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Analysis of an Interlobate Boundary in the Wisconsinan Drift of Kalamazoo County and Adjacent Areas in Southwestern Michigan

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ANALYSIS OF AN INTERLOBATE BOUNDARY IN THE WISCONSINAN DRIFT OF KALAMAZOO COUNTY AND ADJACENT AREAS IN SOUTHWESTERN MICHIGAN

by

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ABSTRACT

A detailed investigation of selected textural and mineralogical aspects of tills in southwestern Michigan is used to define an interlobate boundary relationship between the Wisconsinan ice of the Lake Michigan and Saginaw lobes. Bedrock underlying the study area contributed little to the bulk composition of the tills investigated. However, morainal development in the study area shows strong correlation with bedrock topography.

In a discussion of the deglaciation of Michigan and the study area, a history of morainal development is reviewed and attention is focused on the reentrant district located in Kalamazoo and neighboring counties. Attempts to delineate tills of the Lake Michigan and Saginaw lobes using textural and magnetic susceptibility data were inconclusive. However, the character and extent of an interlobate boundary relationship in the study area is delimited by ratios of heavy minerals, as well as, ratios of the 7Å/10Å peaks produced by clays in X-ray diffractograms.

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INTRODUCTION

Development of the surface geology of southwestern Michigan occurred during the Wisconsinan glaciation of North America. Of particular interest to this study are the glacial deposits in Kalamazoo County and the adjacent areas produced by the interplay of the Lake Michigan and Saginaw lobes of the Wisconsinan ice. To date, no reliable statistical data have been used to delineate the limits of these deposits; however, a complete understanding of the glacial history of Michigan necessitates some comprehension of the boundary relationships between them.

Chamberlin (1883a and 1883b) introduced the term "interlobate moraine" for features "formed by the joint action of two glaciers (or glacial lobes) pushing their marginal moraines together" to produce a common boundary. Realizing the complex regional nature of the interplay of glaciers in an interlobate area, a more general definition would be of greater value. Thus, as defined by Rieck (1976) and used herein, an interlobate area is an area of drift accumulation developed in or near the reentrant district between two lobes of glacial ice. Moraines developed in such an area may have formed when active glacial moraines were in contact or when the active glacial ice margins had retreated and exposed a narrow zone, 1 mile

(1.6 km) to several miles, between them (Rieck, 1976).

Using the above definition, much of southwestern Michigan, and in particular Kalamazoo County, is a classic interlobate area (Leverett and Taylor, 1915; Wayne and Zumberge, 1965; Farrand and Eschman, 1974). Shah (1971) defined and drew an interlobate boundary depicting the eastern most extension of the Lake Michigan lobe in southwestern Michigan (Fig. 1) based on the morphology of weak morainal ridges that parallel known deposits of the Lake Michigan lobe.

The present study is an effort to statistically define and establish the interlobate boundary relationship produced by the interplay of the Lake Michigan and Saginaw lobes in areas in and adjacent to Kalamazoo County, Michigan, by determining the provenance of glacial tills. Rieck (1976) delineated tills of the Saginaw and Huron-Erie lobes in southeastern Michigan utilizing X-ray diffraction techniques, and Bleuer (1975) distinguished tills in Indiana derived from different source areas by establishing ratios of various heavy minerals. Studies in surrounding regions have also been successful in establishing till provenance by using mineralogic and other techniques (Gravenor, et al., 1976; Derry, 1934; Anderson, 1957; Gravenor, 1951). In the present study, textural and mineralogic data are utilized to describe the character, extent, and contact relationship of the tills left by the

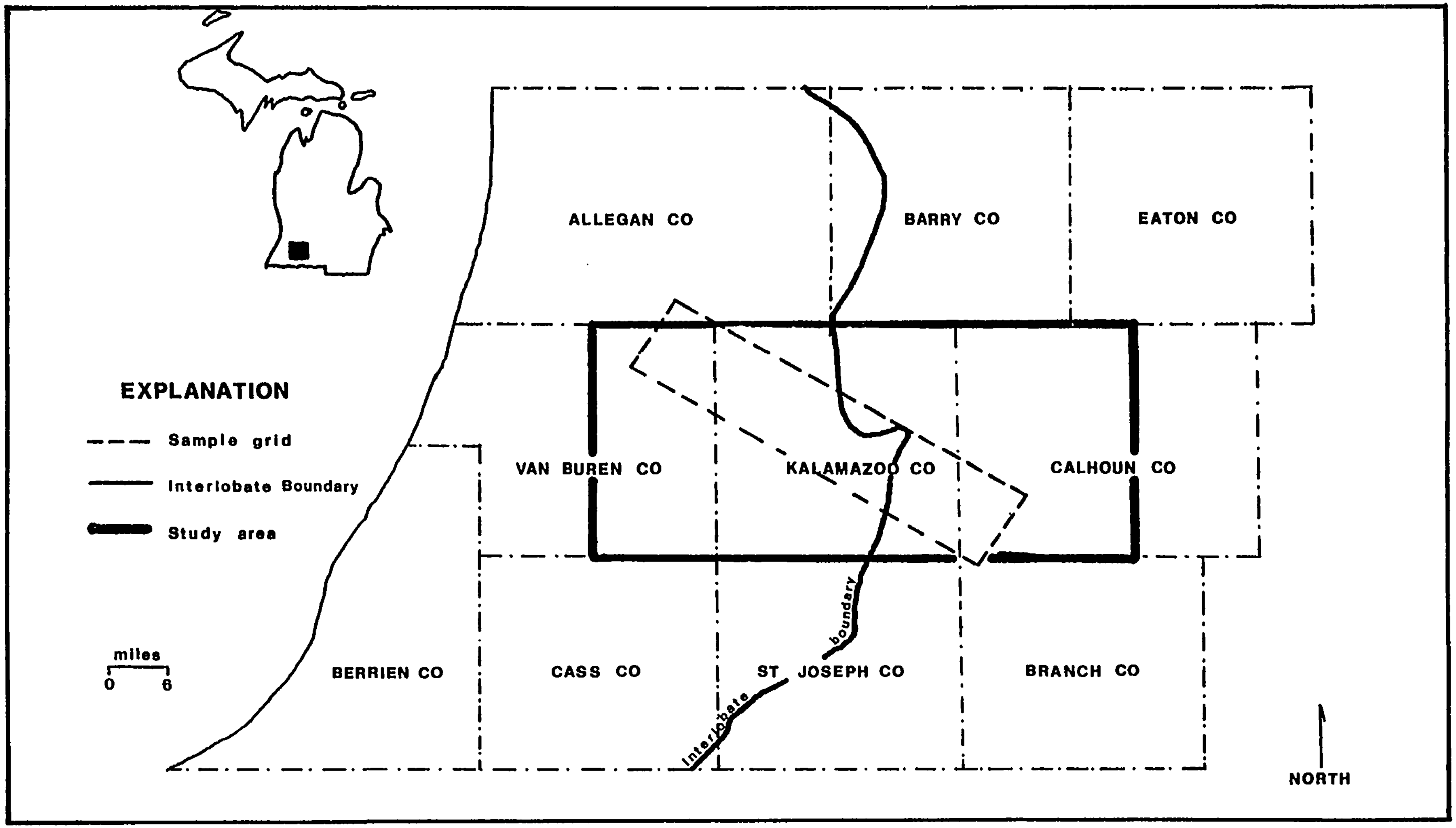

Figure 1. Map of southwestern Michigan showing the study area and sampling grid, and the maximum eastward extension of the Lake Michigan lobe during Wisconsinan glaciation according to Shah (1971).

Lake Michigan and Saginaw glacial lobes. Not only is an understanding of the nature of deglaciation in southwestern Michigan enhanced, but also relatively new techniques proven successful in other regions are used and tested in establishing the interlobate boundary in the study area.

BEDROCK GEOLOGY

The bedrock geology of Michigan consists of two distinct provinces (Wayne and Zumberge, 1965). All of the Southern Peninsula and the eastern half of the Upper (Northern) Peninsula consists of Cambrian to Pennsylvanian shales, sandstones, carbonates, and evaporites of the Michigan Basin. The western half of the Upper Peninsula of Michigan exposes rocks of the Precambrian Canadian Shield. These rocks are mainly Early Precambrian, Keewatin through Algoman, granites, greenstones (metamorphosed lava flows), and metasediments; Middle Precambrian, Animikian, iron formations and intrusives; and Late Precambrian, Keweenawan, lava flows, conglomerates, and sandstones (Wayne and Zumberge, 1965; Dorr and Eschman, 1971).

Unconsolidated glacial sediments of the study area are underlain by the Lower Mississippian Coldwater Shale and Marshall Sandstone (Fig. 2). No known bedrock outcrops appear in the study area. The present knowledge of bedrock characteristics within the study area is based on well logs from Kalamazoo County and bedrock outcrops in

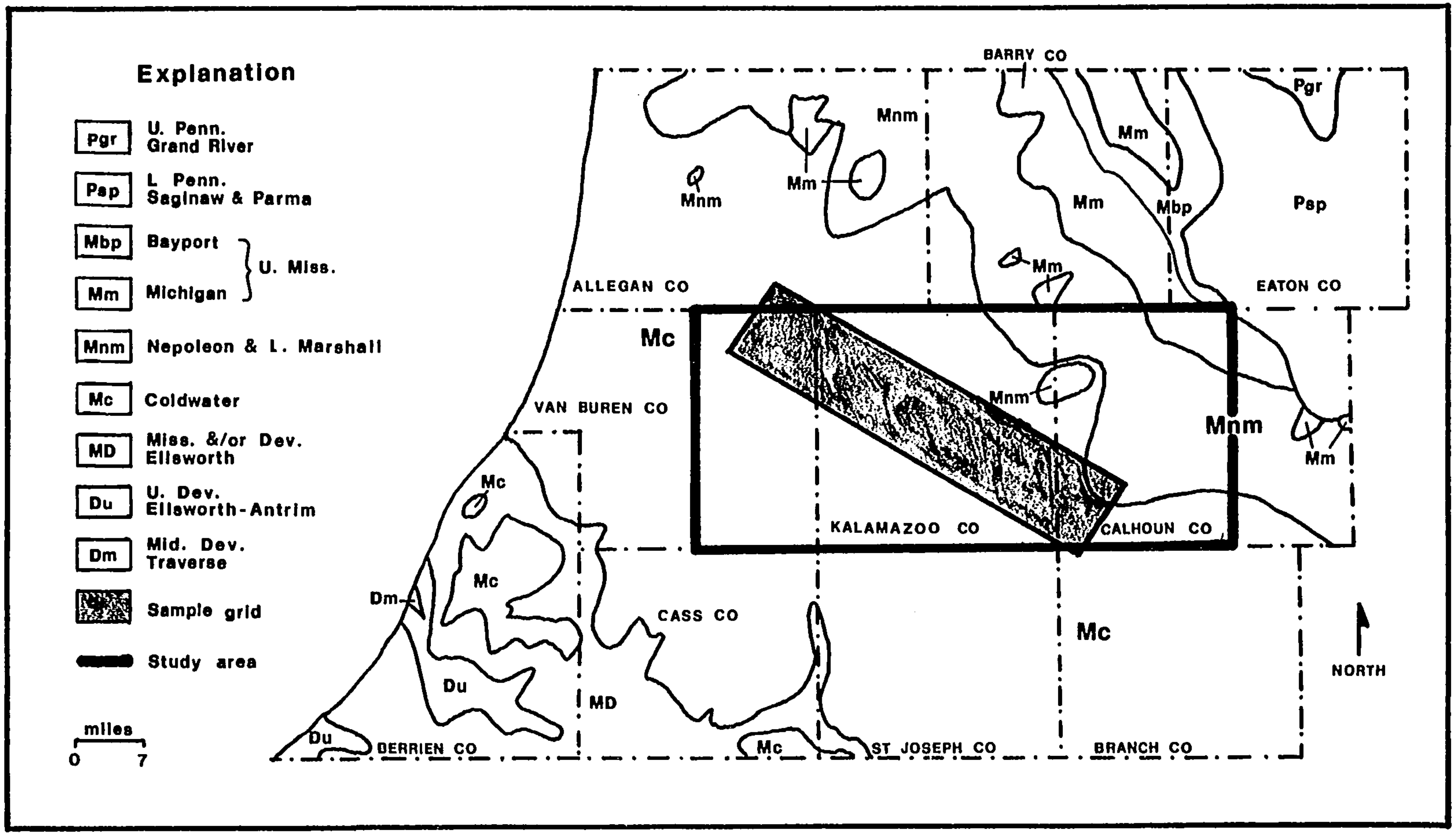

Figure 2. Bedrock geology of southwestern Michigan (after the Michigan Geological Survey, 1968) illustrating the study area (heavy line) and the sample grid (grey).

adjacent areas (Shah, 1971).

As reported by Shah (1971), the Coldwater Shale in southwestern Michigan is dominantly blue to grey and grades upward into the Lower Marshall Sandstone. Trending northwestward across Kalamazoo County, the Coldwater Shale forms a belt approximately 25 miles (40 km) in width beneath the surface drift material (Shah, 1971). Within the shales are thin discontinuous zones of limestone, dolomite, and clay ironstone concretions.

The Lower Marshall Sandstone occupies portions of the northeast corner of the study area (Fig. 2). Winchell (1861) described the Lower Marshall Sandstone as being white, grey, green, and red in color. Clay ironstone concretions are present in sandy shale lenses which are locally micaceous. Plant impressions and pockets of coal have also been reported (Shah, 1971). Paralleling the Coldwater Shale within the study area, the Marshall Sandstone strikes northwest and dips gently northeastward toward the basin's center.

GLACIAL GEOLOGY

Introduction

The Pleistocene Epoch was marked by several worldwide, synchronous glaciations. In North America at least four separate periods of continental glaciation have been recorded (Fig. 3).

The Nebraskan glaciation extended as far south as Kansas and Missouri (Fig.4). Buried beneath younger drift wherever it occurs, Nebraskan drift is best developed in northern Missouri, eastern Nebraska, and northeastern Kansas (Flint, 1957). At the close of the Nebraskan glaciation a period of climatic warming occurred and has been named the Aftonian Interglacial (Chamberlin, 1895).* During the Aftonian and before subsequent glacial advance, grasses and trees flourished as recorded in the pollen of soil profiles and peat lenses lying between Nebraskan and Kansan drift sheets (Flint, 1957).

Glacials	Interglacials	Y.B.P.
		0
	Recent	
Wisconsinan		10,000
	Sangomonian	
Illinoian		
	Yarmouthian	
Kansan		
	Aftonian	
Nebraskan		
		1.5 Million

Figure 3. Subdivisions of the Pleistocene in North America (after Dorr and Eschman, 1971).

*Interglacials are periods of climatic warming between periods of glacial advance or glacials.

West of the Mississippi River Kansan Age drift extends beyond younger drift sheets but is overlapped by Illinoian drift in Illinois, Indiana, and Ohio. Two lobes of Kansan ice are shown in Illinois (Fig. 4); however, Flint (1957) stated that the existence of two Kansan lobes in Illinois is questionable considering the "scanty" subsurface data available. The Yarmouthian Interglacial separating the Kansan and Illinoian glacials is represented by a soil zone developed in Kansan drift. Simonson (1954) compared soils developed in Kansan drift with modern equivalents and stated that the Yarmouthian climate was much like that of the present.

Illinoian drift is best developed in Illinois with its overall drift border following a similar outline as the subsequent Wisconsinan glaciation (Fig. 4). Tills of Illinoian Age are reported as being rich in clay and silt. Leverett and Taylor (1915) described a till in southeastern Michigan which they attributed to Illinoian glaciation.

Evidence for multiple periods of glacial advance during Illinoian time exists. Frye and Leonard (1954) established that a soil zone developed within the Illinoian sediments of Kansas implies a period of warm climate that endured for several thousand years. Studies in Nebraska and Missouri yield correlative results (Thorp, et al. 1951; and Davis, unpublished data in Flint, 1957).

The Illinoian and Wisconsinan glaciations are separa-

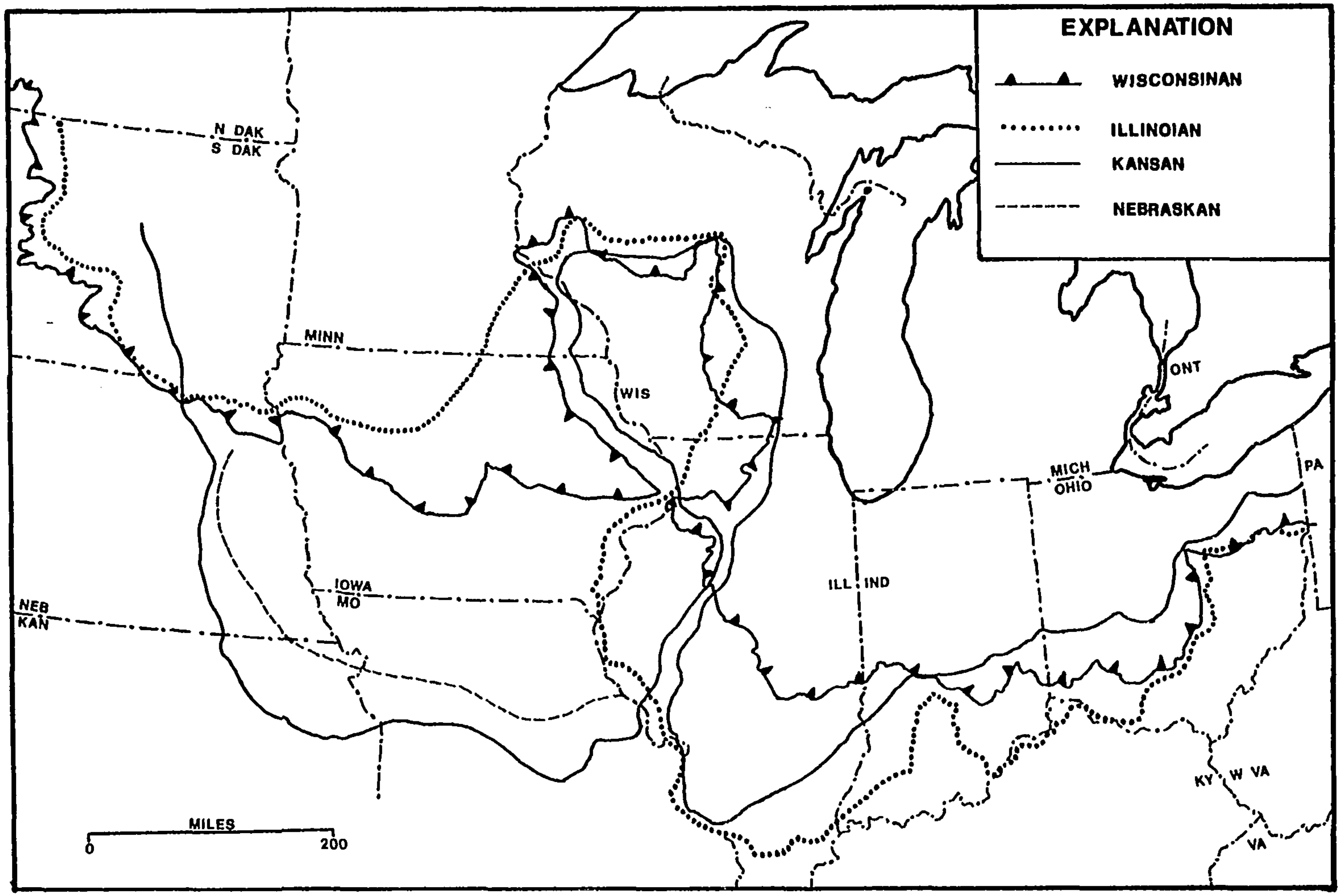

Figure 4. Nebraskan, Kansan, Illinoian, and Wisconsinan drift borders in North America (modified from Flint, 1957).

ted by a period of warmer climate called the Sangamon Interglacial. Sangamon soils are well developed and show about the same regional changes as do modern soils (Flint, 1957; Flint, 1971).

Perhaps the best known and differentiated period of paleoglaciation is that of the Wisconsinan Age. This is easily understood when it is realized that Wisconsinan glaciation ended less than 10,000 years ago. At its maximum extent, Wisconsinan ice reached into southern Ohio, Indiana, and Illinois. From Illinois, the Wisconsinan border extends westward and north through Iowa, Nebraska, and the Dakotas, then on to the Rocky Mountains (Fig. 4).

The stratigraphy of the Wisconsinan deposits are better known than that of any other glacial age. Since around 1950, a detailed reexamination of Wisconsinan Age deposits has been undertaken and their classification reviewed. Leighton (1960) and Willman and Frye (1970) espoused classifications of Wisconsinan stratigraphy which are in use today. However, the classification of Leighton (1960) appears to be preferred by researchers studying Michigan's glacial deposits.

Practically all of the surface deposits covering Michigan's lower peninsula are glacial in origin. The majority of these deposits are the result of ice advance and retreat phases of the Cary, Port Huron (Mankato), and Valders substages of the Wisconsinan glaciation (Fig. 5).

Radio-carbon y.b.p.	MODIFIED AFTER LEIGHTON, 1960				MODIFIED AFTER FRYE AND WILLMAN, 1970
0 5,000	RECENT			HOLOCENE	
10,000	WISCONSINAN AGE		Late	WISCONSINAN AGE	VALDERAN STAGE
		VALDERS GLACIAL Twocreek Int. MANKATO (PORT HURON) GLACIAL Bowmanville Int.			TWOCREEKAN STAGE
15,000 20,000		CARY GLACIAL St. Charles Int. TAZAWELL GLACIAL Gardena Int. IOWAN GLACIAL	Middle		WOODFORDIAN STAGE
25,000		Farm Creek Interglacial			FARMDALIAN STAGE
30,000 35,000		FARMDALE GLACIAL	Early		ALTONIAN STAGE
75,000	SANGAMON AGE				SANGAMONIAN AGE

Figure 5. Stratigraphic classification of the Wisconsinan glacial deposits in Illinois (modified from Shah, 1971).

Very few, if any, exposures of pre-Wisconsinan tills occur at the surface in Michigan. Thus, only the glacial history of Michigan during Wisconsinan time, more precisely from Cary time to the Recent, is discussed.

Till Classification

Prior to the evolution of the glacial theory in the second quarter of the 19th century, erratic boulders were recognized as being deposits of transported materials (Charlesworth, 1957; Flint, 1971). Originally these deposits were believed to have been lowered to the earth's surface after floating on ice across the landscape during the great Biblical deluge. Subsequently, Sir Charles Lyell, in 1830, espoused the "Drift Theory" to explain the distribution of these erratics and Murchison (1836) recommended the term drift be used in order to avoid further religious connotations. With time, and the development of the idea that glaciers once occuppied regions far more extensive than at present, the term "Glacial Drift" has evolved to embrace all rock material in transport by glacial ice, all deposits made by glacial ice, and all deposits largely of glacial origin (Flint, 1971).

Drift has subsequently been subdivided into three basic categories based primarily on the sedimentological characteristics: stratified drift, unstratified drift, and erratic boulders and clasts. Stratified drift (outwash) is that material deposited indirectly from the ice by the action of glacial meltwaters. As outwash and erratic boulders are not topics of discussion in this paper, no further attempt will be made to define or classify them. But, because this study deals with unstratified drift (till) the definition and classification of such material is included.

Till, a Scottish word used to describe a coarse obdurate land, is defined as an aggregate whose components are brought together and deposited directly by glacier ice (Boulton, 1972). Being more variable than any other sediment, till is a mixture of grain sizes and rock types (Goldthwait, 1971; Flint, 1957). Any given grain size may constitute the bulk of an accumulated till, and the rock types are dependent on the geologic formations over which the glacier has ridden.

Tills have been variously classified by origin, color, texture, degree of compaction, lithologic composition, and mode of deposition (Dreimanis, 1971). Perhaps the most useful and fundamental classification is based on genesis; however, the most distinctive and easily recognized properties of tills are those acquired during the process of deposition. Thus, the most satisfactory classification is one based on depositional modes (Flint, 1957; Boulton, 1972).

Using the above definition and utilizing the subglacial, englacial, and supraglacial criterion of glacial debris in transport (Fig. 6), tills may be classified in the following manner:

A. Lodgement or basal till, deposited subglacially from drift in transport in the base of an active glacier. The debris is released from the ice by slow pressure melting of the flowing ice and lodged in the accumulating drift on the subglacial floor (Chamberlin, 1894; Dreimanis, 1967a; Flint, 1957; Boulton, 1972). The resulting till lacks sorting, is compact, and often acquires a fissile structure (Flint, 1971).

B. Ablation till, deposited from englacial and supraglacial debris in the terminal area of a glacier. The glacial material is lowered to the ground as the ice melts inward from the terminus, top, and base (Flint, 1957). Tills produced by this method are characteristically loose, noncompact, and nonfissile.

Following several years of research with modern arctic glaciers as depositional models, Boulton (1972) suggested that, by using the above classification, existing models for the interpretation of ancient tills and the sequences in which they lie are often too simple. Going even further, Boulton stated that "many Pleistocene and earlier sequences, currently thought of as products of repeated glacier advance and readvance, may be products of a single retreat phase by a glacier with a thick englacial debris load."

With this in mind Boulton offers a refinement of the ablation till category as follows:

A. Flow till, released supraglacially

Glacial Drift in transport		Boulton, 1972	Flint, 1957	Dreimanis, 1967a
Supraglacial drift		Flow till	Ablation till	Ablation till (by means of surface melting)
Glacial ice	Englacial drift	Melt-out till		
	Subglacial drift	Lodgement till	Basal or Lodgement till	Basal till (by lodgement or basal melting)
Bedrock or Sediment		Local till Deformation till		

Figure 6. Classification of tills showing the relationship between glacial drift in transport to the type of till developed (modified from Flint, 1957; Dreimanis, 1967a; and Boulton, 1972).

and undergoing subsequent deformation as a result of subaerial flow (Boulton, 1972). Tills developed by this method are very often brought from a subglacial position to a supraglacial position along debris bands within the ice and therefore may contain many features characteristic of basal tills (Boulton, 1968).

B. Melt-out tills, deposited either supraglacially or subglacially from stagnant ice beneath a confining overburden (Boulton, 1970b; Boulton, 1972). In a glacial sequence from which the ice has vanished, melt-out tills represent the stratigraphic position of the depositing glacier (Boulton, 1970).

The significance in Boulton's refinement (1972) is that the ablation till/basal till doublet postulated by Flint (1957) may develop entirely supraglacially. As subglacial till is brought to a supraglacial position along glacial debris bands, subsequent downslope flow may translate parts of the till to the upper surface of the ice. Once exposed to subaerial processes, sorting of the upper portion of the till may produce a lower massive element with an upper, washed and often crudely stratified element. If then, given the association of supraglacial outwash, tripartite till/outwash/till sequences may develop which are the result of a single glacial retreat phase rather than multiple advance and retreat (Boulton, 1968; 1971; 1972).*

*For information on fabric data as related to tills, see Holmes, 1941, Flint, 1957, 1971, and Boulton, 1971.

