICE LOBE DRIFT STRATIGRAPHY

INTRODUCTION

Over the past two decades much research has been directed towards the establishment of an objective stratigraphy for Wisconsinan drift in the Lake Michigan basin (Frye and Willman, 1960; Willman and Frye, 1970; Johnson, 1976; Lineback, et al., 1974, 1979; Acomb, 1978; Acomb et al., 1982; McCartney and Mickelson, 1982). While most of these investigations have relied on unique lithologic criteria for correlating and differentiating till sheets, the subdivision of the Wisconsinan in western Michigan (Melhorn, 1954; Bretz, 1954a, 1954b; Eschman and Farrand, 1970; Evenson, 1973; Farrand and Eschman, 1974; and Dreimanis, 1977) is still based essentially on morpho-stratigraphic correlations that have not changed significantly since Frank Leverett originally mapped the state around the turn of the century (Leverett and Taylor, 1915). In recent years, some of these correlations have been supplemented by radio-carbon dates of organic material buried between till units (Farrand, et al., 1969; Zumberge and Benninghoff, 1969; Miller and Benninghoff, 1969; Eschman, 1968).

The purpose of this chapter is: 1) to establish lithologic criteria for recognizing Lake Michigan Lobe till units exposed along the Lake Michigan shoreline in southwestern Michigan, and 2) using these lithologic criteria, to correlate the till units along the lakeshore with Lake Michigan Lobe tills exposed 2 to 50 kilometers further inland. In addition, the tills in Michigan will be correlated with Lake Michigan Lobe till units already defined by Willman and Frye (1970) in northern Illinois.

COASTAL TILLS

One of the most complete multi-till exposure in southwestern Michigan, informally named the Glenn Shores section (Gephart and Larson, in prep.), occurs in a wave-cut cliff along the Lake Michigan shoreline just west of the town of Glenn in Allegan County (Figure 1-1). Here, three tills separated by lacustrine sediments are exposed in a 20 to 25 meter high bluff. The section (Figure 1-2) begins at the present Lake Michigan beach level (177 m) with a dense, silty-clay till which is informally named the Glenn Shores till. The total thickness of this till unit is not known and only the uppermost meter is exposed. This till sheet is locally intruded by clay diapirs and dips beneath the present Lake Michigan beach both to the north and south of the section. The till has not been observed at any other locality.

The Glenn Shores till is overlain by a 5 to 10 centimeter thick discontinuous deposit of beach gravel containing detrital spruce wood and peat balls. Two meters of lacustrine sand and laminated silt, also containing detrital organic material, overlies this gravel deposit. Organics from both the beach gravel and sand/silt deposits have been radio-carbon dated from $37,150 \pm 540$ (BETA-3311) to >48,000 (ISGS-948) years BP (table 1). No organic material has

FIGURE 1-1.

Map of Late Wisconsinan moraines and location of till sampled from the Lake Michigan Ice Lobe in southwestern Michigan. Location of sections shown by closed circles. Location of morainal samples shown by open circles with 7A/10A ratios values labeled beside each point.

Moraines of the Lake Michigan and Saginaw Lobes in southwestern Michigan:

Lake Michigan Lobe Moraines:
- Lake Border System:
  - LBM -- Inner and Outer Lake Border moraines
- Valparaiso System:
  - IVM -- Inner Valparaiso Moraine
  - OVM -- Outer Valparaiso Moraine
- Sturgis-Kalamazoo System:
  - IKM -- Inner Kalamazoo Moraine
  - OKM -- Outer Kalamazoo Moraine
  - STM -- Sturgis Moraine

Saginaw Lobe Moraines:
- TkM -- Tekonsha Moraine
- KM -- Kalamazoo Moraine
- LaM -- Lansing Moraine

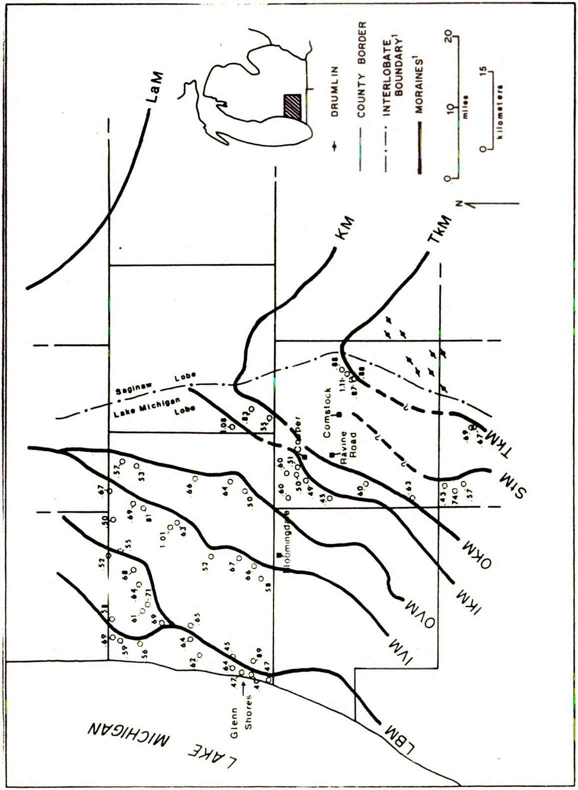
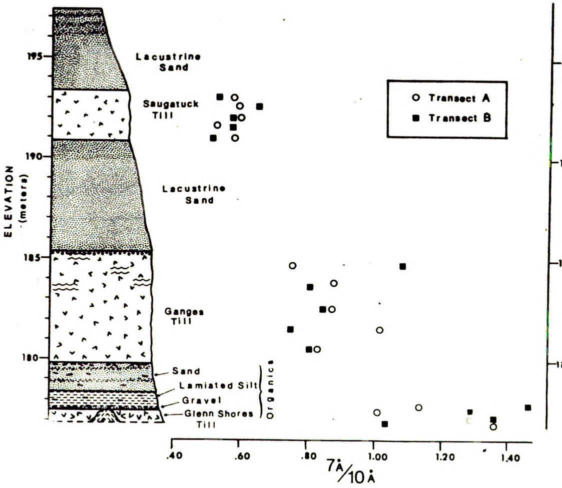

LaM
KM
TkM
StM
OKM
IKM
OVM
IVM
LBM
LAKE MICHIGAN
Saginaw Lobe
Lake Michigan Lobe
Comstock
Ravine Road
Cooper
Bloomingdale
Glenn Shores
DRUMLIN
COUNTY BORDER
INTERLOBATE BOUNDARY[1]
MORAINES[1]
0 10 20
miles
0 15
kilometers
N

FIGURE 1-2.
The Glenn Shores Section showing the clay mineral variability of the till units along two vertical sampling transects.


ELEVATION (meters)
195
190
185
180
Lacustrine Sand
Saugatuck Till
Lacustrine Sand
Ganges Till
Sand
Lamiated Silt
Gravel
Glenn Shores Till
Organics
Transect A
Transect B
.40
.60
.80
1.00
1.20
1.40
7Å/10Å

been observed above the sand and silt deposits.

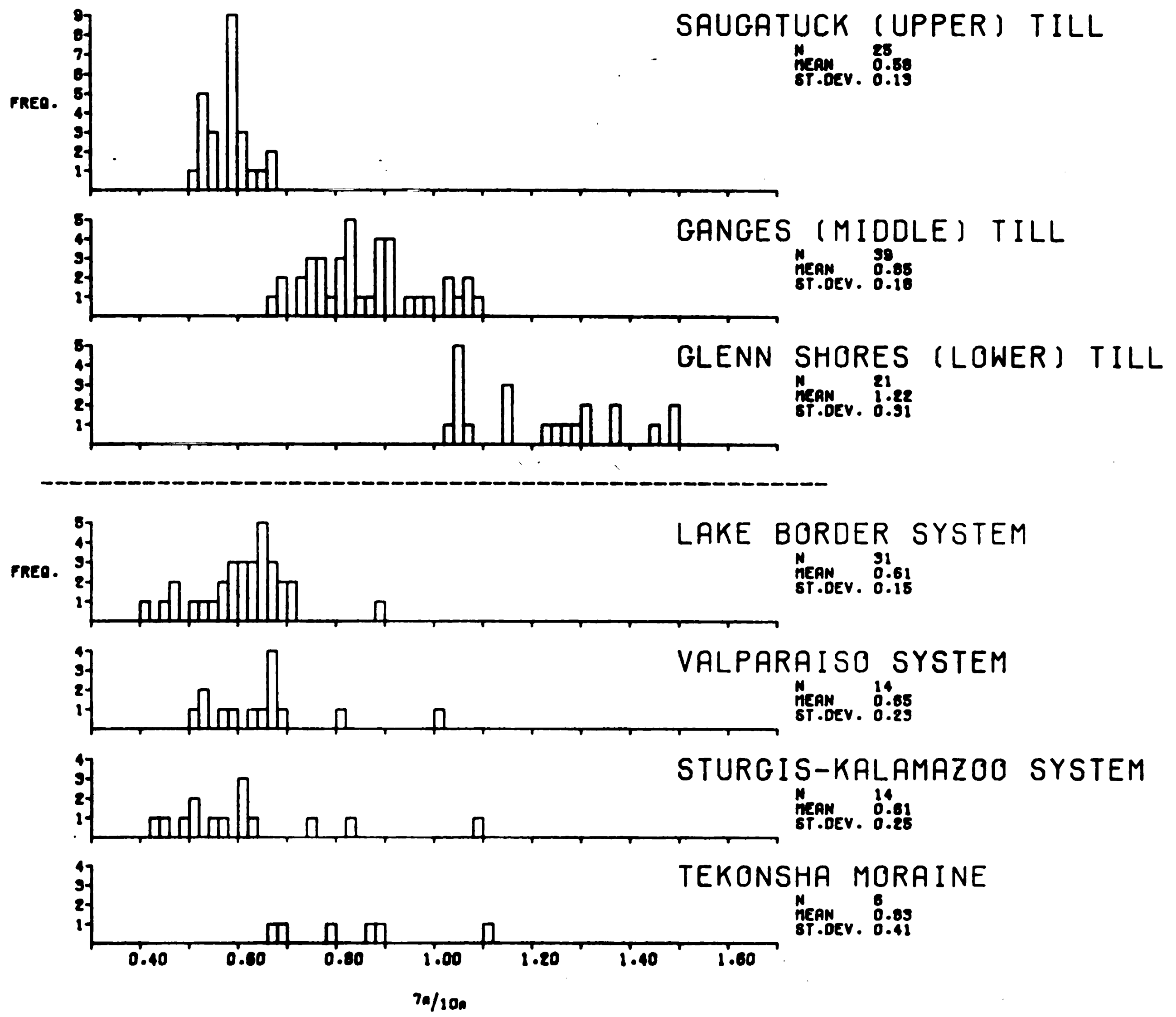
TABLE 1.
Radio-Carbon dates form organics at the Glenn Shores Section

SAMPLE (NO.)	RADIOCARBON AGE yrs. BP	LAB. NUMBER
Wood (GS001)	37,150 ± 540	BETA-3311
Wood (GS002)	38,130 ± 740	BETA-3310
	> 37,000	GX-8193
Peat (GS003)	>43,000	SI-5183
Wood (GS005)	>48,000	ISGS-948

Above the lacustrine sand and silt is a 5 to 6 meter thick blue-grey, clay-rich till informally named the Ganges till. A 5 to 6 meter thick lacustrine sand deposit overlies the Ganges till; the contact between these two deposits is sharp. The lacustrine deposit above the Ganges till is overlain by a third till that is 2.5 meters thick and is informally named the Saugatuck till. This till is blue-grey in color and is clay-rich; the upper 0.3 meters consists of a brownish-red silty clay. The section is capped by 3 to 4 meters of Lake Chicago (Glenwood Level) sediments. The contact between this deposit and the underlying Saugatuck till is sharp.

FIGURE 1-3.

Frequency histograms showing clay mineralogy of the three tills exposed at the Glenn Shores section (above dashed line) compared with till sampled from Lake Michigan Lobe moraines (below dashed line).


SAUGATUCK (UPPER) TILL
N 25
MEAN 0.58
ST.DEV. 0.13
GANGES (MIDDLE) TILL
N 39
MEAN 0.85
ST.DEV. 0.18
GLENN SHORES (LOWER) TILL
N 21
MEAN 1.22
ST.DEV. 0.31
LAKE BORDER SYSTEM
N 31
MEAN 0.61
ST.DEV. 0.15
VALPARAISO SYSTEM
N 14
MEAN 0.65
ST.DEV. 0.23
STURGIS-KALAMAZOO SYSTEM
N 14
MEAN 0.61
ST.DEV. 0.25
TEKONSHA MORAINE
N 6
MEAN 0.83
ST.DEV. 0.41
FREQ.
0.40
0.60
0.80
1.00
1.20
1.40
1.60
7A/10A

CLAY MINERALOGY: In order to further define the lithologic characteristics of each of the three tills exposed in the Glenn Shores section, semi-quantitative X-ray diffraction analyses were performed on the clay-size fraction of 85 till samples. These samples were collected at set intervals along both vertical and horizontal transects, as well as randomly throughout the section.

Each sample, weighing 25 to 50 grams, was first pre-treated to removed soluble salts, free calcium carbonates, and free iron oxides (Jackson, 1956; Carroll, 1972). The clay-size (<2 mu) fraction was then separated out by gravity fractionation, deposited on glass slides, and air-dried. Prior to X-ray analysis, the slides were placed in a desiccator containing ethylene glycol to expand the vermiculite to 14A and the smectite to 17A - 18A (Jackson, 1956; Carroll, 1972). The prepared slides were then scanned from 2 to 15 degrees 2θ on a General Electric X-ray diffractometer (model no. XRD-5), rotated 180 degrees, and scanned again. The diffraction patterns were analyzed by comparing the intensities of the 7A and 10A peaks. These peak heights were measured to the nearest .025 cm from a predetermined base line (Grim, 1968; Carroll, 1972) and the 7A/10A ratio reported as an average of the two rotations.

The results of the clay mineral analyses are presented in Figures 1-2 and 1-3. The clay mineral data displayed in Figure 1-2 are from two of the vertical transects. The elevation of each sample point is shown along the vertical axis, while its 7A/10A ratio value is shown along the horizontal axis. Figure 1-3, on the other hand, shows composite histograms of all the clay mineral data from each of the three tills exposed at Glenn Shores. The horizontal axis of each histogram represents the calculated 7A/10A peak height ratio values and the vertical axis indicates the number of samples that have a particular 7A/10A value.

The data in Figures 1-2 and 1-3 suggest that the three tills exposed in the Glenn Shores section have significantly different clay mineral compositions. Figure 1-2 shows that there is no regular vertical trend in clay mineralogy within a till unit, while Figure 1-3 suggests the occurrence of a significant step-wise increase in the amount of 10A clay, relative to 7A clays, from the lowermost till unit to the uppermost till. Based on the data shown in Figure 1-3, the mean 7A/10A ratio for the lowermost till unit is 1.22; the mean ratio value for the middle till is 0.85; and the mean ratio for the uppermost till is 0.58. Application of the T-test to this data shows that the clay mineralogy of each of the three tills is significantly different to the 99.9% confidence level. Since they have significantly different clay mineralologies, the three till units are unlikely to represent till facies of the same ice advance.

In addition to semi-quantitative analysis, qualitative clay mineral determinations were also performed on several samples. Sample pre-treatments were identical to that used for semi-quantitative analysis. However, after gravity separation the clay-size fraction was deposited on porous ceramic plates, instead of glass slides. Each sample was then X-rayed after the following treatments: 1) Mg saturated and glycerol solvated; 2) K-saturated and air-dried; 3) K-saturated and heated to 300° C; and 4) K-saturated and heated to

550° C. Following techniques outlined by Jackson (1956) and Carrol (1972), it was determined that although minor amounts of the minerals chlorite and vermiculite were present in the samples, kaolinite was the dominate mineral occurring in the 7A peak while illite was the dominate mineral in the 10A peak.

INLAND SURFACE TILLS

Inland from the Glenn Shores section, consecutively younger Late Wisconsinan (late Woodfordian) ice-edge positions of the Lake Michigan Lobe are represented by a series of end moraines (Figure 1-1) that were first identified by Frank Leverett (Leverett and Taylor, 1915) in the early 1900's. From oldest to youngest, they are: the Tekonsha, Sturgis*, Outer and Inner Kalamazoo, Outer and Inner Valparaiso, and Lake Border moraines. These moraines trend in a northeast-southwest direction and roughly parallel the present shoreline of Lake Michigan. To simplify discussion, several of the morainal ridges have been grouped into the following morainal systems: The Sturgis-Kalamazoo, Valparaiso, and Lake Border morainic systems (see Figure 1-1).

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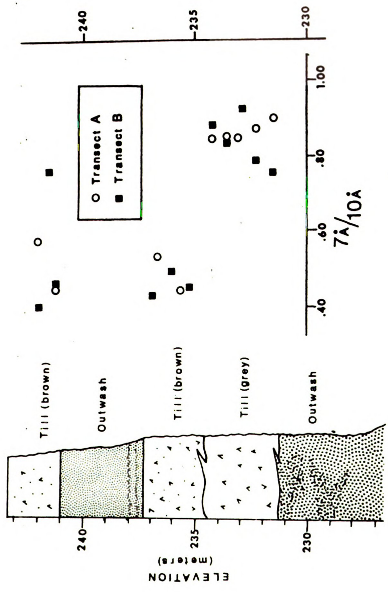
* Although Leverett (Leverett and Taylor, 1915) suggested that the Sturgis Moraine in Kalamazoo and western St. Joseph counties, Michigan, was formed by the Lake Michigan Lobe, he considered it time equivalent to the Sturgis Moraine of the Saginaw Lobe and, thus, stratigraphically older than the Tekonsha Moraine. Recent detailed mapping of the surficial deposits in southwestern Michigan by the author and others (Monaghan, et. al., 1983), however, shows that the Lake Michigan Lobe portion of the Sturgis Moraine more likely represents the outermost ridge of the Kalamazoo Morainic System and is therefore younger than the Tekonsha Moraine. Because of this relationship, the author and others have preferred to call Leverett's Kalamazoo Morainic System (Leverett and Taylor, 1915) the Sturgis-Kalamazoo System.

FIGURE 1-4.
Bloomingdale section showing the clay mineral variability of the three till units along two vertical sampling transects.



