THE IMLAY OUTLET OF GLACIAL LAKE MAUMEE, IMLAY CITY, MICHIGAN

by

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ABSTRACT

This study relates use of the Imlay outlet to the Huron-Erie lobe ice events which controlled formation of the three Glacial Lake Maumee stages.

Pebble composition and matrix texture have differentiated two till sheets in the vicinity of Imlay City, Michigan. The older till has a high limestone pebble content and sandy matrix and is restricted in surface exposure to the interlobate area west of the Imlay channel. The younger till has a high sandstone pebble content and more clayey matrix texture; it occurs at the surface eastward from the Imlay channel at least to Yale, Michigan. The Imlay outlet thus marks a significant contrast in till petrologies. Because the pebble compositions of the two tills reflect different source areas, these tills are attributed to two different ice advances. A period of ice retreat is inferred between these advances.

Deposition of the older limestone till in the interlobate area is correlated with Lake Maumee I which stood at 800 feet above sea level and discharged southwestward through the Fort Wayne outlet. Some lake water may have used the Imlay outlet route at this time. With subsequent ice retreat a lower, unknown outlet was opened in the "thumb" of Michigan, and lake level fell to Lake Maumee II at 760 feet; this lake discharged westward to the Glacial Grand River. When the Huron-Erie lobe readvanced, the Maumee II outlet was overridden, and lake level rose to Lake Maumee III at 780 feet. Sandstone till was deposited during this readvance to and retreat from the Imlay channel during Maumee III time. Lake Maumee III drained simultaneously through the Imlay and Fort Wayne outlets.

ACKNOWLEDGEMENTS

This paper would not have been possible without the patient, ready, and excellent advice of Dr. Donald F. Eschman, who suggested this topic for research, and of Dr. William R. Farrand; their generosity with their time in the field, laboratory, and office has been greatly appreciated. Efficient and enjoyable field assistance was rendered by Jan Miller in the summer of 1968 and subsequently by Mr. and Mrs. Richard W. Burgis, John R. Burgis, Mary Lee Muhlenkort, and Susan E. Hays. A special thanks must be said to Mr. and Mrs. Arthur Molzon, the Harold Molzon family, and the innumerable curious people who made living and working in Lapeer County a pleasure.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

INTRODUCTION

Leverett and Taylor's (1915) classic monograph established the existence of three stages of Glacial Lake Maumee on the basis of topographic and morphologic evidence. This approach to study of the Cary history of the "thumb" of Michigan has, however, produced controversy about the outlet or outlets used by each Lake Maumee stage. This paper examines sedimentologically and stratigraphically topographic features near Imlay City, Michigan, to which Leverett and Taylor (1915) assigned a Lake Maumee age. The debate about Lake Maumee's outlets provides a framework in which to compare the effectiveness of the morphological and sedimentological approaches in deciphering the glacial history of an area.

So reverent was the reception of Leverett and Taylor's (1915) impressive monograph (Hough, 1963) that little systematic field work has been done in the "thumb" since their original horseback and buckboard surveys. In the last twenty years new evidence has prompted re-evaluation of Great Lakes history, but recent research has concentrated upon glacial lake stages younger than the Maumees. The only recent field studies related to Glacial Lake Maumee deal with the morphology of the Fort Wayne outlet and Wabash valley (Fidlar, 1948; Thornbury, 1950; Wayne and Thornbury, 1951; Thornbury, 1958). Bergquist and MacLachlan (1951) discuss in detail the glacial features near Lake Maumee's Imlay outlet, but they rely heavily upon Leverett and Taylor's interpretations. The present study of till petrologies demands new interpretations of some of these features, but it substantiates Leverett and Taylor's (1915) basic concept of Lake Maumee drainage.

THE LAKE MAUMEE OUTLET CONTROVERSY

The highest or first stage of Glacial Lake Maumee, Maumee I, is generally thought to have stood at 800 feet above sea level and to have drained down the Fort Wayne outlet to the Wabash River. The lowest or second stage of this lake, Maumee II, is generally thought to have stood at 760 feet above sea level and to have drained westward to the Glacial Grand River. Whether a presently unknown outlet northeast of the Imlay outlet or the Imlay outlet itself carried water from this lake has been a subject for debate. Discharge from the middle or third stage, Maumee III, which stood at 780 feet above sea level, is thought to have flowed solely through the Imlay channel westward to the Glacial Grand River; or solely through the Fort Wayne outlet to the Wabash River; or simultaneously through both the Imlay and Fort Wayne outlets. The three stages of Glacial Lake Maumee date approximately between 14,000 and 13,000 years B.P. (Farrand, 1962).

Leverett and Taylor (1915) give the first and only detailed, comprehensive account of Glacial Lake Maumee written to date. A small, narrow, crescentic Lake Maumee I formed between the newly-constructed Fort Wayne moraine and the retreating Huron-Erie lobe ice front. The lake expanded northeastward with continued ice retreat. Lake level rose until the water found an outlet through the Fort Wayne moraine, thus initiating the "Maumee torrent" (Thornbury, 1958, p. 465) down the Fort Wayne outlet and Wabash spillway. These conclusions are based upon the presence of Maumee I beaches which converge on and enter the Fort Wayne outlet on the inner slope of the Fort Wayne moraine (Taylor, 1897; Leverett, 1902). Maumee I beaches are found also on both the outer and inner slopes of the Defiance moraine. Leverett and Taylor thus believe that, although its size and shape varied with ice margin fluctuations, the lake's level and outlet remained essentially unchanged during ice retreat from the Fort Wayne moraine and during readvance to, construction of, and retreat from the Defiance moraine. Beaches on both flanks of the next younger Birmingham moraine indicate that Lake Maumee I existed during and immediately after deposition of this moraine. As the ice front retreated eastward from the Birmingham moraine, a new, lower outlet a few miles east of Imlay City, Michigan, was opened, lake level fell to that of Maumee II, and the Fort Wayne outlet was abandoned:

> "... it was during the activity of this outlet that the lowest beach of Lake Maumee was made ... The location of the outlet channel at the time of the lowest beach is not definitely known. In southeastern Lapeer County ... it appears to have been overridden and destroyed."
> (Leverett and Taylor, 1915, p. 348)

Maumee II beaches are characteristically faint and fragmentary because of their submergence and modification by the succeeding, higher Maumee III stage, about 20 feet above Maumee II. The lowest Maumee stage was contemporaneous with ice front retreat of unknown magnitude and with the subsequent readvance until the ice overrode and closed the low, unknown Maumee II outlet. The ice "... moved [farther] westward to a position close along the east side of the great Imlay outlet channel ... This channel shows evidence of having been crowded westward by the ice as it was building the [Imlay] moraine along its east side" (Leverett and Taylor, 1915, p. 322). Dreimanis and Karrow (1965, p. 95) believe that enough time elapsed between closing of the Maumee II outlet and opening of the Maumee III outlet for a beach deposit inter-