Deglaciation of Michigan

The glaciation of Michigan during Cary time was accomplished by the nearly simultaneous advance of glacial ice via the Lake Michigan, Lake Erie, and Saginaw basins (Wayne and Zumberge, 1965). Completely covering Michigan, the Cary ice extended into southern Illinois, Indiana, and Ohio. At its maximum extension, 18,000 years ago, the Cary ice stood near the Ohio River and resulted in the deposition of the Minooka, Iroquois-Packerton, and Union City terminal moraines (Fig. 7) of the Lake Michigan lobe, Saginaw lobe, and Erie lobe respectively (Eschman and Farrand, 1974).

As the ice of all three glacial lobes began to retreat from its position of maximum extension, the Saginaw lobe ice dissipated more rapidly than the ice of the Lake Michigan and Lake Erie lobes. Leverett (1915) reasoned that, during advance, the Saginaw lobe ice had overridden an area of greater topographic relief than either the Lake Michigan or Lake Erie lobes. The resulting thickness of Saginaw ice must, therefore, have been less than that of its counterparts and the movement of Saginaw ice correspondingly weaker. Additionally, Leverett (1915) added that excessive loading of Saginaw lobe ice resulting from convergence with the adjacent Lake Michigan and Lake Erie lobes may also have effected the weaker movement of the Saginaw lobe. With con-

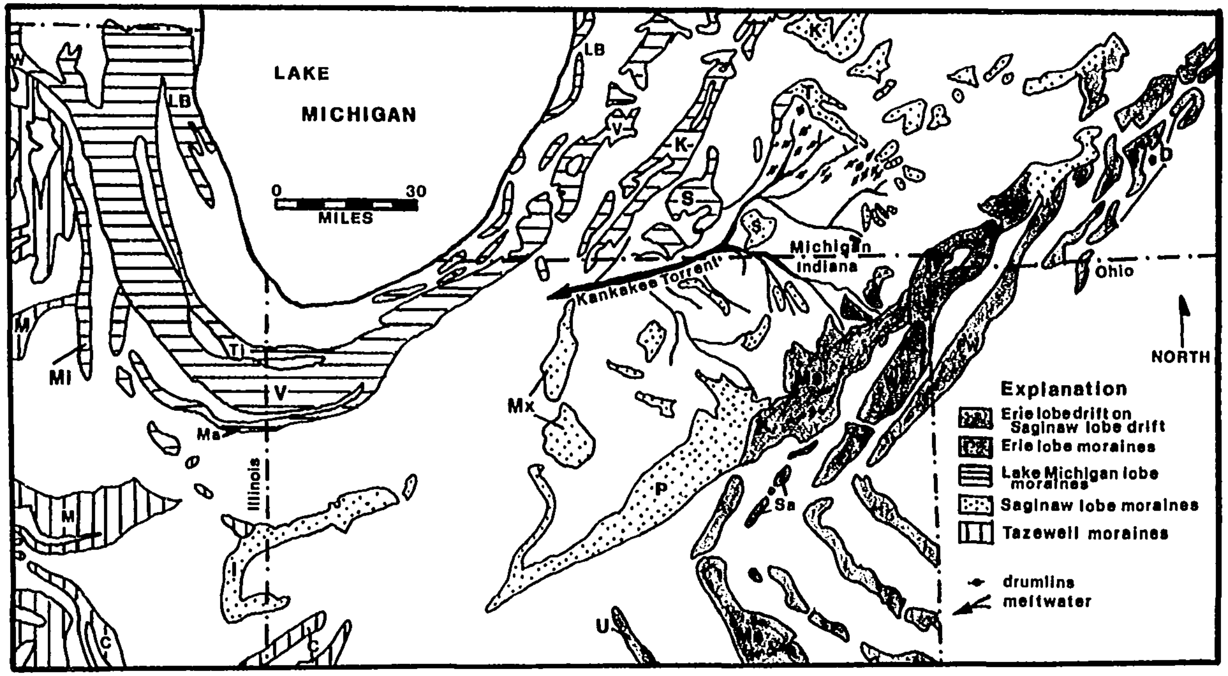

Figure 7. Map illustrating Wisconsinan morainal development of the Lake Michigan, Saginaw, and Lake Erie lobes in southern Michigan, and northern Illinois, Indiana, and Ohio (after Zumberge, 1960: W, West Chicago moraine; M, Marseilles moraine; Mi, Minooka moraine; Ma, Manhattan moraine; C, Chatsworth moraine; LB, Lake Border moraine; Ti, Tinley moraine; V, Valparaiso moraine; I, Iroquois moraine; K, Kalamazoo moraine; S, Sturgis moraine; T, Tekonsha moraine; Mx, Maxinkuckee moraine; P, Packerton moraine; U, Union City moraine; Ms, Mississinewa moraine; Sa, Salamonie moraine; Fw, Fort Wayne moraine; Wa, Wabash moraine; D, Defiance moraine).

tinued retreat of Cary ice, the first portion of Michigan (south-central Michigan) to become ice free occurred approximately 15,000 years b.p. (Wayne and Zumberge, 1965).

Evidence for the more rapid retreat of Saginaw lobe ice as compared with ice of the Lake Michigan and Lake Erie lobes is found 28 miles (45 km) southwest of Ann Arbor, Michigan, and in Steuben and DeKalb Counties, Indiana. At these locations clay-rich tills of the Erie lobe overlie sandier textured tills of the Saginaw lobe (Zumberge, 1960; Wayne and Thornbury, 1955; Wayne and Zumberge, 1965). Additional support exists in northeastern Indiana and south-central Michigan where outwash sands and gravels of the Erie lobe occupy areas previously inhabited by the Saginaw lobe (Wayne and Zumberge, 1965).

The strongest evidence supporting rapid recession of Saginaw ice, as well as providing a means of correlation for Cary age moraines, is the Kankakee Torrent. Ekblaw and Athy (1925) established the coalescence of melt-water channels heading at the Tekonsha moraine of the Erie lobe (Fig. 7). The Kankakee Torrent discharged southwestward along the east-southeastern edge of the Lake Michigan lobe and across the northwestern corner of Indiana to Illinois.

Dreimanis and Morner (1973) recognized a major fluctuation in the Erie lobe ice that was synchronous with the torrent, the Erie Interstade. Kunkle (1963) correlated lake beds in southwestern Ontario with erosional channels in the Huron River valley which indicates ice recession north of Lake Erie approximately 15,600 years ago. Farrand and Eschman (1974) noted that an oscillation of this magnitude has not yet been recognized for the ice of the Lake Michigan lobe.

Following the Erie Interstade, the ice readvanced into southeastern Michigan culminating about 14,800 years ago (Dreimanis and Morner, 1973). From this point in time the Cary ice continued its overall retreat with only minor readvances.

The Cary ice retreated northward to approximately the Straits of Mackinac. A bryophyte bed is exposed nine miles (14.4 km) south of the straits in Cheboygan County (Farrand, et al., 1969). Radiocarbon dates of 13,300 y.b.p. are given for material from this bed. This 1 cm thick mat of mosses indicates that the Cary ice front must have retreated at least this far north (Farrand and Eschman, 1974).

Readvance of the ice in Port Huron time resulted in the formation of the Port Huron moraine, 13,000 y.b.p. (Hough, 1958) (Fig. 8). According to Dorr and Eschman (1971), all glacial deposits south of the Port Huron moraine are Cary in age. The Port Huron ice reached as far south as Muskegon and Milwaukee (Farrand and Eschman, 1974). Tills of this moraine are characterized as being blue to grey-blue and quite sandy in places (Wayne and

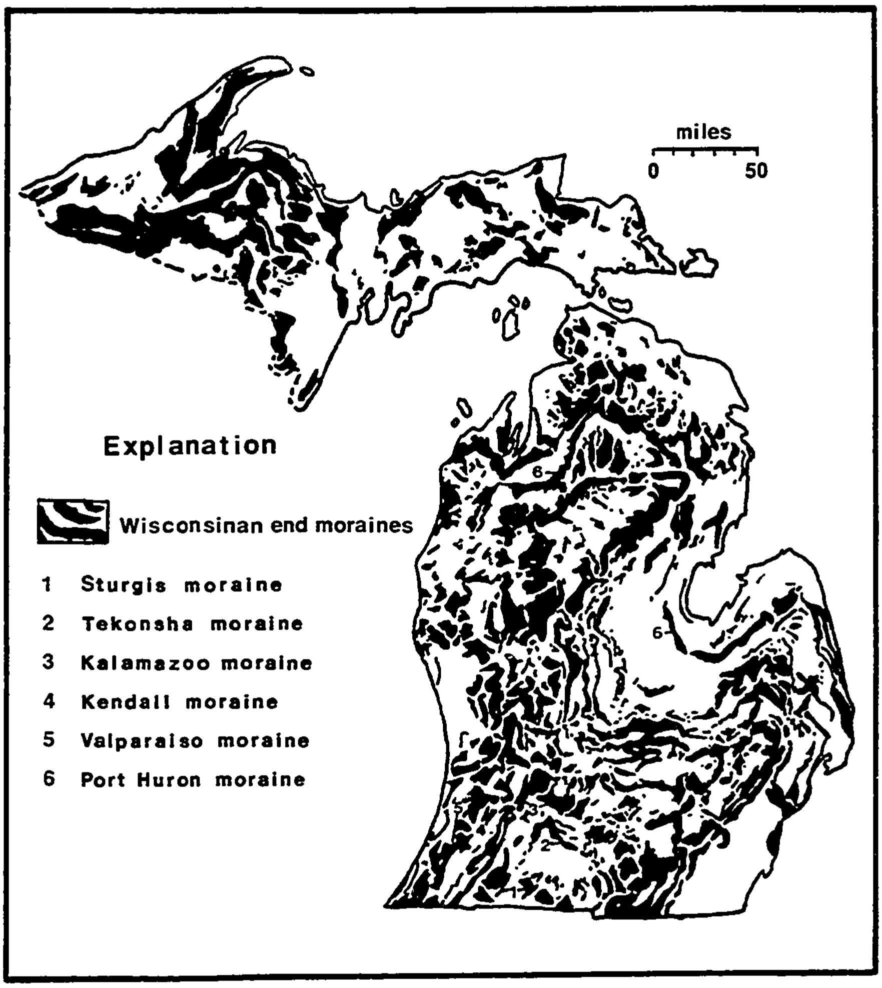

Figure 8. Wisconsinan morainal systems in Michigan (after Michigan Geological Survey, 1975).

Zumberge, 1965). In contrast, the later Valderan tills are red to pink.

With recession of Port Huron ice, Valders ice advanced from the northeast to a position proximal to the Port Huron Moraine in the northern part of the Southern Peninsula (Wayne and Zumberge, 1965). No end moraines were built by Valderan ice, but drumlins near Grand Traverse Bay trend northwestward indicating a radial flow from the central

Lake Superior region (Wayne and Zumberge, 1965). With retreat of the last Valderan ice, all of Michigan was ice free about 10,000 years b.p. (Broecker and Farrand, 1963) leaving behind the present glacial landforms (Fig. 8).

Terminal and Lateral Moraines in the Study Area

The study area, which centers in Kalamazoo County, was completely covered by two lobes of the Wisconsinan continental glacier. The Lake Michigan lobe advanced into the study area from the northwest. The Saginaw lobe advanced from the northeast. With final retreat of the ice fronts in Cary time, bold morainic systems were left to cover the landscape.

Portions of five (5) morainal systems in the study area were left by the Lake Michigan and/or Saginaw lobes. The Lake Michigan lobe is responsible for portions or all of the Valparaiso, Kendall, Kalamazoo, Tekonsha, and Sturgis moraines. The Saginaw lobe built portions of the Kalamazoo, Sturgis, and Tekonsha moraines (Fig. 9).

The following morainal descriptions are based largely on work by Leverett and Taylor (1915).

Valparaiso morainic system

A segment of the Valparaiso morainic system of the Lake Michigan lobe occupies the northwestern corner of the study area in southeastern Allegan County and northeastern Van Buren County, Michigan (Fig. 9). This morainic system extends from the Wisconsin-Illinois line around the southern end of Lake Michigan through northern Indiana and northward to near Rockford, Michigan. Here it joins its correlative moraine of the Saginaw lobe.

The Valparaiso morainic system constitutes the drainage divide at the head of Lake Michigan separating waters flowing to the St. Lawrence and Mississippi Rivers. Topo-

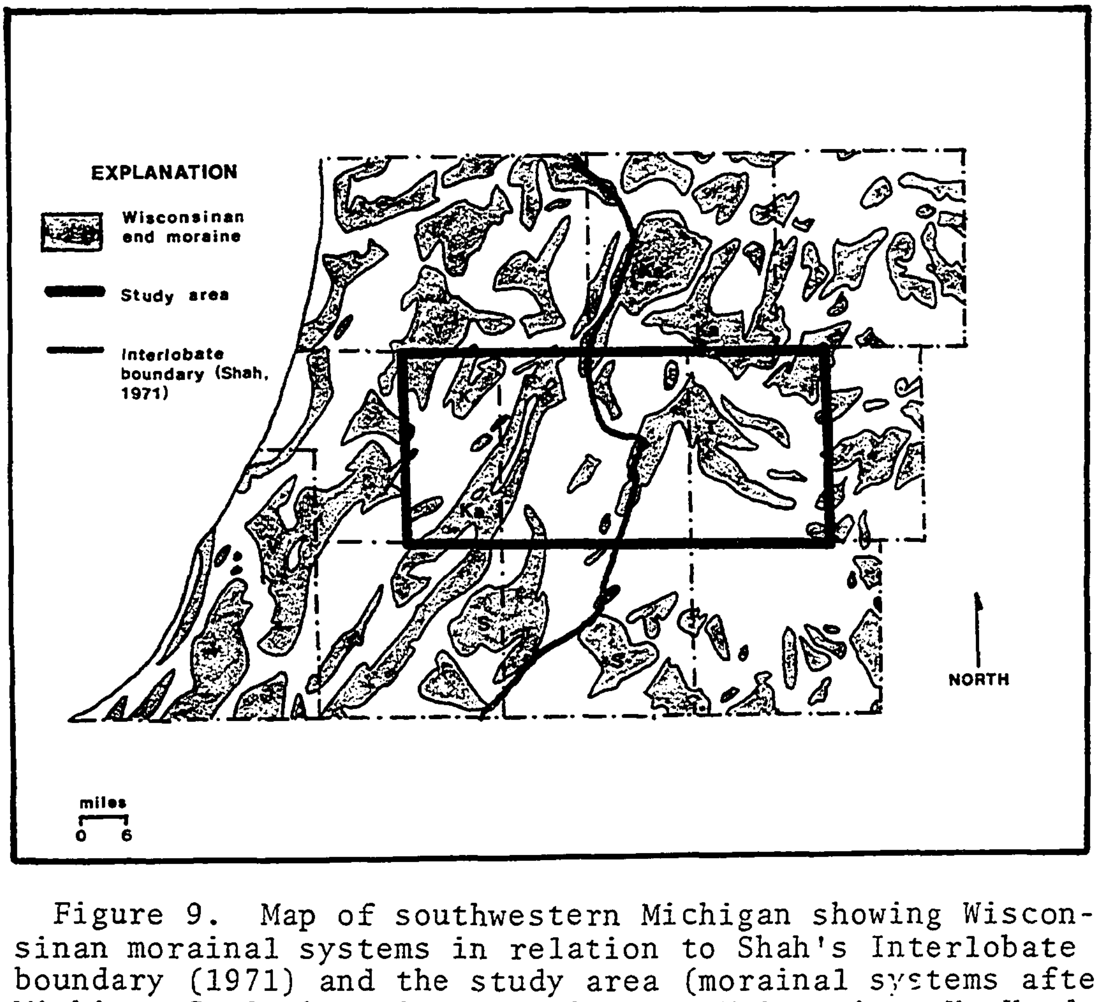

Figure 9. Map of southwestern Michigan showing Wisconsinan morainal systems in relation to Shah's Interlobate boundary (1971) and the study area (morainal systems after Michigan Geological Survey, 1975; V, Valparaiso; K, Kendall; T, Tekonsha; Ka, Kalamazoo; S, Sturgis).

graphic relief along the inner border of the moraine is quite conspicuous, rising 100 to 200 feet or more to its crest (Leverett and Taylor, 1915). Conversely, the relief along the outer border is somewhat less, ranging in general from 50 feet or less to around 75 feet.

The thickness of drift averages about 200 feet along the entire extent of the moraine in Indiana and Michigan, but a wide range of till compositions exists over this distance. The Wisconsinan drift in Illinois tends to be a blue clayey till. Eastward toward Valparaiso, Indiana, clay continues to predominate over sand and gravel, but beyond this, to the northeast, sand and gravel are predominate over clay. Sample stations 58 and 59 (Fig. 10) are located on the Valparaiso moraine. Tills at these localities are very sandy with boulders ranging to 8 inches (20.32 cm) in diameter. Most boulders consist of igneous and metamorphic lithologies of Canadian Shield derivation.

Kendall moraine

The Kendall moraine is located in the northeastern corner of Van Buren County a few miles north of Paw Paw, Michigan (Fig. 9). Approximately nine miles (14.4 km) long in a northeast-southwest direction, the Kendall moraine averages 1.5 to 2.5 miles (2.4 to 4 km) in width.

North of the village of Kendall knolls exhibit a relief of 60 to 80 feet (18.28 to 24.38 m), whereas, south

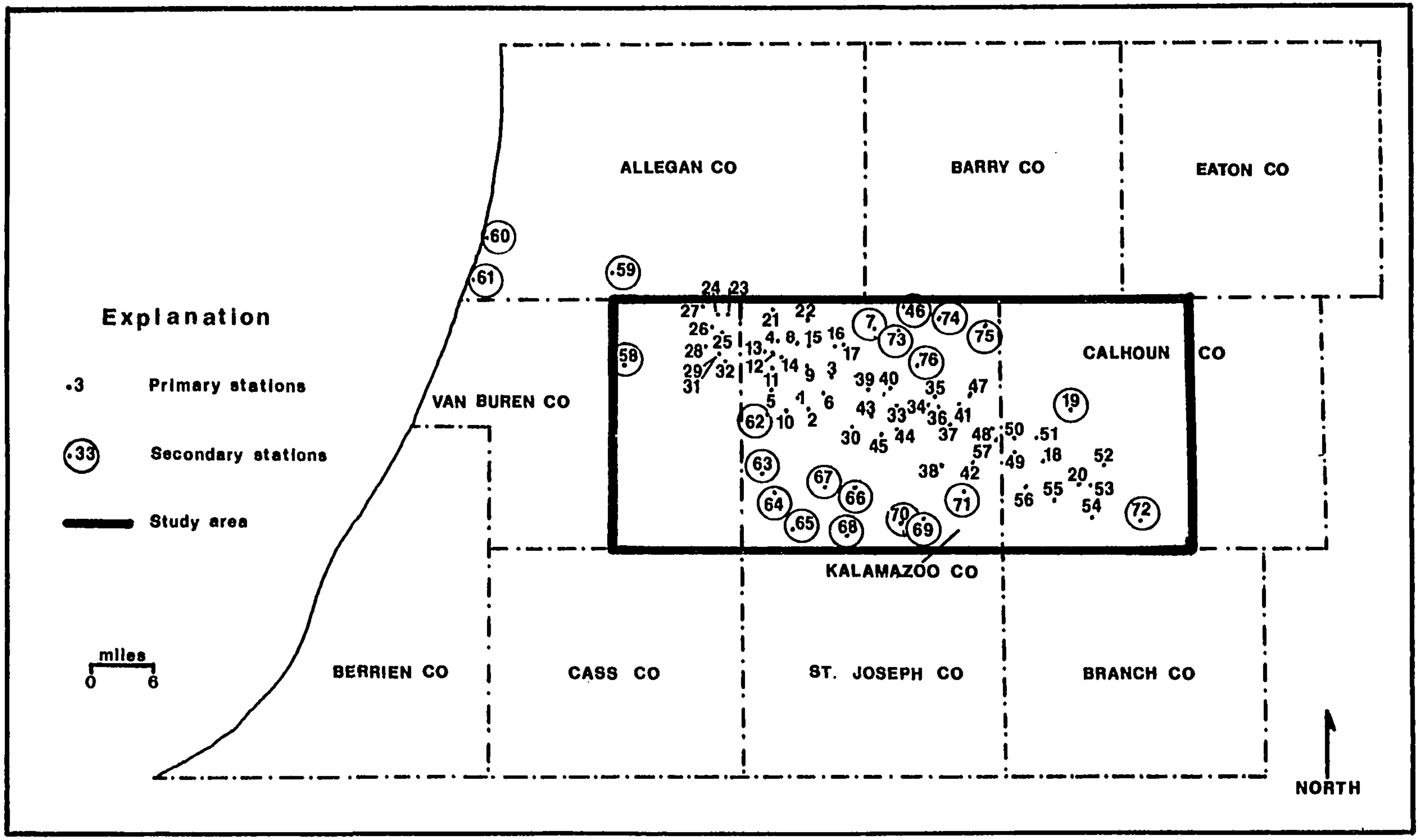

Figure 10. Map of southwestern Michigan and the study area (heavily outlined) showing the location of sample stations. Secondary sample stations are circled.

of the village the relief averages 25 to 30 feet (7.62 to 9.14 m).

Extending northeastward, the Kendall moraine terminates in a swamp. East of this swamp a weak ridge extends to the northeast and connects with the inner border of the Kalamazoo moraine. Because of this relationship, Leverett (1915) assigned the Kendall moraine to the Kalamazoo morainal system of the Lake Michigan lobe. Disagreeing with Leverett, Terwilliger (1954) correlated the Kendall moraine with the Valparaiso morainic system. By studying terraces of equal elevation along the sides of the Dowagiac Drainageway and the east side of Prospect Hill, Terwilliger concluded that Prospect Hill and the low moraine upon which Decatur is situated are contemporaneous with the Kendall moraine.

Till samples from eight locations were collected along the Kendall moraine (Fig. 10, stations 23 through 29, and 31). Its tills are generally poorly consolidated, sandy to bouldery, and red to red-brown in color. Leverett (1915) reported blue till at depths within the moraine and characterized the surface appearance as being bouldery. Shah (1971) recorded the presence of red jasper conglomerate at the north end of the Kendall moraine. Because the red jasper conglomerate is predominantly associated with Saginaw lobe deposits, Shah (1971) asserted that the Kendall moraine is a deposit of the Saginaw lobe. In a paper concerning the source of the above red jasper conglomerate erratics, Slawson (1925) stated the following:

> "In the Wisconsin drift the eastern limit of these erratics is marked in Michigan by the moraines bordering the glacial lake beds and in Ohio by a line running south of Norwalk through Mansfield and east of Dayton. On the west a limited number of the boulders have been deposited by the eastern half of the Lake Michigan lobe. In general, though, the great bulk of them were transported by the ice of the Saginaw lobe."

X-ray data and analysis of heavy minerals on samples collected on the Kendall moraine show conclusively that tills of the Kendall moraine belong to the Lake Michigan lobe.

Kalamazoo morainic system

The Kalamazoo morainic system was constructed by the joint action of the Lake Michigan and Saginaw lobes. The junction of the two correlative morainic systems is located slightly north of the study area in Barry County (Fig. 9). It is here that the Kalamazoo morainic system reaches its greatest elevation, 1050 feet above sea level.

In Michigan the Kalamazoo moraine of the Lake Michigan lobe is comprised of two nearly parallel ridges which trend in a northeast-southwest direction. The outer ridge (eastern ridge) extends from Prairieville southwestward to South Bend, Indiana, where it is interrupted by a gravel plain along the St. Joseph River. The inner or western ridge parallels the outer ridge and is traceable to a location approximately six miles (9.6 km) west of South Bend.

The relief along the outer border is slight as a gravel plain is built up nearly to its crest throughout its length. Conversely, the relief along the inner border ridge ranges from 50 feet (15.2 m) in southern Michigan to 200 feet (60.9 m) as the moraine extends northward.

Surface tills of both the inner and outer moraines are loose textured and range from clay-rich to very sandy. Cobbles to 8 inches (20.3 cm) in diameter commonly occur dispersed in the till. In most instances the surface drift is less than 1.5 meters thick and is underlain by stratified and often crossbedded sands and gravels. A grey or bluish clay-rich compact till is located at sample station 3 (Fig. 10) at the corner of Ravine Road and Douglas Avenue in Kalamazoo, Michigan. Similar tills are found exposed in 30 to 50 foot cliffs in the Lake Border moraine along the Lake Michigan shore line in Allegan County (Fig. 10, stations 60 and 61). Perhaps the blue clay-rich nature is due to the underlying Lower Mississippian Coldwater Shale (Fig. 2).

The Kalamazoo morainic system of the Saginaw lobe joins its correlative system of the Lake Michigan lobe in southwestern Barry County (Fig. 9). From this junction the Saginaw lobe portion of these moraines extends southeastward and eventually connects with the Mississinawa moraine of the Huron-Erie lobe in Washtenaw County.

Relief along the Saginaw lobe portion of the morainic system is slight. In most places it is little more than 30 feet (9.1 m) and rarely exceeds 50 feet (15.2 m). In Jackson County the area around Portage swamp has 150 feet (45.7 m) of relief and is the most prominent portion of the moraine.

Tills within the moraine are generally sandy, resulting from erosion of the underlying sandstone units. Boulders of local bedrock and Canadian Shield derivation are commonly abundant.

Tekonsha morainic system

Within the study area, the Tekonsha morainic system is located in western Calhoun County and eastern Kalamazoo County (Fig. 9). The Tekonsha moraine of the Saginaw lobe is joined at its northwest and southeast ends by correlative moraines of the Lake Michigan and Huron-Erie lobes, respectively, and has a general width of 4 to 5 miles (6.4 to 8 km). Its counterpart from the Lake Michigan lobe extends southwestward from the junction and averages approximately 3 miles (4.8 km) in width.

The southwestward extension of the Tekonsha moraine of the Lake Michigan lobe is well developed for approximately 8 miles (10.8 km). Based on the location and morphology of the eastern side of the Sturgis moraine of the Lake Michigan lobe, Straw (1977, personal communication) is of the opinion that this portion of the Sturgis moraine may have developed synchronously with, and therefore, represent an extension of the Tekonsha moraine.

Tills of the Tekonsha moraine are typically sandy and boulder strewn. The sandy nature results in large part from the underlying and neighboring Lower Marshall Sandstone. It should be noted that boulders of the Lake Michigan lobe's Sturgis and Tekonsha moraine are lithologically similar.

A north trending spur of the Sturgis moraine in Cass and St. Joseph Counties projects into the study area. Sample stations 64 and 65 (Fig. 10) indicate that tills of this moraine are sandy textured and lithologically similar to those of the Tekonsha moraine. As only a small portion of the Sturgis moraine is represented in the study area (Fig. 9), a discussion of this morainal system is omitted.

LOCATION

The area under investigation, centering in Kalamazoo County, lies in the southwestern Michigan interlobate region of the Central Lowlands physiographic province (Fig. 1). Located on the southwestern flank of the Michigan basin, the entire study area is covered by glacially derived sediments. Here the glacial materials are characterized by bold morainal deposits and associated sand and gravel outwash plains. Tills within the area are generally loose textured although compact tills are locally distributed. Ibrahim (1969) reported that the drift thickness in Kalamazoo County ranges from 50 to 650 feet (15.2 to 198.1 m) and according to Malanchak (1973) the average thickness is between 290 to 390 feet (88.4 to 118.9 m).