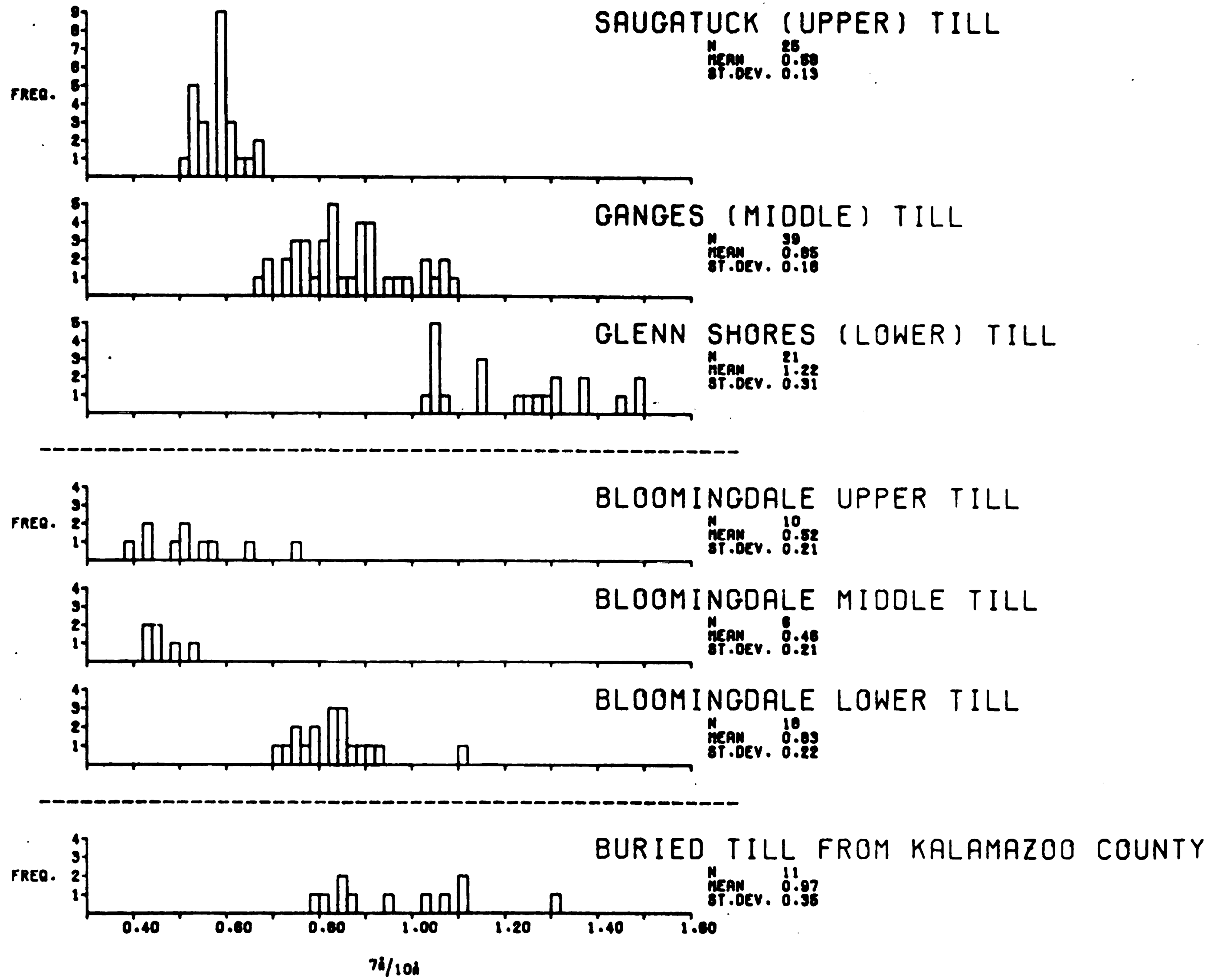
ELEVATION (meters)
240
235
230
Till (brown)
Outwash
Till (brown)
Till (grey)
Outwash
Transect A
Transect B
.40
.60
.80
1.00
7Å/10Å

CLAY MINERALOGY: In an attempt to correlate till associated with the inland moraines to the tills exposed at the Glenn Shores section, X-ray diffraction analyses were performed on the clay-size fraction of 65 till samples collected from exposures within these moraines. The location of the sample points and associated 7A/10A ratio values is shown in Figure 1-1. Samples were taken generally 2 to 3 meters below the ground surface from fresh exposures. The till samples were analyzed using the same methods applied to the Glenn Shores samples.

The results of the above analyses are presented in Figure 1-3 as a series of frequency histograms comparing the calculated 7A/10A ratios of the moraines with the three tills exposed at Glenn Shores. These histograms show that the clay mineralogy of till associated with the Sturgis-Kalamazoo, the Valparaiso, and the Lake Border morainic systems is most similar to that of the Saugatuck till, while the clay mineralogy of till associated with the Tekonsha Moraine is most similar to that of the Ganges till. Application of the T-test indicates that these associations can be supported to the 99% confidence level. Hence, on the basis of the statistical similarity of clay mineralogy, the author proposes that the till comprising the Lake Border, Valparaiso, and Sturgis-Kalamazoo morainic systems correlates with the Saugatuck (upper) till at Glenn Shores, and that the till comprising the Tekonsha Moraine correlates with the Ganges (middle) till.

FIGURE 1-5.

Frequency histograms showing clay mineralogy of till from the Bloomingdale (below the upper dashed line) and Kalamazoo County (below lower dashed line) sections compared with the clay mineralogy of till from the Glenn Shores section.


SAUGATUCK (UPPER) TILL
N 25
MEAN 0.58
ST.DEV. 0.13
GANGES (MIDDLE) TILL
N 39
MEAN 0.65
ST.DEV. 0.18
GLENN SHORES (LOWER) TILL
N 21
MEAN 1.22
ST.DEV. 0.31
BLOOMINGDALE UPPER TILL
N 10
MEAN 0.52
ST.DEV. 0.21
BLOOMINGDALE MIDDLE TILL
N 6
MEAN 0.46
ST.DEV. 0.21
BLOOMINGDALE LOWER TILL
N 18
MEAN 0.83
ST.DEV. 0.22
BURIED TILL FROM KALAMAZOO COUNTY
N 11
MEAN 0.97
ST.DEV. 0.36
FREQ.
0.40
0.60
0.80
1.00
1.20
1.40
1.60
7Å/10Å

INLAND SUB-SURFACE TILLS

In addition to the surface tills, four inland sections that contain buried or multiple tills were sampled. The locations of these sections (Bloomingdale, Cooper, Ravine Road, and Comstock sections) are shown in Figure 1-1.

The Bloomingdale section (Figure 1-4) occurs within a gravel pit southeast of the Inner Valparaiso Moraine near the town of Bloomingdale in northeastern Van Buren County. It contains three till units that are best exposed in the south wall of the gravel pit. Here, the lowest unit is represented by a 4 to 6 meter thick outwash which is composed of very coarse sand, pebbles, and cobbles. A 2 to 3 meter thick, grey, clay-rich till overlies the outwash. This till unit dips towards the south and is completely absent in the north wall of the pit. Directly overlying the grey till is a 2 to 3 meter thick brown, sandy-clay till. The contact between these two till units is sharp. Overlying the brown till is a 2 to 4 meter thick outwash composed of medium to coarse sand and pebbles. The section is capped by a third till that is 1 to 2 meters thick. This till is brown, sandy, and pinches-out in a few places; the contact between it and the underlying outwash is sharp. The texture and discontinuous nature of the surface till suggests that it may be a flow till.

CLAY MINERALOGY: In order to correlate the till units exposed at the Bloomingdale section with those exposed at Glenn Shores, clay mineral analyses (identical to those described for the Glenn Shores tills) were performed on a total of 34 till samples. These samples were collected along both vertical and horizontal sample transects, as well as randomly throughout the Bloomingdale section.

The results of the analyses are presented in Figures 1-4 and 1-5. Figure 1-4 shows the clay mineral data from two of the vertical transects, while Figure 1-5 is a series of 7A/10A histograms of all samples taken from each of the tills. Also shown in Figure 1-5 are the histograms of the clay mineral data from the till units exposed at Glenn Shores. Comparison of the Bloomingdale and Glenn Shores clay data (Figure 1-5) suggests that the Bloomingdale lower till is most similar to the Ganges (middle) till at Glenn Shores, while the Bloomingdale middle and upper tills are most similar to the Saugatuck (upper) till. Application of the T-test indicates that these above associations can be supported to at least the 99% confidence level. Therefore, based on the clay mineral similarities, the author proposes that the Bloomingdale middle and upper tills correlate with the Saugatuck (upper) till at Glenn Shores, while the Bloomingdale lower till correlates with the Ganges (middle) till.

Three additional sections, each containing a single till unit buried beneath outwash, occur within gravel pits located east of the Bloomingdale section in Kalamazoo County (Figure 1-1). The Ravine Road and Comstock sections contain a brown, sandy, and loose-textured till, while the till in the Cooper section is brown, dense, and clay-rich. The clay mineralogies o. samples taken from these exposures is shown in Figure 1-5 as a composite histogram and suggests that the till in each of these exposures correlates with the Ganges (middle) till at Glenn Shores.

FIGURE 1-6.

Generalized section showing stratigraphic relationships of the Lake Michigan Lobe till units in southwestern Michigan.

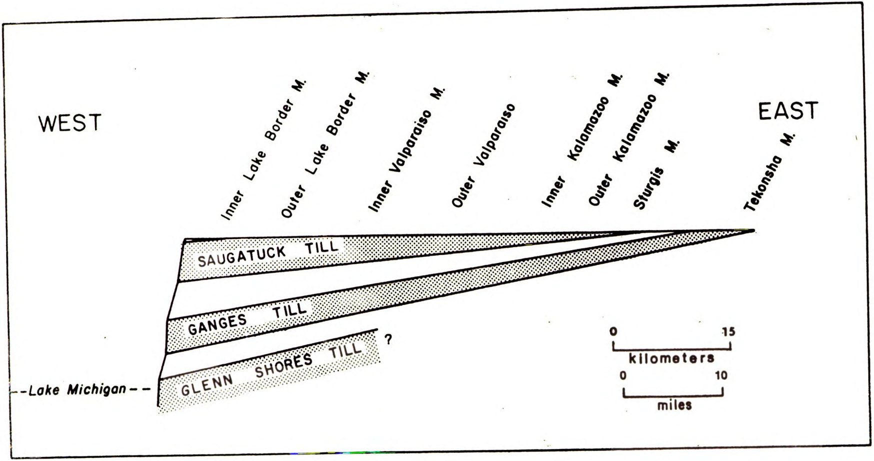
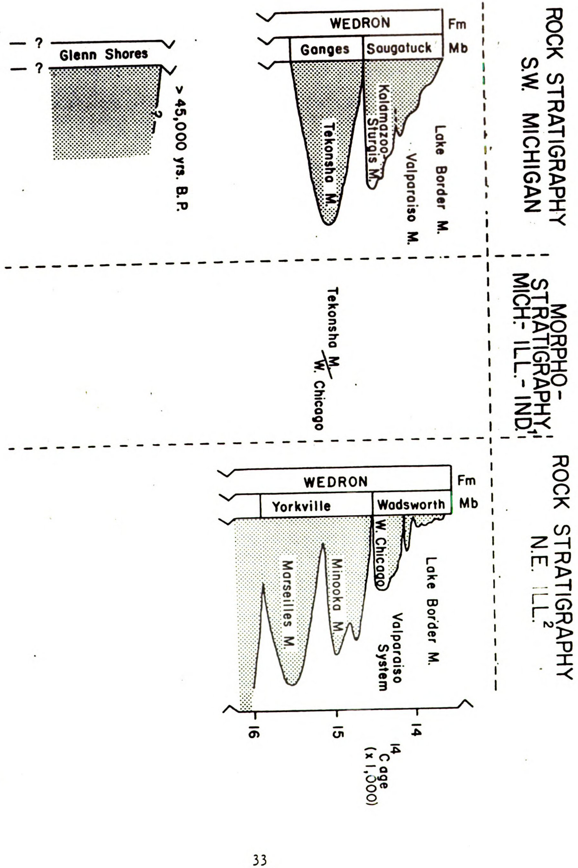

WEST
EAST
Inner Lake Border M.
Outer Lake Border M.
Inner Valparaiso M.
Outer Valparaiso
Inner Kalamazoo M.
Outer Kalamazoo M.
Sturgis M.
Tekonsha M.
SAUGATUCK TILL
GANGES TILL
GLENN SHORES TILL
?
--Lake Michigan--
0
15
kilometers
0
10
miles

FIGURE 1-7.

Correlation chart of the proposed Lake Michigan Lobe till units in southwestern Michigan with the Lake Michigan Lobe till stratigraphy from northern Illinois.

Notes: 1 - After Zumburge (1960)
2 - After Frye and Willman (1973)


ROCK STRATIGRAPHY
S.W. MICHIGAN
WEDRON
Fm
Ganges
Saugatuck
Mb
Kalamazoo-Sturgis M.
Tekonsha M.
Lake Border M.
Valparaiso M.
Glenn Shores
?
?
?
>45,000 yrs. B.P.
MORPHO-STRATIGRAPHY
MICH.- ILL.- IND.[1]
Tekonsha M./W. Chicago
ROCK STRATIGRAPHY
N.E. ILL.[2]
WEDRON
Fm
Yorkville
Wadsworth
Mb
W. Chicago
Lake Border M.
Valparaiso System
Minooka M.
Marseilles M.
16
15
14
14C age
(x 1,000)

SUMMARY OF TILL CORRELATIONS IN SOUTHWESTERN MICHIGAN

A generalized east-west cross-section through southwest Michigan is presented in Figure 1-6 and summarizes the correlations proposed in this paper for tills of the Lake Michigan Lobe. It shows that the Saugatuck till can be traced inland, along the surface, from the Lake Michigan shoreline to the Sturgis-Kalamazoo Morainic System, while the Ganges till can be traced in the subsurface from Lake Michigan to where it crops out at the Tekonsha Moraine.

The presence of lacustrine sands between the Ganges and Saugatuck tills at Glenn Shores (Figure 1-2) suggests that a significant retreat of the Lake Michigan Ice Lobe into the Lake Michigan basin must have occurred following the formation of the Tekonsha Moraine. This retreat also suggests that the distinct increase in 10A clay incorporated into the Saugatuck till resulted as the Lake Michigan Lobe ice subsequently readvanced to the Sturgis-Kalamazoo Morainic System.

REGIONAL LAKE MICHIGAN LOBE CORRELATIONS

In 1915, Leverett (Leverett and Taylor, 1915; plate V) suggested that the Kalamazoo Morainic System in Michigan is time correlative to the outermost ridges of the Valparaiso Morainic System in Illinois. More recent morpho-stratigraphic correlations proposed by Zumberge (1960), however, disagree with Leverett's original interpretation. Based on reconnaissance mapping of terrace deposits associated with the Kankakee Flood (Ekblaw and Athy, 1925), Zumburge suggests that the Tekonsha Moraine in Michigan and the West Chicago Moraine (outermost ridge of the Valparaiso System) in Illinois are time equivalent (Figure 1-7). Fullerton (1980) has agreed with the correlation proposed by Zumburge (1960) and has further suggested that till associated with both the Tekonsha and West Chicago moraines represents the base of the Wadsworth till member of the Wedron Formation as defined by Willman and Frye (1970) in Illinois. If correct, the conclusions of Zumberge and Fullerton would not only imply that the Ganges and Saugatuck tills exposed in southwestern Michigan both correlate with the Wadsworth Till Member (Figure 1-7), but would also suggest that the retreat of the Lake Michigan Lobe, which occurred between the formation of the Tekonsha Moraine and the Sturgis-Kalamazoo Morainic System in southwestern Michigan, must have taken place in Illinois during the formation of the Valparaiso Morainic System.

However, a significant Late Wisconsinan (late Woodfordian) retreat of the Lake Michigan Lobe, on the order of that recorded at Glenn Shores, has not been recognized within the lower part of the Wadsworth Till. Such a retreat, though, has been documented between the top of the Yorkville and base of the Wadsworth tills (Willman and Frye, 1970). Therefore, the author proposes it is more reasonable to conclude that the Ganges till in southwestern Michigan correlates with the upper part of the Yorkville Till, and that the overlying Saugatuck till correlates with the Wadsworth Till (Figure 1-7). These correlations, which generally agree with the morainal correlations first proposed by Leverett (Leverett and Taylor, 1915), suggest that the Sturgis Moraine (outermost ridge of the Sturgis-Kalamazoo System) in Michigan is time equivalent to the West Chicago Moraine in Illinois, while the Tekonsha Moraine in Michigan must be approximately time equivalent to the Minooka or Marselles moraines in northeastern Illinois.

CHAPTER 2
SAGINAW ICE LOBE DRIFT STRATIGRAPHY

INTRODUCTION

The establishment of an objective Wisconsinan drift stratigraphy for the Great Lakes Region has been the focus of much recent research, particularly, as was noted in Chapter 1 of this paper, with respect to the Lake Michigan Ice Lobe (Willman and Frye, 1970, 1975; Johnson, 1976; Acomb, 1978; Lineback, et al., 1974, 1979; Glass, 1981; Acomb et al., 1982) and Huron-Erie Ice Lobe (Gooding, 1961, 1963, 1971; Dreimanis and Karrow, 1972; Dreimanis and Goldthwait, 1973; Dreimanis, 1977; Eschman, 1978). To date, however, and primarily because of the absence of any multiple till exposure, few studies have attempted to establish a stratigraphy for till deposits associated with the Saginaw Ice Lobe. In fact, the stratigraphy of the Saginaw Lobe is still based on the morphologic relationships of moraines that were first described by Frank Leverett around the turn of the century (Leverett and Taylor, 1915). Even in recent summaries by Dreimanis (1977), Fullerton (1980), and Mickelson et al. (1983) the stratigraphy of the Saginaw Ice Lobe has been described either as a series of 12 to 16 named moraines (Figure 2-1), or has been ignored.

The focus of this chapter is two fold. First, to establish lithological criteria that can be used to define till sheets associated with the Saginaw Lobe in south-central Michigan, and second, to suggest probable correlation of these till sheets with the

FIGURE 2-1.
Map showing moraines in southern Michigan (after Leverett and Taylor, 1915).