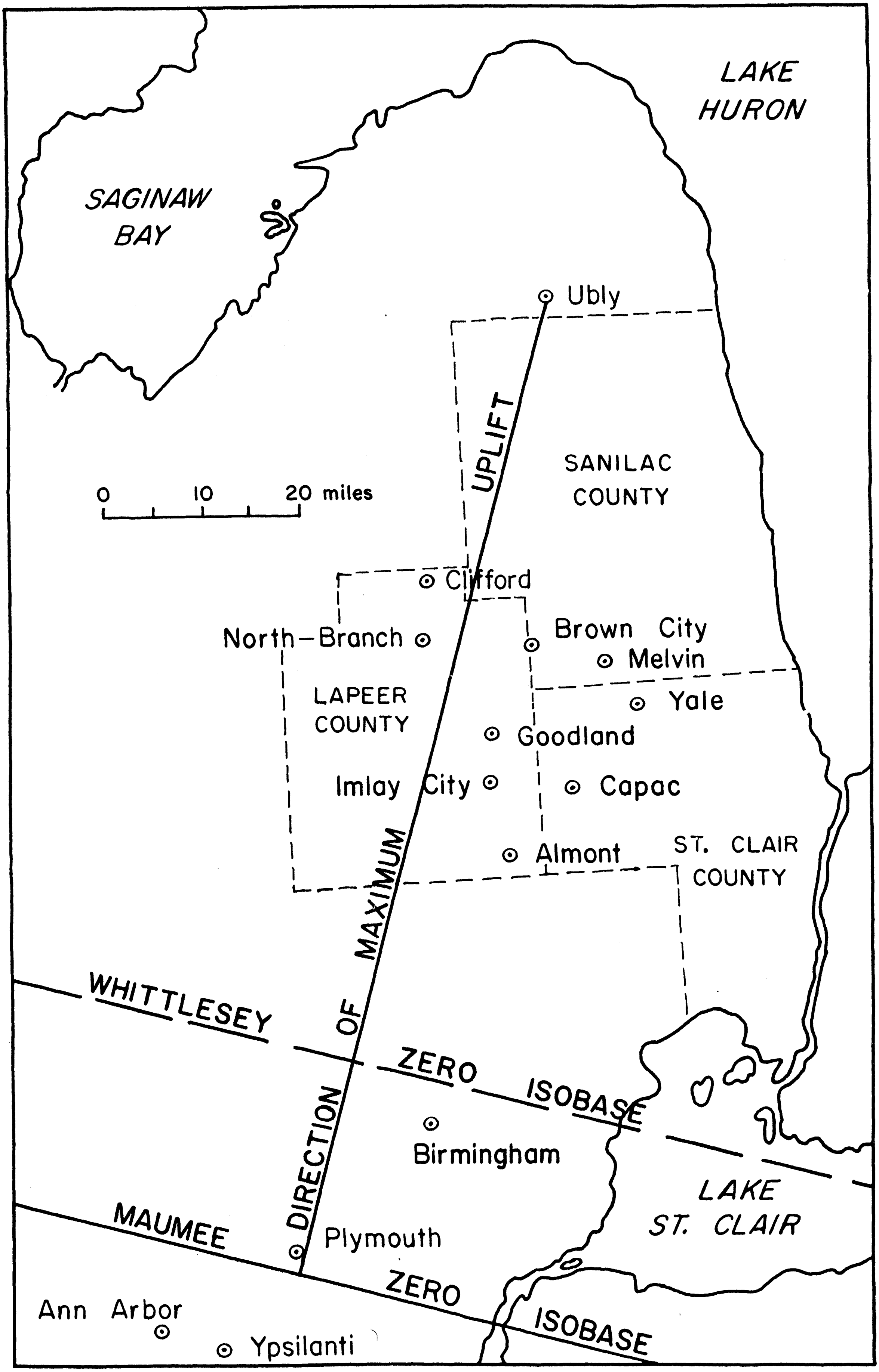


Figure 1. Location map of southeastern Michigan showing the relationship of the Lake Maumee and Lake Whittlesey zero isobases and the direction of maximum postglacial uplift.

mediate in elevation between those lakes to have developed in southern Ontario as the water rose during this Maumee II-III transition.

Because the Imlay outlet stood at a higher elevation than the obliterated Maumee II outlet, lake level rose to that of Maumee III. Taylor in 1897 and Leverett in 1902 tentatively identified Maumee III beaches in the heads of the Fort Wayne and Imlay outlets and therefore suggested simultaneous discharge of this lake stage through both channels. In 1915 (p. 322), however, they concluded that Maumee III "... was barely too low to overflow at Fort Wayne ..." and used only the Imlay outlet. But the present study has not confirmed the Maumee III beach features which Taylor (1897) traced into the Imlay outlet. The best criteria for determining whether Maumee III used both the Fort Wayne and Imlay outlets are the elevations of the outlet divides at the end of Maumee III time with respect to lake level: discharge from 780-foot Lake Maumee III could have occurred through both outlets, for the Fort Wayne outlet head stood at 757 feet, as measured by Leverett, and the Imlay channel divide stood at 760 feet, as determined from recent topographic maps. Leverett and Taylor feel that the Imlay, Goodland, Deanville, and Yale moraines were deposited during Maumee III ice retreat from the eastern bank of the Imlay channel. Retreat from the Yale moraine opened a new outlet farther north and lower than the overridden Maumee II outlet, and lake level fell to produce Glacial Lake Arkona.

Therefore, according to Leverett and Taylor (1915, p. 469), Maumee I discharged through the Fort Wayne outlet and was dammed by ice which stood temporarily at the Defiance and Birmingham moraines; the final location of the retreatal ice dam of Maumee II is unknown, but the lake drained northward and westward through a channel near Imlay City, Michigan, which was subsequently obliterated by ice advance to the eastern bank of the Imlay channel; and, contemporaneously with deposition of the Imlay through Yale moraines, Maumee III discharged through the Imlay channel, with only small-volume, intermittent drainage possible through the Fort Wayne outlet.

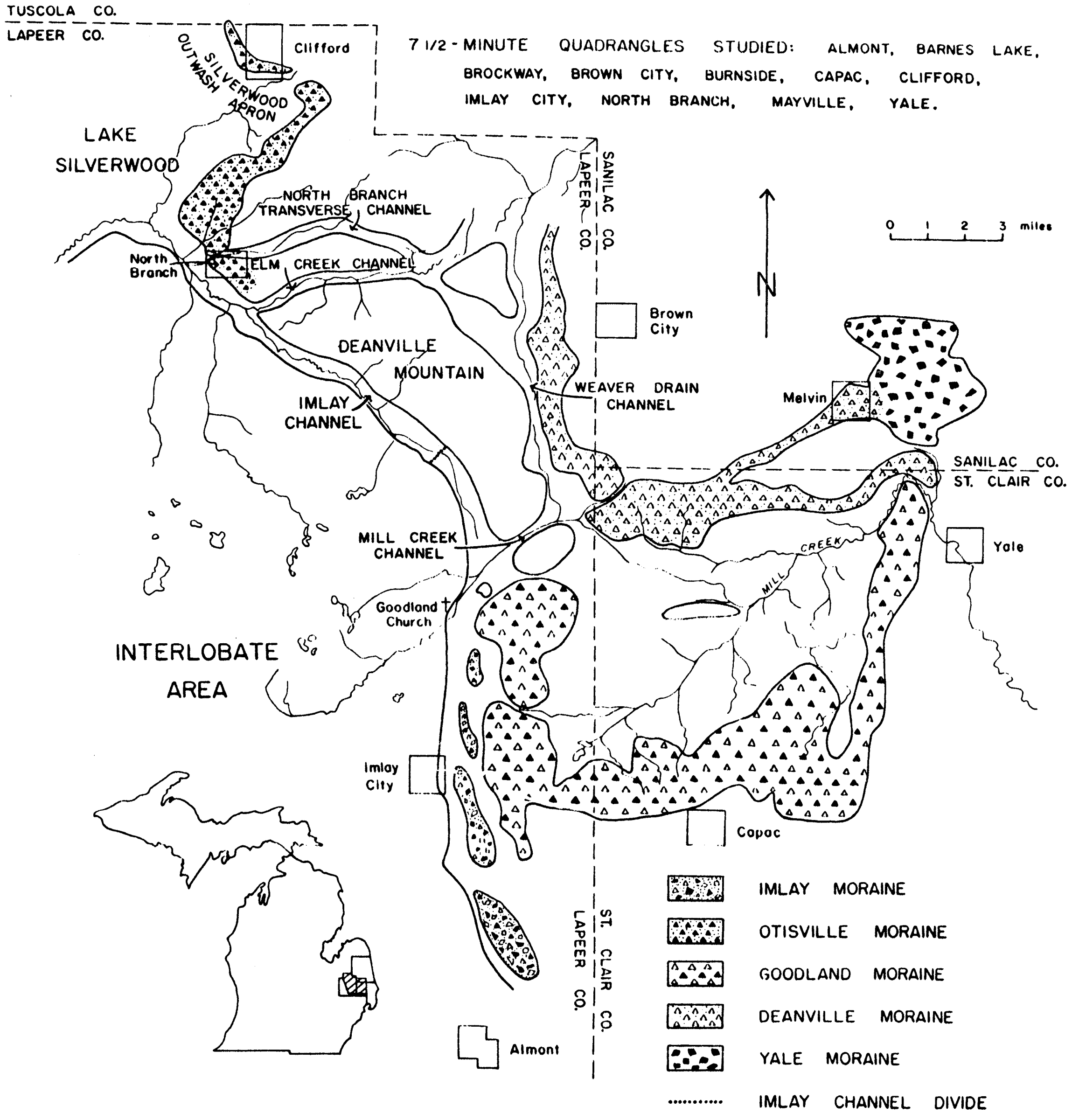
Bergquist and MacLachlan (1951) suggest brief use of the Imlay outlet during post-Birmingham Maumee I time simultaneous with the main Maumee I discharge through the Fort Wayne outlet.

> "... retreat of the ice front [from the Birmingham moraine] ultimately opened an outlet at the present site of Imlay City, Michigan, which was several feet lower than the Wabash outlet at Fort Wayne. At first the channel past Imlay City was neither low enough nor wide enough to carry the full discharge of the expanded lake and for a while both the Imlay outlet and the Wabash outlet operated simultaneously. This initial use of the Imlay outlet was of but short duration, for the ice front continued to retreat until it reached a position somewhere northeast of Imlay City and uncovered an outlet about fifteen feet lower than the Imlay outlet. The use of this low outlet marks the second or lowest Maumee stage." (Bergquist and MacLachlan, 1951, p. 3)

Thus, ice retreat during late Maumee I time uncovered a natural low in the position of the present Imlay channel. Running water first began to modify this depression as ice-border discharge and drainage from Lake Maumee I. Because modification began in the infant Imlay channel much later than initial cutting of the Fort Wayne outlet, the Imlay channel was less well defined topographically than the Fort Wayne outlet in late Maumee I time. Bergquist and MacLachlan therefore feel that the increase in discharge capacity produced by opening the infant Imlay channel was insufficient to lower the level of Lake Maumee I.

FIGURE 2.