The midpoint of the study area lies approximately 136 miles (217.6 km) west of Detroit, 50 miles (80 km) south of Grand Rapids, and 112 miles (179.2 km) east of Chicago.

TECHNIQUES

Field Sampling

In order to establish a statistical basis for initial sampling, a grid was designed which traversed the study area in a northwest-southeast direction (Fig. 1). Using the interlobate boundary mapped by Shah (1971) as a focal point, the grid area was extended into regions of known Lake Michigan and Saginaw lobe deposits, thereby insuring the positioning of the interlobate boundary within the grid.

Sample collection was controlled by till outcrop exposure, and representative till samples were collected by entrenching the exposures. The location of each station is recorded in Table 1 of Appendix I and in Figure 10.

Following the laboratory analysis of the initial or primary samples, an interlobate boundary was established within the grid. Subsequently, additional or secondary stations were randomly established and representative samples were collected and analyzed in order to define an interlobate boundary throughout the remainder of the study area.

Laboratory Analysis

Analytical techniques described in this section include various methods for obtaining textural, magnetic susceptibility, X-ray, and heavy-mineral data. Results utilizing these techniques are then presented in the section titled "Analysis of an Interlobate Boundary Relationship."

Using modifications of procedures outlined by Folk (1968), all samples were dried at 100°F for a minimum of eight hours. Samples were then transferred to the laboratory preparation room where they were disaggregated and allowed to equilibrate with room temperature and humidity. The gravel portion of each sample was removed by passing the entire sample through a 10 mesh (2.00 mm) sieve. Gravel portions of each sample were marked and stored; a split (approximately 200 grams) of the remaining clays, silts, and sands was obtained and washed in 200 ml of calgonated de-ionized water for a minimum of 24 hours. A second split (75 to 100 grams) of the remaining clays, silts, and sands was obtained. This representative of the "bulk sample"* was taken to Indiana University (Bloomington) for analysis of magnetic susceptibility (see section on magnetic susceptibility).

Clays and silts were separated from the sand fractions by wet sieving using a 63 micron (230 mesh, 0.0625 mm) sieve and de-ionized water. The muds were washed into a 1000 ml graduated cylinder, stirred, and allowed to settle for 24 hours. Subsequently, basally-oriented clay mounts were prepared for X-ray diffraction analysis by pippetting a clay-rich suspension onto glass slides and drying at room temperature. Dried basally-oriented clay mounts were placed in a dessicator partially filled with ethylene glycol for an additional 24 hours. It should be noted that slides number 3c, 10, 12, 14, 16a, 17, 18, 20, 23, 27, 29, and 31 had to be remade because of shrinkage during drying. Remaking was accomplished by passing the residual silts and clays through a 325 mesh sieve, mixing with distilled de-ionized water, and preparing clay mounts as described above. The remaining mud/water solution was transferred to 1000 ml beakers, dried, and stored.

After wet sieving and removal of the mud fractions

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*Bulk sample is defined as the split sample excluding the gravel fraction and is recorded in Table 1 of Appendix I.

from the sand fractions of each sample, the cleaned sands were washed into beakers and dried at 125°F. Dried sand samples were then split and weighed. The splits of each sand sample were sieved into very coarse, coarse, medium, fine, and very fine sand fractions (10, 18, 35, 60, 120, and 230 mesh sieves), and each fraction weighed (Table 1 of Appendix I). Sands from the 120 and 230 mesh sieves were combined for heavy mineral analysis.

Following the procedure outlined by Krumbein and Pettijohn (1938) and modified by Kuenzi (1974), heavy mineral separations in the fine and very fine sand fractions (120 + 230 mesh) were accomplished using bromoform ($CHBr_3$, d=2.89 at 20°C) and washing with acetone ($(CH_3)_2CO$). Each combined 120 plus 230 mesh sample was poured into a separatory funnel filled with bromoform having a specific gravity of 2.89 at 20°C. The samples were stirred every thirty minutes for three hours, then allowed to settle for two hours (5 hours total) before the heavy minerals were drawn off. Upon final separation of heavy-mineral concentrations, each sample was air dried, weighed, and split into portions preparatory to mounting on glass slides.

Grain mounts were prepared by coating heated petrographic slides with a combination of approximately 0.110 grams of heavy minerals per sample and caedex (synthetic Canada balsam). Upon final curing of the caedex, a glass cover slide was applied and grains dispersed by manipulation of the cover glass. Grinding of the grain mounts was unnecessary as grains ranging from 100 to 200 mesh yield first order colors when illuminated under a polarizing microscope (Bloss, 1961).

Using a Lietz polarizing microscope and mechanical stage, a total of 500 garnet versus epidote plus hornblende determinations were counted per slide. Data accumulated using this technique may be found in Table 1 of Appendix I.

ANALYSIS OF AN INTERLOBATE BOUNDARY

In the past, the history of the deglaciation of any given area has been based primarily on the morphology of bold morainal systems left by the retreating ice mass. Michigan has been no exception. The deglaciation of Michigan during Wisconsinan time left the state covered with bold morainal systems (Fig. 8). Careful examination of these moraines and other data have resulted in major works by Leverett and Taylor (1915), Hough (1958), and Wayne and Zumberge (1965), as well as many others. Their contributions have tremendously added to the knowledge of continental deglaciation during the Pleistocene.

Recent studies have focused more and more attention on the problem of unraveling the history of areas which developed by the complex interaction of two or more lobes of ice during the same or repeated glaciation. To do this, many analytical techniques have been developed and tested.

In this study, textural, magnetic susceptibility, X-ray diffraction, and heavy mineral data are used to establish the character of an interlobate boundary in the study area.

Textural parameters have been frequently utilized in describing and differentiating glacial sediments. In this study, two techniques based on textural analysis of till matrix (material $<$ 2 mm) were used in an attempt to differentiate till (Dreimanis and Vagners, 1972). The percent sand/percent mud ratio and the percent heavy minerals in the 120 plus 230 mesh sands were calculated. Both parameters were statistically analyzed. The results are presented in following sections. Textural data accumulated by exercising the above methods of analysis can be found in Tables 1-3 of Appendix I.

The use of magnetic susceptibility (MS) as a tool for the differentiation of glacial sediments based on provenance has been well established in the last decade (Vonder Haar and Johnson, 1973; Gravenor and Stupavsky, 1974; Gravenor, et al., 1976). Utilizing the facilities of Indiana University's Department of Geology (Bloomington), the magnetic susceptibility of samples from the initial grid area were determined and statistical analysis subsequently performed. The results are presented in following sections and the Appendix.

It has long been recognized that the composition of a till is reflective of the bedrock lithologies over which the glacier traversed. Thus, it follows that if two distinct glaciers or glacial lobes originated in similar but different areas, the composition of their resulting tills should be dissimilar, or at the very least, show differing ratios between any given suite of minerals. Based on this assumption, heavy mineral analysis was undertaken and a ratio of garnet/epidote plus hornblende calculated for all samples. The data was statistically analyzed and the results are presented in subsequent sections and Appendix I and II.

The use of X-ray diffraction techniques to differentiate glacial drift from differing sources has been investigated in a number of studies (Frye, 1968; Castillion, 1972). Rieck (1976), working in an interlobate area of southeastern Michigan, was able to differentiate tills of the Saginaw and Huron-Erie lobes by using X-ray diffraction of clays. Modifying the methods of Rieck (1976), and Glass (personal communication, 1976) and Gluskoter (1967) of the Illinois Geological Survey, analysis of the 7Å and 10Å clay peaks was undertaken. The results are statistically analyzed and presented in succeeding sections and the Appendix.

Textural Analysis

Tills are more variable than any other sediment (Goldthwait, 1971). Gravels, sands, silts, and clays individually may constitute the bulk of any given till and local variation from one extreme to another is common. Examination of textural data (Table 1 of Appendix I and Fig. 11) shows that the percent of sand in samples collected from deposits of the Lake Michigan lobe ranges from 25 to 97 percent. The percent of mud for the same lobe ranges from 3 to 75 percent. Samples collected from Saginaw lobe material exhibit some overlap, having a range of 50 to 94 percent sand and 6 to 50 percent mud. It is noteworthy that within the study area Lake Michigan lobe ice eroded bedrock parallel to the strike of the underlying Coldwater Shale and Marshall Sandstone; whereas, Saginaw lobe ice eroded bedrock perpendicular to this strike. Thus, it may be hypothesized that the resulting Lake Michigan lobe tills within the study area may contain a greater proportion of clay than the opposing Saginaw lobe tills. On this assumption, a ratio of percent sand to percent mud (%sand/%mud) was calculated and statistically analyzed for all surface data (see Appendix II). Comparison of the mean sand/mud ratio for the Lake Michigan and the Saginaw lobe tills support the above hypothesis (Fig. 11 and 12). Lake Michigan lobe tills exhibit a mean sand/mud ratio of 2.249 while Saginaw lobe tills show a mean of 4.095 (Fig. 12). The Chi Square Test indicates that the sand/mud ratio of the sample population

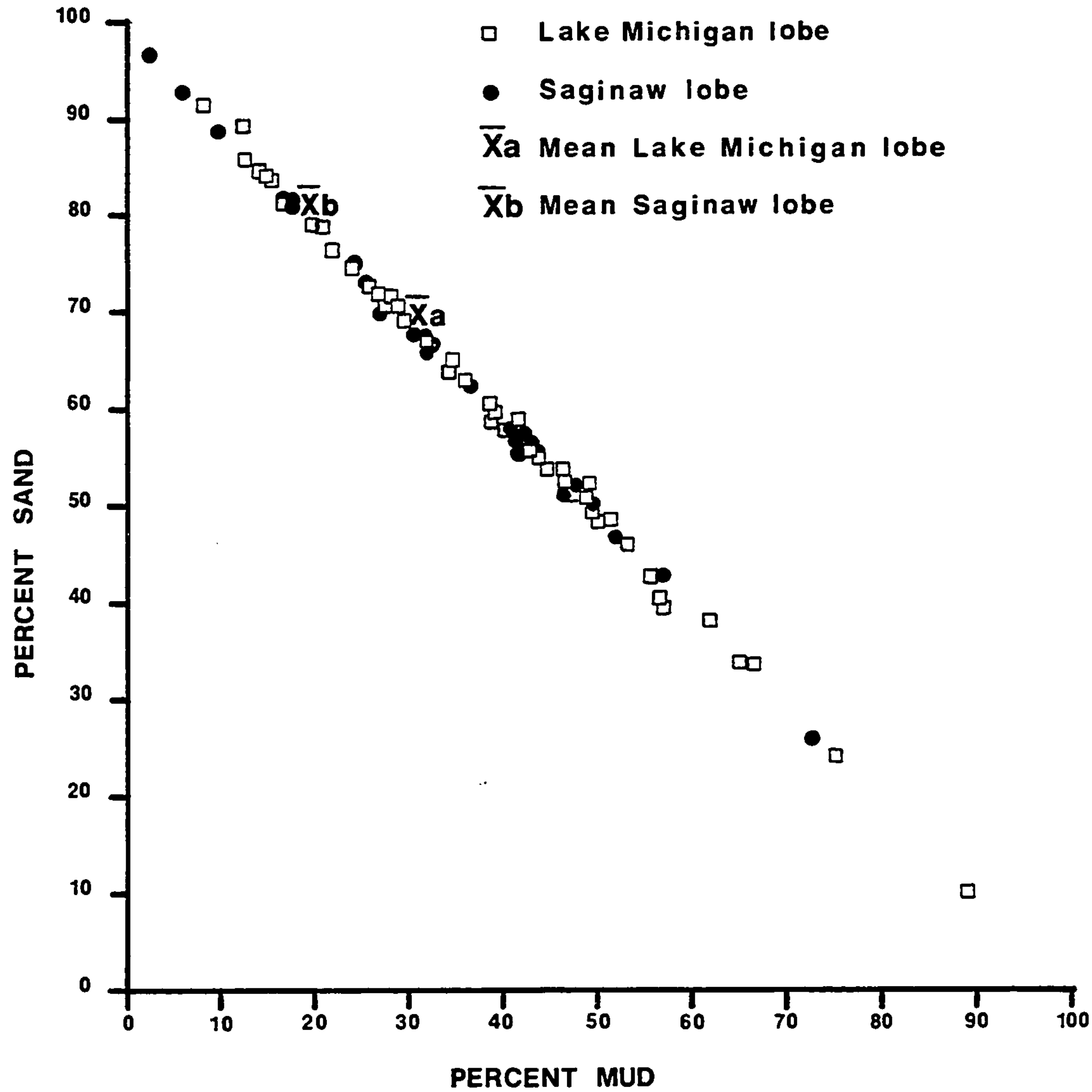


Figure 11. Plot of percent sand versus percent mud for samples from deposits of the Lake Michigan and Saginaw lobes ($\bar{X}a$, mean for Lake Michigan lobe = 69.45 percent sand and 31.55 percent mud; $\bar{X}b$, mean for Saginaw lobe = 81.10 percent sand and 19.90 percent mud).

from each lobe is not normally distributed (see Appendix II). The Mann-Whitney U Test for independence showed no significant difference in the populations from each lobe (Table 7, Appendix II). Yet, according to the Student T Test (Table 10, Appendix II) the difference in the mean sand/mud ratio for each lobe is significant at the 0.10 level. However, only levels of significance less than or equal to 0.05 are considered geologically significant in this study, although a level of significance of 0.10 clear-

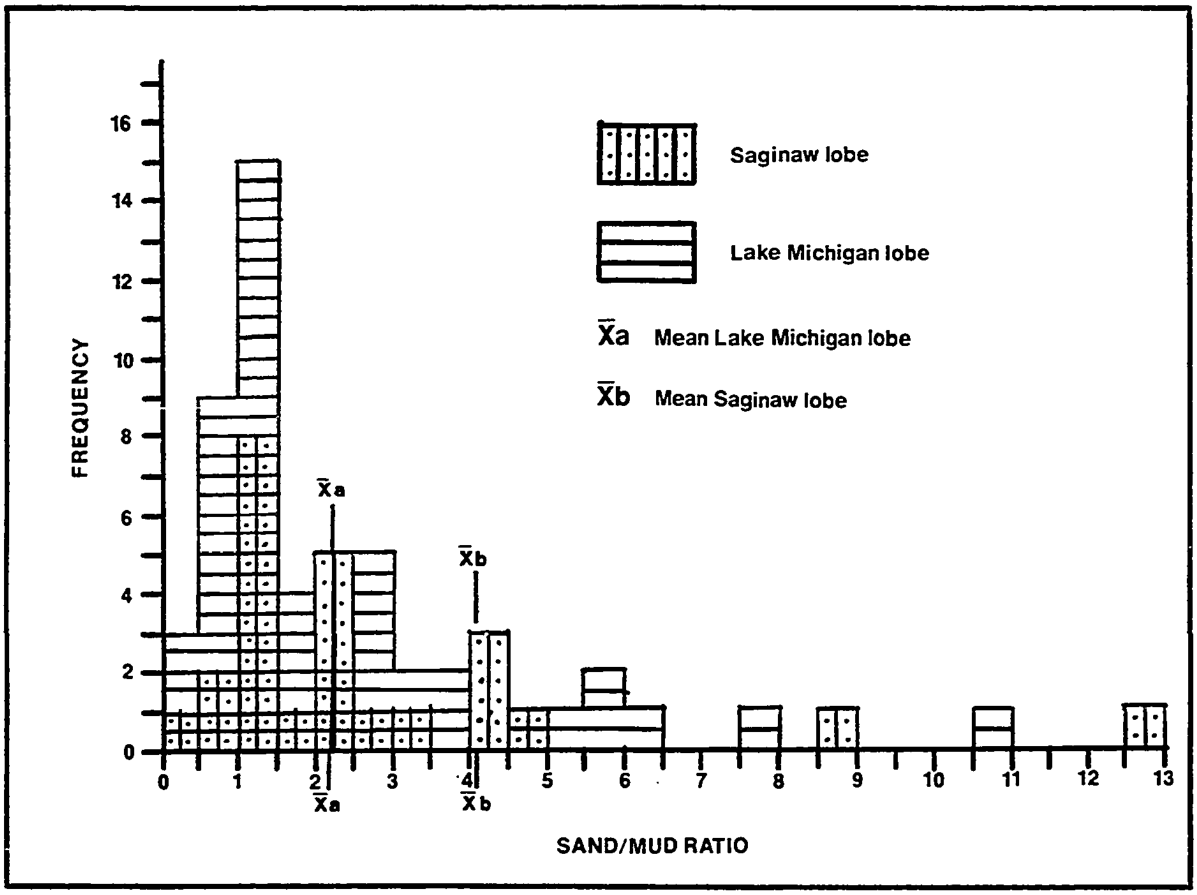


Figure 12. Histogram of the sand/mud ratio of samples from the Lake Michigan and Saginaw lobes showing the mean sand/mud ratio for each group of samples ($\bar{X}a$, mean Lake Michigan lobe = 2.249; $\bar{X}b$, mean Saginaw lobe = 4.095).

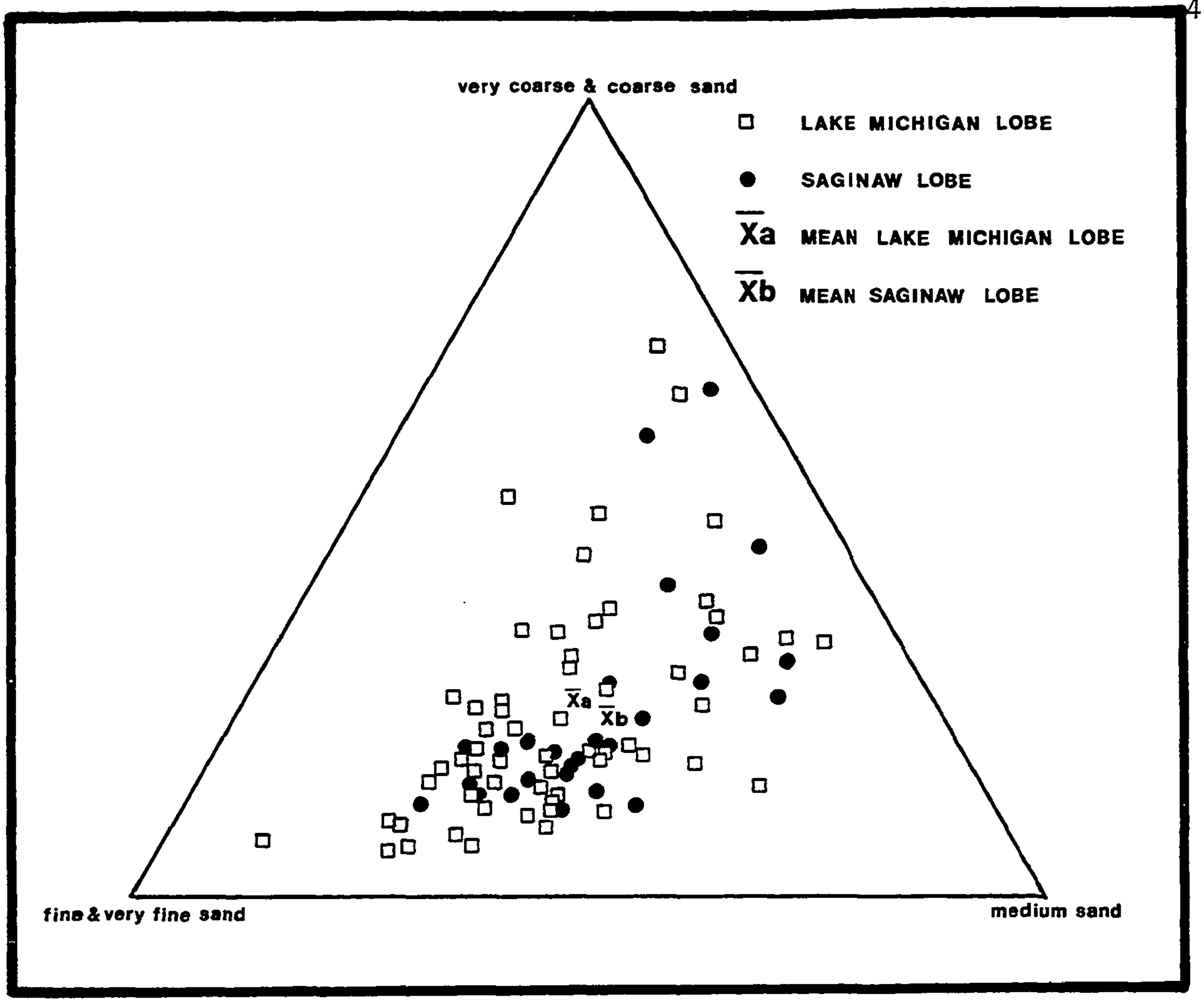


Figure 13. Ternary plot of the very coarse-coarse (18+35 mesh), medium (60 mesh), and fine-very fine (120+230 mesh) sand fractions in samples from both the Lake Michigan and Saginaw lobes showing the mean from each group of samples.

ly indicates the general truth of the assumption.

A ternary plot of the very coarse-coarse, medium, and fine-very fine sand fractions in samples from both the Lake Michigan and Saginaw lobe deposits illustrates that differences in texture of the matrix sand are small and overlap (Fig. 13). Similar overlap is observed when the percent of fine and very fine sand (120 plus 230 mesh) is plotted against the percent of heavy minerals from those fractions

(Fig. 14) and in the histogram of percent heavy minerals in the fine plus very fine sand (120 plus 230 mesh) from both lobes (Fig. 15). The Student T Test indicates that the difference in the heavy mineral content of the fine plus very fine sand fraction (120 plus 230 mesh) occurring in samples from both the Lake Michigan and Saginaw lobes

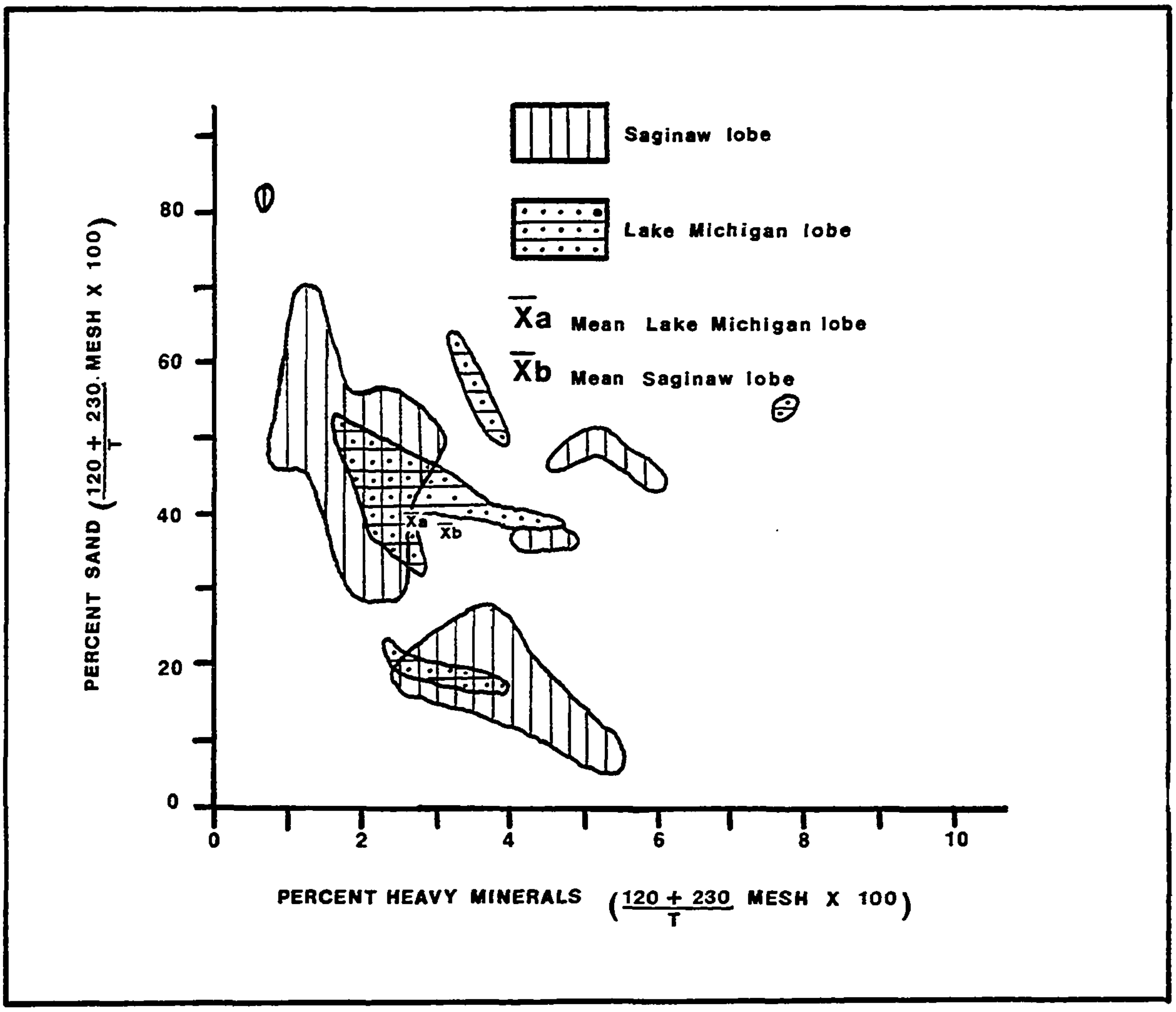


Figure 14. Graph of percent heavy minerals in the fine plus very fine (120+230 mesh) sand fractions in samples from Lake Michigan and Saginaw lobe deposits illustrating the mean percentage from each group of samples (T, total sand recalculated to 100%; X̄a, mean Lake Michigan lobe = 2.670; X̄b, mean Saginaw lobe = 3.133).

is significant at the 0.10 level. Again, however, the results are considered inconclusive (see Table 7, Appendix II).