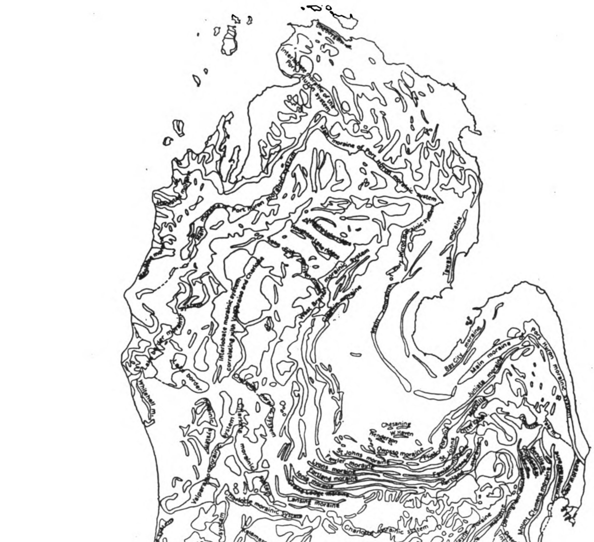

Port Huron morainic system
Chesaning
W. Haven
Henderson
Owosso moraine
St Johns moraine
Fowler moraine
Lyons moraine
Portland moraine
Ionia moraine
Lansing moraine
Charlotte morainic system
Kalamazoo morainic system
Bay City moraine
Main moraine
Juniata moraine
Tawas moraine
Mount Clemens moraine
Fort Wayne moraine
Mississinawa
Defiance moraine
Bowlder belt
Grosse Isle
Tekonsha
Sturgis moraine
Valparaiso morainic system
Inner ridge
Outer ridge
Middlebury
Lagrange
Bremen
Maxinkuckee
Kalamazoo
Marseilles morainic system
Nebo-Gilboa
Wabash moraine
Salamonie moraine
Mississinawa morainic system

FIGURE 2-2.

Map showing Late Wisconsinan moraines of the Lake Michigan and Saginaw lobes and till sample point locations in southwestern Michigan.

NOTE: 1 - After Leverett and Taylor (1915)

Moraines of the Lake Michigan and Saginaw Lobes in southwestern Michigan:

Lake Michigan Lobe Moraines:
- Lake Border System:
  - LBM -- Inner and Outer Lake Border moraines
- Valparaiso System:
  - IVM -- Inner Valparaiso Moraine
  - OVM -- Outer Valparaiso Moraine
- Sturgis-Kalamazoo System:
  - IKM -- Inner Kalamazoo Moraine
  - OKM -- Outer Kalamazoo Moraine
  - STM -- Sturgis Moraine

Saginaw Lobe Moraines:
- TkM -- Tekonsha Moraine
- KM -- Kalamazoo Moraine
- LaM -- Lansing Moraine

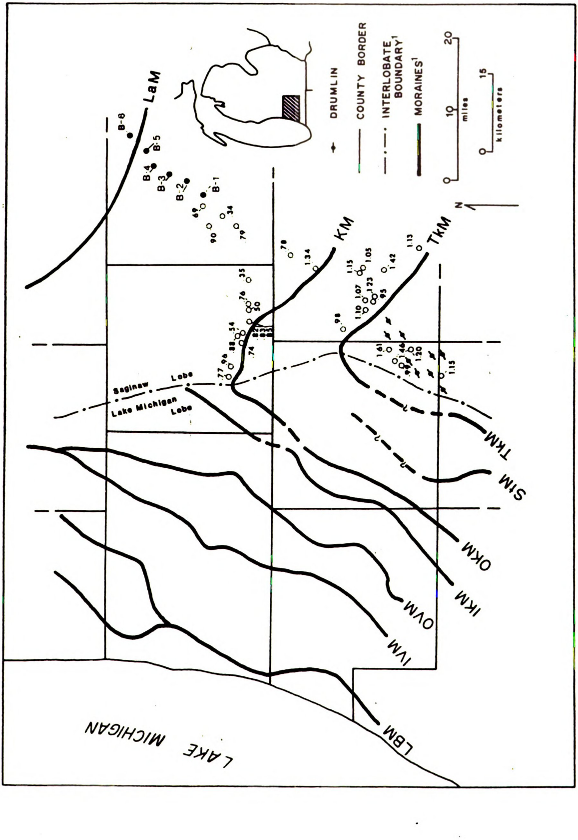
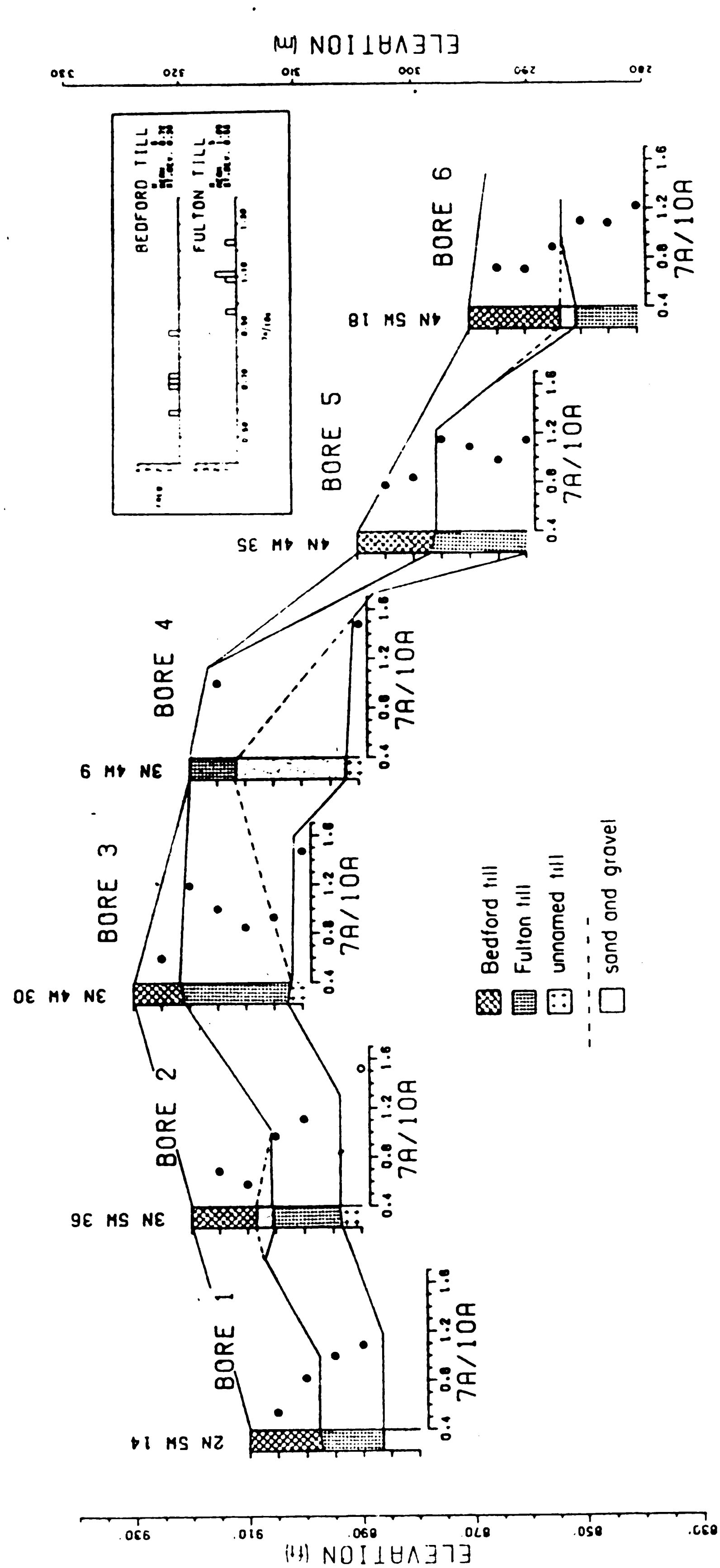

LaM
KM
TkM
StM
OKM
IKM
OVM
IVM
LBM
LAKE MICHIGAN
Saginaw Lobe
Lake Michigan Lobe
B-1
B-2
B-3
B-4
B-5
B-6
DRUMLIN
COUNTY BORDER
INTERLOBATE BOUNDARY[1]
MORAINES[1]
0 10 20
miles
0 15
kilometers
N

FIGURE 2-3.

Cross-section showing lithology and clay mineralogy of the Bedford and Fulton tills sampled from the Eaton County borings. Contacts shown between tills sheets are based on an intervening sand unit between tills, and/or on a significant difference in clay mineralogy. The insert 7A/10A frequency histogram shows the distinct difference in clay mineralogy between the Bedford and Fulton tills in BORE-2 AND BORE-6.



ELEVATION (m)
ELEVATION (ft)
BEDFORD TILL
FULTON TILL
BORE 1
BORE 2
BORE 3
BORE 4
BORE 5
BORE 6
2N 5W 14
3N 5W 36
3N 4W 30
3N 4W 9
4N 4W 35
4N 5W 18
7A/10A
Bedford till
Fulton till
unnamed till
sand and gravel

established drift stratigraphy of the Huron-Erie and Lake Michigan ice lobes.

TILL SHEETS OF THE SAGINAW LOBE

In an attempt to establish a till stratigraphy for drift of the Saginaw Lobe in south-central Michigan, six 9 meter deep borings were drilled between the cities of Charlotte and Grand Ledge in Eaton County, Michigan. The locations of these borings are shown on Figure 2-2 (B-1 to B-6). For each boring, detailed lithologic descriptions were logged; in addition, split-spoon samples of the drift were taken at approximately 1.5 meter intervals. The lithologies and sampling intervals for each bore-hole is shown on the cross-section presented in Figure 2-3.

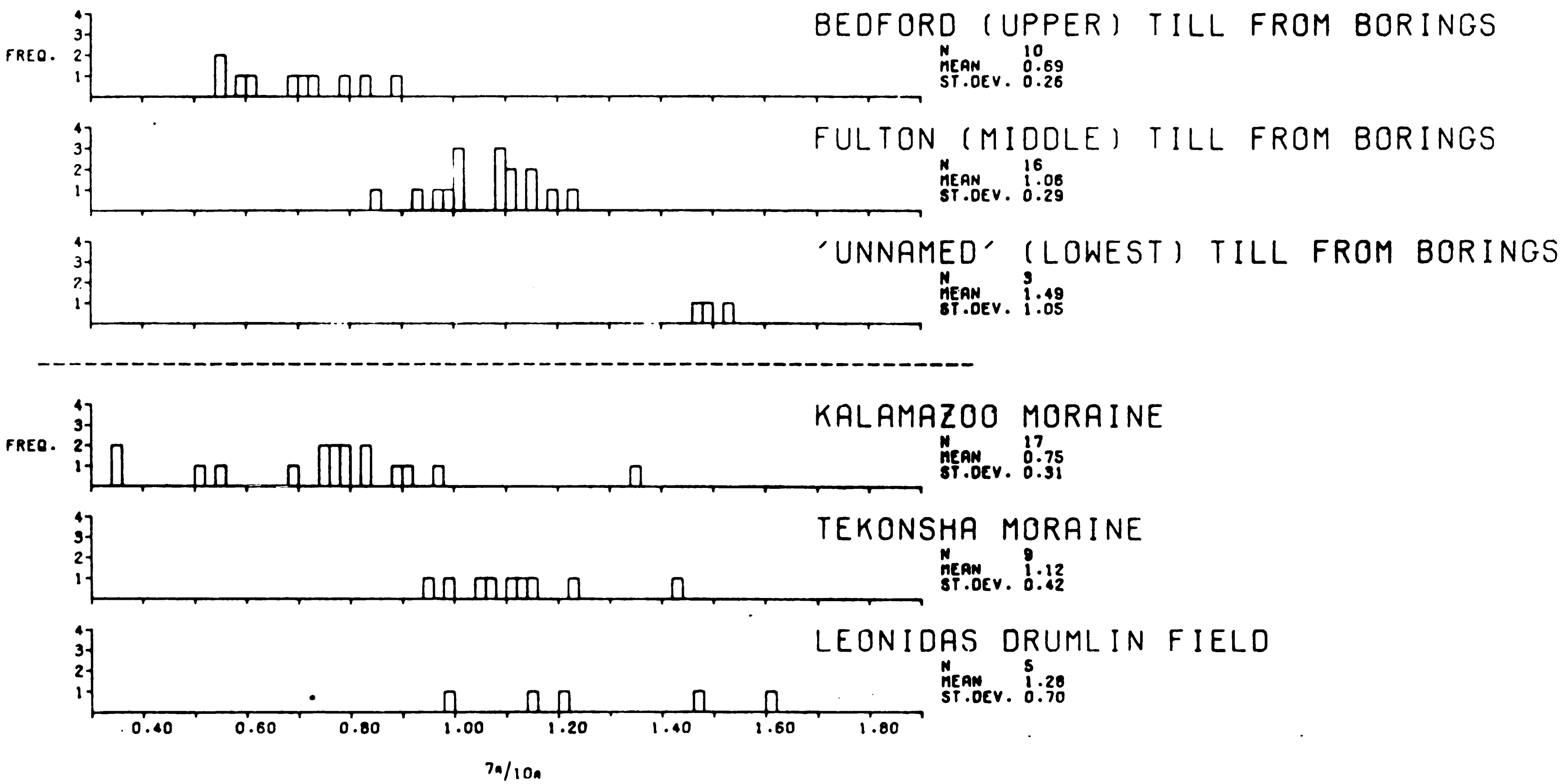
Based on the lithologic logs, at least two till units, separated by sand and gravel, were identified in BORE-2 AND BORE-6 (Figure 2-3). The upper unit, informally named the Bedford till, consists of a red to brown, sandy to sandy clay till. The lower unit is composed chiefly of a grey to tan, dense, clay-rich till, and is informally named the Fulton till.

CLAY MINERALOGY: To further define their lithologic characteristics, semi-quantitative X-ray diffraction analyses were performed on the clay-size fraction of samples taken from the two tills. Preparation of the till samples for analysis included pre-treatments that removed soluble salts and free calcium carbonates for each 25 to 50 gram sample (Jackson, 1956; Carroll, 1972). The clay-size (<2 mu) fraction was then separated out by gravity fractionation, deposited on glass slides, and air dried. Prior to X-ray analysis, the slides were placed in a desiccator with ethylene glycol to expand the vermiculite to 14A and the smectite to 17A - 18A (Jackson, 1956; Carroll, 1972). The prepared slides were then scanned from 2 to 15 degrees 2θ on a General Electric X-ray diffractometer (model XRD-5), rotated 180 degrees, and scanned again. The diffraction patterns were analyzed by comparing the intensities of the 10A and 7A peaks. These peak heights were measured to the nearest .025 cm from a predetermined base line (Grim, 1968; Carroll, 1972). The 7A/10A peak height ratio was calculated and reported as an average of the two rotations.

The results of the clay mineral analyses are presented in the cross-section shown on Figure 2-3. The lithology of the logs is indicated on the Figure 2-and the 7A/10A ratio at each sampling interval is shown to the right of each log. These data clearly show that where they are separated by sand deposits in BORE-2 and BORE-6, the Bedford (upper) and Fulton (lower) tills have distinct clay mineralogies. The clay mineralogy of till from these two borings has been compiled in Figure 2-3 as 7A/10A frequency histograms. The horizontal axis of each histogram represents the calculated 7A/10A ratio, while the vertical axis represents the number of samples with a particular ratio value. It shows that in BORE-2 and BORE-6, the Bedford till has ratio values less than 0.90 while the Fulton till has ratio values greater than 0.90. On the basis of the distinct difference at the 0.90 ratio value of till sampled from these two borings, contacts between the till units in adjacent borings were drawn. The samples from the 10 meter (30 foot) interval in BORE-2,

FIGURE 2-4.

Frequency histograms showing clay mineralogy of the Bedford and Fulton tills from Eaton County bore-holes (above dashed line) compared with histograms of till sampled from Saginaw Lobe moraines in south-central Michigan (below dotted line).


BEDFORD (UPPER) TILL FROM BORINGS
N 10
MEAN 0.69
ST.DEV. 0.26
FULTON (MIDDLE) TILL FROM BORINGS
N 16
MEAN 1.06
ST.DEV. 0.29
'UNNAMED' (LOWEST) TILL FROM BORINGS
N 3
MEAN 1.49
ST.DEV. 1.05
KALAMAZOO MORAINE
N 17
MEAN 0.75
ST.DEV. 0.31
TEKONSHA MORAINE
N 9
MEAN 1.12
ST.DEV. 0.42
LEONIDAS DRUMLIN FIELD
N 5
MEAN 1.28
ST.DEV. 0.70
FREQ.
0.40 0.60 0.80 1.00 1.20 1.40 1.60 1.80
7A/10A

BORE-3, and BORE-4 show ratio values that are greater than 1.45. Their stratigraphic position within the borings, as well as the distinct difference in their clay mineralogies, suggests that these samples may represent the top of an even older till sheet.

The clay mineral data from all samples associated with the Bedford and Fulton tills have been compiled as 7A/10A frequency histograms (Figure 2-4). These histograms show the probable range of clay mineralogy of the two till units. The mean ratio value for the Bedford till is 0.69, while the mean ratio value for the Fulton till is 1.06. Application of the T-test to the clay data indicates that the Bedford and Fulton tills are different to the 99% confidence level.