TOPOGRAPHIC FEATURES OF THE IMLAY CITY AREA



Bergquist and MacLachlan's proposal of brief Maumee I discharge through the infant Imlay channel is conceptually logical given lake level and the present Imlay channel divide elevation corrected for uplift. According to Leverett and Taylor's (1915) interpretation of Lake Maumee III drainage, however, the Imlay channel is also the product of main Maumee III discharge. The original elevation of the Imlay channel depression and the amount of possible downcutting during Maumee I time relative to possible downcutting during Maumee III time are unknown. I looked for the gravel terraces that Taylor (1897) claims to have found in the Imlay channel to see if they might provide evidence of two periods, Maumee I and III, of discharge through the outlet, but no such terraces were identified in the field. Therefore, the exact Imlay channel divide elevation at the end of Maumee I time, the elevation which was to determine whether Lake Maumee II water could flow through the Imlay channel, remains unknown.

The presence of high kamic masses on both sides of the Imlay channel along the western flank of Deanville Mountain indicates that the original Imlay channel low was not, contrary to Bergquist and MacLachlan's (1951) suggestion, opened by the simple retreat of active ice during Maumee I time. Ice blocks were probably trapped in a pre-existing depression in the present position of the Imlay channel during pre-Maumee I or Maumee I time as the kames were built. These abandoned ice blocks may have stood too high in Maumee I time to have permitted brief northward lake discharge. Use of the Imlay channel by the various stages of Lake Maumee was dependent not only upon the original elevation of the topographic low there but also upon the time of abandonment, size, and rate of melting of these ice blocks and upon the timing and magnitude of any downcutting in the channel. Of the controlling factors only the present Imlay channel divide elevation is known, and therefore Maumee I discharge through an infant Imlay channel must remain an unproven possibility.

Bergquist and MacLachlan (1951) feel that the ice which closed the Maumee II outlet readvanced to and deposited the Mount Clemens moraine, a correlative of the Deanville moraine (Leverett and Taylor, 1915, p. 30), at the beginning of Maumee III time. Leverett and Taylor (1915), however, conceive of a more extensive ice readvance from the final Maumee II retreatal position and identify the Imlay and Goodland moraines as the oldest Maumee III moraines. Bergquist and MacLachlan imply that the Imlay and Goodland moraines were deposited as the ice front retreated from their postulated infant Imlay channel during Maumee I time. Petrology of the till in the Imlay through Yale moraines reported in this paper supports Leverett and Taylor's age assignments, however.

In 1958 Hough agrees that the Maumee II outlet has been overridden by a subsequent ice advance and that its location is unknown. But by 1967 he identifies the Imlay channel as the outlet of Lake Maumee II (J. L. Hough, personal communication). This conclusion is based upon Leverett and Taylor's statement that there are three flat divides in the Imlay channel, none of which stands higher than 802 feet (1915, p. 276-277). Uplifted beaches of the three Maumee stages rise at the rate of one foot per mile north of their zero isobase and have not experienced differential uplift (Farrand, 1962). Confusion about the exact location of the Maumee zero isobase exists in the literature. In their text Leverett and Taylor

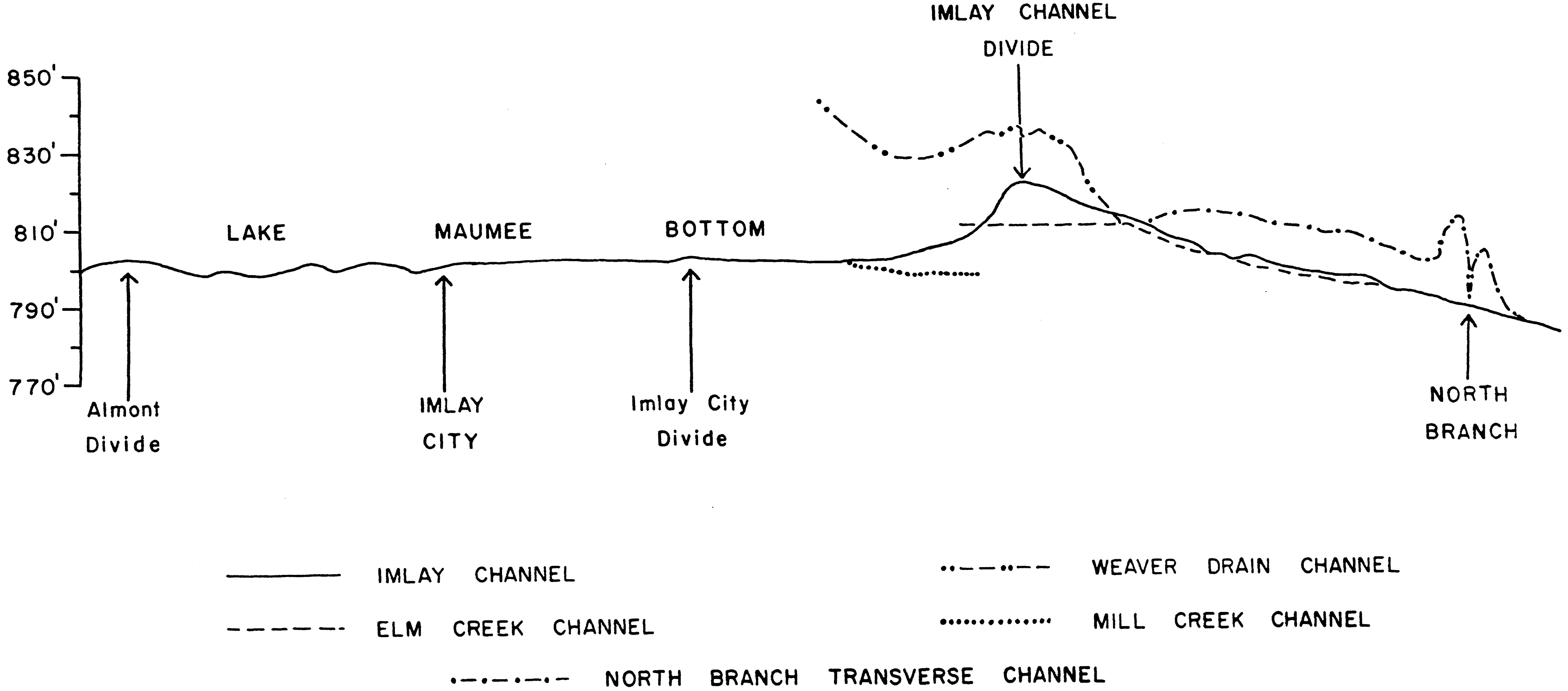


Figure 3. Longitudinal profiles of channels discussed in this paper. Profiles drawn from topographic maps issued in 1963. Vertical exaggeration approximately 335 X. Profiles not corrected for effect of postglacial uplift. Imlay and Weaver Drain channels flowed northwestward in study area. Elm Creek and North Branch Transverse channels flowed westward to the Imlay channel. Gradient of Mill Creek channel slopes eastward. Almont and Imlay City "divides" in Imlay channel located by Leverett and Taylor (1915).

(1915) refer to Maumee beaches as undeformed as far north as 4 to 5 miles north of Birmingham, Michigan, the location of the Lake Whittlesey zero isobase (Figure 1). In Plate XX, however, they show Maumee beaches beginning to rise farther south; the zero isobase used in this paper is taken from Plate XX and passes through a point 2 miles south of Plymouth, Michigan (Figure 1).[1] Leverett and Taylor thought that the channel divide near Imlay City, 52 miles north of the Maumee zero isobase, stood at approximately 750 feet before uplift and was low enough for Lake Maumee II water at 760 feet to have covered it. The divide farther north at Deanville Mountain was uplifted 60 feet, standing at 742 feet before uplift according to Leverett and Taylor's elevations; in Hough's 1967 (personal communication) interpretation the Deanville Mountain divide thus lies farther downstream on the gradient of Maumee II drainage than the Imlay City divide. Topographic maps issued in 1963, however, show that this northern divide has a present elevation of just over 820 feet, not 802 feet, but that the Imlay City divide does in fact stand between 800 and 810 feet (Figure 3). Therefore the northern divide controlled northwesterly flow through the Imlay outlet. The Imlay City divide, which stood at 750 feet before uplift, and the Almont divide, which stood at approximately 755 feet before uplift, are simply small irregularities on the lake bottom; the southern portion of the Imlay outlet is not a true river channel but rather a long, narrow arm of Lake Maumee

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[1] In the following discussion of Maumee II drainage, possible evolutionary changes in the configuration of the Imlay channel are ignored. The channel during Maumee II time is assumed to have been morphologically the same as at the end of Maumee III time. Although the assumption is probably invalid, it simplifies the discussion.

restricted by the Imlay moraine, which was built into it in Maumee III time. The northern divide elevation before 60 feet of uplift was about 760 feet according to recent maps. This divide stood approximately at the level of Lake Maumee II, not at 742 feet as calculated from Leverett and Taylor's elevations. Therefore, Lake Maumee II could have discharged through the Imlay channel only during periods of high water. If the effects of probable evolutionary changes on the outlet are taken into account, even such small-volume, intermittent flow from Maumee II through the Imlay channel may have been impossible. Another outlet in the "thumb" must have carried most, if not all of Maumee II's discharge. Hough's (1967, personal communication) erroneous conclusion that the Imlay outlet was low enough to carry large-volume Maumee II drainage may have resulted from choice of a Maumee zero isobase farther south than the one used in this paper or from failure to check Leverett and Taylor's (1915) northern divide elevation against new topographic maps.