Local variation in texture is often observed. For example, stations 22a and b, 31a and b, and 32a through d (Fig. 10) show variation in texture within a very local area (Table 1 of Appendix I). Samples a and b from station

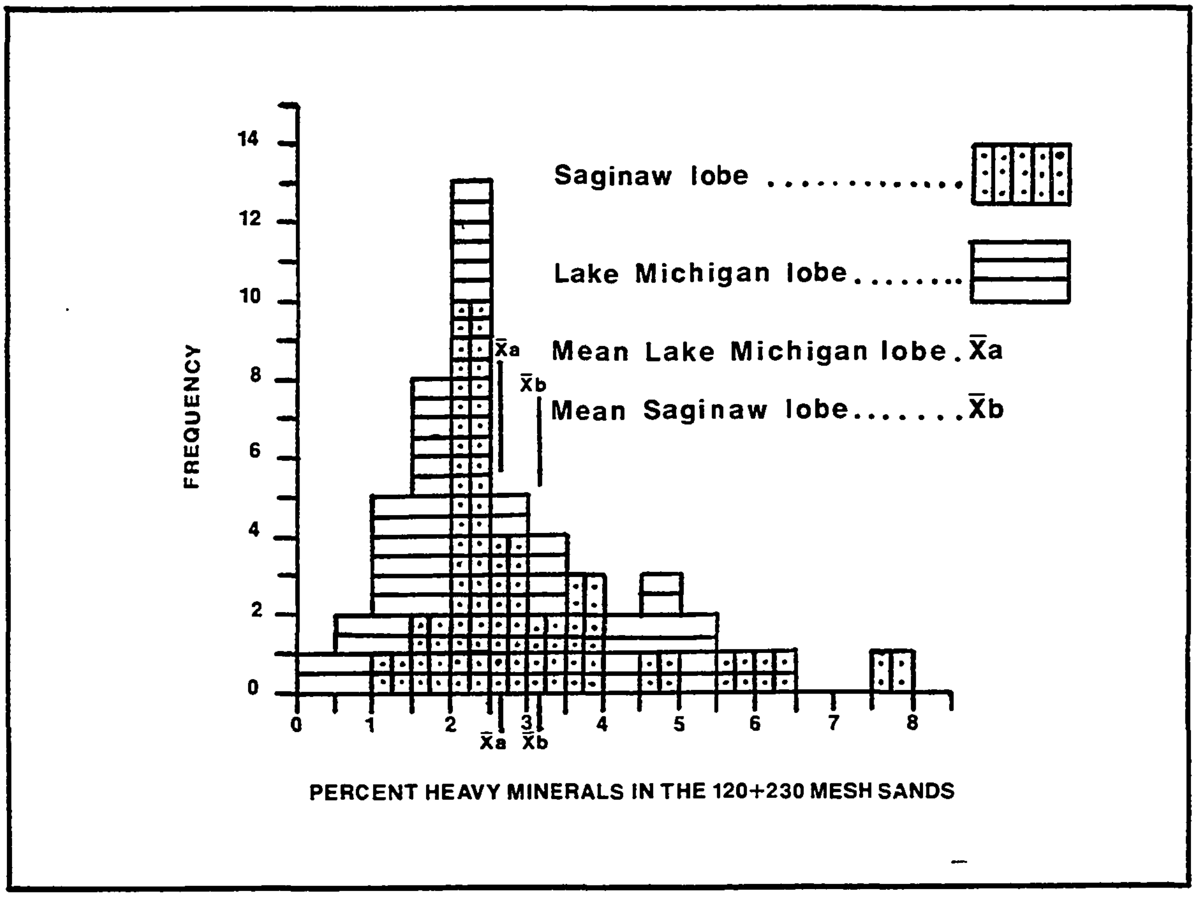


Figure 15. Histogram of the percent heavy minerals in the fine plus very fine (120+230 mesh) sands in samples from deposits of the Lake Michigan and Saginaw lobes illustrating the mean percentage for each group of samples ($\bar{X}a$, mean Lake Michigan lobe = 2.670; $\bar{X}b$, mean Saginaw lobe = 3.133).

22 (Fig. 10) were collected from sites separated by a lateral distance of approximately 30 feet (9.14 m). Station 22a contains 31.25 percent sand and 68.75 percent mud, whereas, 22b contains 60.64 percent sand and 39.36 percent mud. Variation in percent sand and mud taken in a vertical sequence was observed at stations 31 and 32 (Table 1 of Appendix I). Thus, because of variation and overlap in matrix textures both regionally and locally, delineation using textural data is inconclusive.

The texture of till is dependent on four factors: lithologic contribution of bedrock, comminution (dependent on mode of transport, either supraglacial, englacial, or subglacial), possible sorting of rocks and minerals during transport, the process of deposition, and post-depositional change (Dreimanis and Vagners, 1972). However, the texture of till matrix (that material less than 2 mm in size) depends mainly on the terminal grades of its constituent minerals (Dreimanis and Vagners, 1972).

A rock or mineral's terminal grade is the final product of comminution. Particle size range in till depends on the original size of the mineral grains when incorporated within the ice, as well as, their resistance during transport and distance of transport (Dreimanis and Vagners, 1972). Larger grade sizes of most rocks and minerals are reduced to under one-tenth of a percent of the original size in 8 to 80 kilometers of transport (Goldthwait, 1971). Most resistant minerals are brought to their terminal grade after 80 to 180 kilometers of glacial comminution (Dreimanis and Vagners, 1972). The terminal grade of garnets and other heavy minerals ranges from 2 to 5Ø (Dreimanis and Vagners, 1971).

The texture, as well as the composition, of till is greatly influenced by the composition of the local bedrock. However, because the study area is almost completely underlain by the Lower Mississippian Coldwater Shale, the effect of the local bedrock on the texture and composition of till is reduced. Therefore, the similarity and overlapping nature of the till matrix textures for the Lake Michigan and Saginaw lobe deposits within the study area can be attributed to the far traveled character of the till matrix.

Magnetic Susceptibility Analysis

The magnetic susceptibility (MS) of tills is dependent on the amount and distribution of the ferromagnetic minerals within the till, as well as, on the strength of the magnetic field employed in its measurement (Nagata, 1961). The property measured is the density magnetic susceptibility and represents the ratio of the intensity of magnetization produced in a substance to the magnetizing force to which it is subjected (Vonder Haar and Johnson, 1973).

Jones and Beavers (1964a) utilized magnetic susceptibility measurements to differentiate loess deposits in Illinois. Differences in susceptibility for these deposits reflected mineralogic differences which were interpreted to reflect differences in provenance. Gravenor and Stupavsky (1974) were able to differentiate tills found south of the Precambrian-Paleozoic boundary in Ontario using magnetic susceptibilities.

Magnetic susceptibility measurements were determined for samples from the initial grid area (stations 1 through 57, Fig. 10). Comparison of MS measurements with lobe designations based on X-ray and heavy-mineral analysis (Table 1 of Appendix I) shows no significant difference between the Lake Michigan and Saginaw lobe deposits. Statistical analysis of these data yield similar results (Appendix II). The Chi Square Test indicates that a non-normal distribution exists for populations from both the Lake Michigan and Saginaw lobes (Appendix II). The Mann-Whitney U Test and Student T Test both accepted their respective Null Hypothesis which state that two independent samples are from the same population, and the means of each population are equal (see Tables 8 and 11 of Appendix II).

The lack of correlation of MS values and till provenance for samples within the study area cannot be singularly explained. Several possibilities exist which could produce inconclusive data. First, inconclusive data may be obtained if the samples are weathered (Bleuer, 1976, personal communication). Oxidation and leaching of the till may change the valence states of the ferromagnetic minerals, thereby creating a likelihood of obtaining unreliable MS data. However, Gravenor and Stupavsky (1974), in Ontario, made MS measurements on samples from four localities in which both oxidized and unoxidized samples were used. The results obtained were identical within their range of accuracy. In a similar study, Vonder Haar and Johnson (1973) found that oxidized samples collected within their study area yielded essentially the same MS as unoxidized samples from the same location. Nonetheless, they further state that "in other situations or types of material, oxidation may influence the magnetic properties."

The question which should be asked is, if the samples are weathered to the point of causing erroneous magnetic susceptibility data, would not the data obtained from clay mineral and heavy mineral analysis also be effected?
In a discussion of weathered samples, Krumbein and Pettijohn (1938) concluded that the effects of oxidation are on the iron-bearing minerals. They further stated that mineralogic changes may or may not occur in oxidized samples. Assuming the conclusion of Krumbein and Pettijohn is true, samples taken from the study area could be oxidized and

therefore yield anomalous magnetic susceptibility while simultaneously yielding definitive mineralogic results. With this in mind, it is noteworthy that in this study, ratios of garnet versus epidote plus hornblende are successfully used to establish lobe provenance.

Second, as the area under investigation is an interlobate zone, the possibility of mixing exists. Oscillating lobes of ice may have mixed the concentrations of ferromagnetic minerals which effect MS. The viability of this explanation is somewhat diminished, however, when it is noted that clay and heavy mineral data are successfully used to delineate deposits of the Lake Michigan and Saginaw lobes. Presumably, had mixing occurred, not only would the concentrations of ferromagnetic minerals have been mixed, but also the clays and heavy minerals used in establishing glacial lobe provenance would have been mixed as well.

In considering the above, a question which arises is, "is it possible that mineralogic mixing could occur such that magnetic susceptibility appears similar in the opposing glacial tills, but yet, the clay mineralogy and heavy mineral content of the tills remain distinctive? Straw (1976, personal communication) observed that Saginaw lobe deposits near the airport in Kalamazoo, Michigan, show evidence of having been pushed by ice from the west (Lake Michigan lobe ice). Shah (1971) designated several weak moraines in Saginaw lobe drift which parallel known deposits of the Lake Michigan lobe as push moraines.

Examination of the mean magnetic susceptibility for deposits of the Lake Michigan and Saginaw lobes may lend support to the above question. The mean MS of the deposits of the Lake Michigan lobe is 3.218×10^{-4} cgs. Similarly, the Saginaw lobe deposits exhibit a mean value of 3.131×10^{-4} cgs. If, however, the deposits delineated as Lake Michigan lobe and Saginaw lobe material are divided into their respective east and west halves, a mean of 2.875×10^{-4} cgs is given for the eastern half of the Lake Michigan lobe and 3.565×10^{-4} cgs for the western half. From observation of magnetite sands along Lake Michigan's shore such an increase might be expected. The eastern half of the Saginaw lobe deposits shows a mean MS of 3.085×10^{-4} cgs while the western half exhibits a 3.114×10^{-4} cgs. The question now arising is, "is this phenomena of the westward increase in mean MS for tills from the Lake Michigan lobe and the eastward decrease in mean MS for the Saginaw lobe tills the result of mixing and if not, then what?"

The final possibility is that there is little or no difference in the values of magnetic susceptibility for samples collected within the study area. Statistical analysis of magnetic susceptibility data tends to substantiate this possibility. Examination of the histogram (Fig.

16) for MS shows overlap in the frequency of occurrence of MS for samples taken from the Lake Michigan and Saginaw lobes. The graph shows a marked similarity in percent frequency of occurrence. Additional support is found when it is noted that a similar overlap occurs when comparing percentages of ferromagnetic and other heavy minerals

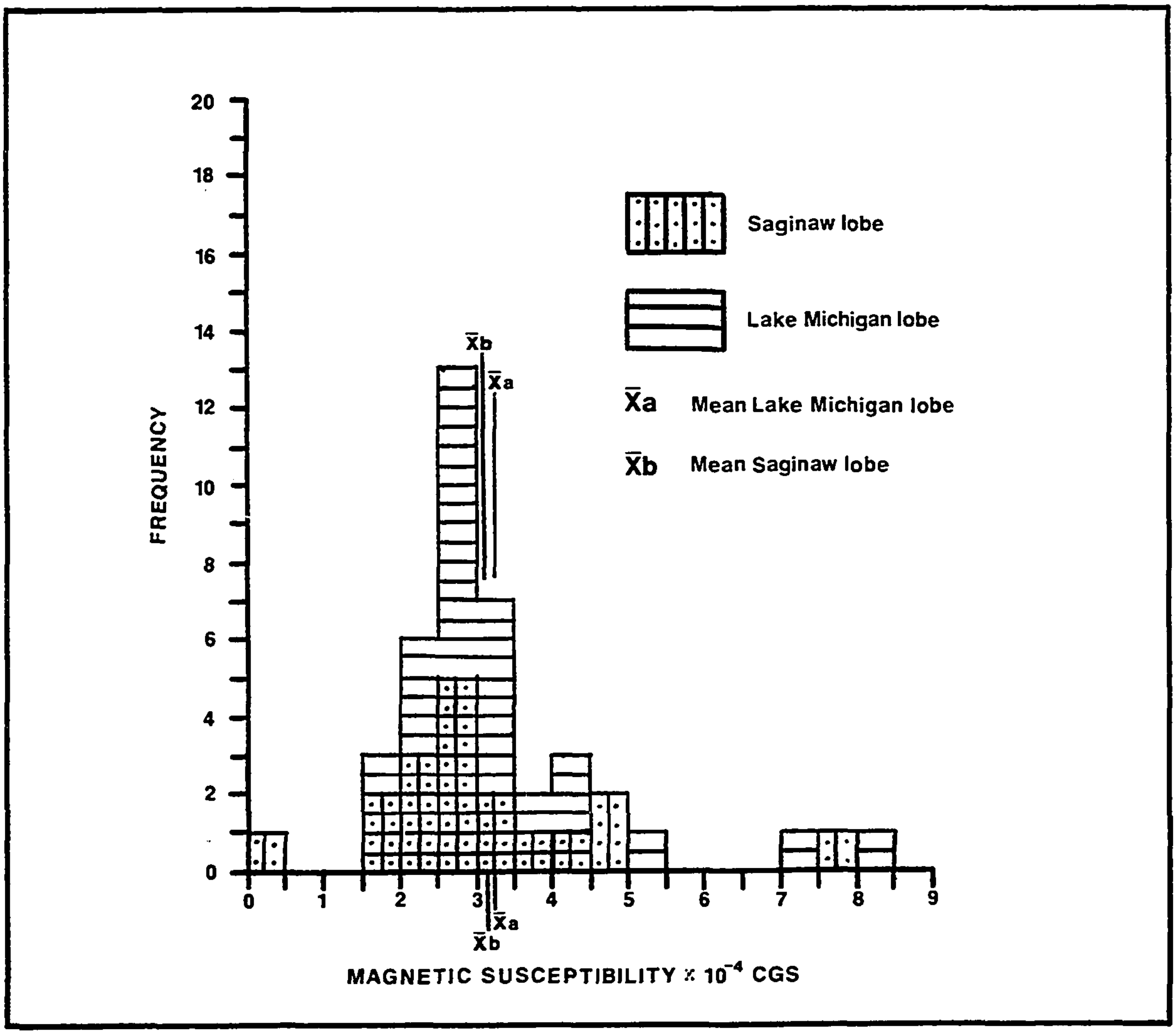


Figure 16. Histogram of the magnetic susceptibility of samples taken from deposits of the Lake Michigan and Saginaw lobes illustrating the mean magnetic susceptibility of each group of samples ($\bar{X}a$, mean Lake Michigan lobe = 3.218; $\bar{X}b$, mean Saginaw lobe = 3.131).

(Table 4).

Gravenor and Stupavsky (1974) established that there is a significant correlation between the amount of magnetic material and the amount of heavy minerals in a till. Till samples taken from the study area show a range of 0.69 to 6.85 percent weight of heavy minerals for Lake Michigan lobe tills and 1.42 to 7.66 percent weight of heavy minerals for Saginaw lobe tills. Therefore, a lack of correlation of magnetic susceptibility and provenance for tills within the study area may be due to the similarity, as well as, the variability of the percent range of heavy minerals. However, as a majority of the samples collected are from oxidized surface exposures, the effect of weathering cannot be discounted.

TABLE 4. Percent range of predominant heavy minerals. Minerals observed but not included in Table are rutile, apatite, staurolite, and kyanite.

Mineral	Range of percent occurrence	
	Lake Michigan lobe	Saginaw lobe
Hornblende	50-63%	37-57%
Magnetite	14-24%	7-28%
Biotite	4- 9%	4-14%
Epidote	7-10%	6-22%
Garnet	6-11%	11-16%
Tourmaline	0- 2%	0- 1%
Sphene	0- 3%	0- 7%
Zircon	0- 1%	0- 1%
Pyrite	0- 2%	0- 1%

Heavy Mineral Analysis

The study of heavy minerals in glacial tills is well established in the geologic literature (Derry, 1934; Dreimanis and Reavely, 1953; Dreimanis, et al., 1957; Breene, 1957; Brophy, 1959; Frye, Williams, and Glass, 1960; Sitler, 1963). Gravenor (1951), in a study of heavy mineral suites from southwestern Ontario tills, concluded that the heavy minerals were contributed mainly by the crystalline rocks of the Canadian Shield. Similar observations were made by earlier workers (Krumbein, 1933; Kruger, 1937) in establishing the provenance of tills.

By assuming that heavy mineral suites in tills are reflective of provenance, it follows that ratios of heavy minerals can be statistically used to distinguish tills from separate glaciers. To test this assumption 15 randomly chosen thin-section grain mounts containing heavy minerals from the fine and very fine sand fractions were selected from samples of each lobe. Three hundred grain determinations were made per slide. Ternary plots of heavy mineral data obtained from this analysis illustrate the viability of delineating tills based on provenance by this method (Fig. 17).

Bleuer (1975) had success in delineating tills of the Lake Michigan, Saginaw, and Erie lobes in Indiana by such a method. He reports that the Lake Michigan lobe tills are

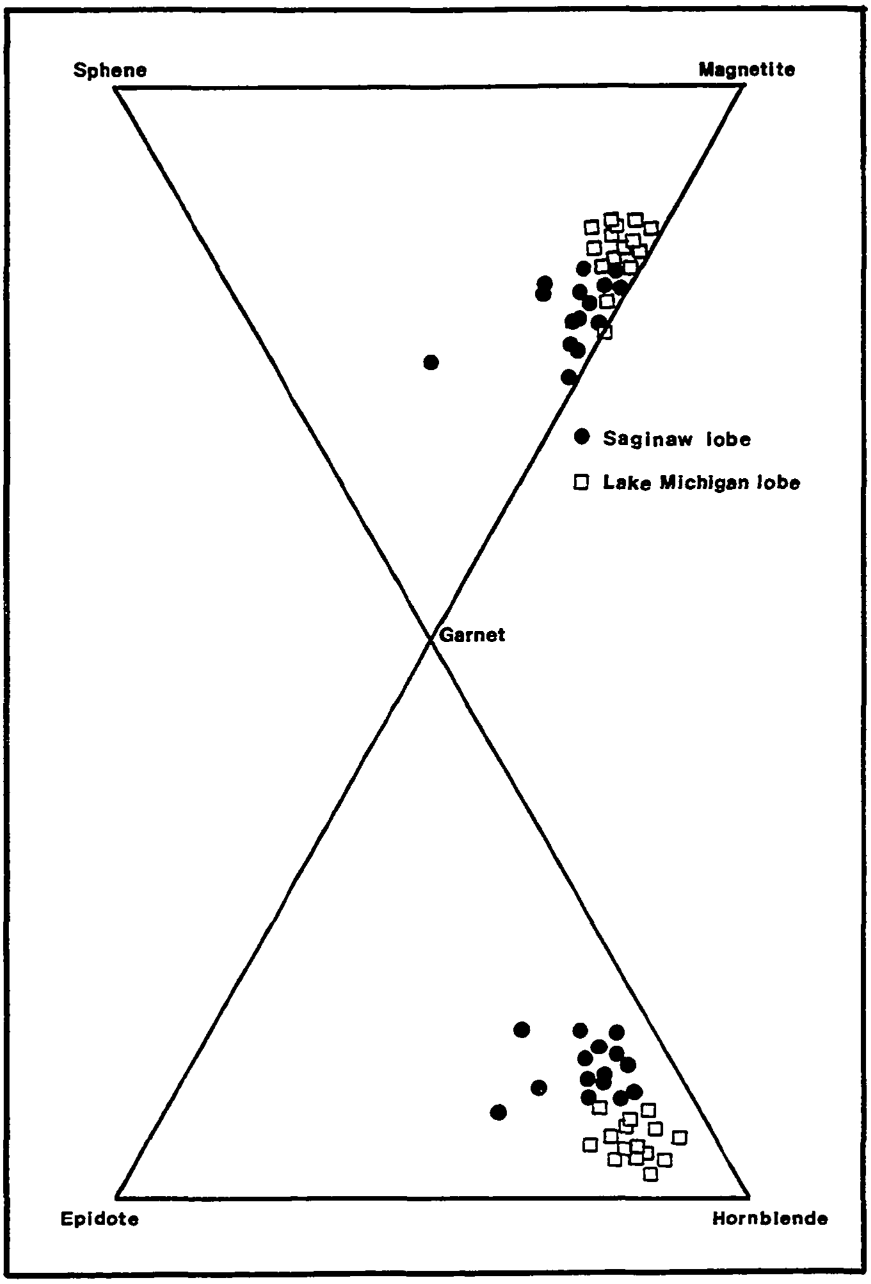


Figure 17. Ternary plots of heavy mineral assemblages occurring in the fine plus very fine (120 + 230 mesh) sand fraction of samples from tills of the Saginaw and Lake Michigan lobes.

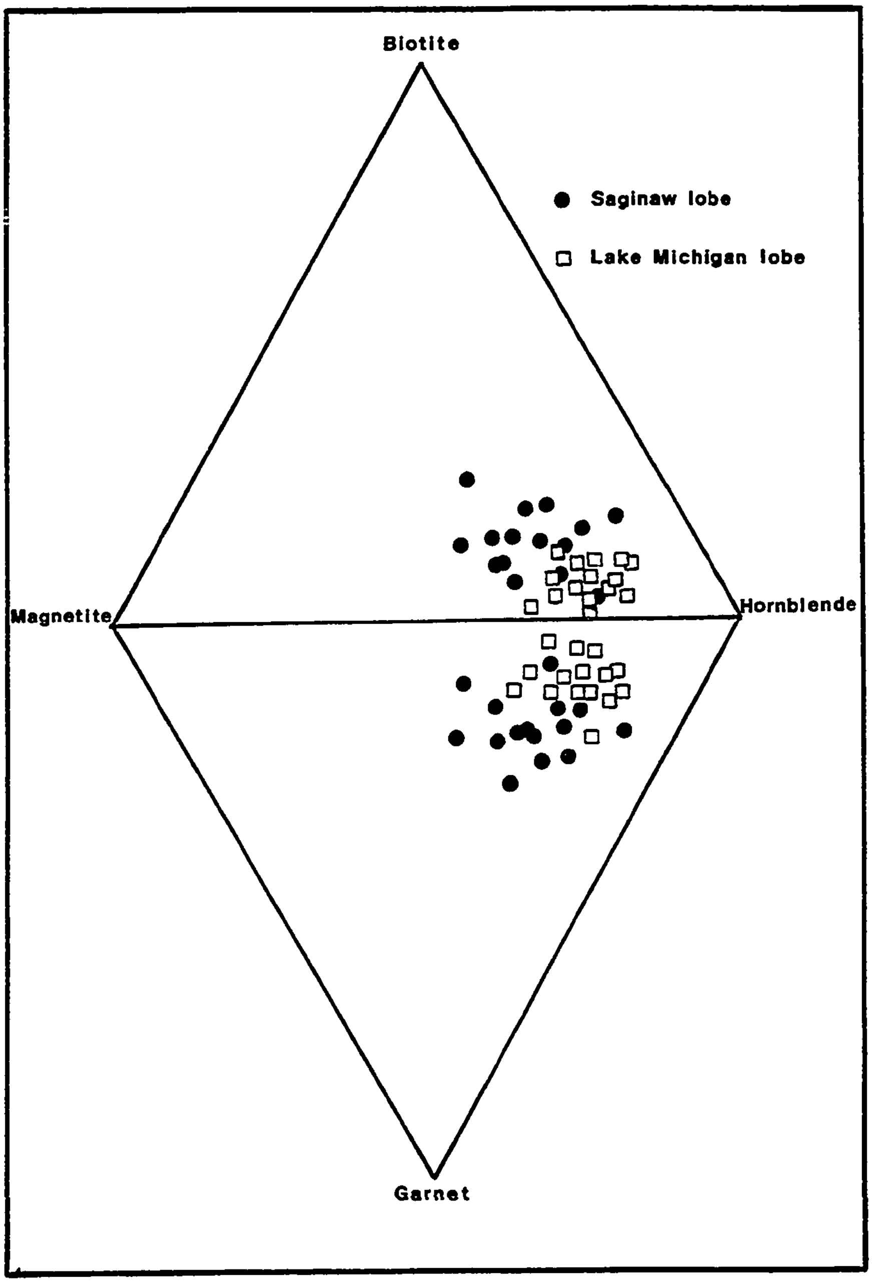
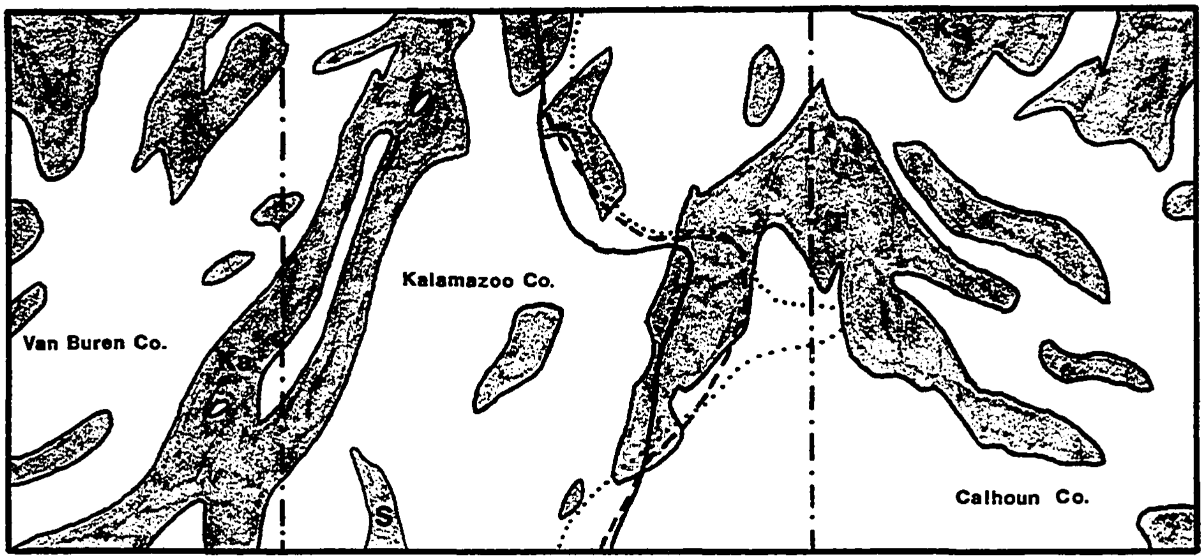


Figure 17. Continued.

characterized by garnet/epidote ratios ranging from 1:1 to 3:1 and the Saginaw and Erie lobe tills were reported as having ratios varying from 3:1 to 4:1. Utilizing the method of Bleuer (1975) on till samples from southwestern Michigan, heavy mineral analysis was performed and a boundary was established between the Lake Michigan lobe and the Saginaw lobe in the interlobate area of Kalamazoo County, Michigan (Fig. 18). Data from this analysis may be found in Table 1 of Appendix I.

Comparison of the interlobate line based on garnet/epidote plus hornblende ratios with Shah's interlobate line (1971) based on the morphology of weak morainal ridges (Fig. 18) show marked similarity. However, the more eastward position of the interlobate line based on heavy mineral ratios, such that it includes completely that portion of the Tekonsha moraine considered as a Lake Michigan lobe deposit, seems more realistic than splitting the moraine, as does Shah's interlobate boundary (Fig. 18).