END MORAINES OF THE SAGINAW LOBE

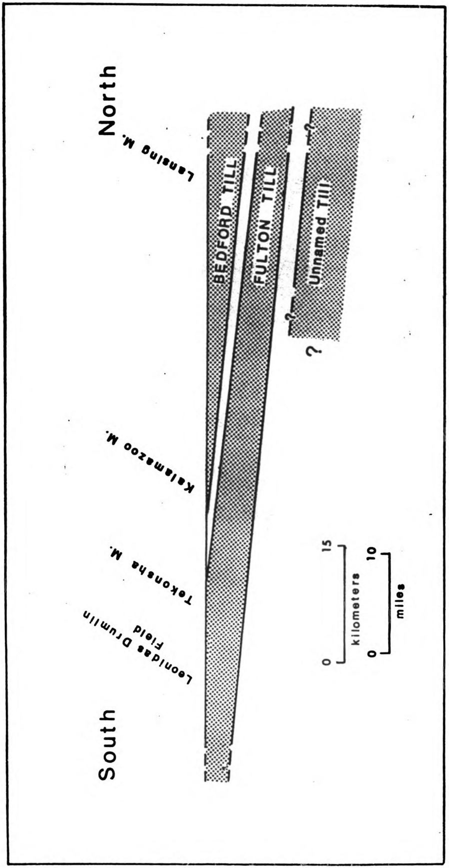
Two ice edge positions of the Saginaw Lobe, the Tekonsha and Kalamazoo moraines, occur approximately 40 to 60 kilometers southwest of the bore-holes. These moraines were first identified by Leverett (Leverett and Taylor, 1915) and are shown on Figure 2-2. Also shown is the location of the Lansing Moraine, which occurs a few kilometers south of boring B-6. A drumlinized till plain (informally named the Leonidas drumlin field) occurs southwest of the Tekonsha Moraine. The southwest-nortneast orientation of these drumlins indicates that they were formed by Saginaw Lobe ice (Leverett and Taylor, 1915; Monaghan, et. al., 1983).

CLAY MINERALOGY: In an attempt to correlate the Bedford and Fulton tills with till occurring south of the bore-holes, clay mineralogical analyses (identical to those described for the till sampled from the bore-holes) were performed on 28 till samples taken from exposures within the Kalamazoo and Tekonsha moraines as well as the Leonidas drumlin field. Samples were generally taken 2 to 3 meters deep from fresh, unweathered exposures. The locations and associated 7A/10A values of these sample points are shown on Figure 2-2.

The results of the analyses are presented on Figure 2-4 in the form of 7A/10A frequency histograms. These data show that the clay mineralogy of the till associated with both the Tekonsha Moraine and the Leonidas drumlin field is significantly different from the till associated with the Kalamazoo Moraine. The mean ratio value for the Leonidas drumlin field is 1.28, the mean ratio value for the Tekonsha Moraine is 1.13 and the mean ratio value for the Kalamazoo Moraine is 0.78.

Comparison of the frequency histograms for the clay data from moraine samples with those associated with the tills defined in the bore-holes (Figure 2-4) suggests that the till from the Kalamazoo Moraine is most similar to the Bedford till, while till from both the Tekonsha Moraine and the Leonidas drumlin field is most similar to the Fulton till. Application of the T-test shows that these associations can be supported to at least the 99% confidence level. Based on the statistical similarity of their clay mineralogy, the author proposes that the till associated with the Kalamazoo Moraine correlates with the Bedford till, while till associated with the Tekonsha Moraine and the drumlin field correlates with the Fulton till.

FIGURE 2-5.
Generalized northeast to southwest stratigraphic cross-section through Saginaw Lobe deposits in south-central Michigan.

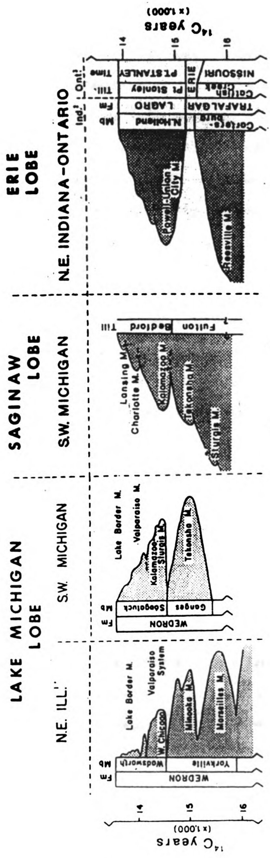


North
South
Lansing M.
Kalamazoo M.
Tekonsha M.
Leonidas Drumlin Field
BEDFORD TILL
FULTON TILL
Unnamed Till
?
0
15
kilometers
0
10
miles

FIGURE 2-6.

Correlation chart showing time stratigraphic relationships of tills of Lake Michigan, Saginaw, and Erie lobes in the Great Lakes region.

Notes: 1 - After Frye and Willman (1973)
2 - After Wayne (1963, 1965) and
by Dreimanis and Goldthwait (1973)
3 - After Dreimanis and Goldthwait (1973)


ERIE LOBE
N.E. INDIANA-ONTARIO
SAGINAW LOBE
S.W. MICHIGAN
LAKE MICHIGAN LOBE
S.W. MICHIGAN
N.E. ILL.
Ind.
Ont.
Mb
Fm
Till
Time
N.Holland
LAGRO
Pt Stanley
PT STANLEY
Cortland-bury
TRAFALGAR
Catfish Creek
ERIE
NISSOURI
Powell-Union City M.
Reesville M.
Bedford
Fulton
Lansing M.
Charlotte M.
Kalamazoo M.
Tekonsha M.
Sturgis M.
Lake Border M.
Valparaiso M.
Kalamazoo
Sturgis M.
Tekonsha M.
Saugatuck
Ganges
WEDRON
Lake Border M.
Valparaiso System
W. Chicago
Minooka M.
Marseilles M.
Wadsworth
Yorkville
14
15
16
14C years
(x 1,000)

SUMMARY OF TILL CORRELATIONS IN SOUTH-CENTRAL MICHIGAN

A generalized northeast to southwest cross-section through south-central Michigan is presented in Figure 2-5 and summarizes the till correlations proposed for the Saginaw Lobe. It shows that the Bedford till can be traced along the surface from just north of the Lansing Moraine to the Kalamazoo Moraine, while the Fulton till can be traced in the sub-surface from the Lansing Moraine to where it crops out in the Tekonsha Moraine and the Leonidas drumlin field.

The distinct difference in clay mineralogy between the Bedford and Fulton tills (Figure 2-4), combined with the intervening sand and gravel layer shown between the two till sheets in Figure 2-2, suggests that a significant retreat (at least 60 kilometers) of the Saginaw Lobe occurred between the formation of the Tekonsha and Kalamazoo moraines.

SAGINAW AND HURON-ERIE LOBE CORRELATIONS

Based on stratigraphic evidence, Morner and Dreimanis (1973) and Dreimanis and Goldthwait (1973) concluded that about 16,000 to 16,500 years ago a major disintegration of the Huron-Erie Ice Lobe, termed the Erie Interstade (Dreimanis, 1958), resulted in a retreat of the ice margin to at least as far north as Goderich, Onterio. Subsequently, by about 15,000 years ago the margin of the Huron-Erie Lobe had readvanced over 200 kilometers to the Powell Moraine in central Ohio.

In 1915, Leverett (Leverett and Taylor, 1915) proposed that the

Kalamazoo Moraine of the Saginaw Lobe is time correlative with the Mississinawa Moraine of the Huron-Erie Lobe, as are the Mississinawa Moraine in Michigan and the Powell Moraine in Ohio. More recently, these correlations have also been suggested by Farrand and Eschman (1974). Based on the above morphologic correlations of Saginaw and Huron-Erie lobe moraines and the stratigraphic correlation of the Fulton till with till comprising the Kalamazoo Moraine, the author suggests that the interval between the deposition of the Fulton and Bedford tills of the Saginaw Lobe is correlative with the Erie Interstade.

SAGINAW AND LAKE MICHIGAN LOBE CORRELATIONS

Recently, the author and others (Gephart, et. al., 1982, 1983) have proposed that two Late Wisconsinan age Lake Michigan Lobe till sheets occur in southwestern Michigan: the Saugatuck (younger) till and the Ganges (older) till. Based on correlation of the Ganges till to till comprising the Tekonsha Moraine (Figure 2-2) and the Saugatuck till to till associated with the Sturgis-Kalamazoo Morainic System (Figure 2-2), they further propose that a significant retreat of the Lake Michigan Lobe occurred between the formation of the Tekonsha Moraine and the Sturgis-Kalamazoo Morainic System (Figure 2-6).

Leverett (Leverett and Taylor, 1915), in 1915, proposed that the Tekonsha moraines and Kalamazoo moraines of both the Saginaw and Lake Michigan lobes were formed at about the same time. Recent detailed mapping of the surficial deposits of Kalamazoo County, Michigan by the author and others (Monaghan, et al., 1983) has confirmed Leverett's interpretations. These correlations would suggest that the Fulton till and Ganges till are time equivalent, as are the Bedford till and Saugatuck till (Figure 2-6).

Leverett (Leverett and Taylor, 1915, plate V) also first suggested that the Kalamazoo System in Michigan is time equivalent to the outermost ridge of the Valparaiso Morainic system in Indiana and Illinois. On the basis of this correlation the author, in chapter 1 of this paper, has proposed that the Saugatuck till in Michigan and the Wadsworth Till in northern Illinois were deposited during the same time interval, as were the Ganges till and at least the upper part of the Yorkville Till (Figure 2-6). If correct, this implies that a significant retreat of the Lake Michigan and Saginaw lobes occurred following the formation of the Tekonsha Moraine. Both lobes must have then subsequently readvanced a distance of at least 60 kilometers: the Saginaw Lobe to the Kalamazoo Moraine and the Lake Michigan Lobe to the outermost ridges of the Sturgis-Kalamazoo System in Michigan and the Valparaiso System in northern Illinois (Figure 2-6).

SUMMARY OF CORRELATIONS

In the absence of absolute chronologic control or direct lithologic correlation, Morner and Dreimanis (1973), Dreimanis and Goldthwait (1973), and Johnson (1976) each has suggested that the Erie Interstade, if significant in the Lake Michigan basin, is probably represented by the interval between either the formation of the Marseilles and Minooka moraines or the formation the Minooka Moraine and Valparaiso Morainic System (Figure 2-6). More recently, Fullerton

(1980) and Mickelson et al. (1983) suggested that the Erie Interstade occurred in the Lake Michigan basin between the formation of the Minooka and West Chicago (outermost ridge of the Valparaiso System) moraines.

A summary of the drift correlations proposed in this study for the Great Lakes Region, particularly with reference to the Erie Interstade, is shown on Figure 2-6. Based on the morpho-stratigraphic correlations of moraines in northern Illinois, southern Michigan and Ohio discussed above, the author proposes that the Valparaiso and Sturgis-Kalamazoo morainic systems of the Lake Michigan Lobe, the Kalamazoo Moraine of the Saginaw Lobe, and the Mississinawa and Powell-Union City moraines of the Huron-Erie Lobe are all time equivalent and were formed as the margins of all three lobes advanced following the Erie Interstade.

The above morpho-stratigraphic relationships would also imply that the interval between the deposition of the Fulton and Bedford tills of the Saginaw Lobe, as well as the interval between the Ganges and Saugatuck tills of the Lake Michigan Lobe are stratigraphically equivalent to the Erie Interstade.

DISCUSSION

A serious problem is apparent from the correlations proposed on Figure 2-6 and arises both from the incompatibility of the ages of moraines in Illinois and central Ohio and from uncertainty as to the age of the Erie Interstade. To date, no inter-till organics of Erie Interstade age have been found in either the Lake Michigan or

Huron-Erie lobes. The age proposed by Dreimanis and Goldthwait (1973) for the Erie Interstade is about 15,500 years BP and is bracketed by dates of 16,500 years BP near the Reesville and Farmers moraines in southern Ohio and by a 14,780 ± 192 BP date (OWU-83; Ogden and Hay, 1965) from a log incorporated in the Powell Moraine in central Ohio. Although, the location and stratigraphic importance of the date from the Powell Moraine is uncertain (Fullerton, 1980, Mickelson, et al., 1983), it implies that the ages of the Mississinawa Moraine of the Huron-Erie Lobe in Michigan and the Kalamazoo Moraine of the Saginaw Lobe must also be older than about 14,800 years BP.

The chronology proposed by Frye and Willman (1973) for deposits of the Lake Michigan Lobe indicates that the outermost ridge of the Valparaiso System (West Chicago Moraine) in Illinois was formed about 14,300 years BP. The age of this moraine is inferred from correlation of the Wadsworth Till to dated loess sequences in western Illinois and from the inferred relationship of the Valparaiso System to Lake Chicago (Glenwood level) deposits. If the age of the distal margin of the Valparaiso System is correct, it implies that the Sturgis-Kalamazoo System of the Lake Michigan Lobe and the Kalamazoo Moraine of the Saginaw Lobe were also formed about 14,300 years BP. Clearly, based on morainal correlations, at least a 500 year age discrepancy exists for the formation of the Kalamazoo Moraine in Michigan.

Several explanations could account for the above age discrepancy. For instance, the chronologic relationships suggested on Figure 2-6 may be in error since they are based on broad, regional morphologic correlations of moraines. Alternatively the proposed ages of the moraines may be correct which suggests that the close of the Erie Interstade is time transgressive and becomes progressively younger westward. However, in light of a recent radio-carbon date of 15,240 $\pm$ 120 (ISGS-465; Springer and Flemmal, 1981) from the bottom of a kettle formed in outwash associated with the outermost ridge of the Valparaiso System in Illinois, a more likely explaination is that the time scale proposed by Frye and Willman is in error. This date indicates that the Valparaiso System in Illinois must, in fact, be older than 15,000 years BP. If so, it suggests that in Michigan, the Sturgis-Kalamazoo System of the Lake Michigan Lobe, the Kalamazoo Moraine of the Saginaw Lobe, and the Mississinawa Moraine of the Huron-Erie Lobe were all formed at least 15,000 year ago. The age of these moraines, then, is in close agreement with the age proposed for the Powell Moraine in Ohio (Figure 2-6). Recent dates of the Jules Soil interval (Willman and Frye, 1974) also suggest that a major ice-free interval occurred in Illinois just prior to 15,000 years BP.

CHAPTER 3
THE GLACIAL GEOLOGY OF KALAMAZOO COUNTY, MICHIGAN

INTRODUCTION

The landscape of Kalamazoo County, south-central Michigan, was formed by two Late Wisconsinan ice lobes: the Saginaw Lobe and the Lake Michigan Lobe (Figure 3-1). Generally, it includes broad, gently-sloping outwash plains and sandors, terraced valley train outwash systems, a drumlinized till plain, and a glacial "lake" plain. Smaller, localized till and kamic deposits also occur throughout the county. In addition, late Pleistocene and Holocene eolian and muck deposits, as well as recent marsh and flood plain sediments, occur in scattered locations. Notably, two prominent morainal systems, the Kalamazoo and Tekonsha systems, clearly demark the retreat of the margin of both ice lobes.

A recently published drift thickness map of Kalamazoo County (Forstat, 1982) shows that the drift in Kalamazoo County varies from less than 30 meters (100 ft) thick in the southeastern part of the county to more than 181 meters (600 ft) thick in the western part of the county. Well log records from the county also show that most of the drift units exposed at the surface are relatively thin and that they are sometimes underlain by older, deeper drift deposits.

Although drift of pre-Late Wisconsinan age is nowhere exposed at the surface of Kalamazoo County, it has been observed west of the

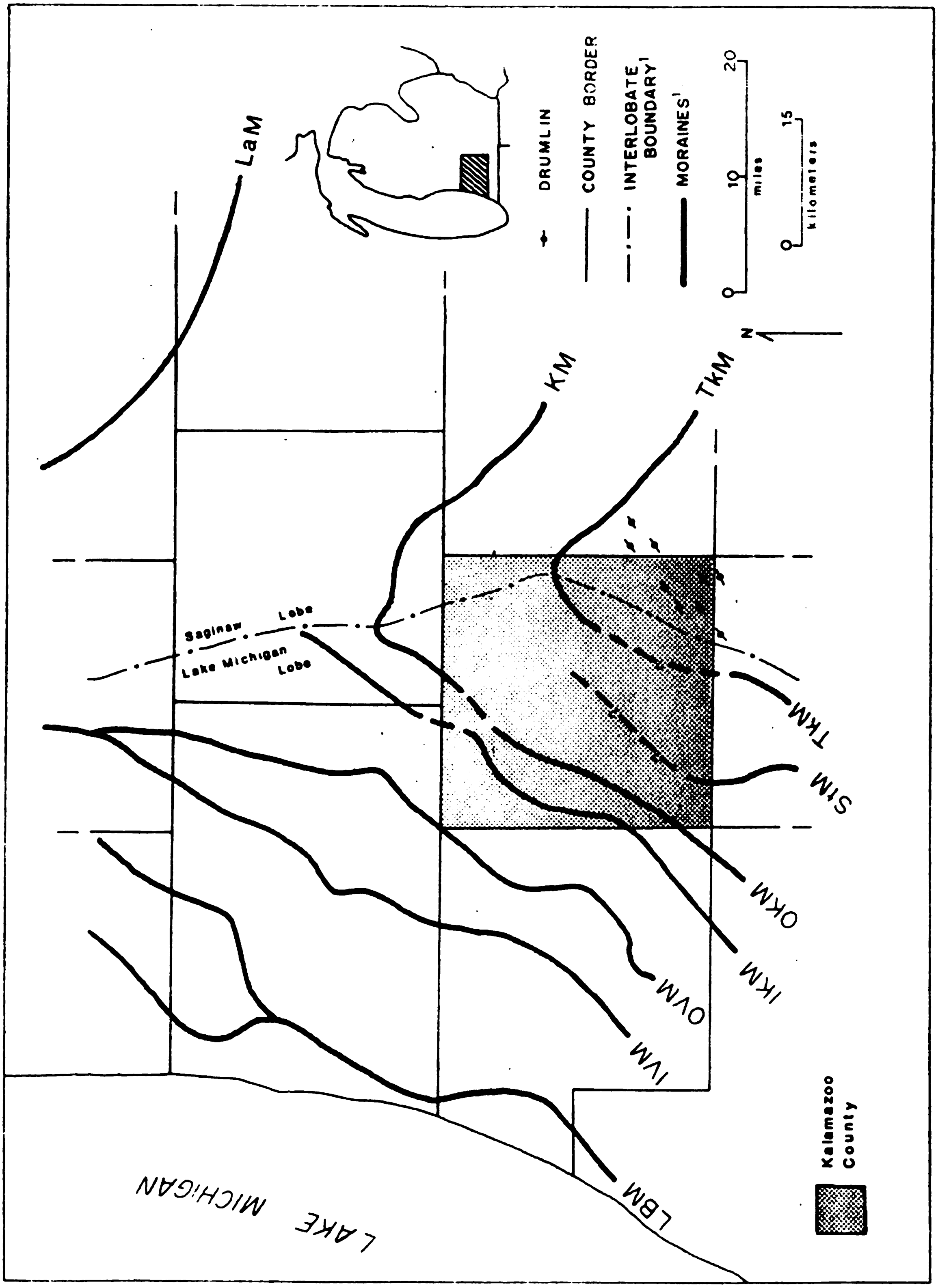


FIGURE 3-1.
Map showing location of Kalamazoo County and the general extent of the Saginaw and Lake Michigan lobes.

county at the Glenn Shores section in Allegan County (Gephart, 1982; Gephart et al., 1982, 1983) and along the eastern shore of Lake Michigan (Zumberge and Potzger, 1956; Eschman, 1981). Pre-Late Wisconsinan drift has also been identified in road cuts and gravel pits north of Kalamazoo County near the city of Grand Rapids (Zumberge and Benninghoff, 1969; Eschman, 1981) and has been observed in wells drilled in several locations throughout southwestern Michigan (Rieck and Winters, 1980; Miller et al., 1969).