Struck by the fact that the Fort Wayne outlet head stands about 20 feet below Lake Maumee III level,[1] Hough (1958) resurrects the idea of simultaneous discharge of this lake through the Fort Wayne and Imlay outlets. This idea had been proposed by Taylor in 1897 and by Leverett in 1902, but they discarded it in 1915.

> "... the present elevation of the bed at the Fort Wayne outlet is 757 feet A.T. ... quite low enough to carry an appreciable part of the discharge from a lake standing at 780 feet A.T. It is suggested here that

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[1] The elevation of 757 feet A.T. cited in the literature for the Fort Wayne outlet head was determined by Leverett in 1902 (p. 712). As in the case of the northern Imlay channel divide, his altitudes are not always accurate.

> the Fort Wayne outlet was cut to this low level during the third or Middle Maumee stage, and that during this process most if not all of the discharge was transferred from the Imlay to the Fort Wayne outlet." (Hough, 1958, p. 145)

In 1963, however, Hough strongly advocates the exclusive discharge of Lake Maumee III down the Fort Wayne outlet:

> "This stage must have discharged down the Wabash River because the divide at the head of the drainage at Fort Wayne, Indiana, is 757 feet above sea level. It is not known whether this divide was cut to this elevation during the waning stages of highest [I] Lake Maumee, or during Middle [III] Lake Maumee, but the latter possibility seems more probable ... [During Maumee III time there was] discharge westward down the Grand River Valley in Michigan, but it is probable that this discharge was not from Middle Lake Maumee but was melt water from the local ice front." (p. 92)

Hough gives no reason why Lake Maumee III could not have flowed over the Imlay channel divides which he believes were as low as or lower than the Fort Wayne outlet head during Maumee III time. Hough's growing conviction that Lake Maumee III drained exclusively through the Fort Wayne outlet may have caused him to reinterpret Maumee II history erroneously. No major lakes older and as high as or higher than the Maumees are known in the "thumb," and the well-developed Imlay outlet is too high to have drained lakes younger and lower than the Maumees. If not used by Maumee III, the Imlay channel, according to Hough's divide elevations, can be explained only as the route of brief Maumee I or of main Maumee II discharge.

Hough's (1958; 1963) hypothesis that the Fort Wayne outlet divide was downcut during Maumee III time suggests that examination of Fort Wayne outlet and Wabash sluiceway terraces may determine whether two Maumee stages, I and III, used this discharge route. Two terraces are generally recognized in that drainage

Table 1.

SUMMARY OF THE LAKE MAUMEE OUTLET CONTROVERSY

ARTICLE	MAUMEE I	MAUMEE II	MAUMEE III
Taylor (1897)	Fort Wayne outlet	Stage not recognized	Imlay outlet (Fort Wayne outlet ?)
Leverett (1902)	Fort Wayne outlet	Stage not recognized	Imlay and Fort Wayne outlets
Leverett & Taylor (1915)	Fort Wayne outlet	Outlet near Imlay City	Imlay outlet
Malott (1922)	Fort Wayne outlet	Outlet lower than Fort Wayne outlet	Not Fort Wayne outlet
Bay (1936; 1938)	Fort Wayne outlet	Outlet north of Imlay City	New outlet at Imlay City
Bergquist & MacLachlan (1951)	Fort Wayne & Imlay (brief use) outlets	Outlet northeast of Imlay City	Imlay outlet
Hough (1958)	Fort Wayne outlet	"Thumb" ice-border discharge	Imlay and Fort Wayne outlets
Hough (1963)	Fort Wayne outlet	"Thumb" ice-border discharge	Fort Wayne outlet (Imlay outlet ?)
Hough (1967, personal communication)	Fort Wayne outlet	Imlay outlet	Fort Wayne outlet
Dreimanis & Karrow (1965)	Fort Wayne outlet	West across Michigan	West across Michigan
Wayne & Zumberge (1965)	Fort Wayne outlet	Edge of Saginaw lobe	Fort Wayne outlet

system: the upper terrace represents the surface of a Tazewell-Early Cary valley train, and the lower is the floodplain-erosional surface left by the Maumee I torrent (Malott and Shrock, 1929). The lower terrace can be firmly associated with Lake Maumee discharge because this surface is preserved almost unaltered in the Fort Wayne outlet, and it joins the Maumee lake plain accordantly (Fidlar, 1948, p. 103). Only one terrace represents Maumee discharge, whether from one or two lake stages. Wayne and Zumberge (1965) believe that Lakes Maumee I and III discharged exclusively through the Fort Wayne outlet and state that the "... erosion surface along the Wabash Valley planed by the overflow waters of the two high phases of Lake Maumee stands 16 to 22 feet above the modern floodplain and is called the Maumee terrace" (p. 77). Because Lakes Maumee I and III differed only 20 feet in surface elevation, it is perhaps possible that even if two distinct episodes of Maumee discharge did occur through this outlet, their features would be virtually indistinguishable. The single Fort Wayne outlet-Wabash sluiceway terrace of Maumee age does not settle the controversy about Lake Maumee III discharge. Interpretation of this terrace's significance apparently depends upon a preconception of Maumee drainage patterns, not upon field evidence. Maumee II and much of Maumee III discharge flowed through the Glacial Grand River channel, but no separate Maumee terrace is found there; rather, one terrace represents discharge from Lakes Maumee, Arkona, and Whittlesey (Leverett and Taylor, 1915, p. 361). On the other hand, the Wabash sluiceway does display a terrace that conclusively proves at least one episode of Maumee discharge.

Evaluation of the literature about the Lake Maumee outlet controversy leads to the following conclusions:

1) Lake Maumee I, after cutting its main outlet through the Fort Wayne moraine, existed during deposition of the Defiance and Birmingham moraines (Figure 4). If ice blocks trapped in a pre-existing depression at the present site of the Imlay channel northern divide stood low enough during late Maumee I time, this lake could have briefly discharged through an infant Imlay channel as well as at Fort Wayne. If the Imlay outlet did function then, its addition to the volume of Maumee I discharge was not sufficient to lower lake level.

2) Ice retreat opened a new, lower outlet northeast of Imlay City, Michigan, and lake level fell to the Maumee II stage (Figure 5). The Maumee I outlet or outlets were abandoned. The Imlay channel northern divide stood too high at the end of Maumee III time to have permitted continuous large-volume Maumee II discharge through this outlet; the divide may have stood even higher during Maumee II time, thus eliminating even intermittent, small-volume flow from the lake. The location of the Maumee II outlet is unknown, and that channel has probably been largely obliterated by a later ice advance.

3) Ice readvance closed the Maumee II outlet, and lake level rose until Lake Maumee III water flowed northwestward through the Imlay channel. Fort Wayne outlet terraces do not give evidence of two separate Maumee discharges; however, the similarity of the Fort Wayne outlet head and Imlay channel northern divide elevations at the end of Maumee III time indicates that simultaneous discharge through both outlets must have occurred during Maumee III time (Figure 6).

4) Glacial Lake Arkona formed when ice retreat from the Yale moraine uncovered an outlet even lower than the buried Maumee II outlet. The Imlay and Fort Wayne outlets were permanently abandoned. Cary time ended with the drop in lake level from Maumee III; Lake Arkona existed during the Cary/Port Huron interval (Bergquist and MacLachlan, 1951, p. 24).

These conclusions, based upon morphological evidence, will now be examined in the light of new sedimentological and stratigraphic evidence.

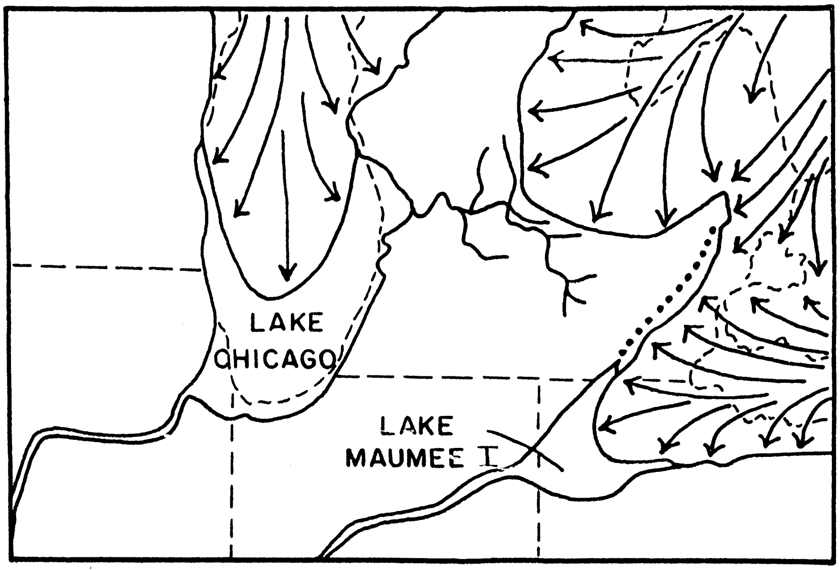


Figure 4. Map showing Lake Maumee I draining southwestward through the Fort Wayne outlet in post-Defiance time. Dotted line indicates position of the newly deposited Defiance moraine. Glacial Grand River flowed from edge of the Saginaw lobe into Lake Chicago, which discharged to the west and south via the Chicago outlet. Arrows indicate direction of ice movement. (Modified from Russell and Leverett, 1908, p. 13)