Statistics were performed on all heavy mineral data (Appendix II). Chi Square Test indicates that the garnet/epidote plus hornblende ratio of the sample population from each lobe is not normally distributed (see Fig. 19 and Appendix II). The Mann-Whitney U Test (Table 9 of Appendix II) shows that the sample population from each lobe is independent and significant at the 0.010 level. The Student T Test (Table 12 of Appendix II) illustrates



V Valparaiso moraine

K Kendall moraine

Ka Kalamazoo moraine

S Sturgis moraine

T Tekonsha moraine

Interlobate boundary of Shah, 1971

Interlobate boundary based on X-ray diffraction data

Interlobate boundary based on heavy mineral data

Figure 18. Map of the study area showing morainal development (grey), and interlobate boundaries based on garnet/epidote+hornblende ratios (dashed line), X-ray diffraction analysis of 7Å/10Å peak-height ratios (dotted line), and the morphology of weak morainal ridges developed by the Lake Michigan lobe (solid line, from Shah, 1971).

that the difference in the mean garnet/epidote plus hornblende ratio for each lobe is significant at the 0.005 level.

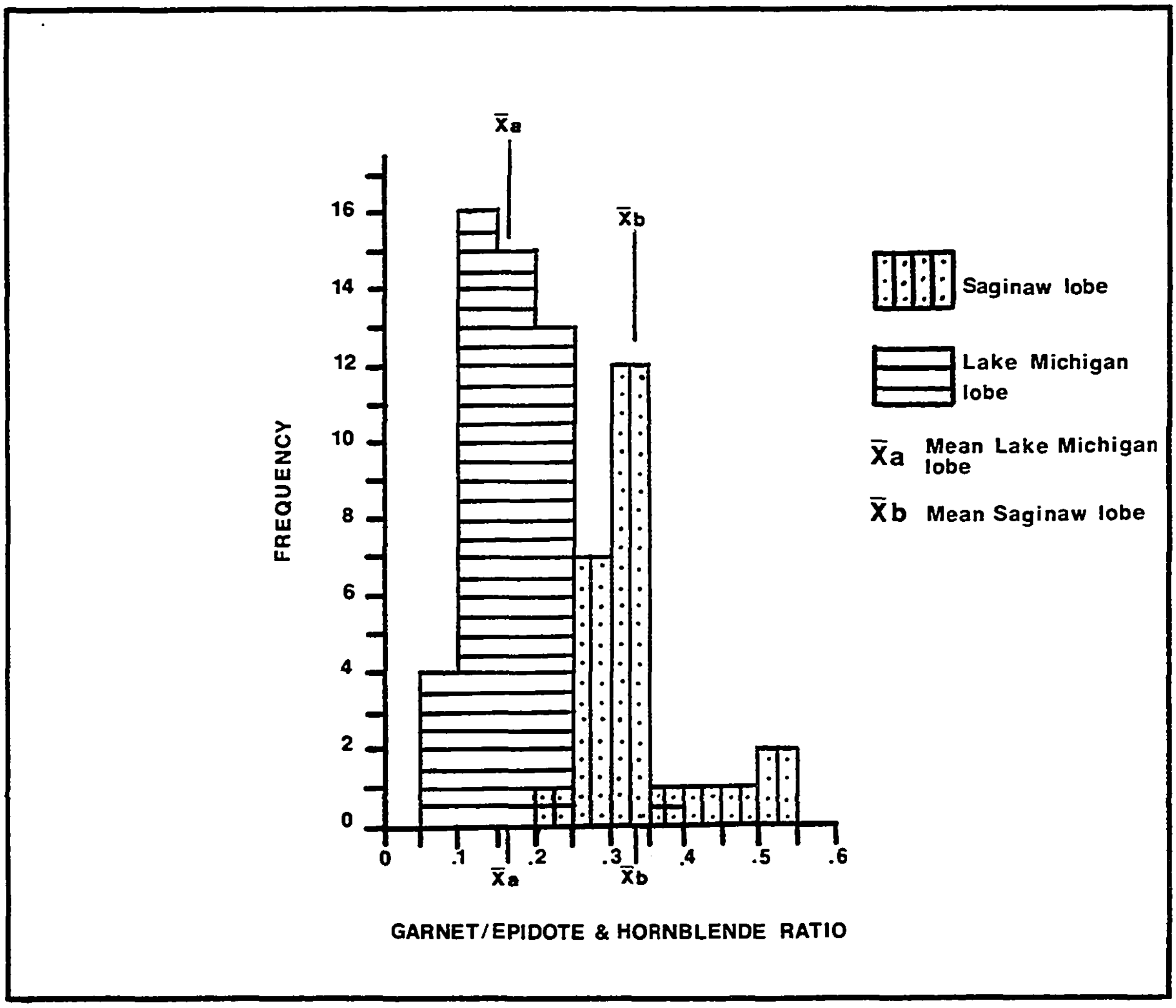


Figure 19. Histogram of garnet/epidote+hornblende ratios from till samples of the Lake Michigan and Saginaw lobes illustrating the mean garnet/epidote+hornblende ratio for each group of samples ($\bar{X}a$, mean Lake Michigan lobe = 0.166; $\bar{X}b$, mean Saginaw lobe = 0.338).

X-ray Diffraction of Clays

The use of X-ray diffraction techniques to differentiate glacial drift has been investigated in numerous studies. Frye (1968), in studies published by the Illinois Geological Survey, discussed the utilization of data derived from clay-mineral studies of drifts of differing ages and areal extent. Castillion (1972) located an interlobate contact between two surficial tills in Illinois partially by the use of clay-mineral data. In Michigan, Rieck (1976) made use of 7Å/10Å peak-height ratios to distinguish tills of Saginaw lobe and Huron-Erie lobe provenance.

Modifying the methods of Rieck (1976), Glass (1976, personal communication), and Gluskoter (1967), X-ray diffractograms (Fig. 20) of basally-oriented clays were obtained using a Norelco, water cooled, X-ray diffractometer. Glycolated samples were run from 2^{o} to 30^{o} 2θ. Copper K-alpha radiation and a nickel filter were used. Subsequently, peak-height ratios of 7Å and 10Å peaks were determined (Table 1 of Appendix I) and an interlobate boundary established within the study area (Fig. 18).

Chlorite, illite, kaolinite, and vermiculite comprise the major clay minerals in the samples. It is assumed that the intensity of the 10Å peak was produced by illite. The

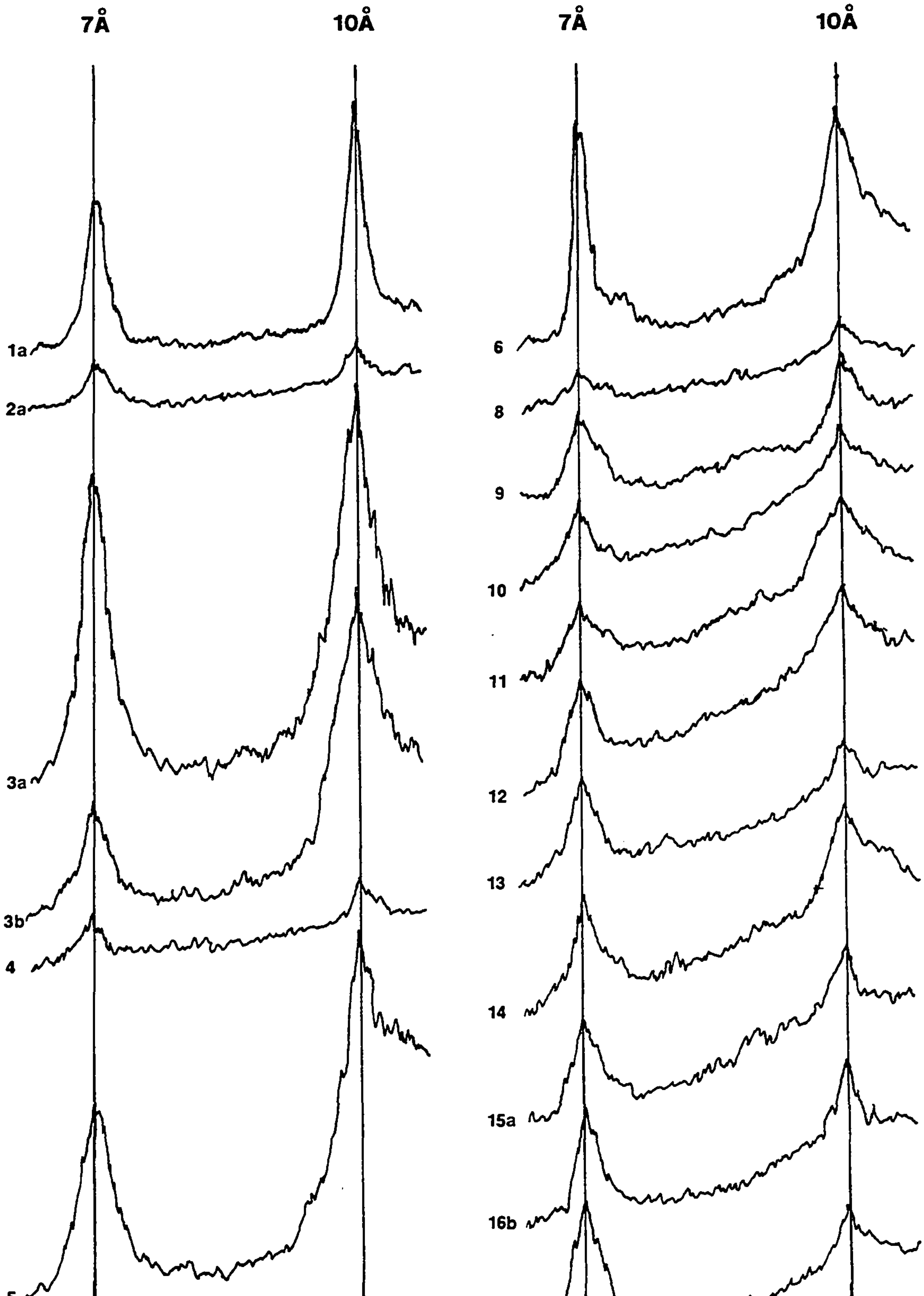


Figure 20. X-ray diffractograms of surface till samples from the Lake Michigan and Saginaw lobes showing the 7Å and 10Å peaks produced by clay minerals (see Fig. 10 and Table 1 of Appendix I for the location and glacial lobe designation).

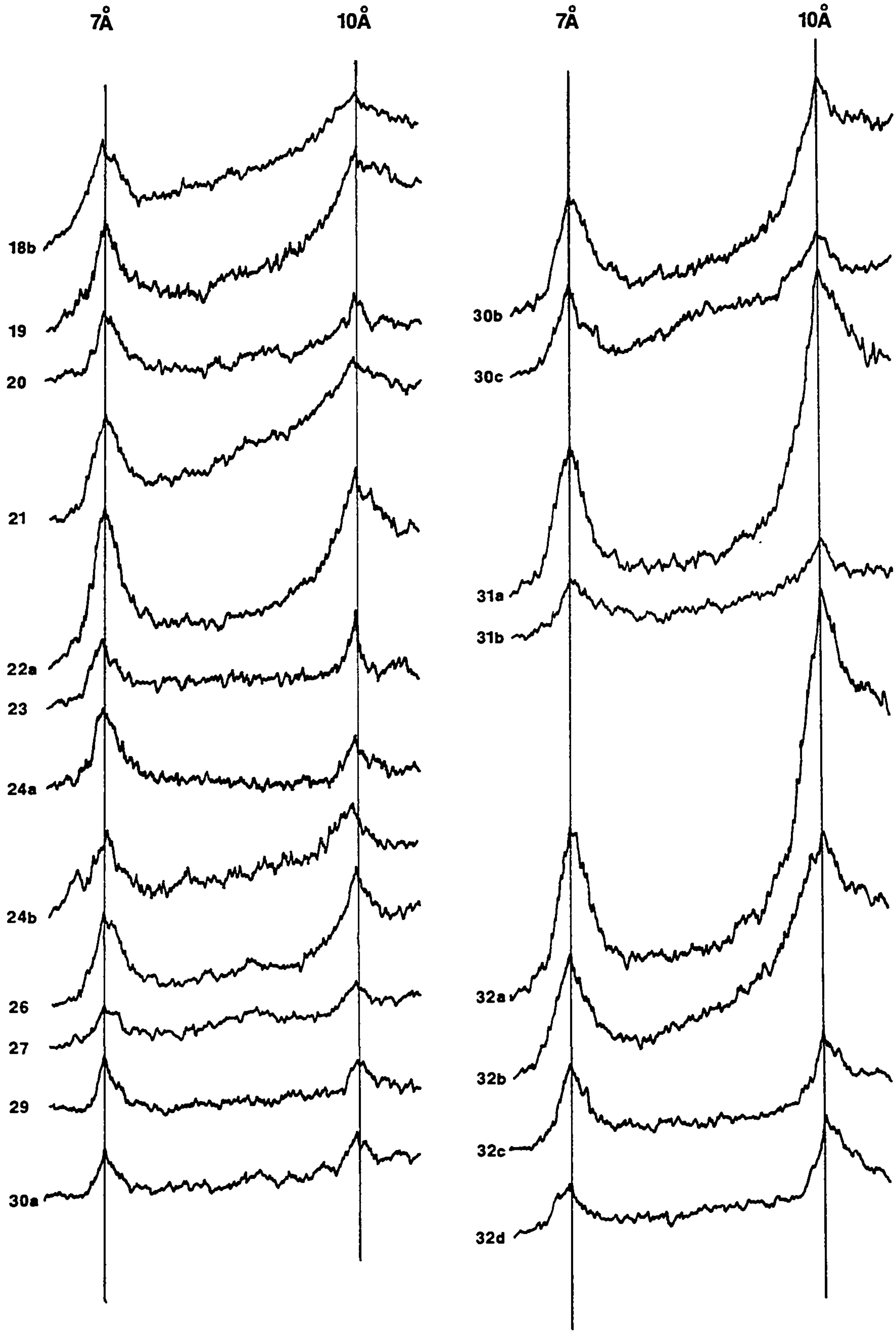
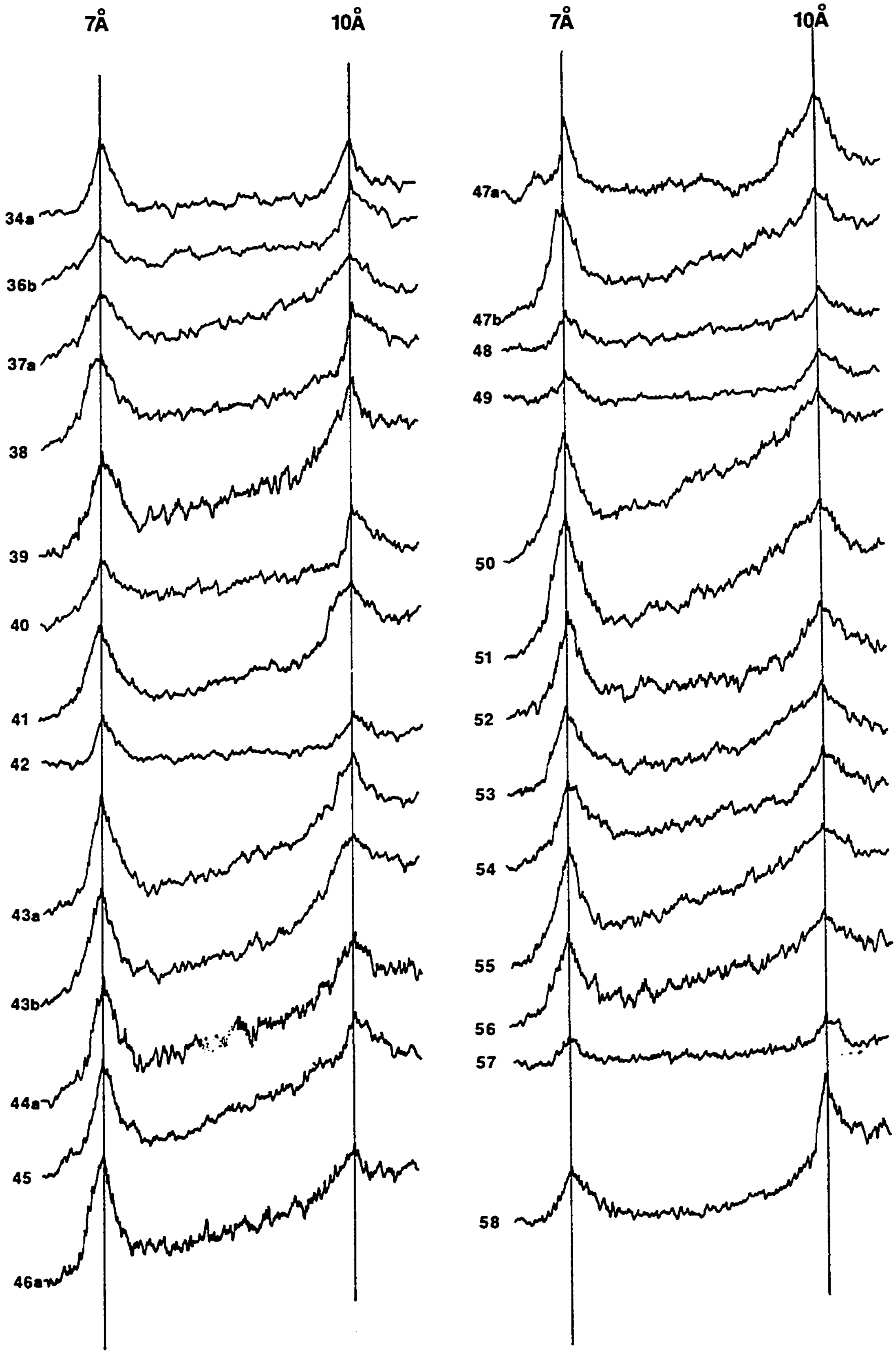


Figure 20. Continued.



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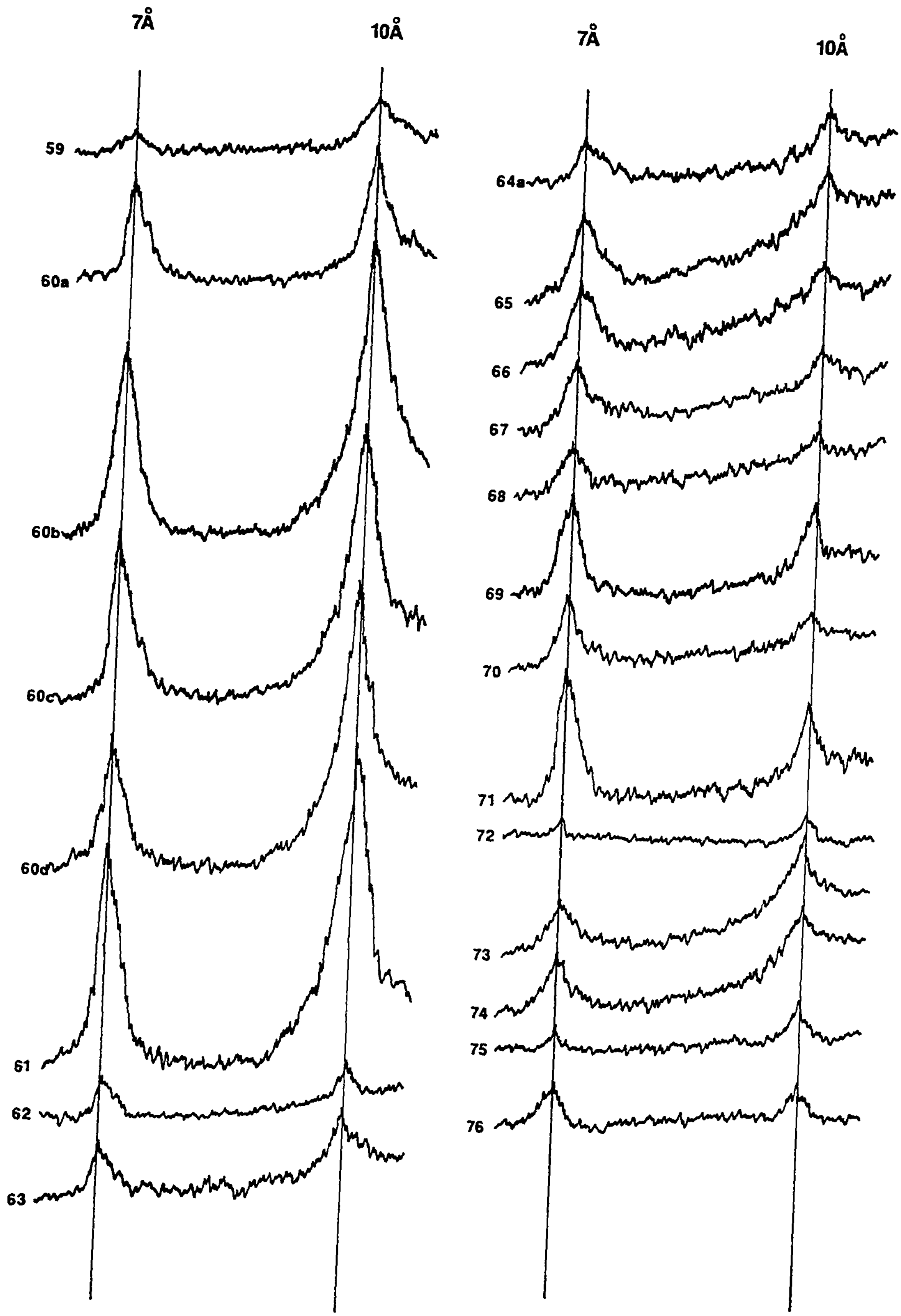

Figure 20. Continued.

7Å peak was produced either individually or by a combination of chlorite, kaolinite, and/or vermiculite. Rieck (1976), in delineating tills from southeastern Michigan, obtained similar results. He stated that "the 7Å/10Å ratio is not a complete mineralogical characterization but is only used to group samples investigated." Thus, because a ratio of the intensities was used and these intensities were observed on the same diffractogram, comparison between different diffractograms can be performed without

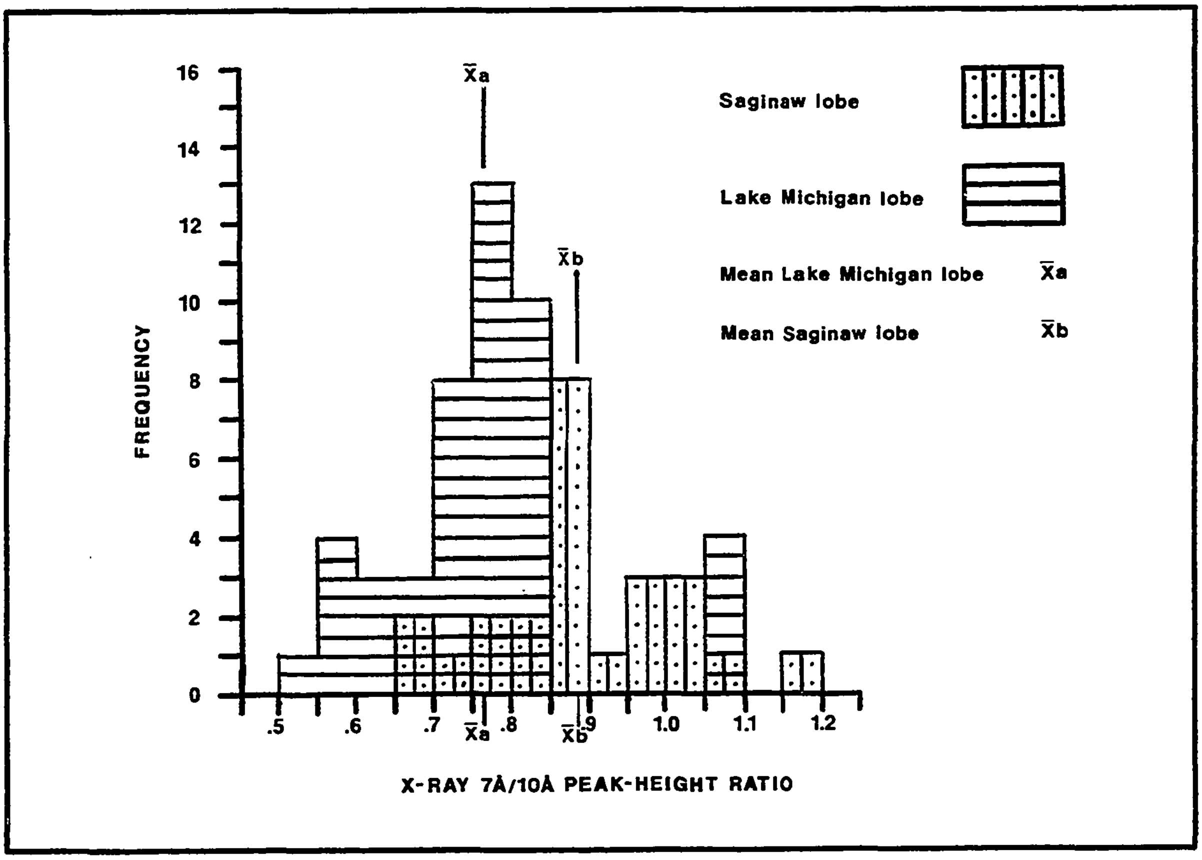

Figure 21. Histogram of 7Å/10Å peak-height ratios from X-ray diffractograms of samples from Lake Michigan and Saginaw lobe deposits showing the mean 7Å/10Å peak-height ratio in each group of samples ($\bar{X}a$, mean Lake Michigan lobe = 0.766; $\bar{X}b$, mean Saginaw lobe = 0.888).

using an internal standard (Rieck, 1976).

All data was statistically analyzed (see Appendix II). The Chi Square Test indicates that the 7Å/10Å ratios for the sample populations from each lobe are not normally distributed (Fig. 21 and Appendix II). The Mann-Whitney U Test (Table 8 of Appendix II) indicates that the samples from each lobe are independent at the 0.01 level. Student T Test illustrates that the difference in the mean 7Å/10Å ratio for each lobe is significant at the 0.005 level (Table 11 of Appendix II).

Relationship of Bedrock Geology to Mineral Content in Local Tills

The composition of a till is greatly influenced by the composition of the local underlying bedrock. Commonly greater than 50 percent of the bulk mineral content of a till may be representative of the composition of the bedrock beneath it. This is not true of tills found within the study area.

As evidenced by the heavy mineral suites from the 120 and 230 mesh sands of till samples collected in the study area, the mineral content of tills within the study area is largely derived from sources outside its boundaries. Large quantities of igneous and metamorphic boulders, cobbles, and gravels also indicate sources foreign to the study area. This is more easily understood when it is observed that an estimated 90 percent of the study area is underlain by the Mississippian Coldwater Shale.

According to Anderson (1957), who examined the pebble and sand lithologies of samples from the axial portion of several major Wisconsinan glacial lobes within the Central Lowlands province, the sand fraction of the Saginaw lobe samples contain 34.4 percent Paleozoic lithologies and 10.6 percent Precambrian lithologies. Lake Michigan lobe samples show 84.5 percent Paleozoic and 4.2 percent Precambrian lithologies. Within the pebble fraction, the Saginaw lobe contains 39.1 percent Precambrian and 60.9 percent Paleozoic lithologies. Of the Paleozoic lithologies, the Mississippian Marshall Sandstone constitutes approximately 3.6 percent. The Lake Michigan lobe pebble lithologies consist of 10.7 percent Precambrian and 89.3 percent Paleozoic rocks. The lithologic indicators point to an eastern source for both lobes.