The bedrock underlying the drift in Kalamazoo County is Mississippian in age. In the northeast corner of the county the bedrock is chiefly sandstone of the Marshal Formation, while the rest of the county is underlain predominantly by shale of the Coldwater Formation (Forstat and Sorensen, 1982).

PLEISTOCENE GEOLOGY

In 1983, Monaghan and Larson (1983) published a surficial geologic map of Kalamazoo County and, based on texture, differentiated the drift in the county into eolian units, outwash and lacustrine units, and till units. Landforms such as end moraines and drumlins were also defined. They further subdivided the outwashes into named morphologic sequences (Jahns, 1941, 1953; Koteff, ????) which were defined by the textural facies and the surface gradient of the outwashes. In general, these morphologic sequence refer to the downstream progression of melt-water deposits from the head of outwash (often related to an end moraine) to a base level. Although an individual morphologic sequence has no time conotation in itself, it can be placed in relative geologic time based on its relationship to other sequences.

Detailed descriptions of the named outwash sequences, as well as of till deposits and moraines are presented in the following discussion. The outwashes are discussed from oldest to youngest. Similarly, descriptions of moraines in the county are also presented from the oldest to the youngest.

Fluvial and Lacustrine Deposits

CLIMAX-SCOTTS OUTWASH PLAIN DEPOSITS. -- Deposits of the Climax-Scotts outwash form an extensive plain in the eastern part of Kalamazoo County south of the Kalamazoo River. The plain was first recognized by Leverett who associated it with the Climax Prairie (Leverett and Taylor, 1915). The plain slopes gently towards the southwest and has a surface gradient of about 1.84 m/km (10 ft/mi). Generally, the northern and northwestern margin of the plain is defined by uplands of the Tekonsha Moraine, but in some places it is also defined by an extensively collapsed head of outwash. The western margin of the plain is defined by an 8 to 9 meters (25 to 30 ft) high scarp that separates it from the topographically lower Galesburg-Vicksburg outwash plain. To the southeast the outwash is bordered by till plain uplands, informally named the Leonidas drumlin field, and by extensive kettle depressions.

The maximum elevation of the Climax-Scotts outwash plain is about 313 meters (1010 ft) and occurs along the northeastern margin of the plain just east of Burnham Lake. The minimum elevation of the plain is 279 meters (900 ft) and occurs along the western margin of the plain, just west of the town of Scotts.

Several low till and gravel knobs project through the surface of the outwash plain. In many places the plain is also pitted by kettle depressions. The largest of the kettles often intercept the water table and contain swamp and muck deposits or small bodies of water (i.e. Portage, Wood, and McGinnis lakes). In several places, such as Dorrance Creek, several kettles are connected with each other to form linear depressions or furrows several kilometers long.

Deposits of the Climax-Scotts outwash plain generally decrease in coarseness from the northeast to the southwest and consist chiefly of medium to coarse sand and gravel. Though boulders and cobbles are common on the surface along the northeastern margin of the plain, they are generally rare near the southwestern margin. Graded bedding and large scale cross-beds of very coarse sand, gravel, and cobbles occur in pit exposures near the northeastern margin of the plain (American Aggregate Pit; NW 1/4 of section 27, T2S R9W). Both bedding and texture of the sediments indicate that they were deposited very near to the ice margin. Sediments in pit exposures along the western margin of the plain fine upwards and show small scale cross-beds and channel scours. Bedding and texture of the sediments observed throughout the plain, as well as the morphology and gradient of the plain's surface, indicate a predominantly northeast source for the outwash sand and gravel.

GALESBURG-VICKSBURG OUTWASH PLAIN DEPOSITS. -- The Galesburg-Vicksburg outwash plain deposits occur within an extensive area in central Kalamazoo County and make up by far the largest single map unit in the county. The western and northwestern margin of the plain is defined by the prominent "outer" ridge of the Kalamazoo Moraine associated with the Lake Michigan Ice Lobe. The outwash plain extends north into Barry County where its northern margin is defined by the Kalamazoo Moraine associated with the Saginaw Ice Lobe (Leverett and Taylor, 1915). North of the Kalamazoo River the eastern edge of the plain extends into Calhoun County where its surface becomes highly collapsed. However, south of the Kalamazoo River the eastern boundary of the plain is clearly defined by the topographically higher Tekonsha Moraine, the Climax-Scotts outwash plain, and the Leonidas drumlin field. To the south, the plain extends into St. Joseph County and eventually joins the drainage of the Glacial St. Joseph River (Leverett and Taylor, 1915).

Within Kalamazoo County, the Galesburg-Vicksburg outwash plain slopes gently towards the south and southwest and has a surface gradient that varies from 5.5 to 6.4 m/km (30 to 35 ft/mi) near the plain's western margin along the Kalamazoo Moraine, to less than 1.3 m/km (7 ft/mi) near the southern border of the county. The plain attains a maximum elevation of about 304 meters (980 ft) near the Kalamazoo Moraine, approximately 5 kilometers (3 mi) west of Gull Lake. The minimum elevation of the plain in Kalamazoo County is 264 meters (850 ft) and occurs along the southern border of the county, approximately 5 kilometers (3 mi) south of Vicksburg.

The outwash surface of the Galesburg-Vicksburg outwash plain is pitted in many places by extensive kettle depressions. Many of these depressions intercept the water table and also contain large lakes (i.e. Gull, Austin, and Indian lakes). Along the Kalamazoo River, long steep-walled furrows, such as Gull Creek, commonly dissect the plain. Other prominent lineaments include a chain of lakes and muck fields that extend southwest from the southern end of Gull Lake, across the Kalamazoo River, to Crooked Lake along the Kalamazoo Moraine. Just northwest of the town of Vicksburg, a similar chain of lakes extends southwest from Indian Lake to Howard Lake. The same lineament apparently extends northeast from Indian Lake, through the Climax-Scotts outwash plain deposits, and ends at Burnham Lake near the Tekonsha Moraine.

Small kames occur within the Galesburg-Vicksburg outwash plain, particularly along the margins of kettle depressions in both southwestern Prairie Rounde and southeastern Schoolcraft townships. South of the Kalamazoo River, ridges of sand and gravel, as well as till, also crop out through the outwash surface. Two of the most extensive ridges occur just east of the city of Vicksburg and just south of the city of Schoolcraft.

The Galesburg-Vicksburg outwash plain deposits consist chiefly of medium to coarse sand and gravel that generally decrease in coarseness from northwest to southeast. For example, large scale beds of very coarse sand, gravel, and cobbles occur in pit exposures along the west and northwestern margin of the outwash plain (Pawpaw Lake exposure, NE 1/4 of section 4, T4S R12W and Ravine Road section, SW 1/4 of section

4, T2S R11W). Both the bedding and texture of these sediments indicate they were derived from very near the ice margin. Recent excavations in the southeastern part of the plain, on the other hand, show channel scours and fine to medium cross-bedded sand and pebbles (NE 1/4 of section 32, T1S R9W; NW 1/4 of section 33, T1S R10W), as well as massive beds of medium to fine sand (NW 1/4 of section 13, T3S R11W). Surface boulders are common along the western margin of the outwash plain near the Kalamazoo Moraine. Sometimes they also occur within the plain near the margin of kettle depressions as well as on and adjacent to the sand and gravel and the till ridges.

AUGUSTA CREEK OUTWASH DEPOSITS. -- The Augusta Creek outwash deposits form a deeply-incised valley train in the northeastern part of the Galesburg-Vicksburg outwash plain. The valley train includes a series of terrace remnants that extend from Fair and Big Gilkey lakes in Barry County, southward, along the present drainage of Augusta Creek to the Kalamazoo River near the town of Augusta. The highest terraces, which lie at a maximum elevation of 291.4 meters (940 ft), slope southward and have a surface gradient of less than 0.66 m/km (3 ft/mi). Although these upper terraces can not be traced further west than the 279 meter (900 ft) level found near the town of Augusta, the author suspects that while they were forming, drainage continued southward from the Kalamazoo River Valley, along the present course of Portage Creek. The lower terraces have a much steeper gradient of about 2.0 m/km (10 ft/mi) and can be related to the lower terraces of the Glacial Kalamazoo-Gun Plain outwash deposits. Kettle hole depressions are common along the whole length of the valley train.

Crevasse filling and small eskers also occur within the upstream portion of the valley train in Barry County.

Where exposed, the Augusta Creek outwash deposits consist chiefly of massive, medium to coarse sand and gravel. There is, however, no evidence for distinct downstream size grading. The crevasse filling and esker deposits, which occur in the upstream portion of the outwash, consist chiefly of poorly sorted sand and gravel and sometimes show collapse along their margins.

GLACIAL KALAMAZOO-GUN PLAIN OUTWASH DEPOSITS. -- The Glacial Kalamazoo-Gun Plain outwash deposits occur in north-central Kalamazoo County. Part of the sequence forms a valley train that is incised 39 to 45 meters (130 to 150 ft) into the the Galesburg-Vicksburg outwash plain. The valley train extends westward along the Kalamazoo River Valley from the eastern border of the county to 10 kilometers (6 mi) north of the city of Kalamazoo. At its western end, the valley train breaches the Kalamazoo Moraine and merges with a broad, southward grading outwash plain. This plain can be traced southward from the Thronapple River, through the northwestern corner of Kalamazoo County, and into Van Buren County. Gephart and Larson (1983) refer to deposits associated with this plain in Allegan County as the Gun Plain outwash.

Several successively lower terrace remnant extend along the valley of the Kalamazoo River westward from the city of Battle Creek in Calhoun County. In Kalamazoo County, the highest of these lie 7 to 15 meters (20 to 50 ft) above the valley floor and attain a maximum elevation of 266 meters (860 ft) just north of Fort Custer State Park. The surface of the the upper terraces grade westward and drop in elevation approximately 0.55 m/km (3 ft/mi). Between the eastern border of the county and the city of Galesburg, the terraces are marked by sharp, relatively continuous scarps; however, west of Galesburg these terraces are not well defined.

Along the whole length of the Kalamazoo River Valley, a series of lower, relatively continuous terraces are also present. They lie 2 to 5 meters (5 to 15 ft) above the Kalamazoo River and, like the upper terraces, grade westward at about 0.55 m/km (3 ft/mi). Kettle hole depressions, which are common in the upper terraces near Fort Custer State Park, are rare in the lower terraces.

A series of southward grading terraces also occur in the plain in the northwestern corner of the county. The highest of these lies at 242 meters (780 ft) near the city of Alamo, between Murry Lake and the gravel uplands west of the Kalamazoo Moraine. They appear to be concordant with the lower terraces found along the Kalamazoo River.

The Glacial Kalamazoo-Gun Plain outwash deposits consist chiefly of cross-bedded, medium to coarse sand and gravel. Beds exposures within the upper terraces along the Kalamazoo River near Fort Custer State Park are generally coarser and more massive than beds exposed downstream and in the lower terraces. Exposures in Alamo Township in northwestern Kalamazoo County show generally medium to fine sand and silt.

GLACIAL LAKE DEPOSITS. -- Generally, fine textured, discontinuous sand and silt deposits occur within an shallow 90 sq km (35 sq mi) depression in the Galesburg-Vicksburg outwash plain along the Kalamazoo River Valley. The surface of this depression forms a plain near the city of Kalamazoo that extends through and northwest of the Kalamazoo Moraine. It is surrounded to the south, east, and west by the Galesburg-Vicksburg outwash plain. North of the Kalamazoo River a distinct 3 to 5 meter (10 to 30 ft.) scarp separates the plain from the topographically higher Galesburg-Vicksburg outwash plain. South of the river, on the other hand, the boundary of the plain is not so distinct. However, a low scarp can be traced from the Kalamazoo River Valley, just south of Marrow Lake, to Crooked and Long lakes, south of the town of Portage.

The maximum and minimum surface elevations of the plain range from 273 meters (880 ft) just south of the Kalamazoo Moraine and west of the Kalamazoo River (se 1/4 of section 27, T1S R11W) to 264 meters (850 ft) just east of the city of Parchment (SW 1/4 of section 2, T2S R11W). The plain shows no distinct surface gradient, but rather forms a slightly rolling surface that has an average relief of 3 to 10 meters (10 to 30 ft).

Leverett (Leverett and Taylor, 1915; pg. 181) have suggested that the above depression was formed by "glacial action" rather than stream erosion. Because of its great size, as well as the irregularities and recesses of its bluff, he proposed that a large mass of stagnant ice persisted between the cities of Kalamazoo and Galesburg while the surrounding outwash gravel was being deposited. When this ice mass subsequently melted, it left a large "sag" in the surface. Later, Shaw (1968) observed clay and silt deposits underlying the surface of the depression south of the Kalamazoo River, as well as north of the city of Kalamazoo near the village of Cooper. He proposed that the depression was at one time occupied by a shallow lake.

The author has also observed clay and silt capping sand and gravel deposits within this depression near the village of Copper and just north of the Kalamazoo Regional Airport. These deposits are generally less than 1 meter (1 to 3 ft) thick and consist chiefly of very discontinuous beds of lacustrine silt and clay and cross-bedded fine sand and pebbles. Beneath the silt and sand deposits are massive and cross-bedded fluvial sands and gravels.

SAND AND GRAVEL, UNDIFFERENTIATED. -- Undifferentiated sand, gravely sand, and pebble to cobble gravel occur throughout most of Kalamazoo County. These deposits form small, local kames such as those found in scattered locations within the Galesburg-Vicksburg and Climax-Scotts outwash plains. In western Kalamazoo County, they also form a broad belt of highly collapsed topography between the Kalamazoo Moraine and the Gun Plain outwash. The largest single kame occurs within the lake plain just west of the Kalamazoo Regional Airport and is composed chiefly of beds that range from massive silt to cross-bedded cobbles. Exposures on the eastern side of this kame show normal faulting and eastward collapse of the sediments. Straw (1976) has also observed till overlying a portion of this kame.

LATE-GLACIAL EOLIAN DEPOSITS. -- Dunes occur in several locations throughout the county, most notably on the Glacial Kalamazoo-Gun Plain outwash south of the town of Alamo and in the highly collapsed, undifferentiated sand and gravel deposit west of the Kalamazoo Moraine. A 10 mile long east-west band of barken and longitudinal dunes also occurs on the Galesburg-Vicksburg outwash plain.

A thin, discontinuous mantle of sand and silt, generally less than 0.5 meters thick (not defined on the map published by Monaghan and Larson, 1983) sometimes overlies the drift in Kalamazoo County. Shaw (1969) has suggested that these silt and sand deposits, particularly in the south and southwestern part of the Galesburg-Vicksburg outwash plain, are eolian in origin.

Till and Moraine Deposits

TEKONSHA MORAINE. -- The Tekonsha Moraine forms a prominent ridge south of the Kalamazoo River in the east-central part of the county. Leverett (Leverett and Taylor, 1915) first identified the ridge and named it after the village of Tekonsha in Hillsdale County. He further speculated that the morainal ridge was built by both the Saginaw and the Lake Michigan ice lobes.

In Kalamazoo County the Saginaw Lobe portion of the Tekonsha Moraine extends northward from the eastern border of the county to Burnham Lake, located 1.5 kilometers (3 mi) north of the village of Climax. There the ridge connects with the Lake Michigan Lobe portion of the moraine which extends southwestward a distance of 16 kilometers (10 mi) to just north of the village of Scotts. Leverett (Leverett and Taylor, 1915) has suggested that the moraine continues south and west along a subtle ridge of sandy, bouldery drift that occurs within the Galesburg-Vicksburg outwash plain east of the city of Vicksburg. The author, however, could not trace the moraine with certainty west of the village of Scotts.

In general, the moraine ridge varies in width from 0.3 to over 0.6 kilometers (0.5 to 1 mi) and, at the interlobate junction, rises to an elevation of slightly more than 318 meters (1050 ft). The surface of the moraine is very rugged and is characterized by high knolls and kettle depressions. Throughout its whole length in Kalamazoo County, the distal edge of the moraine is in direct contact with the deposits of the Climax-Scotts outwash plain. The proximal edge of the Saginaw Lobe portion of the moraine is defined by a series of kamic knobs and kettle depressions, while the proximal edge along the Lake Michigan Lobe segment of the moraine is defined by the south wall of the deeply incised Kalamazoo River valley and by the topographically lower Galesburg-Vicksburg outwash plain.

Exposures within the Tekonsha Moraine show that it is composed chiefly of massive to poorly bedded coarse sandy to sandy clay till, as well as massive to poorly bedded sand and gravel. Boulders and cobbles commonly occur on the surface of the moraine, particularly along its crest and distal margin.

STURGIS MORAINE. -- The Sturgis Moraine forms a short, well-defined ridge within the southwestern part of Kalamazoo County. The ridge extends for a few kilometers north from the southern border of the county, to just south of the city of Schoolcraft. There the ridge is buried by outwash associated with the Galesburg-Vicksburg outwash plain. Well log records, however, indicate that deposits associated with the moraine may actually extend northward, under the outwash. The Sturgis Moraine can be traced southward to just northwest of the city of Three Rivers, in St. Joseph County. From there the ridge can not be distinguished with certainty from the surrounding hummockey till plain and collapsed outwash.

In Kalamazoo County, the eastern boundary of the moraine is defined by sand and gravel deposits of the Galesburg-Vicksburg outwash plain. The western boundary, on the other hand, is defined by highly collapsed outwash associated with the Galesburg-Vicksburg outwash plain.