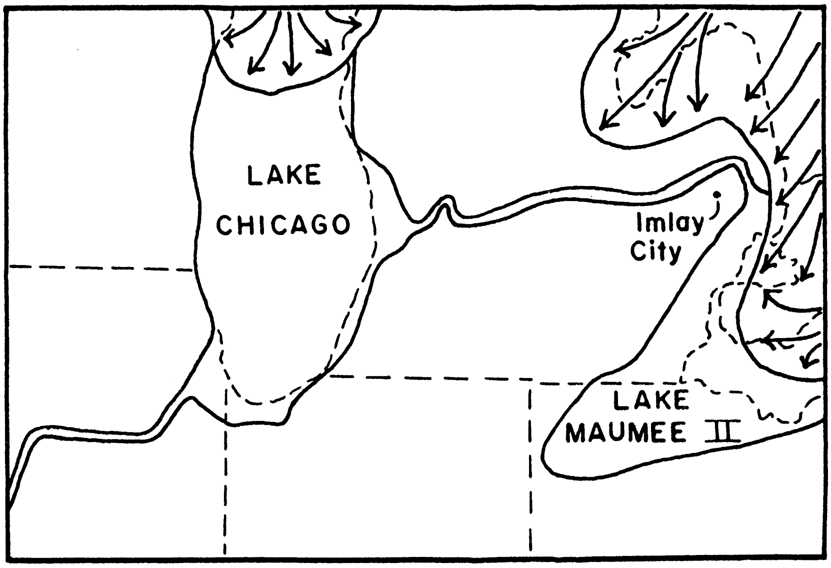


Figure 5. Map showing discharge of Lake Maumee II through an unknown outlet northeast of Imlay City, Michigan, westward to the Glacial Grand River and Lake Chicago during a period of ice retreat. Lake Chicago drained to the west and south via the Chicago outlet. Arrows show direction of ice movement. (Modified from Russell and Leverett, 1908, p. 13)

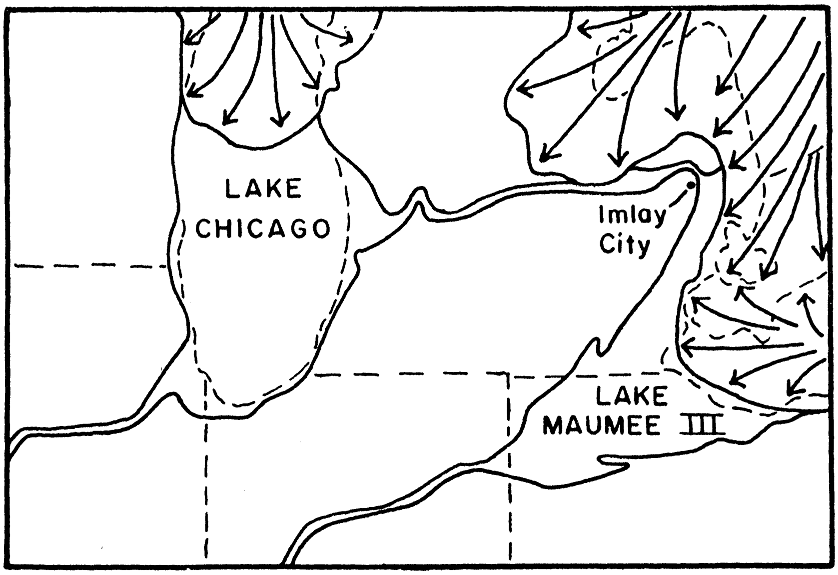


Figure 6. Map showing simultaneous discharge of Lake Maumee III through the Imlay outlet westward to the Glacial Grand River and Lake Chicago and southwestward through the Fort Wayne outlet during a period of ice readvance. Lake Chicago drained to the west and south via the Chicago outlet. Arrows indicate direction of ice movement. (Modified from Russell and Leverett, 1908, p. 13)

SEDIMENT	%LS$_i$	%SS$_i$+Sh	% CRYSTALLINE	% SAND	% SILT	% CLAY
LIMESTONE TILL	51.9 ± 2.6	16.6 ± 2.3	31.4 ± 2.1	44.8 ± 4.7	34.3 ± 2.0	20.8 ± 3.0
SANDSTONE TILL	32.0 ± 2.1	51.9 ± 2.8	16.1 ± 1.4	28.8 ± 1.8	40.3 ± 0.9	30.9 ± 2.0
DEANVILLE MOUNTAIN TILL	25.6 ± 5.2	51.3 ± 6.3	23.1 ± 3.7	40.0 ± 4.4	33.8 ± 2.1	26.2 ± 3.6
SANDSTONE-DEANVILLE MTN. TILL	30.5 ± 2.0	51.7 ± 2.6	17.8 ± 1.5	31.3 ± 1.9	38.9 ± 1.0	29.8 ± 1.7
LIMESTONE GRAVEL	52.4 ± 3.0	17.2 ± 3.5	30.5 ± 3.6	—	—	—
SANDSTONE GRAVEL	40.0 ± 6.1	38.3 ± 7.9	21.7 ± 4.4	—	—	—
DEANVILLE MOUNTAIN GRAVEL	57.3 ± 2.5	14.0 ± 2.2	28.3 ± 2.0	—	—	—

Table 2. Pebble composition and matrix texture means and confidence intervals (0.05 level of significance) for sediments in the study area. Three samples of non-surface limestone till excluded from calculations.

TILL: PEBBLE COMPOSITION

Pebble composition, determined by counts of 100 stones 1 to 3 inches in maximum dimension from unleached till, sharply differentiates the till west of the Imlay channel from the till east of it. Pebbles from both the till and gravel of the Imlay City area fall into four main groups: sandstone, black shale, limestone, and crystalline rocks. The crystalline group consists primarily of acidic and basic intrusive igneous rocks, quartzite, and basic and acidic volcanics, all derived from the Canadian Shield. The limestone originates from the Early to Middle Paleozoic sediments which encircle the Michigan Basin and underlie the present Lake Huron basin. The sandstone and black shale from the Mississippian Marshall sandstone and Coldwater shale, respectively, are the local bedrock of the study area. To facilitate data treatment and to emphasize different source areas for sedimentary till pebbles these indices have been defined:

1) LS_i = limestone + dolomite + chert till pebbles. Although from various formations, these lithologies are related geographically and in age. They originate from a source area located between the distant Canadian Shield source and the immediate study area. Because most carbonate pebbles effervesced within a few seconds of HCl application, few true dolomite pebbles were present.

2) SS_i = sandstone + siltstone + conglomerate + iron claystone concretion till pebbles. Most of these lithologies are derived from the Marshall sandstone, but some come from sandstone and siltstone lenses in the Coldwater shale. Sandstone of various grain sizes is the dominant lithology in this group, often constituting 80% or more of it.

3) $SS_i + Sh = SS_i$ + black shale till pebbles. These lithologies together represent local bedrock. Because it is soft and easily abraded, many pebble counts contain no black shale, so that frequently $SS_i = SS_i + Sh$.