Anderson (1957) postulated a Huronian source for both lobes. He stated, however, that the Lake Michigan lobe has fewer Huronian rocks as it appears to have by-passed the main Huronian source area of Lake Huron and acquired more granitic material farther northwest. A Huronian provenance for Saginaw lobe tills is more conclusively established by the presence of jasper conglomerate and rare pebbles of the Precambrian Gowganda tillite (Slawson, 1933) which are commonly associated with Saginaw lobe deposits. As demonstrated by Slawson (1933), the source of the jasper conglomerate is localized in the Bruce Mines area (Fig. 22). The location of this jasper conglomerate in the Bruce Mines area brings it to the axis of the Lake Michigan and Lake Huron lobes such that most fragments from this area were transported by the Saginaw lobe of the Huronian ice. It should be noted, however, that Lake Michigan lobe ice also transported, at the very least, several of the red jasper conglomerate and the Precambrian tillite erratics. Leverett (1915), Terwilliger (1954), and Shah (1971) all reported finding jasper conglomerate in the Kendall moraine considered herein as a Lake Michigan lobe deposit. Furthermore, this author found boulders of the Precambrian Gowganda tillite in Lake Michigan lobe deposits in Kalamazoo County.

Relationship of Bedrock Topography to Morainal Development

A moraine, in the strictest sense, is a morphologic feature composed of sediments deposited directly by active glacial ice. Numerous morainal classifications exist and within each there are a number of morainal types. However, the classification of moraines is beyond the scope of this text and only those moraines deposited within the study area at the margin of an active continental glacier are considered herein.

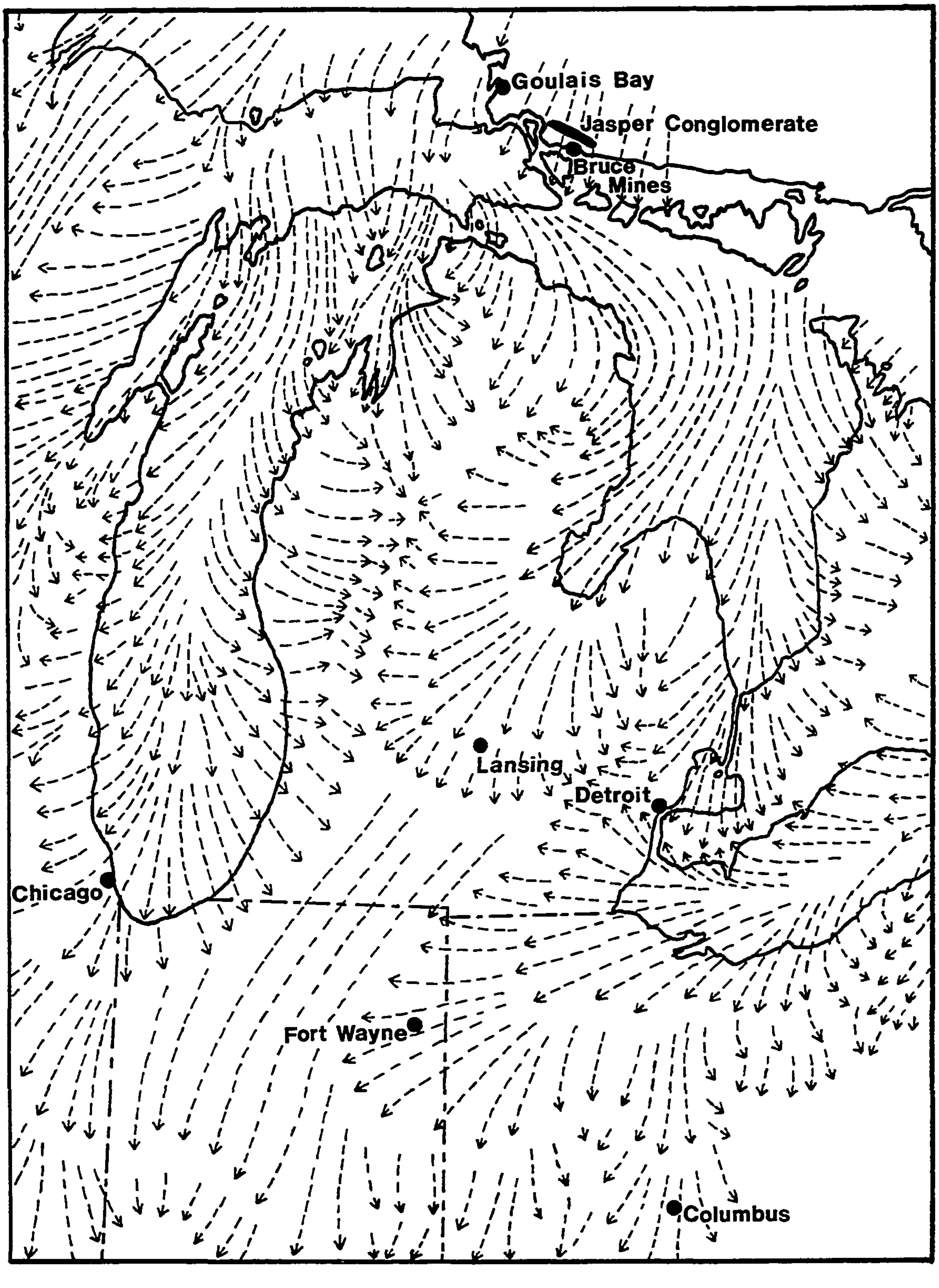

Figure 22. Map of ice flow directions during the Wisconsinan glaciation of North America showing the provenance and possible movement directions of the jasper conglomerate erratics associated primarily with Saginaw lobe tills (after Leverett and Taylor, 1915, in Slawson, 1933).

The Saginaw and Lake Michigan glacial lobes may be regarded as independent ice flows of the major Wisconsinan continental glacier; each being greatly, though not totally, controlled by bedrock topography (Anderson and Horberg, 1956). The position of ice centers, configuration of ice sheets, and deflection by adjacent glacial lobes is of secondary importance (Anderson and Horberg, 1956).

Morainal development may occur when the ablation rate, or rate of back wasting by melting and ablation, approximately equals the rate of forward movement of the ice. The net result being a stationary ice front. At such a stationary ice front, the forward movement of the ice continually brings glacial drift to the terminus where it is released from the ice, forming a moraine (end moraine).

The topographic expression of an area may influence morainal development. A topographic high or low, as well as a sharp break in slope may impede the forward movement of glacial ice and effect deposition of drift if the landform acts as a barrier to forward movement. Shah (1971) postulated that the general northwestward slope of the bedrock surface in southwestern Michigan toward the Lake Michigan lowland may have promoted movement of Lake Michigan lobe ice toward the east and southeast. The result of such movement being enhanced glacial modification of existing bedrock topography. Similarly, the effectiveness of erosion by Saginaw lobe ice may have been lessened when encountering the bedrock highland in the southeastern portion of the area (Shah, 1971; Fig. 23).

Comparison of the bedrock topography to the distribution of moraines in southwestern Michigan (Fig. 24) illustrates the relationship of bedrock topography and morainal development. Note the position of the Kalamazoo moraine (K) of the Saginaw lobe located in the northeast corner of the study area, and the Tekonsha moraine (T) in the eastern portion of the study area. Both moraines are located on topographic ridges. The Sturgis moraine (S) on the border of Cass and St. Joseph Counties is illustrative of bedrock valley or depression control while the Kalamazoo moraine of the Lake Michigan lobe shows morainal development with "ridge control" in its southwestern portion and "valley and slope break control" as the moraine extends northeastward.

In comparing the relationship of bedrock topography to the distribution of Wisconsinan moraines in southwestern Michigan, the effect of pre-Wisconsinan glaciation should be considered. Assuming, therefore, that bedrock topography influences morainal development, sequential glaciation should result in a repetition of morainal development. Thus, although Wisconsinan ice may not have actually contacted true bedrock, the influence of bedrock topography on Wisconsinan morainal development may have been transmitted, at least partially, through prior glacial landforms.

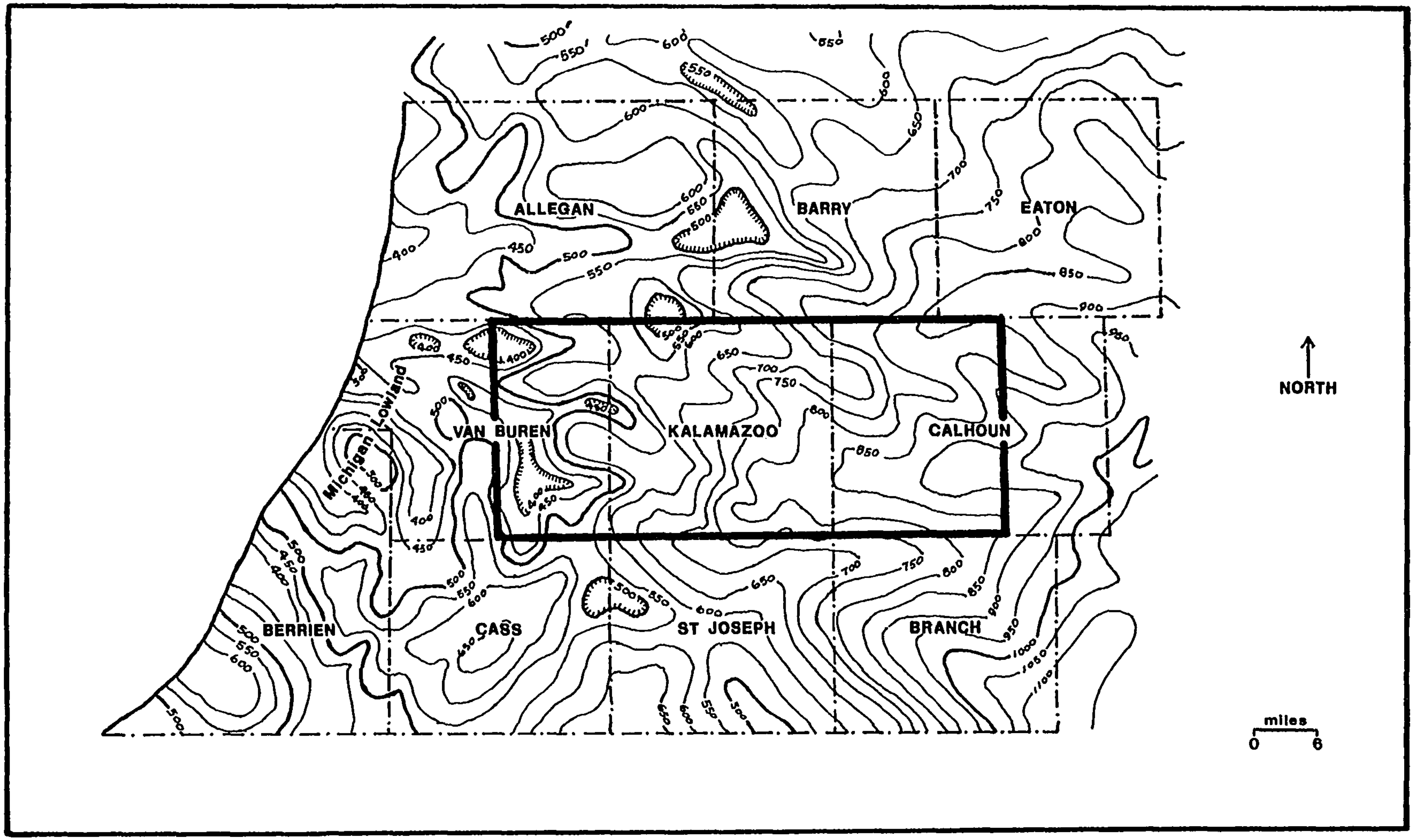

Figure 23. Map showing the bedrock topography of southwestern Michigan (modified from Shah, 1971). Study area heavily outlined.

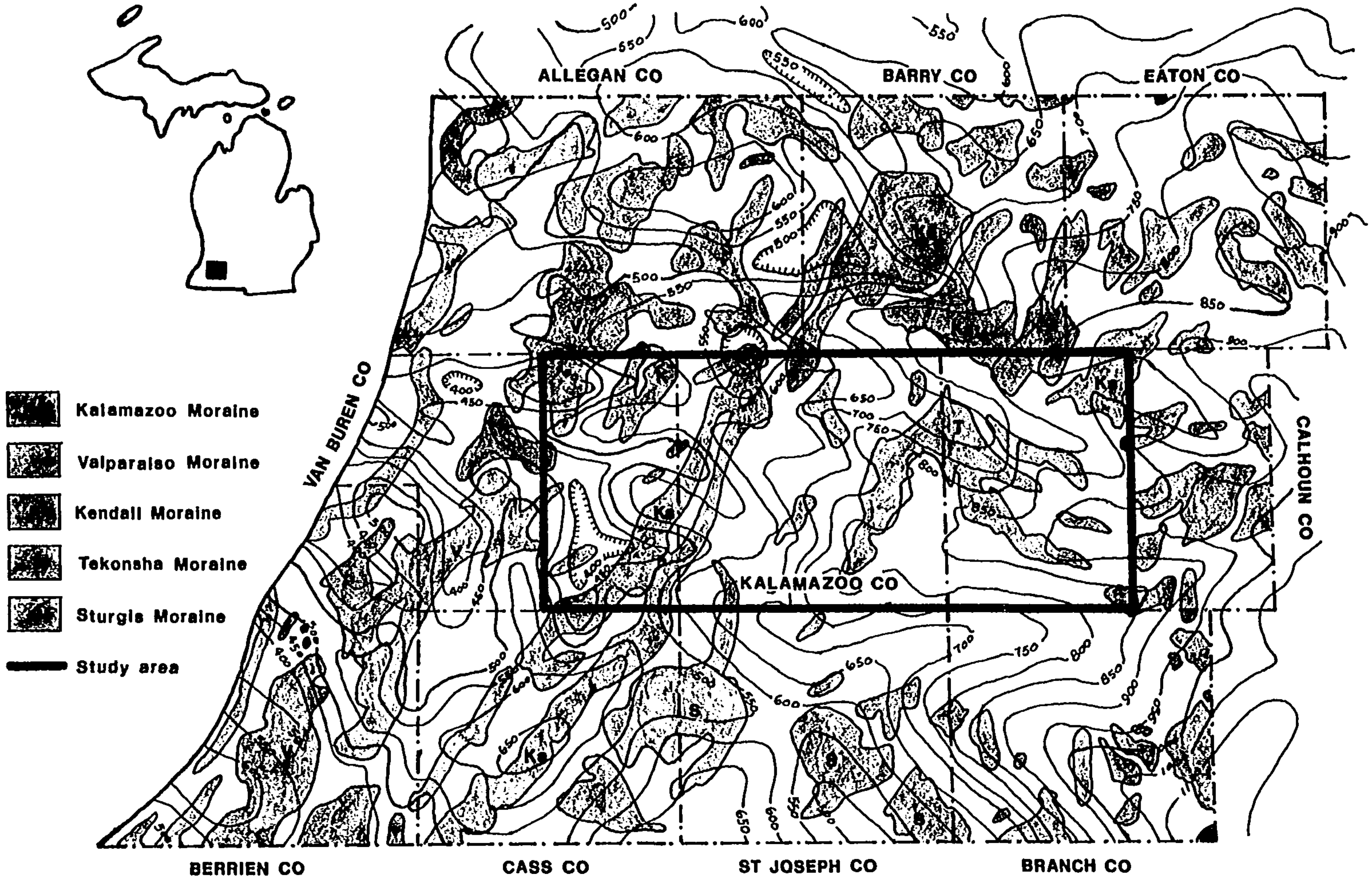

Figure 24. Map illustrating the relationship of bedrock topography to morainal development (shaded) in southwestern Michigan (modified from Shah, 1971, and the Michigan Geological Survey, 1975).

Deglaciation of the Study Area

At the beginning of deglaciation of southwestern Michigan and the study area, Saginaw lobe ice extended slightly south of the Michigan-Indiana border, while Lake Michigan lobe ice was well contained in its basin to the west. As the Lake Michigan lobe advanced slowly to the south-southeast, Saginaw lobe ice retreated to the position of the Sturgis moraine in St. Joseph County, Michigan (Fig. 25). Shah (1971) stated that when the Saginaw lobe was in this position, it deposited the Alamo and Kendall moraines in northwestern Kalamazoo and northeastern Van Buren Counties. With additional retreat of the Saginaw lobe and continued advance of the Lake Michigan ice, Shah (1971) further postulated that the Lake Michigan lobe overrode the Kendall and Alamo moraines while advancing to and stagnating at a position near the present main axis of the Kalamazoo moraine. Till samples collected on the Kendall and Alamo moraines were analyzed using X-ray diffraction and heavy mineral suites as previously described. The results indicate that the Kendall and Alamo moraines are deposits of the Lake Michigan lobe. Thus, when the Saginaw lobe was positioned at the Sturgis moraine in St. Joseph County, the Lake Michigan lobe probably was at or near the present Kalamazoo moraine in Kalamazoo and Cass Counties.

Following the formation of the Sturgis moraine in St. Joseph County, the Saginaw lobe continued its retreat leaving a series of till and outwash plains (Fig. 25). At the position of the Tekonsha moraine the Saginaw ice halted to develop a strong recessional moraine. The Lake Michigan lobe, however, began to advance from its position near the Kalamazoo moraine, overriding it and pushing its way toward the western border of the present Tekonsha moraine. At this position the Lake Michigan ice deposited the northeast-southwest trending arm of the Tekonsha moraine and began or continued development of the Sturgis moraine in western St. Joseph County and eastern Cass County. Contemporaneous with the above is the development of weak morainal ridges in Saginaw lobe sediments which Shah (1971) defined as the outermost limit of the Lake Michigan lobe in southwestern Michigan (Fig. 9).

Overriding of the Kalamazoo moraine is supported by several lines of evidence. First, the presence of ablation till from the Lake Michigan lobe over the Kalamazoo moraine implies that ice passed over the moraine and at some point became stationary and melted lowering the ablation till to the surface. Second, Shah (1971) reported the presence of thin till plains over outwash plains in Cooper and Prairie Ronde Townships of Kalamazoo County. This implies a rapid retreat of a thin sheet of ice leaving ground moraine (Fig. 25). Third, the presence of weak morainal ridges (push

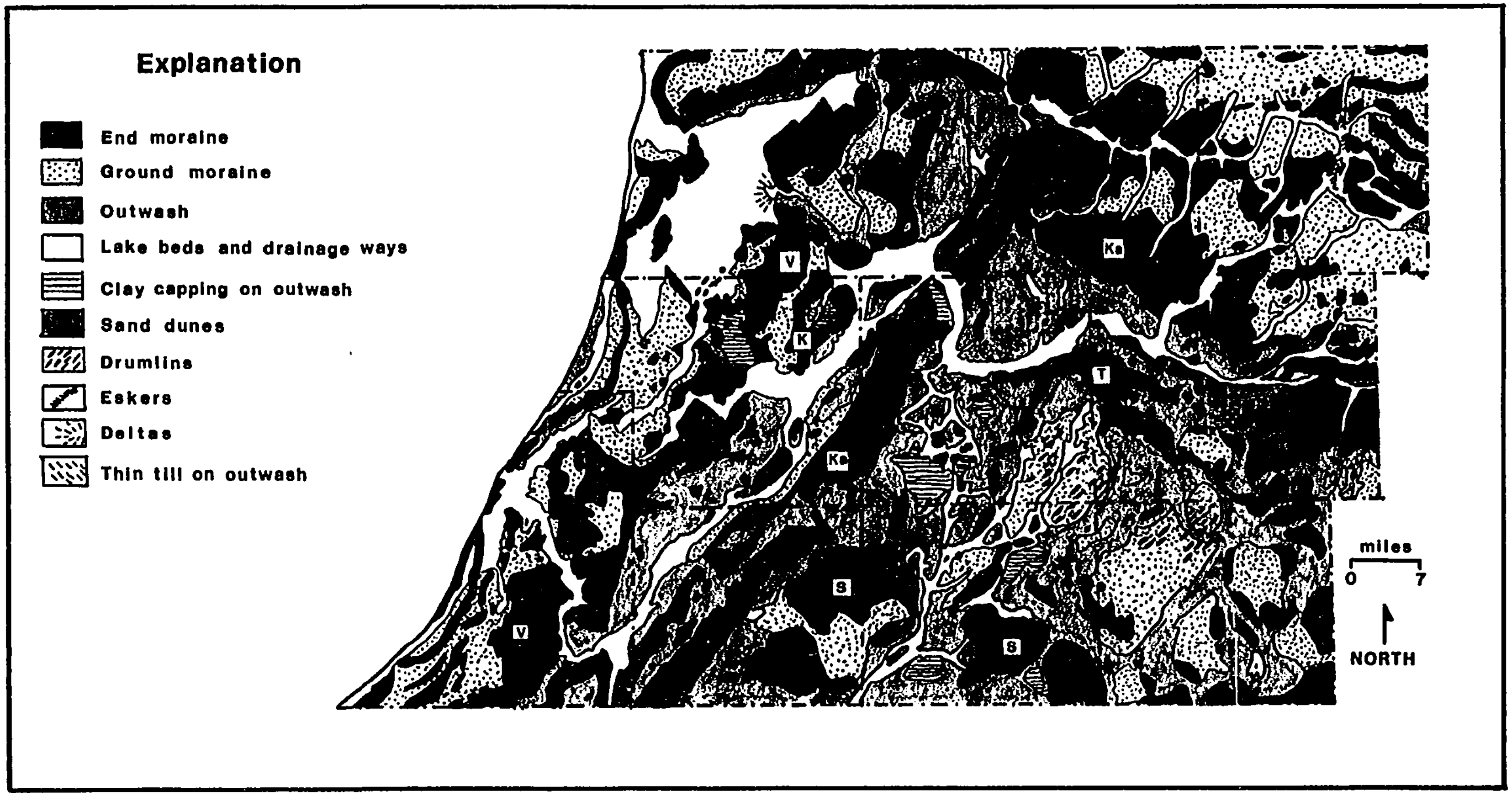

Figure 25. Surface geology of southwestern Michigan (after Shah, 1971) showing Wisconsinan glacial deposits (V, Valparaiso moraine; K, Kendall moraine; Ka, Kalamazoo moraine; T, Tekonsha moraine; S, Sturgis moraine).

moraines of Shah, 1971) east of the Kalamazoo moraine which parallel other known moraines of the Lake Michigan lobe and possibly indicate glacial surges resulting from differential flow-lag. Fourth and last, folding occurs in the drift material of the Kalamazoo moraine (Fig. 26). Such folding indicates overriding of the moraine and subsequent deformation of the underlying drift resulting from stresses imparted by the moving ice.

With the ice fronts of both lobes standing at their respective positions of the Tekonsha moraine, melt-waters

Figure 26. Photograph of a fold occurring in the drift of the Kalamazoo moraine of the Lake Michigan lobe indicating the overriding and deformation of the moraine by Lake Michigan lobe ice in Wisconsinan time (photograph taken by W. T. Straw, 1973, on the campus of Western Michigan University).

from both lobes combined with melt-waters from the Erie lobe ice to form the Kankakee Torrent (Fig. 7, see previous discussion). The Kankakee Torrent discharged to the southwest as an ice marginal stream bordering the Lake Michigan lobe ice.

A slight readvance of the Saginaw lobe is indicated by drumlins and a thin ablation till on the northwest-southeast trending Tekonsha moraine. The ice front advanced at least as far as the drumlin field southeast of Kalamazoo County. The small morainic forms extending northwest from Bronson Township in Branch County (T7S,R8W) may represent the outer limit of this oscillation.

As the Saginaw lobe retreated rapidly back to the Tekonsha moraine, the Lake Michigan ice retreated slowly westward toward the Kalamazoo moraine. Oscillation of the Lake Michigan ice front is marked by thin linear moraines in Prairie Ronde, Portage, and Cooper Townships of Kalamazoo County.

The Saginaw lobe continued its retreat from the Tekonsha moraine slowly to the position of the northwest-southeast trending Kalamazoo moraine. With both lobes stationary at their corresponding Kalamazoo moraine, a period of standstill resulted in the massive morainic system of today.

Continued westward retreat of the Lake Michigan lobe ice resulted in deposition of the Kendall, and later, the

Valparaiso morainic system previously discussed. The history of the Saginaw and Lake Michigan lobes outside of the study area through the remainder of their retreat during Wisconsinan time is generally described in Leverett and Taylor (1915). References discussing the deglaciation of Michigan during Wisconsinan time include the following: Dorr and Eschman (1971), Eschman and Farrand (1974), and Wayne and Zumberge (1965).

SUMMARY AND CONCLUSIONS

Tills within the study area are generally poorly consolidated, although compact tills may be found in localized areas or at depth. Gravels are common and a wide range of lithologies are represented, the majority being derived from Canadian Shield bedrock sources.

The effect of local bedrock on the composition of till within the study area is markedly lessened because approximately 90 percent of the study area is underlain by the Lower Mississippian Coldwater Shale. Heavy mineral suites in the 120 and 230 mesh sands also are reflective of a Canadian Shield provenance.

Morainal development shows a strong correlation with bedrock topography in the study area. The Kalamazoo and Tekonsha moraines of the Saginaw lobe are located on bedrock highs. It is possible that forward movement of the Saginaw ice was impeded by these bedrock highs and resulted in the deposition of the present-day morainal systems. The Sturgis moraine in Cass and St. Joseph Counties is located in a bedrock low. Argument is made that any break in slope may halt the forward movement of a weak ice front and, thereby, "trigger" the deposition of till and subsequent morainal development.

The deglaciation of Michigan in Wisconsinan time left the state covered with the present-day glacial landforms. While the history of deglaciation in the past has been based primarily on morphologic evidence (the morainal systems) and has dealt with broad regional areas, recent studies have turned to a more detailed description of localized areas. Analytical techniques have been developed and utilized which allow the discrimination of glacial sediments with differing source areas. These techniques have proven particularly effective in areas of glacial lobe convergence.

Portions of five (5) morainal systems are found in the study area. Lake Michigan lobe ice is responsible for part or all of the Valparaiso, Kendall, Sturgis, and the northeast trending Kalamazoo and Tekonsha moraines. The Saginaw lobe developed the northwest trending arms of the Kalamazoo and Tekonsha moraines and a portion of the Sturgis moraine in St. Joseph County and eastward.

The interplay of the Lake Michigan lobe and Saginaw lobe ice in southwestern Michigan resulted in the development of a classic interlobate area. In the past, morphologic characteristics of the area have been utilized to describe the character and relationship of the ice fronts during deglaciation. In the present study, textural and mineralogic parameters are used to enhance the knowledge of the interlobate boundary relationship of the Lake Michigan and Saginaw lobes in Kalamazoo County, Michigan.

Results using textural and magnetic susceptibility data to delineate tills of the Lake Michigan and Saginaw lobes are inconclusive. Marked variability in till texture in localized areas precludes any textural correlation on a regional scale. A ratio of percent sand/percent mud, however, shows that Lake Michigan lobe tills have a statistically higher clay content than Saginaw lobe tills. The inconclusive nature of results from magnetic susceptibility analysis cannot be singularly explained. It is hypothesized that either the results are truely inconclusive, or the mixing of tills by the interplay of the two ice lobes and weathering, either singularly or in combination, resulted in poor magnetic susceptibility measurements.