The Sturgis Moraine was first identified by Leverett (Leverett and Taylor, 1915) and named for the city of Sturgis in St. Joseph County. Leverett originally associated the Sturgis Moraine with both the Lake Michigan and Saginaw lobes. He also suggested that the Sturgis moraines of both lobes were formed at approximately the same time. On the basis of morphology and clay mineralogy, Gephart, et. al. (1983) and Monaghan and Larson (1983) have concurred with Leverett's interpretation that the northward extension of the Sturgis Moraine in Kalamazoo and St. Joseph counties was formed by the Lake Michigan Lobe. However, they suggest further that it more likely represents the outermost ridge of the Kalamazoo Morainic System and is therefore significantly younger than the Sturgis Moraine of the Saginaw Lobe.

Exposures within the Sturgis Moraine show that it is composed chiefly of massive, cobbley, sandy to very sandy till. Pit exposures in St. Joseph County also show that in places till of the moraine may overly outwash sand and gravel. Cobbles and boulders are common on the top of the moraine as well as along its eastern margin. A few exposures of clay-rich till can also be observed along the western margin of the moraine.

KALAMAZOO MORAINE. -- In Kalamazoo County, the Kalamazoo Moraine forms an approximately north-south trending prominent ridge near the western border of the county. Outside of the county, the ridge can be traced for a distance of over 130 kilometers (80 mi), making it one of the longest continuous morainal ridges in southern Michigan. Leverett (Leverett and Taylor, 1915) first identified the moraine and named it after the city of Kalamazoo. North of Kalamazoo County, the moraine joins with a broad, generally east-west trending moraine which was also named the Kalamazoo Moraine by Leverett. Leverett (Leverett and Taylor, 1915) suggested that the north-south trending portion of the Kalamazoo Moraine was formed by the Lake Michigan Lobe, while the east-west trending portion was formed by the Saginaw Lobe. He also proposed that both portions of the moraine were time correlative.

Leverett traced the Lake Michigan Lobe portion of the moraine from the valley of the St. Joseph River near the city of South Bend, Indiana, northeastward into Michigan through Cass, Van Burren, and Kalamazoo counties, to the village of Prairieville in Barry County. (The author has traced the same distinctive morainal ridge even further north to within several kilometers of the town of Hastings in

Barry County.)

At Prairieville the Kalamazoo Moraine associated with the Lake Michigan Lobe joins with its Saginaw Lobe correlative and extends east and southeast through Barry and Calhoun Counties and passes through the city of Albion in Jackson County. In contrast to the prominent ridge of the Lake Michigan Lobe segment of the Kalamazoo Moraine, the Saginaw Lobe segment is characterized by a series of high knolls and kettle depressions. Though Leverett (Leverett and Taylor, 1915) considered this portion of the moraine as a broad belt up to 32 kilometers (20 mi) wide, recent field work by the author has shown that it is actually a series of ridges and kettle depressions only a few kilometers wide.

In 1915, Leverett (Leverett and Taylor, 1915, 1924) defined distinct ridges of the Kalamazoo Moraine associated with the Lake Michigan Lobe. He called both ridges the Kalamazoo Morainic System and informally refered to each as the "inner" and "outer" Kalamazoo moraines. The "outer" Kalamazoo Moraine, which is the eastern most ridge, enters Kalamazoo county 10 kilometers (6 mi) west of Schoolcraft. It extends northward, past the city of Otsego, across the Kalamazoo River, to the northern border of the county. The ridge varies from 0.3 to over 0.5 kilometers (0.5 to 1 mi) wide and, in a few places, attains an elevation of over 317 meters (1050 ft). Throughout most of its length in Kalamazoo County, however, the crest of the ridge seldom lies above 305 meters (1010 ft).

The distal edge of the "outer" Kalamazoo Moraine is defined by a marked change in surface gradient that separates the high, rolling topography of the moraine from the gently undulating surface of the Galesburg-Vicksburg outwash plain. In fact, throughout its length in Kalamazoo County, the "outer" Kalamazoo Moraine is easily discernible because it stands between 12 to 30 meters (40 and 100 ft) above the flat surface of the outwash plain. The proximal edge of the moraine, on the other hand, is less distinct, but can be defined by knob and kettle topography associated with the undifferentiated sand and gravel deposit that lies between it and the Glacial Kalamazoo-Gun Plain outwash. Occasionally, the morainic ridge is broken by depressions and kettle lakes, such as Twin, Crooked, and Pawpaw lakes. One such break, over 6 kilometers (4 mi) wide and 50 meters (150 ft) deep, occurs where the Kalamazoo River Valley cuts through both the "inner" and "outer" ridges of the morainic system.

Leverett's "inner" Kalamazoo Moraine is not easily recognized within Kalamazoo County. Although some very broad, prominent till and gravelly knolls occur west of the "outer" Kalamazoo Moraine, there is no continuous ridge that extends for more than a few kilometers.

Exposures within the Kalamazoo Morainic System show that it is composed chiefly of sandy to very sandy till as well as massive to poorly bedded cobbley sand. Isolated lenses and pockets of sandy clay till are sometimes also present. These may be flow tills. Surface boulders and cobbles are commonly found along the crest and on the distal side of the moraine.

TILL, UNDIFFERENTIATED. -- One of the most extensive deposits of till found in Kalamazoo County occurs within the drumlin field located south of the Climax-Scotts outwash plain. The field covers an area of over 130 sq km (50 sq mi) and is informally named the Leonidas drumlin field. The drumlins were first noted by Leverett (1924) who, on the basis of their southwest-northeast orientation, suggested that they were formed by ice of the Saginaw Lobe.

The till associated with the drumlin field varies from clayey to sandy and is generally quite thin. In fact, except within the drumlins, it is seldom more than a few meters thick and often overlies sand and gravel deposits. Cobbles and boulders commonly occur on the surface of the drumlin field.

A veneer of discontinuous sandy to sandy-clay till a few meters to several meters thick also occurs along the morainal ridges in Kalamazoo County. The till within the Kalamazoo Morainic System is particularly coarse and is often indistingushable from adjacent sand and gravel deposits. In some areas till of the Kalamazoo Moraine System may overlie sand and gravel of the Galesburg-Vicksburg outwash plain.

POST-PLEISTOCENE GEOLOGY

Sediments deposited following deglaciation occur in scattered locations throughout Kalamazoo County. In general, these materials represent either flood plain deposits, or muck deposits associated with kettle depressions.

MARSH AND SWAMP DEPOSITS. -- Marsh and swamp deposits commonly occur in kettle depressions, along the margins of ponds and lakes, and along several rivers and streams within the county. They are comprised chiefly of decaying freshwater plants, mixed with sand and silt, and are mostly Holocene in age. Some of these deposits, however, may be late Pleistocene in age. For instance, an extinct musk ox skull, radiocarbon dated at 13,000 years BP (Benninghoff and Hibbard, 1961), has been excavated from a muck field in the Climax-Scotts outwash plain.

RECENT FLOODPLAIN DEPOSITS. -- Modern floodplain deposits occur in small, scattered locations along rivers and streams within Kalamazoo County. The most extensive of these deposits occurs within the Kalamazoo River Valley. Though not mapped, they sometimes also occur along the floor of erosional furrows. The floodplain deposits consist mostly of bedded sand and silt, as well as alluvium and colluvium.

PLEISTOCENE HISTORY

Introduction

The maximum Late Wisconsinan advance of the Laurentide Ice Sheet in the Great Lakes region occurred approximately 19,000 to 22,000 years ago and extended nearly to the Ohio River (Gooding, 1961, 1963, 1971; Dreimanis and Goldthwait, 1973; Morner and Dreimanis, 1973; Farrand and Eschman, 1974; Johnson, 1976; Dreimanis, 1977). This is based on radiocarbon dates of spruce and other organic material incorporated in sediments buried beneath tills near the terminal position of the ice. The margin of the ice oscillated back and forth near the terminal zone until about 15,000 to 17,000 years ago (Dreimanis, 1977). It then began a general retreat that culminated in the total deglaciation of Michigan by about 10,000 years ago (Farrand and Eschman, 1974). This retreat was interrupted several times by minor readvances of the ice margin, with each readvance generally falling short of the previous advance (Evenson, 1973; Farrand and Eschman, 1974; Evenson, et al., 1976; Dreimanis, 1977; Black, 1978).

Within southern Michigan, the Laurentide Ice Sheet divided into three major lobes: the Lake Michigan, Saginaw, and Huron-Erie lobes (Leverett and Taylor, 1915; Dreimanis and Karrow, 1972; Farrand and Eschman, 1974; Dreimanis, 1977). Since Kalamazoo County occupies a pivotal region between two of these lobes (Figure 3-1), it has a particularly interesting deglaciation history.

Deglaciation of Kalamazoo County

Age relationships of the glacial deposits in Kalamazoo County are complicated not only by their interlobate origin, but also by the paucity of radio-carbon dates in the region. The glacial deposits mapped at the surface in Kalamazoo County were probably laid down between about 14,000 and 18,000 years ago. This age is inferred from radio-carbon dates of organics associated with the Saginaw and Lake Michigan lobes north and south of Kalamazoo County. These dates show that the county was covered by ice between about 22,000 to 18,000 years ago (Johnson, 1976; Dreimanis, 1977; Dreimanis and Goldthwait, 1974) and that the ice margins had retreat north of the county by approximately 13,000 years ago (Dreimanis, 1977; Farrand and Eschman, 1974; Farrand, et. al., 1969; Fullerton, 1980; Johnson, 1976).

Formation of the Leonidas drumlin field and Tekonsha moraines

The deglaciation of Kalamazoo county probably began sometime after about 18,000 years ago when the Saginaw Lobe retreated northeast from the Sturgis Moraine in St. Joseph County. During this retreat a drumlinized till plain, informally named the Leonidas drumlin field, was exposed in the south-eastern part of the county, near the town of Fulton. The southwest-northeast orientation of the drumlins confirms that they were formed by Saginaw Lobe ice. The absence of well defined morainal ridges or indication of ice marginal drainage within the plain suggests that this retreat may have been rapid. The position of the Lake Michigan Lobe during the formation of the drumlin field is not known, but was probably some distance west of the city of Kalamazoo.

After the Leonidas drumlin field was exposed, the Saginaw Lobe margin continued to retreat northeastward, probably out of the county. It then subsequently readvanced to the position of the Tekonsha Moraine. This is suggested by the interlobate apex of the Tekonsha Moraine, the next youngest glacial deposit within the county. It lies well east of the western edge of the drumlin field and could only have been formed by a simultaneous advance of both the Saginaw and Lake Michigan lobes. South of the villages of Scotts and Climax numerous drumlins, which are exposed through the surface of the Climax-Scotts outwash plain, indicates that the Leonidas drumlin field may actually extend in the subsurface north of its mapped margin. Much of it was evidently buried by outwash as the ice advanced to the Tekonsha Moraine.

Formation of the Climax-Scotts outwash plain

The Climax-Scotts outwash plain was formed by meltwater when the ice margin of both the Lake Michigan and Saginaw lobes stood along the Tekonsha Moraine. Although Leverett (Leverett and Taylor, 1915) proposed that the moraine marks an approximately time equivalent position of both lobes, the predominantly southwest gradient of the outwash plain suggests that most of the sediment comprising at its upper surface was derived from the Saginaw Lobe. Because the downstream portion of the outwash plain is truncated by deposits of the younger Galesburg-Vicksburg outwash, the plain can be

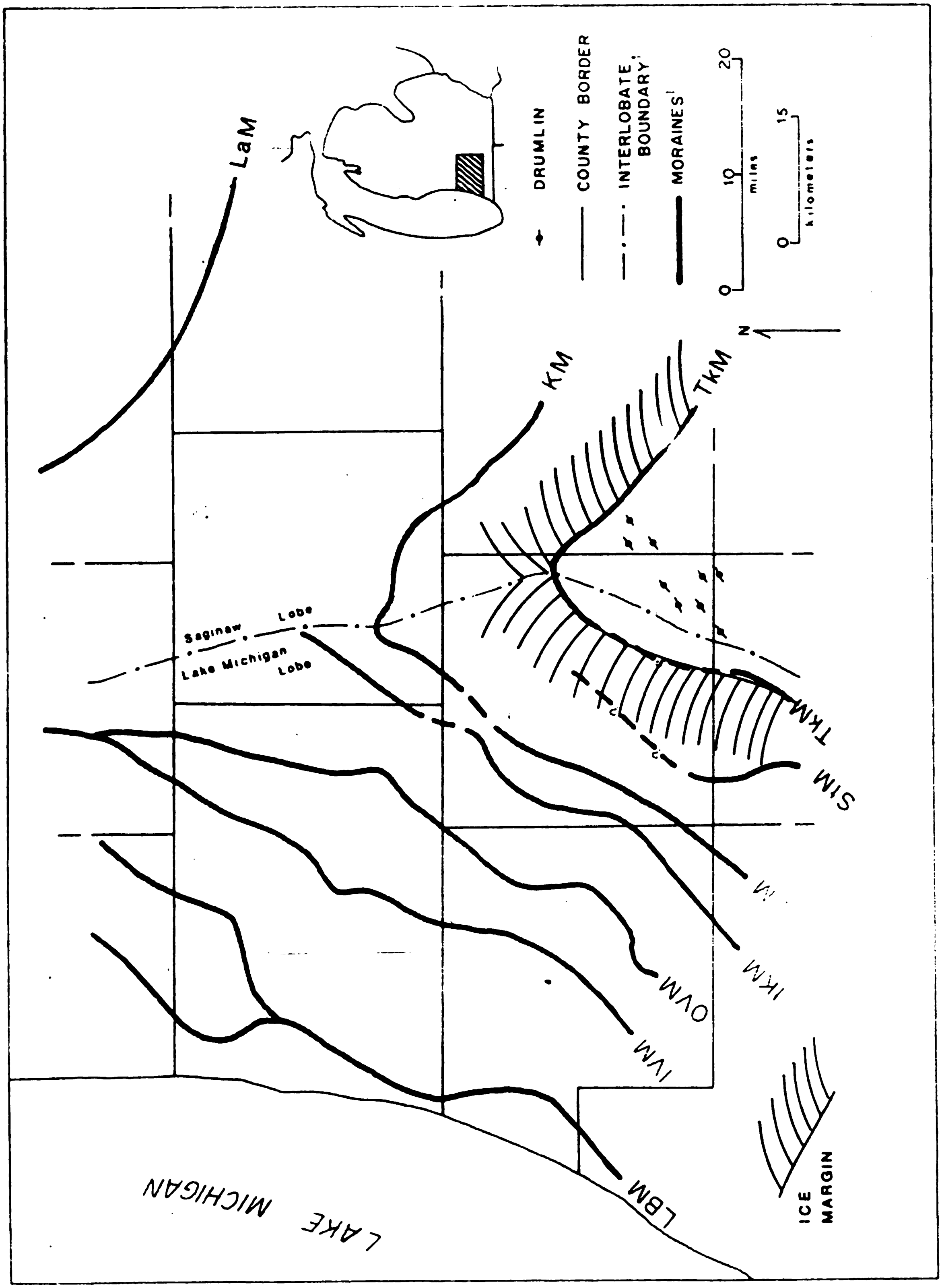


FIGURE 3-2.
Map showing reconstructed position of the Lake Michigan and Saginaw lobes at about 16,500 BP during the construction of the Tekonsha moraines and the Climax-Scotts outwash plain.

traced no further than just west of the village of Scotts.

The meltwater that produced the Climax-Scotts outwash plain probably drained south, along the distal margin of the Lake Michigan Lobe, and then into the glacial St. Joseph River (Leverett and Taylor, 1915). From there, drainage may have continued south and west into Illinois down the Kankakee River Valley (Zumberge, 1960). At least some of the drainage associated with the outwash plain was also channeled south down narrow valleys in the Leonidas drumlin field. When traced into St. Joseph County, these valleys terminate at the upper terraces of the St. Joseph River. The surface gradient for these channels is the same as that of the Climax-Scotts outwash plain. This suggests that the channels and the plain were formed at approximately the same time and were likely graded to the same drainage threshold. Deposition of outwash sediments on the Climax-Scotts outwash plain ended when the ice from both lobes retreated from the Tekonsha Moraine.

General retreat of the Saginaw and Lake Michigan lobes

Subsequent to the formation of the Tekonsha Moraine and the Climax-Scotts outwash plain, both the Saginaw and Lake Michigan lobes began to progressive retreat across Kalamazoo County. This retreat, which probably began about 16,500 to 17,000 years ago (Chapters 1 and 2 of this paper), may have been characterized by minor still-stands of the margin of both lobes. Leverett and Taylor (1915, 1924) has cited as evidence for one such still-stand a 15 sq km (6 sq mi) undifferentiatated, high gravel plain located north of the Kalamazoo

River Valley, just east of the town of Augusta. He associated it with the Saginaw Lobe and suggests that it was formed by a "later moraine" (probably the Battle Creek Moraine) after the ice margin had retreated from the Tekonsha Moraine. Though too small to define with certainty as an outwash sequence, this remnant has an apparent southwestward gradient of about 6.5 m/km (12 ft/mi) and may represent an outwash deposited during the northward retreat of the Saginaw Lobe.

The magnitude of the retreat of the Lake Michigan and Saginaw lobes following the formation of the Tekonsha Moraine is not clear from drift deposits within Kalamazoo County alone. Recent stratigraphic research, however, does suggest that it was significant. For example, Gephart, et.al. (1983) and Monaghan (Chapters 1 and 2 of this paper) have traced the till within the Tekonsha Moraine of the Lake Michigan Lobe west to an exposure of buried till along the Lake Michigan shoreline in Allegan County. They further suggest that following the formation of the Tekonsha Moraine the margin of the Lake Michigan Lobe retreated at least as far as the Lake Michigan shoreline, a distance of 60 kilometers (40 mi). In Chapters 1 and 2 of this paper, the author also has suggested that during the same time interval the Saginaw Lobe retreated as far north as the city of Lansing, a distance of 60 kilometers (40 mi). He bases his interpretation on correlation of till from the Leonidas Drumlin field and till occurring in the subsurface in northeastern Eaton County.