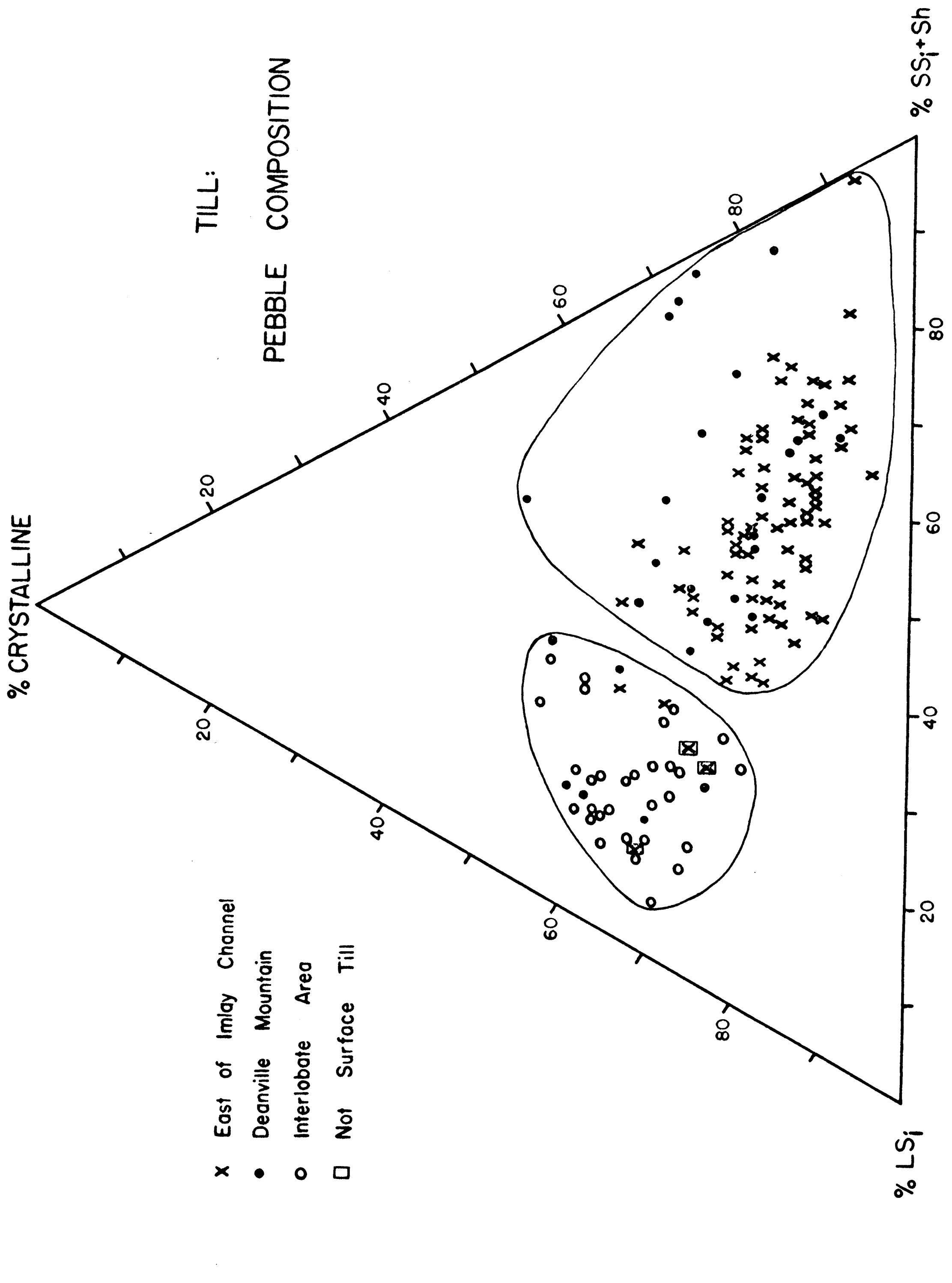

TILL:
PEBBLE COMPOSITION
% CRYSTALLINE
% LSi
% SSi+Sh
20
40
60
80
20
40
60
80
20
40
60
80
× East of Imlay Channel
● Deanville Mountain
o Interlobate Area
□ Not Surface Till

FIGURE 7.

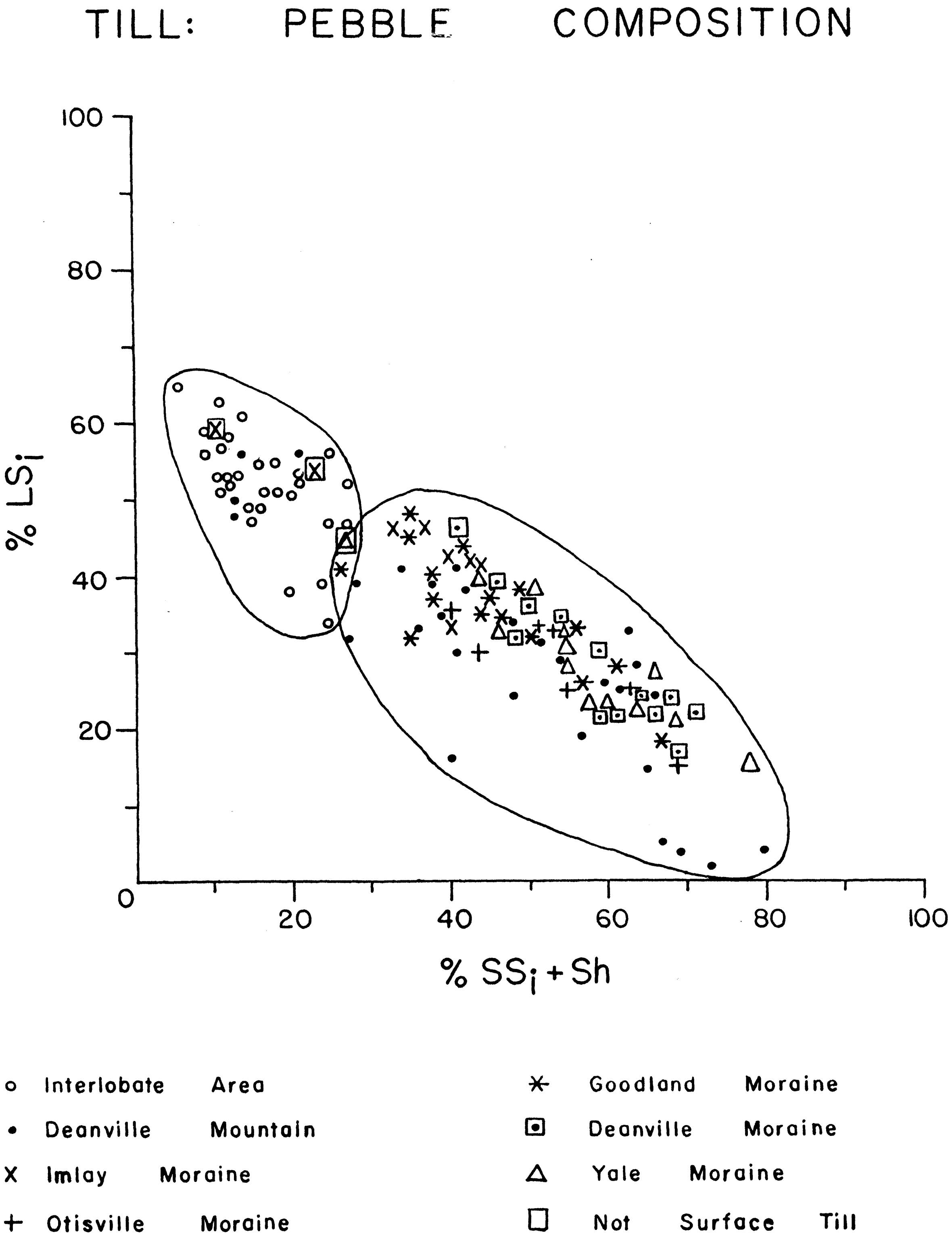


Figure 8. Limestone and sandstone till sheets differentiated on the basis of sedimentary pebble composition. Sample points identified by topographic feature.

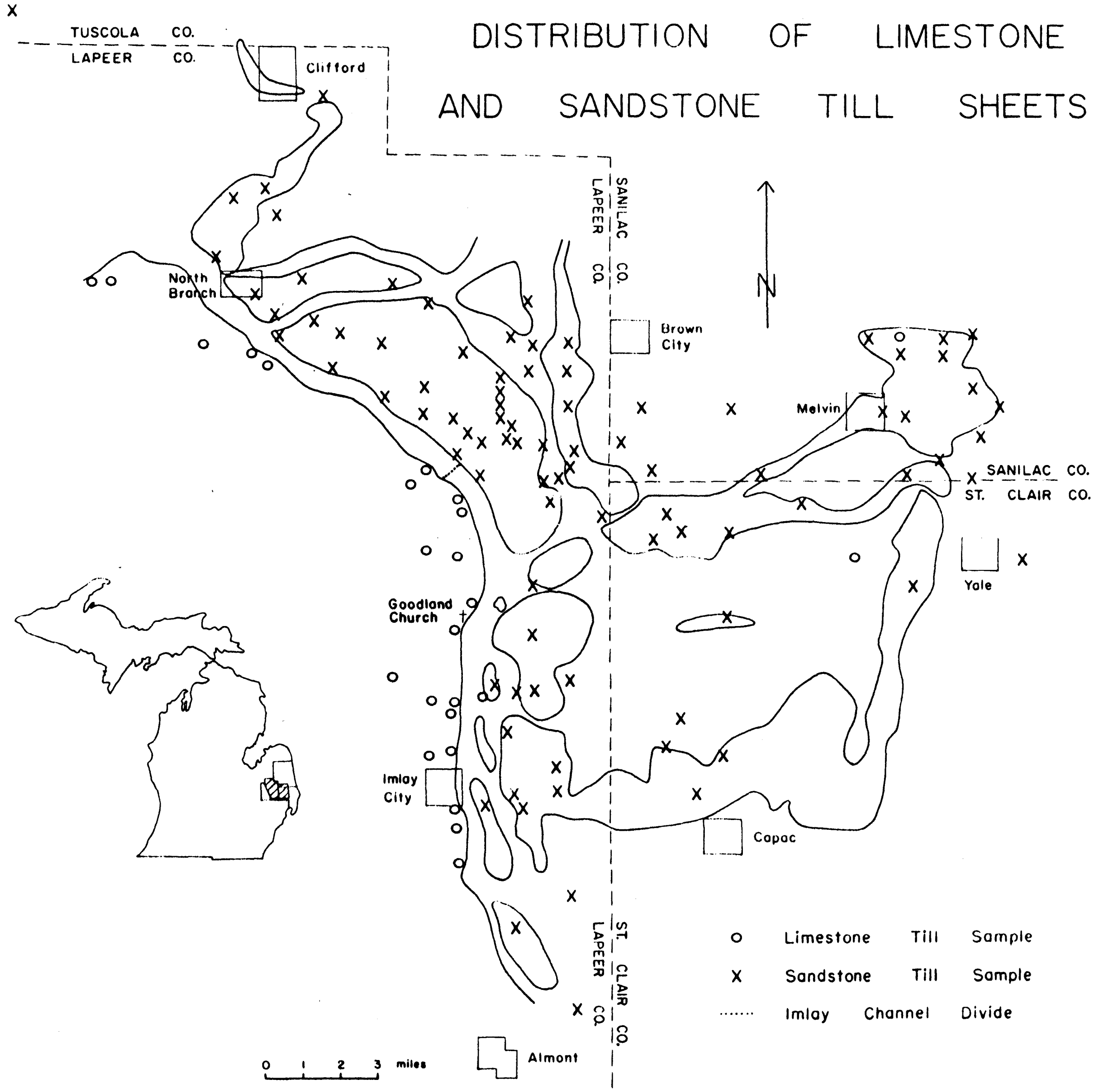
Thus the ratio LS_i/SS_i + Sh is a measure of the abundance of more distantly derived lithologies relative to the abundance of local bedrock in the sedimentary pebble fraction of a till in the Imlay City area.