An interlobate boundary relationship is established using differences in ratios of heavy minerals and clay mineralogic data. Comparison of the interlobate boundaries using the above methods with Shah's interlobate boundary

(1971) based on the morphology of weak morainal ridges shows similar results. However, the position of the interlobate boundary further to the east, as defined in this study, appears more reasonable as it includes the entire northeast trending limb of the Tekonsha moraine.

Suggestions for Future Research

The use of heavy mineral suites to delineate tills of differing provenance has been established in past literature. Although heavy mineral separations often prove to be tedious and time consuming, the results from such data are the least effected by outside variables such as weathering, etc. It is therefore suggested that future research in delineating till by provenance consider the use of heavy mineral analysis as an especially viable tool.

Field observations and literature review characterize the morainal deposits within the study area as containing relatively large amounts of stratified drift. Attention should be given this fact and a detailed study of the proportions of stratified and unstratified drift embodied by the moraines of the area is recommended. Such a knowledge would greatly add to the understanding of morainal development within the study area.

As it is questioned whether the weathering of tills and the mixing of tills within the study area are singularly or jointly responsible for inconclusive magnetic susceptibility analysis, attention should be given to the effects of weathering and mixing on analytical techniques used to delineate tills of differing provenance.

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APPENDIX I

TABLE 1. Location, textural, magnetic susceptibility, X-ray diffraction, and garnet/epidote + hornblende ratio data (symbols: X, X-ray; H, heavy minerals; B, bulk weight, defined as the sample weight of the original sample minus the gravel fraction; S, Saginaw lobe; L, Lake Michigan lobe; A, anomaly; O, outwash; Ga, garnet; Ep, epidote; Hbd, hornblende)

Sample station	1/4 Section	Section	Township	Range	Bulk Wt. (grams)	Mag. Susc. X 10^{-4} cgs	7Å/10Å Peak Height	Ga/Ep + Hbd	Percent Sand	Percent Mud	Lobe Provenance	Sand/Mud Ratio
1.	NE	13	2S	12W	203.10	4.30	0.721	0.210	53.80	46.20	L	1.164
2.	SW	30	2S	11W	198.00	2.70	0.796	0.144	50.21	49.79	L	1.008
3a.	SW	9	2S	11W	212.80	2.84	0.793	0.243	54.53	45.77	L	1.191
3b.	SW	9	2S	11W	202.40	2.49	0.400	-	56.40	43.60	L	1.293
3c.	SW	9	2S	11W	205.00	2.20	0.611	0.288	65.42	34.58	L	1.891
4.	SW	27	1S	12W	201.00	2.42	0.748	0.144	89.22	11.78	L	7.573
5.	NE	21	2S	12W	210.00	1.74	0.579	0.207	33.83	66.17	L	0.511
6.	NE	20	2S	11W	216.00	4.00	1.068	0.125	91.36	8.64	XAL	10.574
7.	NW	19	1S	10W	203.00	1.65	-	0.295	42.28	57.72	S	0.732
8.	SW	25	1S	12W	203.60	5.45	0.661	0.210	70.73	29.27	L	2.416

TABLE 1. Continued.

Sample station	1/4 Section	Section	Township	Range	Bulk Wt. (grams)	Mag. Susc. X 10^{-4} cgs	7Å/10Å Peak Height	Ga/Ep + Hbd	Percent Sand	Percent Mud	Lobe Provenance	Sand/Mud Ratio
9.	SW	6	2S	11W	203.50	2.32	0.750	0.196	79.76	20.24	L	3.940
10.	NW	35	2S	12W	200.00	2.51	0.696	0.190	50.98	49.02	L	1.039
11.	NE	9	2S	12W	202.80	3.70	0.593	0.231	52.80	47.20	L	1.118
12.	NE	4	2S	12W	201.00	3.25	0.704	0.170	54.97	45.03	L	1.220
13.	SW	16	2S	12W	204.30	3.15	0.809	0.219	84.22	15.78	L	5.337
14.	NE	23	2S	12W	201.10	3.90	0.645	0.196	48.72	51.28	L	0.950
15a.	SW	30	1S	11W	201.00	2.26	0.674	-	-	-	L	-
15b.	SW	30	1S	11W	206.10	2.24	0.476	-	-	-	L	-
16a.	NE	33	1S	11W	201.80	4.40	0.776	0.216	56.39	43.61	L	1.293
16b.	NE	33	1S	11W	211.60	3.40	0.804	0.154	84.58	15.42	L	5.485
17.	SW	27	1S	11W	196.20	2.48	1.063	0.108	24.45	75.55	XAL	0.323
18a.	SW	23	3S	8W	210.20	3.85	0.786	0.336	56.80	43.20	XAS	1.314

TABLE 1. Continued.

Sample station	1/4 Section	Section	Township	Range	Bulk Wt. (grams)	Mag. Susc. X 10^{-4} cgs	7Å/10Å Peak Height	Ga/Ep + Hbd	Percent Sand	Percent Mud	Lobe Provenance	Sand/Mud Ratio
18b.	SW	23	3S	8W	199.90	4.70	0.769	-	-	-	XAS	-
19.	NE	31	2S	7W	201.90	4.70	0.695	0.347	50.36	49.64	XAS	1.014
20.	NE	5	4S	7W	199.70	3.40	0.854	0.319	57.81	42.19	S	1.370
21.	SE	9	1S	12W	214.40	2.85	0.744	0.118	42.78	57.22	L	0.747
22a.	SW	7	1S	11W	200.00	1.72	0.848	0.144	31.25	68.75	L	0.454
22b.	NW	18	1S	11W	212.00	1.72	-	0.199	60.64	39.36	L	1.540
23.	SE	11	1S	13W	204.50	1.86	0.810	0.154	72.49	27.51	L	2.635
24a.	SE	10	1S	13W	189.70	2.12	1.245	0.144	63.45	36.55	L	1.735
24b.	SE	10	1S	13W	197.70	2.70	0.846	0.138	59.35	40.65	L	1.460
25.	SW	23	1S	13W	198.00	2.68	-	0.199	84.84	15.16	L	5.596
26.	NW	22	1S	13W	202.60	7.42	0.791	0.146	64.19	35.81	L	1.792
27.	NW	4	1S	13W	195.80	2.67	0.833	0.118	71.48	28.52	L	2.506

TABLE 1. Continued.

Sample station	1/4 Section	Section	Township	Range	Bulk Wt. (grams)	Mag. Susc. X 10^{-4} cgs	7Å/10Å Peak Height	Ga/Ep + Hbd	Percent Sand	Percent Mud	Lobe Provenance	Sand/Mud Ratio
28.	NE	33	1S	13W	208.70	3.12	-	0.136	48.84	51.16	L	0.954
29.	SE	34	1S	13W	200.30	2.67	1.068	0.131	43.74	56.26	XAL	0.777
30a.	SW	2	3S	11W	213.90	3.60	0.832	0.347	96.92	3.08	L	31.467
30b.	SW	2	3S	11W	198.00	3.21	0.595	0.149	48.03	51.97	L	0.924
30c.	SW	2	3S	11W	224.80	3.32	0.720	0.355	71.46	28.54	L	2.503
31a.	NE	34	1S	13W	208.90	1.64	0.553	0.312	34.03	65.97	L	0.515
31b.	NE	34	1S	13W	196.40	8.40	0.773	0.193	69.85	30.15	L	2.316
32a.	NW	2	2S	13W	188.00	1.72	0.484	0.136	28.67	71.33	L	0.401
32b.	NW	2	2S	13W	196.00	2.48	0.596	0.149	73.18	26.82	L	2.728
32c.	NW	2	2S	13W	222.70	2.10	0.785	0.144	45.32	54.68	L	0.828
32d.	NW	2	2S	13W	200.30	2.95	0.557	0.123	77.22	22.78	L	3.389
33.	NW	28	2S	10W	195.70	3.22	-	0.201	75.14	24.86	L	3.022

TABLE 1. Continued.

Sample station	1/4 Section	Section	Township	Range	Bulk Wt. (grams)	Mag. Susc. X 10^{-4} cgs	7Å/10Å Peak Height	Ga/Ep + Hbd	Percent Sand	Percent Mud	Lobe Provenance	Sand/Mud Ratio
34.	SW	25	2S	10W	197.30	2.16	1.057	0.259	97.89	2.11	S	46.393
35a.	NW	30	2S	9W	200.30	2.17	-	-	-	-	O	-
35b.	NW	30	2S	9W	202.90	2.00	-	-	-	-	O	-
36a.	SW	30	2S	9W	200.10	3.95	0.744	0.126	69.18	30.82	L	2.244
36b.	SW	30	2S	9W	163.13	3.45	0.637	0.142	63.45	36.55	L	1.735
37a.	NW	5	3S	9W	204.90	2.70	0.764	0.173	71.92	28.08	L	2.561
37b.	NW	5	3S	9W	202.90	2.35	0.836	0.295	93.79	6.21	HAL	15.103
38.	NW	20	3S	9W	200.20	2.54	0.795	0.201	49.07	50.93	L	0.963
39.	SE	13	2S	11W	214.90	2.80	0.732	0.182	60.37	39.63	L	1.523
40.	SE	17	2S	10W	201.08	2.13	0.762	0.131	46.87	53.13	L	0.882
41.	NW	28	2S	9W	211.50	2.48	0.794	0.219	71.79	28.21	L	2.544
42.	NW	27	3S	9W	202.60	2.65	1.000	0.278	51.35	48.65	S	1.055

TABLE 1. Continued.

Sample station	1/4 Section	Section	Township	Range	Bulk Wt. (grams)	Mag. Susc. X 10^{-4} cgs	7Å/10Å Peak Height	Ga/Ep + Hbd	Percent Sand	Percent Mud	Lobe Provenance	Sand/Mud Ratio
43a.	SE	36	2S	11W	216.28	2.51	0.808	0.170	73.48	26.52	L	2.770
43b.	SE	36	2S	11W	212.50	2.98	0.770	0.160	59.70	40.30	L	1.481
44a.	SW	4	3S	10W	200.90	3.10	0.825	0.204	52.19	47.81	L	1.091
44b.	SW	4	3S	10W	-	-	-	-	-	-	O	-
44c.	SW	4	3S	10W	-	-	-	-	-	-	O	-
45.	NW	8	3S	10W	196.66	2.17	0.784	0.141	38.55	62.45	L	0.617
46a.	NW	10	1S	10W	200.70	2.95	0.947	0.366	67.41	32.59	S	2.068
46b.	NW	10	1S	10W	201.14	1.89	1.015	-	-	-	O	-
47a.	SW	22	2S	9W	197.50	7.80	0.890	0.420	81.88	18.12	S	4.518
47b.	SW	22	2S	9W	197.45	8.30	0.930	0.385	70.52	29.48	S	2.392
48.	SW	1	3S	9W	198.62	3.29	0.867	0.315	73.53	26.47	S	2.777
49.	NW	20	3S	8W	190.50	2.64	0.865	0.291	75.84	24.16	S	3.139

TABLE 1. Continued.

Sample station	1/4 Section	Section	Township	Range	Bulk Wt. (grams)	Mag. Susc. X 10^{-4} cgs	7Å/10Å Peak Height	Ga/Ep + Hbd	Percent Sand	Percent Mud	Lobe Provenance	Sand/Mud Ratio
50.	NW	17	3S	8W	194.33	4.20	0.818	0.319	52.69	47.31	XAS	1.113
51.	SW	10	3S	8W	205.47	4.95	0.971	0.483	58.34	41.66	S	1.400
52.	NE	27	3S	7W	212.83	2.80	1.000	0.282	67.33	32.67	S	2.060
53.	NW	4	4S	7W	203.32	0.12	0.865	0.515	68.90	31.10	S	2.215
54.	NE	21	4S	7W	189.47	2.90	0.955	0.347	93.51	6.49	S	14.400
55.	SE	11	4S	8W	179.51	2.29	0.892	0.322	89.48	10.52	S	8.505
56.	SW	4	4S	8W	207.00	2.09	0.881	0.315	56.12	43.88	S	1.278
57.	SE	12	3S	9W	187.40	1.93	0.833	0.333	80.38	19.62	S	4.096
58.	SE	6	2S	14W	214.00	-	0.577	0.204	58.92	41.08	L	1.434
59.	SW	19	1N	14W	225.00	-	0.662	0.084	59.05	40.95	L	1.442
60a.	NW	30	2N	16W	229.00	-	0.837	0.091	56.15	43.85	L	1.280
60b.	NW	30	2N	16W	212.40	-	0.664	0.131	26.40	73.60	L	0.358

TABLE 1. Continued.

Sample station	1/4 Section	Section	Township	Range	Bulk Wt. (grams)	Mag. Susc. X 10^{-4} cgs	7Å/10Å Peak Height	Ga/Ep + Hbd	Percent Sand	Percent Mud	Lobe Provenance	Sand/Mud Ratio
60c.	NW	30	2N	16W	202.00	-	0.671	0.190	20.12	79.88	L	0.251
60d.	NW	30	2N	16W	218.10	-	0.540	0.173	10.30	89.70	L	0.114
61.	SW	13	1N	16W	204.30	-	0.713	0.054	34.21	65.79	L	0.519
62a.	NW	33	2S	12W	248.00	-	0.819	0.213	61.68	38.32	L	1.609
62b.	NW	33	2S	12W	207.60	-	-	0.298	77.34	32.66	HAL	2.368
63.	SE	29	3S	12W	218.10	-	0.732	0.160	79.70	20.30	L	3.926
64a.	NW	4	4S	12W	232.00	-	0.705	-	55.70	44.30	L	1.257
64b.	NW	4	4S	12W	230.00	-	0.616	0.094	55.80	44.20	L	1.262
65.	NW	26	4S	12W	210.50	-	0.754	0.152	52.85	47.15	L	1.120
66.	NW	2	4S	11W	200.00	-	0.835	0.077	82.19	17.81	L	4.614
67.	NE	5	4S	11W	210.00	-	0.847	0.101	86.15	13.85	L	6.220
68.	SE	27	4S	11W	215.00	-	0.815	0.152	84.97	15.03	L	5.653

TABLE 1. Continued.

Sample station	1/4 Section	Section	Township	Range	Bulk Wt. (grams)	Mag. Susc. X 10^{-4} cgs	7Å/10Å Peak Height	Ga/Ep + Hbd	Percent Sand	Percent Mud	Lobe Provenance	Sand/Mud Ratio
69.	NE	23	4S	10W	228.10	-	1.021	0.329	63.32	36.68	S	1.726
70.	SE	21	4S	10W	242.00	-	1.091	0.179	57.10	42.90	XSHL	1.331
71.	SE	4	4S	9W	207.00	-	1.173	0.250	67.71	32.29	S	2.096
72.	NW	20	4S	6W	208.40	-	0.884	0.333	68.34	31.66	S	2.158
73.	SE	16	1S	10W	227.00	-	0.657	0.246	56.09	43.91	AS	1.277
74.	NE	19	1S	9W	209.00	-	0.714	0.312	26.55	73.45	XAS	0.361
75.	SE	23	1S	9W	235.00	-	0.780	0.515	81.32	18.68	XAS	4.353
76.	SW	2	2S	10W	254.00	-	0.972	0.298	47.59	52.41	S	0.908

TABLE 2. Sieve Data.

	WEIGHT (GRAMS)						
Station	18 Mesh	35 Mesh	60 Mesh	120 Mesh	230 Mesh	Pan	Total (T)
1.	1.274	3.323	21.179	20.930	7.031	1.127	54.717
2.	2.872	5.389	21.000	14.463	5.309	0.678	49.711
3a.	3.206	5.870	16.499	19.876	10.800	1.776	58.027
3b.	3.036	5.720	15.983	20.239	10.890	1.216	57.084
3c.	3.352	7.301	21.642	22.463	11.557	0.644	67.059
4.	3.776	11.117	36.614	30.877	6.784	0.507	89.675
5.	0.864	3.193	14.545	12.550	4.145	0.231	35.528
6.	12.778	33.047	39.955	11.240	1.471	0.181	98.672
7.	1.423	1.697	19.470	18.928	1.399	0.000	42.917
8.	11.453	12.610	21.647	17.118	8.968	0.212	72.008
9.	1.102	9.294	37.572	28.022	6.836	0.333	81.159
10.	0.246	0.932	5.671	13.072	28.541	2.526	50.988
11.	0.982	3.367	22.160	21.170	5.341	0.521	53.541
12.	0.707	3.075	17.870	22.244	11.005	0.344	55.245
13.	7.161	16.425	39.112	19.888	3.109	0.137	86.032
14.	1.948	3.692	15.382	18.724	8.653	0.599	48.998
15a.	-	-	-	-	-	-	-
15b.	-	-	-	-	-	-	-
16a.	1.617	6.755	21.663	20.586	5.923	0.362	56.906

TABLE 2. Continued.

Station	18 Mesh	35 Mesh	60 Mesh	120 Mesh	230 Mesh	Pan	Total (T)
			WEIGHT (GRAMS)				
16b.	4.373	11.637	38.256	27.487	7.553	0.190	89.496
17.	2.117	2.979	6.333	6.745	5.321	0.491	23.986
18a.	2.141	5.759	22.691	21.764	7.130	0.219	59.704
18b.	-	-	-	-	-	-	-
19.	2.277	6.845	22.265	15.604	3.676	0.180	50.847
20.	1.313	5.409	23.727	20.171	7.003	0.110	57.733
21.	3.353	5.981	14.517	15.972	5.790	0.256	45.869
22a.	0.796	2.494	10.336	12.335	5.107	0.183	31.251
22b.	1.098	2.959	21.952	28.235	9.894	0.143	64.281
23.	1.774	6.695	29.845	30.665	4.947	0.204	74.130
24a.	2.684	6.198	17.889	24.828	8.269	0.318	60.186
24b.	1.989	1.442	16.084	30.595	8.209	0.353	58.672
25.	4.961	8.992	27.191	33.892	8.713	0.246	83.996
26.	2.904	8.316	24.276	22.716	6.442	0.378	65.032
27.	4.128	11.441	25.262	22.461	6.486	0.204	69.982
28.	8.754	8.155	13.426	16.418	4.016	0.205	50.974
29.	1.520	2.089	11.340	21.315	7.281	0.266	43.811
30a.	12.510	25.403	46.136	16.782	2.503	0.326	103.660
30b.	3.400	8.961	18.624	10.534	5.773	0.260	47.552

TABLE 2. Continued.

Station	18 Mesh	35 Mesh	WEIGHT (GRAMS) 60 Mesh	120 Mesh	230 Mesh	Pan	Total (T)
30c.	3.783	10.307	33.240	25.562	6.751	0.683	80.326
31a.	0.452	1.263	9.158	15.269	8.975	0.434	35.551
31b.	8.365	8.260	19.565	25.732	6.382	0.295	68.599
32a.	4.869	1.727	6.244	10.980	3.018	0.120	26.958
32b.	17.451	8.059	24.778	18.482	2.771	0.181	71.722
32c.	3.739	3.047	13.078	20.852	9.318	0.434	50.468
32d.	25.955	11.816	13.033	18.197	7.719	0.621	77.341
33.	15.173	35.401	17.281	4.351	1.152	0.173	73.531
34.	9.130	16.643	56.940	15.699	1.100	0.171	99.683
35a.	-	-	-	-	-	-	-
35b.	-	-	-	-	-	-	-
36a.	8.708	11.768	23.344	19.650	5.409	0.341	69.220
36b.	12.162	12.233	14.265	10.532	2.397	0.167	51.756
37a.	6.720	17.323	40.553	7.882	1.081	0.125	73.684
37b.	7.547	22.882	56.493	7.427	0.718	0.083	95.150
38.	1.801	5.124	18.834	16.608	6.547	0.207	49.121
39.	5.900	13.508	21.852	20.004	3.456	0.150	64.870
40.	3.759	12.644	21.950	8.231	0.449	0.092	47.125
41.	3.201	8.990	29.205	26.249	8.163	0.120	75.928

TABLE 2. Continued.

Station	WEIGHT (GRAMS)						
	18 Mesh	35 Mesh	60 Mesh	120 Mesh	230 Mesh	Pan	Total (T)
42.	2.084	5.766	18.750	17.813	7.406	0.201	52.020
43a.	5.519	13.034	23.109	27.564	10.013	0.228	79.467
43b.	7.522	14.245	21.377	15.193	4.910	0.192	63.439
44a.	2.611	10.392	23.187	12.072	3.825	0.340	52.427
44b.	-	-	-	-	-	-	-
44c.	-	-	-	-	-	-	-
45.	1.659	4.884	17.882	10.092	3.121	0.269	37.907
46a.	2.338	12.332	30.663	17.576	4.445	0.298	67.652
46b.	-	-	-	-	-	-	-
47a.	4.928	9.573	25.662	27.459	12.829	0.409	80.860
47b.	2.757	4.896	18.102	27.472	15.749	0.648	69.624
48.	2.210	6.803	32.817	24.784	5.815	0.597	73.026
49.	2.818	7.523	24.258	27.201	9.996	0.447	72.243
50.	2.928	5.929	20.692	16.621	4.912	0.119	51.201
51.	2.393	8.991	25.075	17.768	5.564	0.153	59.944
52.	3.307	8.402	28.798	22.170	8.662	0.317	71.656
53.	4.743	7.999	19.157	23.572	14.007	0.566	70.044
54.	5.453	11.632	30.112	31.389	9.813	0.196	88.595
55.	8.308	18.566	37.778	13.919	1.639	0.111	80.321

TABLE 2. Continued.

Sta-tion	18 Mesh	35 Mesh	WEIGHT (GRAMS) 60 Mesh	120 Mesh	230 Mesh	Pan	Total (T)
56.	1.537	5.039	29.030	19.447	2.902	0.133	58.088
57.	8.976	20.030	30.011	14.974	1.276	0.058	75.325
58.	2.863	5.623	20.294	22.416	11.610	0.245	63.051
59.	8.791	19.471	18.829	14.658	4.311	0.376	66.436
60a.	2.853	5.084	21.861	23.214	11.078	0.211	64.301
60b.	1.644	2.451	7.839	9.321	6.582	0.205	28.042
60c.	1.309	1.757	5.288	6.689	5.022	0.261	20.326
60d.	1.206	1.781	5.693	4.804	7.688	0.362	21.534
61.	1.113	1.894	8.425	12.649	10.611	0.261	34.953
62a.	7.068	16.179	39.868	10.869	2.377	0.123	76.484
62b.	7.565	19.928	38.061	12.936	1.343	0.456	80.289
63.	4.106	11.934	39.611	25.250	5.765	0.311	86.917
64a.	4.243	7.465	22.249	21.439	9.007	0.212	64.615
64b.	9.556	14.820	25.237	10.777	3.733	0.048	64.171
65.	5.525	12.504	26.514	9.109	1.859	0.122	55.633
66.	16.860	36.151	22.401	4.626	2.003	0.155	82.196
67.	2.356	10.560	55.292	19.621	2.321	0.311	90.461
68.	2.515	19.087	46.050	22.203	1.229	0.263	91.347
69.	2.916	6.744	20.843	22.765	14.790	0.011	68.069

TABLE 2. Continued.

Station	WEIGHT (GRAMS) 18 Mesh	35 Mesh	60 Mesh	120 Mesh	230 Mesh	Pan	Total (T)
70.	12.251	24.852	18.049	8.368	1.306	0.301	65.127
71.	2.706	6.452	22.051	22.126	16.514	0.237	70.086
72.	4.701	13.797	34.944	12.638	4.821	0.310	71.211
73.	8.016	19.667	29.807	5.394	0.736	0.048	63.668
74.	1.688	5.451	11.083	6.237	3.118	0.168	27.745
75.	7.915	19.353	54.697	11.374	1.808	0.375	95.522
76.	18.012	17.371	18.756	4.719	1.470	0.112	60.440

TABLE 3. Textural Data (B, bulk weight = total sand + mud; T, total sand weight)

Sample Station	Weight (grams) 120+230 Mesh	Weight (grams) Heavy Minerals 120+230 Mesh	Percent Heavy Minerals 120+230 Mesh	Percent Weight $\frac{120+230 \text{ Mesh}}{T} \times 100$	Percent Weight $\frac{120+230 \text{ Mesh}}{B} \times 100$	Percent Weight $\frac{60 \text{ Mesh}}{T} \times 100$	Percent Weight $\frac{60 \text{ Mesh}}{B} \times 100$	Percent Weight $\frac{18+35 \text{ Mesh}}{T} \times 100$	Percent Weight $\frac{18+35 \text{ Mesh}}{B} \times 100$
1.	27.961	0.824	2.948	51.10	13.76	38.70	10.42	10.20	2.26
2.	19.772	0.494	2.502	39.77	9.98	42.24	10.60	17.99	4.17
3a.	30.676	0.773	2.522	52.86	14.41	28.43	7.75	18.71	4.26
3b.	31.129	0.716	2.302	54.53	15.37	27.99	7.89	17.48	4.32
3c.	34.020	0.717	2.110	50.73	16.59	32.27	10.55	17.00	5.19
4.	37.661	0.705	1.874	41.99	18.73	40.82	18.21	17.19	7.40
5.	16.695	0.351	2.104	46.99	7.95	40.93	6.92	12.08	1.93
6.	12.711	0.561	4.419	12.88	5.88	40.49	18.49	46.63	21.21
7.	20.327	0.460	2.262	47.36	10.01	45.36	9.59	7.26	1.53

TABLE 3. Continued.

Sample Station	Weight (grams) 120+230 Mesh	Weight (grams) Heavy Minerals 120+230 Mesh	Percent Heavy Minerals 120+230 Mesh	Percent Weight $\frac{120+230\ \text{Mesh}}{T} \times 100$	Percent Weight $\frac{120+230\ \text{Mesh}}{B} \times 100$	Percent Weight $\frac{60\ \text{Mesh}}{T} \times 100$	Percent Weight $\frac{60\ \text{Mesh}}{B} \times 100$	Percent Weight $\frac{18+35\ \text{Mesh}}{T} \times 100$	Percent Weight $\frac{18+35\ \text{Mesh}}{B} \times 100$
8.	26.086	1.241	4.760	36.22	12.81	30.06	10.63	33.72	11.81
9.	34.858	0.714	2.050	42.95	17.12	46.29	18.46	10.76	5.10
10.	41.613	0.288	0.693	81.61	20.80	11.12	2.83	7.27	0.58
11.	26.511	0.651	2.457	49.51	13.07	41.38	10.92	9.11	2.14
12.	33.249	0.459	1.380	60.18	16.54	32.34	8.89	7.48	1.88
13.	22.997	0.883	3.843	26.73	11.25	45.46	19.14	27.81	11.54
14.	27.377	0.656	2.396	55.87	13.61	31.39	7.64	12.74	2.80
15a.	-	-	-	-	-	-	-	-	-
15b.	-	-	-	-	-	-	-	-	-

TABLE 3. Continued.