Stratigraphic evidence for a retreat of the Lake Michigan Lobe has also been observed at several exposures in Kalamazoo County. These show outwash both overlying and underlying till. The author and others (Chapters 1 and 2 of this paper and Gephart, et al., 1983) suggest that the till from these exposures is stratigraphicly equivalent to till of the Tekonsha Moraine. This relationship is particularly apparent within exposures along the western wall of the Kalamazoo River Valley north of the city of Kalamazoo. In one such exposure, located just north of and behind the outermost ridge of the Kalamazoo Moraine (Cooper section, sw of sw, sect. 15, T1s R11w), dense basal till is overlain by south and southwestward dipping, cross-bedded outwash that fines upward. The till is underlain by medium to fine sand and silt. A pebble fabric of the till from this exposure also suggests that it was deposited by the Lake Michigan Lobe.

In Chapters 1 and 2 of this paper, the author has proposed that, following the retreat of the Saginaw Lobe north of the city of Lansing, it readvanced to the Kalamazoo Moraine in Barry County (Figure 3-3). This readvance is based on shallow boring in Eaton County which show that the till comprising the Kalamazoo Moraine stratigraphically overlies till associated with the Tekonsha Moraine.

A similar readvance of the Lake Michigan Lobe has been proposed by the author and others (Chapters 1 and 2 of this paper and Gephart, et al., 1983). They suggest that, following the retreat of the Lake Michigan Lobe west of the Lake Michigan shoreline, it readvanced to the position of the Sturgis Moraine (in Kalamazoo County)*. This is based on correlation of till within the Sturgis Moraine to that associated with the Kalamazoo, Valaraiso, and Lake Border morainic systems. Exposures between Kalamazoo County and the Lake Michigan shoreline also show that this till stratigraphicly overlies till correlated with the Tekonsha Moraine.

Formation of the Galesburg-Vicksburg outwash plain

The formation of the Galesburg-Vicksburg outwash plain began during the early phases of the westward retreat of the Lake Michigan Lobe from the Sturgis Moraine and culminated when the ice margin of the Lake Michigan and Saginaw lobes occupied a position defined by the Kalamazoo moraines (Figure 3-3). The author suspects that the retreat of Lake Michigan Lobe ice across Kalamazoo County from the position of the Sturgis Moraine probably occurred by progressive back-wasting of the ice margin, and that the Galesburg-Vicksburg outwash plain was constructed in stages. The "outer" Kalamazoo Moraine most likely represents a final forward "push" of the ice during this construction.

During the initial construction of the Galesburg-Vicksburg outwash plain, meltwater* was channeled between the retreating ice front and the topographically higher Leonidas drumlin field and the Climax-Scotts outwash plain. Erosion associated with this meltwater formed the prominent scarp that defines the western boundary of the

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* In 1915, Leverett (Leverett and Taylor, 1915) originally proposed that the Sturgis Moraine of the Lake Michigan Lobe in Kalamazoo County and the Sturgis Moraine of the Saginaw Lobe in St. Joseph County were formed at the same time. However, based on the above correlations, the author feels that this moraine more likely represents the outermost ridge of the Kalamazoo Morainic System. Although the name (Sturgis) given by Leverett to the morainal ridge has been kept, the author and others have elsewhere (Gephart, et al., 1983) informally refered to Leverett's Kalamazoo Morainic System as the Sturgis-Kalamazoo Morainic System.

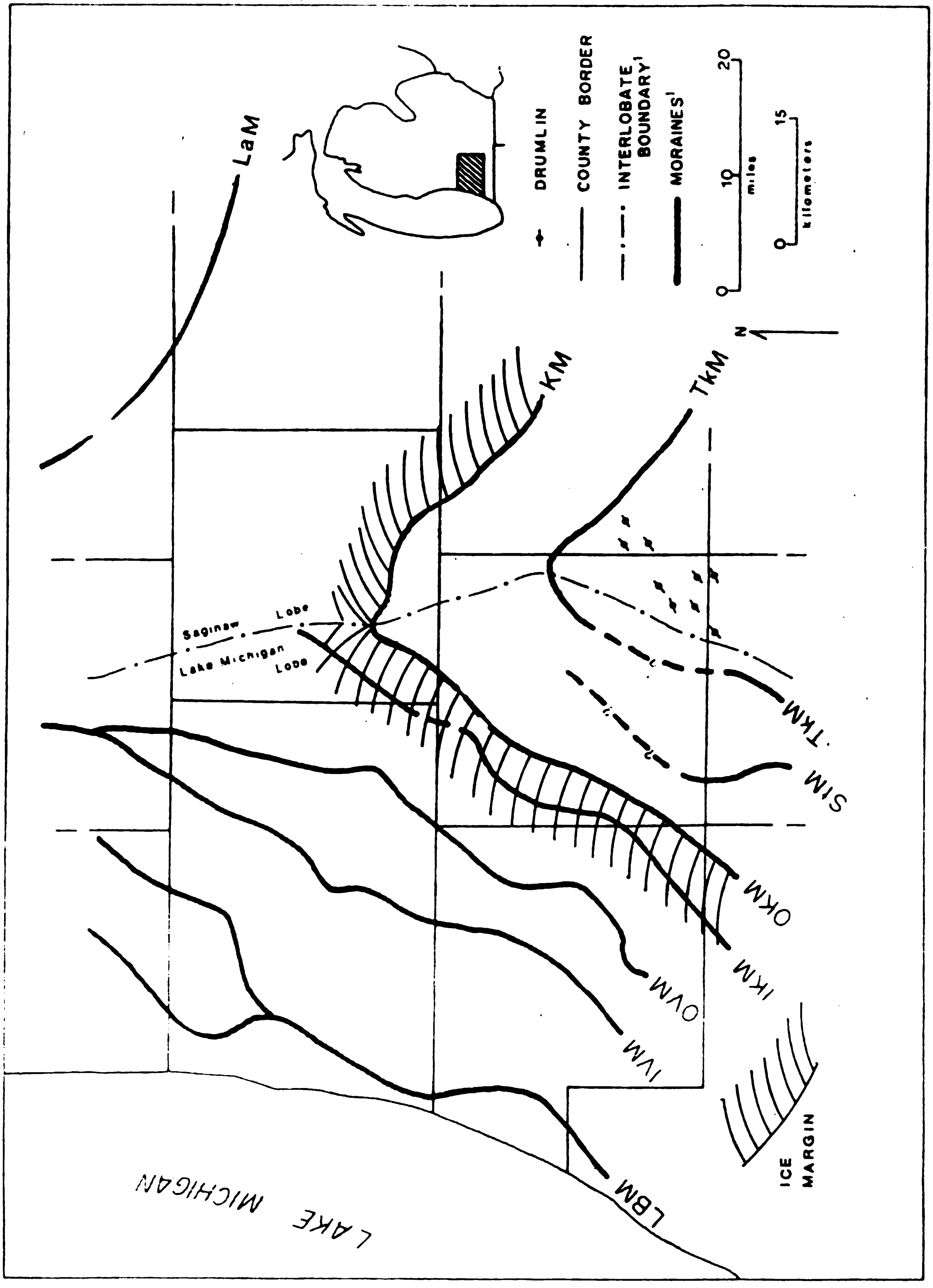

FIGURE 3-3.
Map showing reconstructed position of the Lake Michigan and Saginaw lobes at about 15,000 BP during the construction of the Kalamazoo moraines and the Galesburg-Vicksburg outwash plain.

Climax-Scotts outwash plain. Meltwater drainage probably also eroded or partly buried the northern extension of the Sturgis Moraine. In addition, remnant ice masses became detached from the ice margin as it retreated towards the west. These masses were subsequently buried by outwash and are represented today by depressions and kettle lakes, such as Gull, Indian, and Austin lakes.

While the ice retreated from the Kalamazoo Moraine to the Valparaiso Moraine in Allegan County (Gephart and Larson, 1983), southeastward drainage along the Galesburg-Vicksburg outwash plain ended. Meltwater was then channeled southward along an irregular back-wasting ice-front. That this margin was irregular is indicated by the extensive kame field which makes-up the undiffereniated sand and gravel deposits between the Galesburg-Vicksburg outwash plain and the Gun Plain outwash.

Development of the Kalamazoo River Valley

As the Lake Michigan Lobe retreated from the Kalamazoo Moraine, the Saginaw Lobe also retreated progressively northward. During the initial phase of this retreat, meltwater was channeled southward along a chain of kettle depressions in the Galesburg-Vicksburg outwash plain and deposited the Augusta Creek outwash. The upper terraces of this valley train system have been traced from north of the Kalamazoo Moraine, in Barry County, to a 290 meter (900 ft) threshold along the Kalamazoo River Valley at the town of Augusta in Kalamazoo County. Originally, this drainage system may have extended further south, along the western margin of the Tekonsha Moraine and Climax-Scotts outwash plain and then down the valley of the Portage River. The lack of terraces along Portage River, however, suggests that this drainage must have been short lived.

Leverett (Leverett and Taylor, 1915) has suggested that a rather large remnant ice mass must have persisted in the Kalamazoo River Valley during the construction of the Galesburg-Vicksburg outwash plain. As evidence for such a mass, he cites a broad 90 sq km (35 sq mi) depression located between the cities of Galesburg and Kalamazoo. The author proposes that as the Lake Michigan Lobe retreated from the Sturgis Moraine this ice mass became detached from the retreating ice margin. The mass was partly buried by sediments associated with the Galesburg-Vicksburg outwash and by sediments deposited during the last push of the Lake Michigan Lobe as it formed the outer ridge of the Kalamazoo Moraine. Subsequently, as the Lake Michigan Lobe retreated westward out of the county, the mass began to melt and left a large depression in the surface of the Galesburg-Vicksburg outwash plain. Today, the occurence of lake sediments within this depression suggests that y, perhaps associated with the Augusta Creek outwash, collected in this basin and formed a shallow lake.

Initially the lake probably drained to the south. However, continued sagging in the northern part of the depression eventually allowed the lake to drain northward through a breach in the Kalamazoo Moraine. Water flowing through this breach, which is located just north of the city of Kalamazoo, then merge with the drainage that formed the Gun Plain outwash. When the Kalamazoo Moraine was breached, it allowed unrestricted westward flow of meltwater down the valley of the Kalamazoo River. As this precussor to the Glacial Kalamazoo River downcut rapidly through the lake plain, it captured the drainage flowing down Augusta Creek and Portage River. That the downcutting was rapid is indicated by the lack of terrace levels from 254 meter (860 ft) to 235 meters (830 ft) elevation along the Kalamazoo River between Kalamazoo and the Allegan County border. Complete westward flow of meltwater along the the valley of the Kalamazoo River initiated the Glacial Kalamazoo-Gun Plain outwash sequence.

The Glacial Kalamazoo-Gun Plain system served as the major meltwater drainageway for the eastern part of the Saginaw Lobe until the ice front retreated north of the city of Lansing (Leverett and Taylor, 1915). This is suggested by recent mapping in Barry County which shows that the Gun Plain continues north to the Thornapple River. Meltwater that formed the upper terraces along the Thornapple River between the towns of Hastings in Barry County and Vermontville in Eaton County probably flowed southward down Gun Plain. Terraces along the glacial Kalamazoo River, on the other hand, can be traced to terraces in the valley of the Battle Creek in Calhoun County. The lower terraces along the Battle Creek have also been traced to the Charlotte Moraine near the town of Charlotte in Eaton County (Monaghan and Larson, 1980).

After both the Lake Michigan and Saginaw lobes had completely retreated from Kalamazoo County, remnant ice masses buried by outwash began to melt and formed kettle depressions. These kettles sometimes coalesced into long, deep elongate depressions, like that between Gull

Lake and the city of Kalamazoo. When the Glacial Kalamazoo-Gun Plain outwash eroded through the Galesburg-Vicksburg outwash plain, it probably lowered the water table in the surrounding area. In response, sapping occured along the margin of the Kalamazoo River Valley and produced deep furrows. Many of these furrows are quite long, such as along Ravine Road between the Kalamazoo Moraine and the City of Kalamazoo.

Most of the major landforms occurring in Kalamazoo County were developed during the retreat of Late Wisconsinan ice. Those materials deposited since deglaciation generally represent minor modification of glacial landscape. They include floodplain deposits along the Kalamazoo River and muck deposits infilling kettle depressions. Significant deposits of wind blown sand also occur in some areas. These deposits were probably formed soon after deglaciation and before significant amounts of vegetation grew on the land surface.

SUMMARY AND CONCLUSIONS

Three till sheets associated with advances of the Lake Michigan Ice Lobe are exposed in a 20 to 25 meter high section (Glenn Shores section) along the Lake Michigan shoreline in Allegan County, Michigan. The lowermost till (Glenn Shores till) is directly overlain by gravel and lacustrine silt and sand containing organic material dated at 37,150 to >48,000 years B.P. The middle (Ganges till) and uppermost (Saugatuck till) tills are also each overlain by lacustrine deposits. All three tills in the section are easily differentiated by the 7A/10A X-ray diffraction peak height ratio of their clay-size fraction.

In an attempt to define litho-stratigraphy for tills associated with the Saginaw and Lake Michigan lobes, X-ray diffraction analyses were performed on over 150 samples collected from moraines, gravel pits, and borings in southwestern Michigan. The results of these analyses show that Lake Michigan Lobe till associated with the Lake Border, Valparaiso, and Sturgis-Kalamazoo morainic systems can be correlated with the Saugatuck (upper) till exposed at the Glenn Shores section, while the Ganges till can be traced in the subsurface from crops out within the Tekonsha Moraine to the Glenn Shores section. The occurrence of lake deposits between the Ganges and Saugatuck tills at Glenn Shores implies a significant retreat of the Lake Michigan

Lobe (greater than 50 kilometers) between the formation of the Tekonsha Moraine and the Sturgis-Kalamazoo Morainic System.

Based on clay mineral analysis of Saginaw Lobe till sampled from six 10 meter borings in Eaton County, Michigan, at least two till units can be defined. The upper till (Bedford till) from the borings can be traced along the ground surface to as far south as the Kalamazoo Moraine, while the lower lower till (Fulton till) can be correlated with till sampled from and just south of the Tekonsha Moraine. The clay mineralogies of these till units suggest a significant retreat of the Saginaw Lobe between the formation of the Tekonsha and Kalamazoo moraines.

Morpho-stratigraphic correlations between moraines of the Lake Michigan, Saginaw, and Erie lobes suggest that the West Chicago and Sturgis-Kalamazoo moraines of the Lake Michigan Lobe, the Kalamazoo Moraine of the Saginaw Lobe, and Powell-Union City Moraine of the Erie Lobe are all the same age and were formed as the margin of all three lobes readvanced following the Erie Interstade. These correlations imply that the interval between the deposition of the Ganges and Saugatuck tills of the Lake Michigan Lobe as well as the interval between deposition of the Fulton and Bedford tills of the Saginaw Lobe are both time equivalent to the Erie Interstade of the Erie Lobe. If correct, these correlations then imply that during the Late Wisconsinan major retreats and readvances of the ice front of the Lake Michigan, Saginaw, and Erie lobes were probably approximately time synchronous.

The clay mineralogy of the stratigraphic units defined for tills in southwestern Michigan suggests that a relative increase in 10A clay occurs in progressively younger tills sheets. The reason for this progressive change in clay mineralogy has not yet been defined, however, it is apparently related to significant retreats of ice. The fact that this progressive change in clay mineralogy occurs within drift of both the Lake Michigan and Saginaw lobes suggests that the processes responsible for this clay fractionation may relate to a more general erosional/deposition system occurring throughout the Great Lakes Region.

Although the processes of clay fractionation in tills in southwestern Michigan are not yet known with certainty, the author suggests that one of the following three models may explain them.

1) The relative increase in 7A clays in consecutively older till units resulted from greater diagenesis of the older tills.

2) The fraction of 7A and 10A clays is related to differential settling velocities of specific clay minerals within the proglacial lake which formed during ice retreat. As the ice front subsequently readvanced, these fractionated lake clays would then be incorporated within the ice and re-deposited as till with increased amounts of 10A clay.

3) The stratigraphy of the Glenn Shores section suggests that the three exposed tills span the entire Wisconsinan. If this is correct, the oldest till unit (Glenn Shores till) should include relatively high amounts of authigenic kaolinite and chlorite

weathered from the Canadian Shield during Sangamon time, as well as illite derived primarily from erosion of Paleozoic shales as the ice advanced. Tills associated with subsequent re-advances of the ice would include mostly illite derived from Paleozoic shales and only small amounts of kaolinite eroded from older tills and from small remnants of the Sangamon surface on the shield. Hence, successive fluctuations of the ice margin, and subsequent dilution of 7A clays, should result in a progressive, step-wise increase of the 10A clay in consecutively younger till units.

APPENDIX A

APPENDIX A
ANALYTICAL TECHNIQUES

Samples used in this study have all undergone some pre-treatments to simplify and standardize the analysis. These pre-treatments included removal of soluble salts and carbonates, and in some cases, free iron oxides. While the use of pre-treatments does involve the risk of altering or destroying some important mineral components, the treatments selected are designed to have minimal effects on important clay mineral constituents.

Removal of soluble salts and carbonates.

Soluble salts and carbonates are removed from the sample because they can act as cementing agents and promote flocculation. They also may interfere with X-ray analysis. All samples used in this study were pre-treated by adding 50 mls of 1N sodium acetate solution (buffer to pH 5 with acetic acid) to each 5 grams of sample. This causes the following reaction:

$$CaCO_3 + 2H^{+}NaAc \rightleftarrows Ca^{2+} + H_2CO_3 \text{ --- } CO_2\uparrow + H_2O$$

The sample solution was heated to 50 to 60 degrees centigrade for a 30 minute period, centrifuged, and washed 3 times with distilled water.

Removal of free iron oxide.

Iron oxides should be removed from samples both because they promote flocculation and can act as dilutant which reduces the X-ray diffraction intensity. Removal of free iron oxides was accomplished as follows:

1) To each sample 40 mls of 0.3N Na-citrate and 5 mls of 1N $NaHCO_3$ were added.

2) The suspension was heated to 75 to 80 degrees centigrade and 1 gram of $Na_2S_2O_4$ added and digested for 15 minutes.

3) The sample was centrifuged and washed with distilled water.

These steps remove the free iron oxides by the following reactions:

$$\text{Na citrate } Fe_2O_3 \longrightarrow Fe^3 + \text{chelates}$$

Addition of bicarbonate maintains neutrality and iron is reduced by:

$$OH^- + S_2O_4^= \longrightarrow 2SO_3^= + 2H_2O + 2e^{\theta}$$
$$2Fe^{3+} + 2e^{\theta} \longrightarrow 2Fe^{2+}$$

Not all samples were treated to remove free iron oxides. Experiments performed on samples from the Bloomingdale section (Appendix C) indicated that the treatment had little regular effect of the calculated 7A/10A ratios.