Pebble compositions of 134 till samples have been plotted with percent LS_i, percent SS_i + Sh, and percent crystalline rocks as coordinates (Figure 7). Two distinct point clusters representing different geographic areas are defined graphically: till from the interlobate area west of the,Imlay channel has a mean pebble composition of 51.9 ± 2.6% LS_i, 16.6 ± 2.3% SS_i+ Sh, and 31.4 ± 2.1% crystalline rocks, while till from the area east of the Imlay channel has a mean pebble composition of 32.0 ± 2.1% LS_i, 51.9 ± 2.8% SS_i+ Sh, and 16.1 ± 1.4% crystalline rocks. Student's t-tests of the difference between the means for the two areas show that this difference is significant at the 0.05 level for each of the three pebble components (Table 3). Thus different tills lie on either side of the Imlay channel (Figure 9). The interlobate till, characterized by a large percentage of pebbles derived from the Lake Huron basin, is here informally named the limestone till, and the till east of the Imlay channel, characterized by a large percentage of local bedrock, is named the sandstone till. I contend in this paper that these tills represent two ice advances separated by a period of ice retreat: the limestone till is a deposit of the older ice advance; readvancing later, the ice picked up large amounts of the sandstone and black shale bedrock local to the study area, the limestone and crystalline pebble content of the ice was diluted, and the sandstone till was deposited.

The occurrence of limestone till 5 to 15 feet below the western

FIGURE 9.

DISTRIBUTION OF LIMESTONE AND SANDSTONE TILL SHEETS



edge of the Imlay moraine demonstrates the extension of the older, stratigraphically lower limestone till sheet east of the Imlay channel. Limestone till also occurs in the channel of Mill Creek near Yale, Michigan. The creek has a sharply incised valley and has presumably cut through the younger sandstone till of the neighboring ridges of the Deanville moraine to encounter the underlying limestone till.

Till pebble compositions from Deanville Mountain are extremely variable: LS_i varies from 2 to 56%, SS_i+ Sh from 14 to 80%, and crystalline content from 8 to 44%; calculated variances are largest for SS_i+ Sh and smallest for LS_i. Three of the five pebble counts containing 5% or less limestone are from the eastern edge of Deanville Mountain. Unusually shallow depths to the Marshall sandstone somewhere just east of the mountain may explain the very high sandstone content of these samples and some of the variance of SS_i+ Sh in Deanville Mountain till.

Deanville Mountain till has a mean pebble composition of 25.6 ± 5.2% LS_i, 51.3 ± 6.3% SS_i+ Sh, and 23.1 ± 3.7% crystalline rocks. Student's t-tests at the 0.05 level show that Deanville Mountain till is significantly different from the limestone till in all pebble-component means, and it is also significantly different from the sandstone till in mean limestone and mean crystalline rock content (Table 3). Deanville Mountain till does not, however, differ significantly from the sandstone till in sandstone content (Table 3). The Deanville Mountain and sandstone tills are identified as deposits of the same ice advance on the basis of their similar, high sandstone content. Student's t-tests of the difference between the limestone till and combined sandstone-

Table 3. Results of Student's t-tests[+] of the significance of differences in pebble composition and matrix texture between tills of the Imlay City area.

[*]Limestone Till vs. Sandstone Till

Parameter	F-Test for Equal Variances	t-Test of Significant Difference
% LS_i	Equal	Significant
% SS_i + Sh	Not Equal	Significant
% Crystalline	Equal	Significant
% Sand	Not Equal	Significant
% Silt	Equal	Significant
% Clay	Equal	Significant

[*]Limestone Till vs. Deanville Mountain Till

Parameter	F-Test for Equal Variances	t-Test of Significant Difference
% LS_i	Not Equal	Significant
% SS_i + Sh	Not Equal	Significant
% Crystalline	Not Equal	Significant
% Sand	Equal	Not Significant
% Silt	Equal	Not Significant
% Clay	Equal	Significant

[+] See Appendix for tests performed at 0.05 level of significance.

[*] Three samples of non-surface limestone till excluded from calculations.

Table 3. (Continued)

Sandstone Till vs. Deanville Mountain Till

Parameter	F-Test for Equal Variances	t-Test of Significant Difference
% LS_i	Equal	Significant
% SS_i+ Sh	Equal	Not Significant
% Crystalline	Not Equal	Significant
% Sand	Equal	Significant
% Silt	Equal	Significant
% Clay	Equal	Significant

*Limestone Till vs. Sandstone-Deanville Mountain Till

Parameter	F-Test for Equal Variances	t-Test of Significant Difference
% LS_i	Not Equal	Significant
% SS_i+ Sh	Not Equal	Significant
% Crystalline	Equal	Significant
% Sand	Equal	Significant
% Silt	Equal	Significant
% Clay	Equal	Significant

---

* Three samples of non-surface limestone till excluded from calculations.

Deanville Mountain till support this conclusion by showing that all pebble-component means of these two sediments differ significantly at the 0.05 level (Table 3).

The slight but significant difference in mean limestone and crystalline content between the sandstone and Deanville Mountain tills is probably the result of incorporation of older Deanville Mountain sediments of different pebble composition by advancing sandstone-rich ice. Some till samples from Deanville Mountain have pebble compositions characteristic of the limestone till. They were taken from the basal few feet of till directly overlying limestone-rich gravel which has essentially the same pebble composition as the limestone till; these samples may be interpreted as a mixture of this gravel with sandstone till.

The stratigraphy of Deanville Mountain requires revision of Leverett and Taylor's (1915) morphological interpretation of this feature and its relationship to the interlobate area west of the Imlay channel. Leverett and Taylor believe that the Defiance and Birmingham moraines of Maumee I age can be followed northward into the interlobate area almost continuously to and beyond Imlay City. However, the contradictions evident in using Leverett and Taylor's (1915, p. 30) correlation of "thumb" moraines (Tables 6 and 7) and a lack of convincing field evidence indicate that these moraines cannot be traced easily, if at all, into the interlobate area in Lapeer County. The bulk of the sediment constituting the topographically sharp interlobate features near Imlay City is sand and gravel; this indicates the kamic nature of the interlobate area. The major deposits of Maumee I age in the "thumb" were left by stagnant ice, not by the active ice responsible for deposition of the Defiance and Birmingham moraines to the south. In many interlobate area gravel pits great thicknesses of sand and limestone-rich gravel are capped by a layer of limestone till. The sharp contact between these sediments suggests that the till may not be of ablation origin but rather the deposit of an ice readvance over the interlobate kames; if such a readvance occurred, it may have correlated with readvance to the Defiance or Birmingham moraine farther south. The dominant morphology of the interlobate area is kamic with superposed till, not morainic topped with occasional kames as Leverett and Taylor claimed.

Leverett and Taylor's (1915) interpretation of Deanville Mountain seems to rest upon the assumption that all features along the eastern bank of the Imlay channel have the same origin and are morphologically continuous. They describe the Imlay and Goodland moraines near Imlay City as faint but distinctly separate as far north as the Mill Creek channel. Between Mill Creek and what Leverett and Taylor call the "Deanville kames" these moraines cannot be distinguished, but from the "Deanville kames" northwest to North Branch, Michigan, the moraines are thought to be once again separate ridges up to a mile apart. Leverett and Taylor maintain that the cluster of high "Deanville kames" rest on top of the combined Imlay and Goodland moraines where these are indistinguishable and that the kames are composed of gravel with till at their base. Leverett and Taylor divide the "Deanville kames" into two groups about a mile apart, each elongated parallel to the northwesterly trend of the combined Imlay and Goodland moraines north of Mill Creek. "If the kames were inset a little from the front of the ice, as seems probable, their relations and the interval between them seems to accord well with the two moraines referred to" (Leverett and Taylor, 1915, p. 272). In other words, although the Imlay and Goodland moraines cannot be distinguished from each other near the "Deanville kames," the two lines of kames represent two ice advances: the western kames were deposited by the earliest Maumee III Imlay advance and the eastern kames by readvance to the younger Goodland moraine. Leverett and Taylor believe that the "Deanville kames" are superposed on slightly older or contemporaneous moraines. Deanville Mountain stratigraphy should therefore consist of till overlain by sand and gravel.