Sample Station	Weight (grams) 120+230 Mesh	Weight (grams) Heavy Minerals 120+230 Mesh	Percent Heavy Minerals 120+230 Mesh	Percent Weight $\frac{120+230\ \text{Mesh}}{T} \times 100$	Percent Weight $\frac{120+230\ \text{Mesh}}{B} \times 100$	Percent Weight $\frac{60\ \text{Mesh}}{T} \times 100$	Percent Weight $\frac{60\ \text{Mesh}}{B} \times 100$	Percent Weight $\frac{18+35\ \text{Mesh}}{T} \times 100$	Percent Weight $\frac{18+35\ \text{Mesh}}{B} \times 100$
16a.	26.509	0.740	2.792	46.58	13.13	38.06	10.73	15.36	4.14
16b.	35.040	0.844	2.409	39.15	16.55	42.74	18.07	18.11	7.56
17.	12.066	0.627	5.198	50.30	6.14	26.40	3.22	23.30	2.59
18a.	28.894	0.891	3.085	43.39	13.74	38.00	10.79	18.61	3.75
18b.	-	-	-	-	-	-	-	-	-
19.	19.280	0.898	4.660	37.91	9.54	43.78	11.02	18.31	4.51
20.	27.174	0.667	2.454	47.06	13.60	41.09	11.88	11.85	3.36
21.	21.762	0.179	0.823	47.44	10.10	31.64	6.77	20.92	4.35
22a.	17.442	0.259	1.488	55.81	8.72	33.07	5.16	11.12	1.64

TABLE 3. Continued.

Sample Station	Weight (grams) 120+230 Mesh	Weight (grams) Heavy Minerals 120+230 Mesh	Percent Heavy Minerals 120+230 Mesh	Percent Weight $\frac{120+230 \text{ Mesh}}{T} \times 100$	Percent Weight $\frac{120+230 \text{ Mesh}}{B} \times 100$	Percent Weight $\frac{60 \text{ Mesh}}{T} \times 100$	Percent Weight $\frac{60 \text{ Mesh}}{B} \times 100$	Percent Weight $\frac{18+35 \text{ Mesh}}{T} \times 100$	Percent Weight $\frac{18+35 \text{ Mesh}}{B} \times 100$
22b.	38.129	0.464	1.218	59.31	17.98	34.15	10.35	6.54	1.91
23.	35.613	0.425	1.194	48.04	17.41	40.26	14.59	11.70	4.14
24a.	33.097	0.320	0.968	54.99	17.44	29.72	9.43	15.29	4.68
24b.	38.804	0.438	1.129	66.13	19.62	27.41	8.13	6.46	1.73
25.	42.605	0.674	1.581	50.72	21.51	28.90	13.73	20.38	7.04
26.	29.158	1.745	5.985	44.83	14.39	37.32	11.98	17.85	5.53
27.	28.947	0.513	1.774	41.36	14.78	36.09	12.90	22.55	7.95
28.	20.434	0.336	1.645	40.08	9.79	26.33	6.43	33.59	8.10
29.	28.596	0.303	1.062	65.27	14.27	25.88	5.66	8.85	1.80

TABLE 3. Continued.

Sample Station	Weight (grams) 120+230 Mesh	Weight (grams) Heavy Minerals 120+230 Mesh	Percent Heavy Minerals 120+230 Mesh	Percent Weight $\frac{120+230\ \text{Mesh}}{T} \times 100$	Percent Weight $\frac{120+230\ \text{Mesh}}{B} \times 100$	Percent Weight $\frac{60\ \text{Mesh}}{T} \times 100$	Percent Weight $\frac{60\ \text{Mesh}}{B} \times 100$	Percent Weight $\frac{18+35\ \text{Mesh}}{T} \times 100$	Percent Weight $\frac{18+35\ \text{Mesh}}{B} \times 100$
30a.	19.285	0.851	4.417	18.60	9.01	44.50	21.56	36.90	17.12
30b.	16.307	0.389	2.386	34.29	8.23	39.16	9.40	26.55	6.24
30c.	32.313	0.790	2.444	40.22	14.37	41.38	14.78	8.40	6.26
31a.	24.244	0.294	1.214	68.19	11.60	25.76	4.38	6.05	0.82
31b.	32.114	1.502	4.679	46.81	16.35	28.52	9.96	24.67	8.46
32a.	13.998	0.160	1.144	51.92	7.44	23.16	3.32	24.92	3.50
32b.	21.253	0.494	2.324	29.63	10.84	34.54	12.64	35.83	13.01
32c.	30.170	0.349	1.156	59.78	13.54	25.91	5.87	14.31	3.04
32d.	25.916	0.488	1.884	33.50	12.93	16.85	6.50	49.65	18.85

TABLE 3. Continued.

Sample Station	Weight (grams) 120+230 Mesh	Weight (grams) Heavy Minerals 120+230 Mesh	Percent Heavy Minerals 120+230 Mesh	Percent Weight $\frac{120+230\ Mesh}{T} \times 100$	Percent Weight $\frac{120+230\ Mesh}{B} \times 100$	Percent Weight $\frac{60\ Mesh}{T} \times 100$	Percent Weight $\frac{60\ Mesh}{B} \times 100$	Percent Weight $\frac{18+35\ Mesh}{T} \times 100$	Percent Weight $\frac{18+35\ Mesh}{B} \times 100$
33.	5.503	0.277	5.033	7.48	2.81	23.50	8.83	69.02	25.84
34.	16.799	0.649	3.865	16.85	8.51	57.12	28.85	26.03	11.54
35a.	-	-	-	-	-	-	-	-	-
35b.	-	-	-	-	-	-	-	-	-
36a.	25.059	1.054	4.209	36.20	12.52	33.72	11.66	30.08	10.23
36b.	12.929	0.412	3.187	24.98	7.92	27.56	8.74	47.46	14.95
37a.	8.963	0.360	4.026	12.16	4.37	55.03	19.79	32.81	11.73
37b.	8.145	0.437	5.366	8.56	4.01	59.40	27.84	32.04	14.99
38.	23.155	0.467	2.017	47.13	11.56	38.34	9.40	14.53	3.45

TABLE 3. Continued.

Sample Station	Weight (grams) 120+230 Mesh	Weight (grams) Heavy Minerals 120+230 Mesh	Percent Heavy Minerals 120+230 Mesh	Percent Weight $\frac{120+230 \text{ Mesh}}{T} \times 100$	Percent Weight $\frac{120+230 \text{ Mesh}}{B} \times 100$	Percent Weight $\frac{60 \text{ Mesh}}{T} \times 100$	Percent Weight $\frac{60 \text{ Mesh}}{B} \times 100$	Percent Weight $\frac{18+35 \text{ Mesh}}{T} \times 100$	Percent Weight $\frac{18+35 \text{ Mesh}}{B} \times 100$
39.	23.460	0.522	2.227	36.16	10.91	33.68	10.16	30.16	9.03
40.	8.680	0.212	2.449	18.41	4.31	46.57	10.91	35.02	8.15
41.	34.412	0.709	2.060	45.32	16.27	38.46	13.80	16.22	5.76
42.	25.219	0.567	2.249	48.47	12.44	36.04	9.25	15.49	3.87
43a.	37.577	0.609	1.620	47.28	17.37	29.07	10.68	23.65	8.57
43b.	20.103	0.451	2.246	31.68	9.46	33.69	10.05	34.63	10.24
44a.	15.897	0.409	2.577	30.32	7.91	53.76	11.54	15.92	6.47
44b.	-	-	-	-	-	-	-	-	-
44c.	-	-	-	-	-	-	-	-	-

TABLE 3. Continued.

Sample Station	Weight (grams) 120+230 Mesh	Weight (grams) Heavy Minerals 120+230 Mesh	Percent Heavy Minerals 120+230 Mesh	Percent Weight $\frac{120+230 \text{ Mesh}}{T} \times 100$	Percent Weight $\frac{120+230 \text{ Mesh}}{B} \times 100$	Percent Weight $\frac{60 \text{ Mesh}}{T} \times 100$	Percent Weight $\frac{60 \text{ Mesh}}{B} \times 100$	Percent Weight $\frac{18+35 \text{ Mesh}}{T} \times 100$	Percent Weight $\frac{18+35 \text{ Mesh}}{B} \times 100$
45.	13.213	0.214	1.624	34.85	6.71	47.17	9.09	17.98	3.32
46a.	22.021	0.600	2.727	32.55	10.97	45.32	15.27	22.13	7.30
46b.	-	-	-	-	-	-	-	-	-
47a.	40.288	1.549	3.846	49.82	20.39	31.73	12.99	18.45	7.34
47b.	43.221	1.414	3.273	62.07	21.88	25.99	9.16	11.94	3.87
48.	30.599	0.688	2.250	41.90	15.40	44.93	16.52	13.17	4.53
49.	37.197	0.599	1.612	51.48	19.52	35.57	12.73	12.95	5.42
50.	21.533	0.666	3.093	42.05	11.08	40.41	10.64	17.54	4.55
51.	23.332	0.916	3.927	38.92	11.35	41.83	12.20	19.25	5.54

TABLE 3. Continued.

Sample Station	Weight (grams) 120+230 Mesh	Weight (grams) Heavy Minerals 120+230 Mesh	Percent Heavy Minerals 120+230 Mesh	Percent Weight $\frac{120+230 \text{ Mesh}}{T} \times 100$	Percent Weight $\frac{120+230 \text{ Mesh}}{B} \times 100$	Percent Weight $\frac{60 \text{ Mesh}}{T} \times 100$	Percent Weight $\frac{60 \text{ Mesh}}{B} \times 100$	Percent Weight $\frac{18+35 \text{ Mesh}}{T} \times 100$	Percent Weight $\frac{18+35 \text{ Mesh}}{B} \times 100$
52.	30.832	0.742	2.408	43.02	14.48	40.18	13.53	16.80	5.50
53.	37.579	2.881	7.666	53.65	18.48	27.34	9.42	19.01	6.26
54.	41.202	0.740	1.796	46.50	21.74	33.98	15.89	19.52	9.01
55.	15.558	0.405	2.605	19.36	8.66	47.03	21.04	33.61	14.97
56.	22.349	0.461	2.066	38.47	10.79	49.97	14.02	11.56	3.17
57.	16.250	0.381	2.348	21.57	8.67	39.84	16.01	38.59	15.47
58.	34.029	0.800	2.352	53.97	15.90	32.18	9.48	13.45	3.96
59.	18.969	0.641	2.352	28.55	8.43	28.34	8.36	42.54	12.56
60a.	34.494	2.358	6.856	53.64	15.06	33.99	9.54	12.37	3.46

TABLE 3. Continued.

Sample Station	Weight (grams) 120+230 Mesh	Weight (grams) Heavy Minerals 120+230 Mesh	Percent Heavy Minerals 120+230 Mesh	Percent Weight $\frac{120+230\text{ Mesh}}{T} \times 100$	Percent Weight $\frac{120+230\text{ Mesh}}{B} \times 100$	Percent Weight $\frac{60\text{ Mesh}}{T} \times 100$	Percent Weight $\frac{60\text{ Mesh}}{B} \times 100$	Percent Weight $\frac{18+35\text{ Mesh}}{T} \times 100$	Percent Weight $\frac{18+35\text{ Mesh}}{B} \times 100$
60b.	15.903	0.249	1.566	56.71	7.48	27.95	3.69	15.34	1.15
60c.	11.711	0.152	1.297	57.61	5.79	26.01	2.61	16.38	1.51
60d.	12.492	0.778	6.229	58.01	5.72	26.43	2.61	15.56	1.36
61.	23.260	0.906	3.896	66.54	11.38	24.10	4.12	9.36	1.47
62a.	13.246	0.330	2.494	17.31	5.34	52.12	16.07	30.59	9.37
62b.	14.279	0.880	6.167	17.78	6.87	47.40	18.33	34.82	13.24
63.	31.015	0.609	1.965	35.68	14.22	45.57	18.16	18.75	5.47
64a.	30.446	-	-	47.11	13.12	34.43	9.59	18.46	5.04
64b.	14.510	0.723	4.987	22.61	6.30	39.32	10.97	38.07	10.59

TABLE 3. Continued.

Sample Station	Weight (grams) 120+230 Mesh	Weight (grams) Heavy Minerals 120+230 Mesh	Percent Heavy Minerals 120+230 Mesh	Percent Weight $\frac{120+230\ Mesh}{T} \times 100$	Percent Weight $\frac{120+230\ Mesh}{B} \times 100$	Percent Weight $\frac{60\ Mesh}{T} \times 100$	Percent Weight $\frac{60\ Mesh}{B} \times 100$	Percent Weight $\frac{18+35\ Mesh}{T} \times 100$	Percent Weight $\frac{18+35\ Mesh}{B} \times 100$
65.	10.968	-	-	19.71	5.21	47.65	12.78	32.64	8.56
66.	6.629	0.205	3.092	8.06	3.31	27.25	11.20	64.69	26.50
67.	21.942	0.514	2.342	24.25	10.44	61.12	26.32	14.63	6.15
68.	23.432	0.455	1.943	25.64	10.89	50.41	21.41	23.95	10.04
69.	37.555	0.880	2.343	55.17	16.46	30.62	9.13	14.21	4.23
70.	9.674	0.320	3.311	14.85	3.99	27.71	7.45	57.44	15.33
71.	38.640	0.930	2.406	55.13	18.66	31.46	10.65	13.41	4.39
72.	17.459	0.470	2.692	24.51	8.39	49.07	16.76	26.42	8.87
73.	6.130	0.165	2.696	9.19	2.70	46.81	13.13	44.00	12.19

TABLE 3. Continued.

Sample Station	Weight (grams) 120+230 Mesh	Weight (grams) Heavy Minerals 120+230 Mesh	Percent Heavy Minerals 120+230 Mesh	Percent Weight $\frac{120+230 \text{ Mesh}}{T} \times 100$	Percent Weight $\frac{120+230 \text{ Mesh}}{B} \times 100$	Percent Weight $\frac{60 \text{ Mesh}}{T} \times 100$	Percent Weight $\frac{60 \text{ Mesh}}{B} \times 100$	Percent Weight $\frac{18+35 \text{ Mesh}}{T} \times 100$	Percent Weight $\frac{18+35 \text{ Mesh}}{B} \times 100$
74.	9.355	0.133	1.424	33.71	4.47	39.94	5.30	26.35	3.41
75.	13.182	0.764	5.802	13.79	5.60	57.26	23.27	28.95	11.60
76.	3.210	0.193	6.015	5.31	1.26	31.03	7.38	63.66	13.93

APPENDIX II

STATISTICS

A statistical study of textural and mineralogical data from surface exposures is presented herein. Analysis was accomplished using the statistical package program (STAT PACK V4) and the PDP 10 time sharing computer in Western Michigan University's Computer Center. The stat pack program is an integrated statistical package written for terminal use. Among the statistical operations calculated and presented within this appendix are the following: mean, standard deviation, variance, median, mode, range, standard error of mean, coefficient of skewness, coefficient of variance, z-score, histogram, Chi Square, T Test, and Mann-Whitney U Test. A complete discussion of the above statistical techniques may be obtained by consulting Folk (1968), Krumbein and Graybill (1965), Spence, et al., (1968), and Mendenhall (1975).

All surface data presented in the text was examined with Chi Square, T, and Mann-Whitney U Tests. The Chi Square Test tests population distributions as a whole (Krumbein and Graybill, 1965) and is used herein as a test of normality of population distribution. The T Test examines the significance of difference between two means, while the Mann-Whitney U Test statistically tests the independence of data and indicates whether two independent samples are from the same population. The Null Hypothesis associated with each test follows.

> Chi Square: The distribution of each population is not normal.
>
> T Test: The means of each population are equal.
>
> Mann-Whitney U Test: Two independent samples are from the same population.

Critical values for the Chi Square and T Tests may be obtained by consulting Mendenhall (1975) Appendix II, Tables 4 and 5. The Mann-Whitney U Test rejects the Null Hypothesis if $|Z| \geq 2.5$ at the 0.01 level of significance, 1.96 at the 0.05 level of significance, and 1.64 at the 0.10 level of significance.

Using the T Test and Mann-Whitney U Test, both between lobe and within lobe analysis were performed. Each lobe was divided into east and west halves and designated as follows:

LM, Lake Michigan lobe

1, Eastern half

2, Western half

S, Saginaw lobe

3, Eastern half

4, Western half

Table 5 records the sample stations associated with each half lobe designation.

TABLE 5. Sample stations associated with each half lobe designation.

half lobe designation	Sample Station
1	2, 3, 6, 9, 16, 17, 22, 30, 33, 35, 36, 37, 38, 39, 40, 43, 44, 45, 66, 67, 70
2	1, 4, 5, 8, 10, 11, 12, 13, 14, 21, 23, 24, 25, 26, 27, 28, 29, 31, 32, 58, 59, 60, 61, 62, 63, 64, 65
3	18, 19, 20, 49, 50, 51, 52, 53, 54, 55, 56, 72
4	7, 34, 41, 42, 46, 47, 48, 57, 69, 71, 73, 74, 75, 76

TABLE 6. Statistical data from sand/mud ratio, percent heavy minerals in the fine + very fine (120+230 mesh) sands, magnetic susceptibility, X-ray diffraction, and garnet/epidote+hornblende ratio analyses indicating the lobe designation (lobes: LM, Lake Michigan lobe; S, Saginaw lobe), number of observations (Obs.), mean, standard deviation (Std. Dev.), variance (Var.), median (Med.), mode, maximum (Max.), minimum (Min.), standard error of mean (SEM), skewness (Sk.), coefficient of variance (C.V.), and more than one mode exists (*).

Lobes	Obs.	Mean	Std. Dev.	Var.	Med.	Mode	Max.	Min.	SEM	Sk.	C.V.
Sand/mud ratio analysis											
LM+S	74	3.007	5.649	31.912	1.470	0.114*	46.393	0.114	0.656	6.394	187.833
LM	49	2.249	2.072	4.293	1.442	0.114*	10.574	0.114	0.296	1.990	92.112
S	25	4.095	8.986	80.753	2.062	0.361*	46.393	0.361	1.797	4.418	219.411
Percent heavy minerals in 120+230 mesh sands											
LM+S	74	2.826	1.423	2.026	2.446	0.352*	7.666	0.352	0.165	1.128	50.372
LM	49	2.670	1.372	1.882	2.396	0.352*	6.229	0.352	0.196	0.844	51.385
S	25	3.133	1.503	2.260	2.605	1.424*	7.666	1.424	0.300	1.565	47.988
Magnetic susceptibility											
LM+S	55	3.190	1.448	2.098	2.840	2.700	8.400	0.120	0.195	1.774	45.406
LM	37	3.218	1.372	1.882	2.840	2.700	8.400	1.720	0.225	2.319	42.633
S	18	3.131	1.634	2.672	2.850	0.120*	7.800	0.120	0.385	1.080	52.200

TABLE 6. Continued.

Lobes	Obs.	Mean	Std. Dev.	Var.	Med.	Mode	Max.	Min.	SEM	Sk.	C.V.
X-ray diffraction											
LM+S	70	0.809	0.136	0.018	0.794	0.732*	1.173	0.540	0.016	0.409	16.859
LM	46	0.766	0.125	0.015	0.767	0.732*	1.091	0.540	0.018	0.766	16.414
S	24	0.888	0.119	0.014	0.875	0.865*	1.173	0.675	0.024	0.239	13.418
Garnet/epidote+hornblende ratio											
LM+S	74	0.224	0.100	0.010	0.202	0.144	0.515	0.054	0.011	0.881	44.849
LM	49	0.166	0.051	0.002	0.160	0.144	0.355	0.054	0.007	0.656	30.969
S	25	0.338	0.072	0.002	0.319	0.295*	0.515	0.246	0.014	1.398	21.293

Chi Square Analysis

<u>Sand/mud ratio analysis</u>

X^2 = 0.000 with 73 df and probability of 1.000

<u>Percent heavy minerals in 120+230 mesh sands</u>

X^2 = 0.000 with 73 df and probability of 1.000

<u>Magnetic susceptibility</u>

X^2 = 6.472 with 48 df and probability of 1.000

<u>X-ray diffraction</u>

LM+S X^2 = 4.285 with 64 df and a probability of 1.000

LM X^2 = 1.666 with 21 df and a probability of 1.000

S X^2 = 1.826 with 43 df and a probability of 1.000

<u>Garnet/epidote+hornblende</u>

LM+S X^2 = 10.729 with 56 df and a probability of 1.000

LM X^2 = 7.632 with 36 df and a probability of 1.000

S X^2 = 3.120 with 18 df and a probability of 1.000

TABLE 7. Mann-Whitney U Test for sand/mud ratio data and for percent heavy minerals in 120+230 mesh sands.

Sand/mud ratio

variable	vs. variable	N_1	N_2	U_1	U_2	Std. Dev.	Mean	Z
1	2	21	27	259.000	308.000	48.117	283.500	-0.509
1	3	21	12	146.000	106.000	26.720	126.000	0.748
1	4	21	24	161.000	133.000	29.698	147.000	0.471
2	3	27	12	197.000	127.000	32.863	162.000	1.065
2	4	27	14	225.000	153.000	36.373	189.000	0.989
3	4	12	14	83.000	85.000	19.442	84.000	-0.051
LM	S	49	25	702.000	523.000	87.500	612.500	1.022

Percent heavy minerals in 120+230 mesh sands

variable	vs. variable	N_1	N_2	U_1	U_2	Std. Dev.	Mean	Z
1	2	21	27	229.000	338.000	48.117	283.500	-1.132
1	3	21	12	141.000	111.000	26.270	126.000	0.561
1	4	21	14	157.000	137.000	29.698	147.000	0.336
2	3	27	12	208.000	116.000	32.863	162.000	1.399
2	4	27	14	235.000	143.000	36.373	189.000	1.264
3	4	12	14	74.000	94.000	19.442	84.000	-0.514
LM	S	49	25	741.000	484.000	87.500	612.500	1.468

TABLE 8. Mann-Whitney U Test for magnetic susceptibility data and for X-ray diffraction data.

Magnetic susceptibility

variable	vs. variable	N_1	N_2	U_1	U_2	Std. Dev.	Mean	Z
1	2	17	19	190.000	133.000	31.558	161.500	0.903
1	3	17	11	107.500	79.500	21.258	93.500	0.658
1	4	17	8	53.500	82.500	17.165	68.000	-0.844
2	3	19	11	99.000	110.000	23.236	104.500	-0.236
2	4	19	8	51.500	100.500	18.832	76.000	-1.300
3	4	11	8	34.000	54.000	12.110	44.000	-0.825
LM	S	37	18	316.000	350.000	55.749	333.000	-0.304

X-ray diffraction

variable	vs. variable	N_1	N_2	U_1	U_2	Std. Dev.	Mean	Z
1	2	20	25	121.000	379.000	43.779	250.000	-2.946*
1	3	20	12	176.000	64.000	25.690	120.000	2.179**
1	4	20	13	173.000	87.000	27.141	130.000	1.584
2	3	25	12	264.000	36.000	30.822	150.000	3.698*
2	4	25	13	271.000	53.500	32.500	162.500	3.353*
3	4	12	13	88.500	67.500	18.384	78.000	0.571
LM	S	46	24	874.500	229.500	80.820	552.000	3.990*

* significant at 0.01 level; ** significant at 0.05 level

TABLE 9. Mann-Whitney U Test for garnet/epidote+hornblende data.

variable vs.	variable	N_1	N_2	U_1	U_2	Std. Dev.	Mean	Z
1	2	21	27	280.000	287.000	48.117	283.500	-0.727
1	3	21	12	242.000	10.000	26.720	126.000	4.341*
1	4	21	14	282.000	12.000	29.698	147.000	4.545*
2	3	27	12	324.000	0.000	32.863	162.000	4.929*
2	4	27	14	376.500	1.500	36.373	189.000	5.154*
3	4	12	14	52.500	115.500	19.442	84.000	-1.620
LM	S	49	25	1205.000	20.000	87.500	612.500	6.771*

* significant at 0.01 level

TABLE 10. T Test for sand/mud ratio data and for percent heavy minerals in 120+230 mesh sands.

Sand/mud ratio data

Std. Dev.	Var. Size	Var. Mean	Var.	Calculated T Value					
				1	2	3	4	LM	S
2.480	21	2.512	1	0.000	-	-	-	-	-
1.758	27	2.034	2	-0.781	0.000	-	-	-	-
4.042	12	3.331	3	0.723	1.409	0.000	-	-	-
11.890	14	5.530	4	1.067	1.436	0.560	0.000	-	
2.249	49	2.249	LM	-	-	-	-	0.000	1.634*
4.095	25	4.095	S	-	-	-	-	1.634*	0.000

Percent heavy minerals in 120+230 mesh sands

Std. Dev.	Var. Size	Var. Mean	Var.	Calculated T Value					
				1	2	3	4	LM	S
1.051	21	2.818	1	0.000	-	-	-	-	-
1.608	27	2.578	2	-0.592	0.000	-	-	-	-
1.657	12	3.172	3	0.753	1.056	0.000	-	-	-
1.382	14	3.021	4	0.493	0.876	-0.253	0.000	-	-
1.423	49	2.670	LM	-	-	-	-	0.000	1.327*
1.503	25	3.133	S	-	-	-	-	1.327*	0.000

* significant at 0.100 level

TABLE 11. T Test for magnetic susceptibility data and for X-ray diffraction data.

Magnetic susceptibility

Std. Dev.	Var. Size	Var. Mean	Var.	Calculated T Value					
				1	2	3	4	LM	S
0.677	17	2.875	1	0.000	-	-	-	-	-
1.758	19	3.565	2	1.520*	0.000	-	-	-	-
1.369	11	3.085	3	0.543	-0.777	0.000	-	-	-
1.967	8	3.114	4	0.455	-0.589	0.037	0.000	-	-
1.372	37	3.218	LM	-	-	-	-	0.000	-0.207
1.634	18	3.131	S	-	-	-	-	-0.207	0.000

X-ray diffraction

Std. Dev.	Var. Size	Var. Mean	Var.	Calculated T Value					
				1	2	3	4	LM	S
0.118	20	0.823	1	0.000	-	-	-	-	-
0.116	25	0.719	2	-2.953*	0.000	-	-	-	-
0.082	12	0.872	3	1.248	4.055*	0.000	-	-	-
0.146	13	0.900	4	1.662**	4.158*	0.586	0.000	-	-
0.128	46	0.766	LM	-	-	-	-	0.000	3.990*
0.119	24	0.890	S	-	-	-	-	3.990*	0.000

* significant at 0.005 level
** significant at 0.050 level

TABLE 12. T Test for garnet/epidote+hornblende data.

Std. Dev.	Var. Size	Var. Mean	Var.	Calculated T Value					
				1	2	3	4	LM	S
0.059	21	0.170	1	0.000	-	-	-	-	-
0.045	27	0.161	2	-0.562	0.000	-	-	-	-
0.072	12	0.350	3	7.784*	9.918*	0.000	-	-	-
0.772	14	0.316	4	6.356*	8.101*	-1.151	0.000	-	-
0.051	49	0.166	LM	-	-	-	-	0.000	11.610*
0.073	25	0.337	S	-	-	-	-	11.610*	0.000

* significant at 0.005 level