Semi-quantitative X-ray analysis.

The clay-size fraction (<2 mu) of each treated sample was separated out by gravity settling, deposited on a glass slide, and air dried, which produced a slide of oriented clay mineral grains. These slides were then placed in a desiccator with ethylene glycol for at least 48 hours to expand the vermiculite to 14A and the smectite to 17A-18A.

The prepared clay slides were scanned for 3 degree to 15 degree 2θ on a General Electric X-ray diffractometer using 1 degree medium range beam slit, a medium range soller and a 0.2 detector slit. Samples were run at the 1,000 to 2,000 cps range (depending on the intensity of the peaks). Each sample was rotated 180 degrees and scanned again. Peak heights were measured to the nearest 0.01 inch on a Numonics digitizer from an established baseline and the 7A/10A ratios reported as the average of the 2 rotations.

Qualitative X-ray analysis.

Methods used to determine which clay minerals are present in Lake Michigan and Saginaw Lobe tills in southwestern Michigan are similar to those described by Jackson (1956), Carroll (1972), and Gephart (1982). Four (two each from tills associated with the Saginaw and Lake Michigan ice lobes) pre-treated, fractionated till samples were deposited on a porous porcelain plate by vacuum suction to produce an oriented sample slide ready for X-ray analysis. Each of these samples was then X-rayed once after each of the following treatments: 1) Mg saturated and glycerol solvated; 2) K saturated and air dried; 3) K saturated and heated to 300 degrees C for a two hour period; and 4) K saturated and heated to 550 degree C for a two hour period.

Illite is the only common clay mineral that produces a 10A peak which is not affected by either the chemical or heat treatments (Carroll, 1972; Grim, 1968). Kaolinite will produce a 7A X-ray peak; however, after heating the sample to 550 degree C the structure of kaolinite is destroyed and the 7A peak associated with kaolinite will disappear (Carroll, 1972; Grim, 1968). Vermiculite and chlorite both produce 14A peaks after Mg saturation and glycerol solvation, and will produce a smaller second order (002) 7A peak (Carroll, 1972; Grim, 1968). Smectite will produce a 17A to 18A peak after Mg saturation and glycerol solvation. Both vermiculite and smectite will collapse to 10A after heating to 300 degrees C (Carroll, 1972; Grim, 1968).

The results of these analyses show that the dominant clay minerals present in Saginaw Lobe tills are illite, kaolinite, and to a lesser extent, vermiculite. Chlorite is generally quite rare in Saginaw Lobe drift. The dominant clay minerals present in Lake Michigan Lobe tills, on the other hand, are illite, kaolinite, and to a lesser extent, chlorite. Vermiculite is rarely present in any significant amounts within Lake Michigan Lobe drift.

APPENDIX B

APPENDIX B
STATISTICS

Population Statistics and Data

The following listing is a compilation of the population statistics for each of the till units and is grouped by moraine, bore holes, or reference section.

LAKE MICHIGAN LOBE MORAINES AND REFERENCE SECTIONS

Kalamazoo (KzM) - Sturgis (StM) Moraine

Sample size ------------------------- 14
Population mean --------------------- 0.61
Population standard deviation ------- 0.25

DATA

Sample	7A/10A	Sample	7A/10A
KzM-1	0.63	KzM-2	0.60
KzM-3	0.45	KzM-4	0.49
KzM-5	0.51	KzM-6	0.50
KzM-7	0.60	KzM-8	0.60
KzM-9	0.55	KzM-10	0.83
KzM-11	1.08		
StM-1	0.57	StM-2	0.74
StM-3	0.43		

Tekonsha Moraine

Sample size ------------------------- 6
Population mean --------------------- 0.83
Population standard deviation ------- 0.41

DATA

Sample	7A/10A	Sample	7A/10A
TkM-1	0.67	TkM-2	0.69
TkM-3	0.88	TkM-4	0.87
TkM-5	1.11	TkM-6	0.88

Bloomingdale Upper till

Sample size -------------------------- 10
Population mean --------------------- 0.52
Population standard deviation ------- 0.21

DATA

Sample	7A/10A	Sample	7A/10A
Bdut-1	0.58	Bdut-2	0.38
Bdut-3	0.75	Bdut-4	0.54
Bdut-5	0.51	Bdut-6	0.43
Bdut-7	0.50	Bdut-8	0.49
Bdut-9	0.64	Bdut-10	0.42

Bloomingdale Middle Till

Sample size -------------------------- 6
Population mean --------------------- 0.46
Population standard deviation ------- 0.21

DATA

Sample	7A/10A	Sample	7A/10A
Bdmt-1	0.43	Bdmt-2	0.43
Bdmt-3	0.49	Bdmt-4	0.52
Bdmt-5	0.44	Bdmt-6	0.45

Bloomingdale Lower Till

Sample size -------------------------- 18
Population mean --------------------- 0.83
Population standard deviation ------- 0.22

DATA

Sample	7A/10A	Sample	7A/10A
Bdlt-1	0.90	Bdlt-2	0.88
Bdlt-3	0.84	Bdlt-4	0.83
Bdlt-5	0.92	Bdlt-6	0.77
Bdlt-7	0.73	Bdlt-8	0.84
Bdlt-9	0.78	Bdlt-10	0.75
Bdlt-11	0.83	Bdlt-12	0.84
Bdlt-13	0.87	Bdlt-14	0.74
Bdlt-15	0.83	Bdlt-16	0.70
Bdlt-17	1.11	Bdlt-18	0.78

Buried Tills in Kalamazoo County

Sample size ------------------------- 11
Population mean --------------------- 0.97
Population standard deviation ------- 0.35

Comstock Section

DATA

Sample	7A/10A	Sample	7A/10A
Cst-1	0.78	Cst-2	0.87

Cooper Section

DATA

Sample	7A/10A	Sample	7A/10A
Cop-1	1.31	Cop-2	1.10
Cop-3	1.03	Cop-4	1.07
Cop-5	0.87		

Ravine Road Section

DATA

Sample	7A/10A	Sample	7A/10A
Rvr-1	0.81	Rvr-2	0.84
Rvr-3	0.83	Rvr-4	0.95

SAGINAW LOBE MORAINES AND BORINGS

Kalamazoo Moraine (and surface samples north of moraine)

Sample size ------------------------- 17
Population mean --------------------- 0.75
Population standard deviation ------- 0.31

DATA

Sample	7A/10A	Sample	7A/10A
KzS-1	1.34	KzS-2	0.78
KzS-3	0.35	KzS-4	0.50
KzS-5	0.76	KzS-6	0.82
KzS-7	0.83	KzS-8	0.75
KzS-9	0.74	KzS-10	0.54
KzS-11	0.38	KzS-12	0.96
KzS-13	0.77	KzS-14	0.79
KzS-15	0.34	KzS-16	0.90
KzS-17	0.69		

Leonidas Drumlin Field

Sample size ------------------------- 5
Population mean --------------------- 1.28
Population standard deviation ------- 0.70

DATA

Sample	7A/10A	Sample	7A/10A
LdfS-1	1.15	LdfS-2	1.20
LdfS-3	0.99	LdfS-4	1.46
LdfS-5	1.61		

Tekonsha Moraine

Sample size ------------------------- 9
Population mean --------------------- 1.12
Population standard deviation ------- 0.42

DATA

Sample	7A/10A	Sample	7A/10A
TkS-1	1.13	TkS-2	1.42
TkS-3	0.95	TkS-4	1.23
TkS-5	1.07	TkS-6	1.10
TkS-7	0.98	TkS-8	1.05
TkS-9	1.15		

Upper Till From Borings

Sample size ------------------------ 10
Population mean -------------------- 0.69
Population standard deviation ------- 0.26

Middle Till From Borings

Sample size ------------------------ 16
Population mean -------------------- 1.06
Population standard deviation ------- 0.29

Lower Till from Borings

Sample size ------------------------ 3
Population mean -------------------- 1.49
Population standard deviation ------- 1.05

Clay Mineral Data from Borings

Boring*	Depth	Till Unit**	Sample	7A/10A
B-1	5'	ut	B-1-5	0.54
B-1	10'	ut	B-1-10	0.82
B-1	15'	mt	B-1-15	1.00
B-1	20'	mt	B-1-20	1.09
B-2	5'	ut	B-2-5	0.69
B-2	10'	ut	B-2-10	0.58
B-2	15'	mt	B-2-15	0.97
B-2	20'	mt	B-2-20	1.11
B-2	30'	lt	B-2-30	1.52
B-3	5'	ut	B-3-5	0.60
B-3	10'	mt	B-3-10	1.19
B-3	15'	mt	B-3-15	1.00
B-3	20'	mt	B-3-20	0.85
B-3	25'	mt	B-3-25	0.93
B-3	30'	lt	B-3-30	1.47
B-4	5'	mt	B-4-5	1.00
B-4	30'	lt	B-4-30	1.48
B-5	5'	ut	B-5-5	0.78
B-5	10'	ut	B-5-10	0.84
B-5	15'	mt	B-5-15	1.15
B-5	20'	mt	B-5-20	1.09
B-5	25'	mt	B-5-25	0.98
B-5	30'	mt	B-5-30	1.14

Clay Mineral Data from Borings (cont.)

Boring*	Depth	Till Unit**	Sample	7A/10A
B-6	5'	ut	B-6-5	0.72
B-6	10'	ut	B-6-10	0.71
B-6	15'	ut	B-6-15	0.84
B-6	20'	mt	B-6-20	1.10
B-6	25'	mt	B-6-25	1.08
B-6	30'	mt	B-6-30	1.12

* Boring number refers to location cn figure 6
** Till Unit refers to named units on figure 9
ut -- upper Till (Bedford till)
mt -- middle till (Fulton till)
lt -- lower till (unnamed till)

T-test Statistics for Selected Populations.

The following is a tabulation of T-test statistics for selected till populations. Till populations are abbreviated as follows:

Glenn Shores upper (Saugatuck) till *	--	GS-UT
Glenn Shores middle (Ganges) till *	--	GS-MT
Bloomingdale upper till	--	BD-UT
Bloomingdale middle till	--	BD-MT
Bloomingdale lower till	--	BD-LT
Kalamazoo-Sturgus Moraine (Lake Michigan Lobe)	--	KzM-M
Tekonsha Moraine (Lake Michigan Lobe)	--	TkM-M
Tekonsha Moraine (Saginaw Lobe)	--	TkM-S
Kalamazoo Moraine (Saginaw Lobe)	--	KzM-S
Upper till from Eaton County borings	--	Br-UT
Middle till from Eaton County borings	--	Br-MT

* Data used in T-test for these samples from Gephart (1982)

LAKE MICHIGAN LOBE TILLS

	GS-UT *		KzS-M
Number -------	25	--	14
Mean ---------	0.58	--	0.61
Variance ------	0.02	--	0.06
St. Dev. ------	0.13	--	0.25

T-statistic ----------- 0.881
Degrees of Freedom ---- 37

	GS-MT *		Tk-M
Number -------	39	--	6
Mean ---------	0.85	--	0.83
Variance ------	0.03	--	0.17
St. Dev. ------	0.18	--	0.41

T-statistic ----------- 0.203
Degrees of Freedom ---- 43

	GS-UT *		BD-UT
Number -------	25	--	10
Mean ---------	0.58	--	0.52
Variance ------	0.02	--	0.04
St. Dev. ------	0.13	--	0.21

T-statistic ----------- 0.986
Degrees of Freedom ---- 33

	GS-UT *		BD-MT
Number -------	25	--	6
Mean ---------	0.58	--	0.46
Variance ------	0.02	--	0.04
St. Dev. ------	0.13	--	0.21

T-statistic ----------- 1.811
Degrees of Freedom ---- 29

	GS-MT *		BD-LT
Number -------	39	--	18
Mean ---------	0.85	--	0.83
Variance ------	0.03	--	0.05
St. Dev. ------	0.18	--	0.22

T-statistic ----------- 0.450
Degrees of Freedom ---- 55

SAGINAW LOBE TILLS

	KzM-S		TkM-S
Number -------	17	--	9
Mean ---------	0.75	--	1.12
Variance ------	0.10	--	0.18
St. Dev. ------	0.31	--	0.42

T-statistic ----------- 2.52
Degrees of Freedom ---- 24

	Br-UT		Br-MT
Number -------	10	--	16
Mean ---------	0.69	--	1.06
Variance ------	0.07	--	0.08
St. Dev. ------	0.26	--	0.29

T-statistic ----------- -3.260
Degrees of Freedom ---- 24

	KzM-S		Br-UT
Number -------	17	--	16
Mean ---------	0.75	--	1.06
Variance ------	0.10	--	0.08
St. Dev. ------	0.31	--	0.29

T-statistic ----------- 0.589
Degrees of Freedom ---- 31

	TkM-S		Br-MT
Number -------	9	--	16
Mean ---------	1.12	--	1.06
Variance ------	0.18	--	0.08
St. Dev. ------	0.42	--	0.29

T-statistic ----------- 1.020
Degrees of Freedom ---- 23

APPENDIX C

APPENDIX C
SECTION DESCRIPTIONS

The following Appendix discribes three of the sections refered to in this paper. Two of these sections were discovered by the author and the third, Ravine Road, was described by Straw (1978).

Comstock Section

The Comstock section is exposed in a gravel pit in the north wall of the Kalamazoo River valley located just east of the town of Comstock (SW of SW of SW, sect. 16, t2s, r10w). It contains about 1 meter (2 to 3 feet) of a brown, coarse, sandy to cobbley till. The till unit pinches out to the north and east which suggests that it was probably deposited as a flow till from the retreating margin of the Lake Michigan Lobe. This is also suggested by deltaic deposits composed of course sand and pebbles which grade into the till where it pinches out. The till and deltaic sediments are underlain by fine to very fine horizontally bedded and laminated sand and silt. The till in overlain by cross-bedded course sand and gravel and the contact between these two units is sharp.

Ravine Road Section

The Ravine Road section occurs in an abandoned gravel pit located just north of the City of Kalamazoo (sw,sw,sw, sec. 9, t 2 s, r 12 w). The base of the exposure is represented by a brown, sandy, loose-textured till unit. The total thickness of this till is not known and only the upper 2 to 3 meters (6 to 8 feet) is exposed. Vertical samples derived from this till do not show any trends. The till is overlain by medium to fine sand with some pebbles. Bedding structures within this sand unit indicate that it was deposited within a braided stream environment and its stratigraphic position, therefore, suggests that it was probably formed during the final stages of the Galesburg-Vicksburg outwash plain (Chapter 3).

Cooper Section

The Cooper section is exposed in a gravel pit within the west wall of the Kalamazoo River Valley (SW of SW of SW, sect. 15, t1s, r11w) located about 8 miles north of the city of Kalamazoo. A 1 to 3 meter (3 to 10 feet) thick brown, dense clay-rich till is directly overlain by 6 to 10 meters (20 to 30 feet) of cross-bedded, coarse sand and gravel, which includes some elongated till balls. Samples taken from a vertical transect within the till do not indicate any significant trends in clay mineralogy. The till is underlain by 3 to 5 meters (9 to 15 feet) of fine sand and silt which becomes coarser at the base of the exposure. In an attempt to verify that the till exposed within this section was deposited by the Lake Michigan Lobe, the orientation of 40 pebbles occurring within the till was measured (Figure C-1). The orientation of these pebbles suggests that the flow direction of the ice which deposited this till was WSW (azimuth of approx. 100-110 degrees) and implies a Lake Michigan Lobe source.

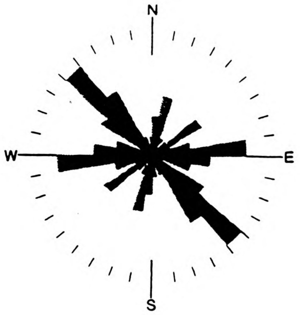

FIGURE C-1. Till fabric from Cooper exposure.

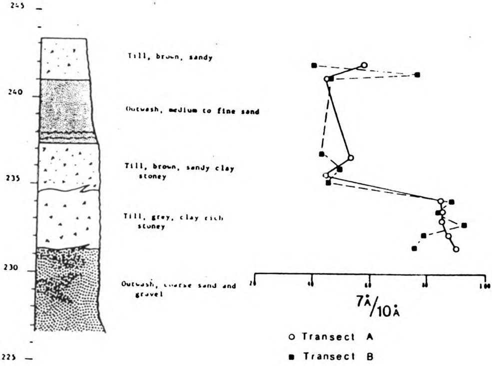

FIGURE C-2. Bloomingdale measured section.

Bloomingdale Section

The Bloomingdale section (Figure C-2) occurs in a gravel pit in north-central Van Buren County (sw, sect. 28, t 1 s, r 14 w). The base of the exposure is represented by a very coarse sand and pebble unit. Large scale cross-beds and channel scours suggest that this unit was deposited as outwash very near the ice margin. In several places in the gravel pit, this outwash shows normal faulting and slump features which suggest that blocks of ice detached from a retreating ice margin were present in the unit and melted, forming small kettle depressions in the surface. Some very fine organic particles occur in one of these kettle depressions.

Directly overlying this outwash unit is a 1 to 2 meter (4 to 6 feet) thick grey, clay-rich till. This till unit dips towards the south and is completely absent in the north wall of the gravel pit. Directly overlying the lowest grey till is a 2 to 4 meter (6 to 12 feet) brown sandy-clay till. The contact between these two till units is sharp and is represented both by a distinct color change and the occurrence of deformation structures such as shears and "flame" structures. Large (>10 cm) cobbles commonly occur in both of these till units. A 2 to 4 meter (6 to 12 feet) thick outwash composed of medium to coarse sand and pebbles overlies the brown till. The section is capped by a brown, sandy and loose-textured till that pinches out in a few places. This till is 1 to 2 meters (2 to 5 feet) thick and the contact between it and the underlying outwash is sharp.

Because of the presence of three distinct till units, detailed sampling was performed in this exposure. Two vertical transects were sampled at 1 foot intervals in each till unit. The clay mineralogy associated with these samples (Figure C-2) does not suggest any significant trends within a till unit, but does show a significant change in 7A/10A ratios between the upper two brown tills and the lower grey till.

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