However, just as in the interlobate area, the stratigraphy characteristic of Deanville Mountain is sand and gravel overlain by till. Furthermore, Leverett and Taylor's (1915) morphological description of the Imlay and Goodland moraines needs revision. These moraines are distinct topographic features as far north as Goodland Church where they merge, but north of the church they do not exist. Leverett and Taylor identify these moraines in and north of Deanville Mountain because they believe that these ridges should continue to line the eastern bank of the Imlay channel. They offer no evidence for their belief that the Goodland moraine was deposited by readvancing ice rather than during a retreatal stillstand. The thick, extensive Deanville Mountain gravel deposits prove that that feature is a kamic rather than a morainic mass.

The limestone till does not differ significantly in mean pebble composition from the interlobate limestone gravel (Table 4); moreover, this till does not differ significantly from Deanville Mountain gravel in mean sandstone content (Table 4); and

Table 4. Results of Student's t-tests[+] of the significance of differences in pebble composition between tills and gravels of the Imlay City area.

[*]Limestone Till vs. Interlobate Limestone Gravel

Parameter	F-Test for Equal Variances	t-Test of Significant Difference
% LS_i	Equal	Not Significant
% SS_i+ Sh	Equal	Not Significant
% Crystalline	Equal	Not Significant

[*]Limestone Till vs. Deanville Mountain Gravel

Parameter	F-Test for Equal Variances	t-Test of Significant Difference
% LS_i	Equal	Significant
% SS_i+ Sh	Equal	Not Significant
% Crystalline	Equal	Significant

Deanville Mountain Till vs. Deanville Mountain Gravel

Parameter	F-Test for Equal Variances	t-Test of Significant Difference
% LS_i	Not Equal	Significant
% SS_i+ Sh	Not Equal	Significant
% Crystalline	Not Equal	Significant

[+] See Appendix for tests performed at 0.05 level of significance.

[*] Three samples of non-surface limestone till excluded from calculations.

the interlobate limestone gravel does not differ significantly from Deanville Mountain gravel in mean sandstone and mean crystalline rock content (Table 5). These similarities in pebble composition indicate that the limestone till, interlobate limestone gravel, and Deanville Mountain gravel were all derived from the same ice source. In other words, Deanville Mountain is an extension of the kamic interlobate area to the eastern side of the Imlay channel. The kames constituting Deanville Mountain do not form two distinct groups but rather are one continuous, topographically irregular, massive deposit. The fosse and steep ice-contact face on the eastern boundary of Deanville Mountain show that ice stood there as these kames formed.

Extension of the sandstone till sheet over limestone-rich Deanville Mountain gravel is the result of ice readvance over the pre-existing kames. These high kames may have protected the Imlay outlet depression from being overridden during the sandstone-rich ice advance. Leverett and Taylor, however, believe that during ice readvance to the Imlay and Goodland moraines the greatest pressure on the Imlay channel low occurred in the Deanville Mountain area and almost resulted in its closure there (1915, p. 277).

Leverett and Taylor (1915) believe that Deanville Mountain consists of the Imlay and Goodland moraines capped by kames and is wholly of Maumee III age. Till and gravel pebble compositions and the general stratigraphy, however, show that Deanville Mountain is part of the kamic interlobate area of Maumee I age and was overridden by sandstone-rich ice during Maumee III time. In the case of Deanville Mountain the sedimentological and stratigraphic approach to glacial history demands a new morphological interpretation.

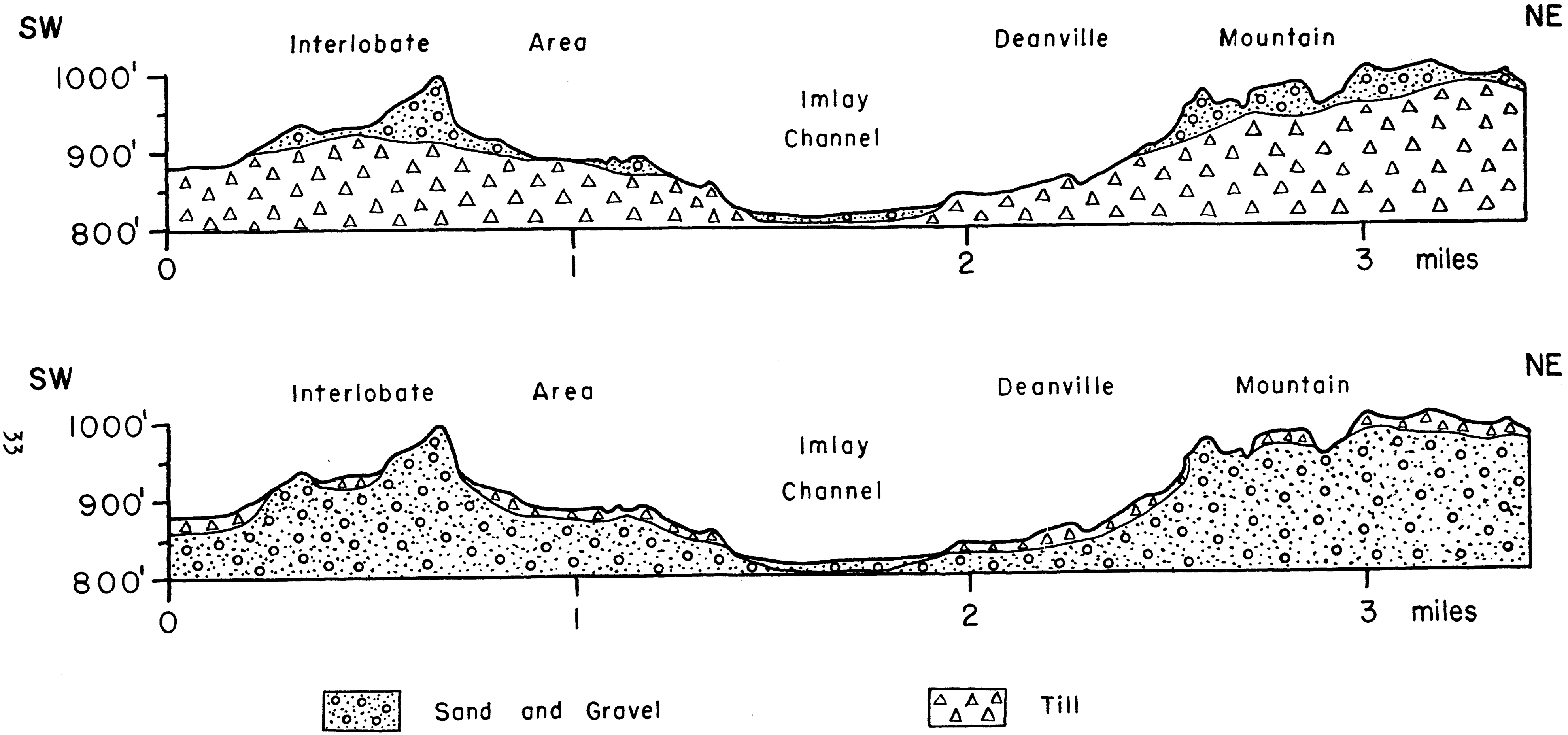


Figure 10. Schematic stratigraphic sections of interlobate area and Deanville Mountain. Topographic profile crosses Imlay channel divide. Vertical exaggeration = 10 X. Sediment thicknesses not to scale. Above: Leverett and Taylor's (1915) interpretation - kames superposed on moraines in interlobate area and Deanville Mountain. Below: interpretation in this paper - thin layer of till caps thick deposits of kamic sand and gravel in interlobate area and Deanville Mountain. Till west of Imlay channel is rich in limestone; till east of Imlay channel is rich in sandstone.

TILL PEBBLE COMPOSITION AND BEDROCK PATTERNS

The geographical distribution of black shale pebbles in the sandstone till sheet closely reflects bedrock type and pattern (Figure 11). Black shale pebbles are numerous in the Imlay moraine between Almont and Imlay City, in and behind the east-west section of the Deanville moraine, and in the Yale moraine. The bedrock contact between the Marshall sandstone on the west and Coldwater shale on the east strikes northeastward through the Imlay, Goodland, and Deanville moraines. This contact is expressed in the surface drift by 2% or fewer black shale pebbles in till to the west and 2 to 27% black shale pebbles in till to the east of this line.

While a black shale pebble content of more than 2% indicates a close bedrock source of this lithology, a lower black shale pebble content need not mean that local bedrock is not black shale: the presence of no more than 1% black shale in some sandstone till pebble counts in the area of black shale bedrock may reflect greater distance to the underlying black shale source, locally greater ice abrasion or dilution of underlying bedrock, or some combination of these factors.

The limestone till sheet contains only an occasional black shale pebble with the exception of a layer of flowtill on the western bank of the Imlay channel. This flowtill's 14% black shale pebble content may be attributed to a local variation in source; to the break-up of a few large black shale boulders; or to the fact that it is flowtill and its pebbles may therefore have experienced less abrasion than those in basal till.

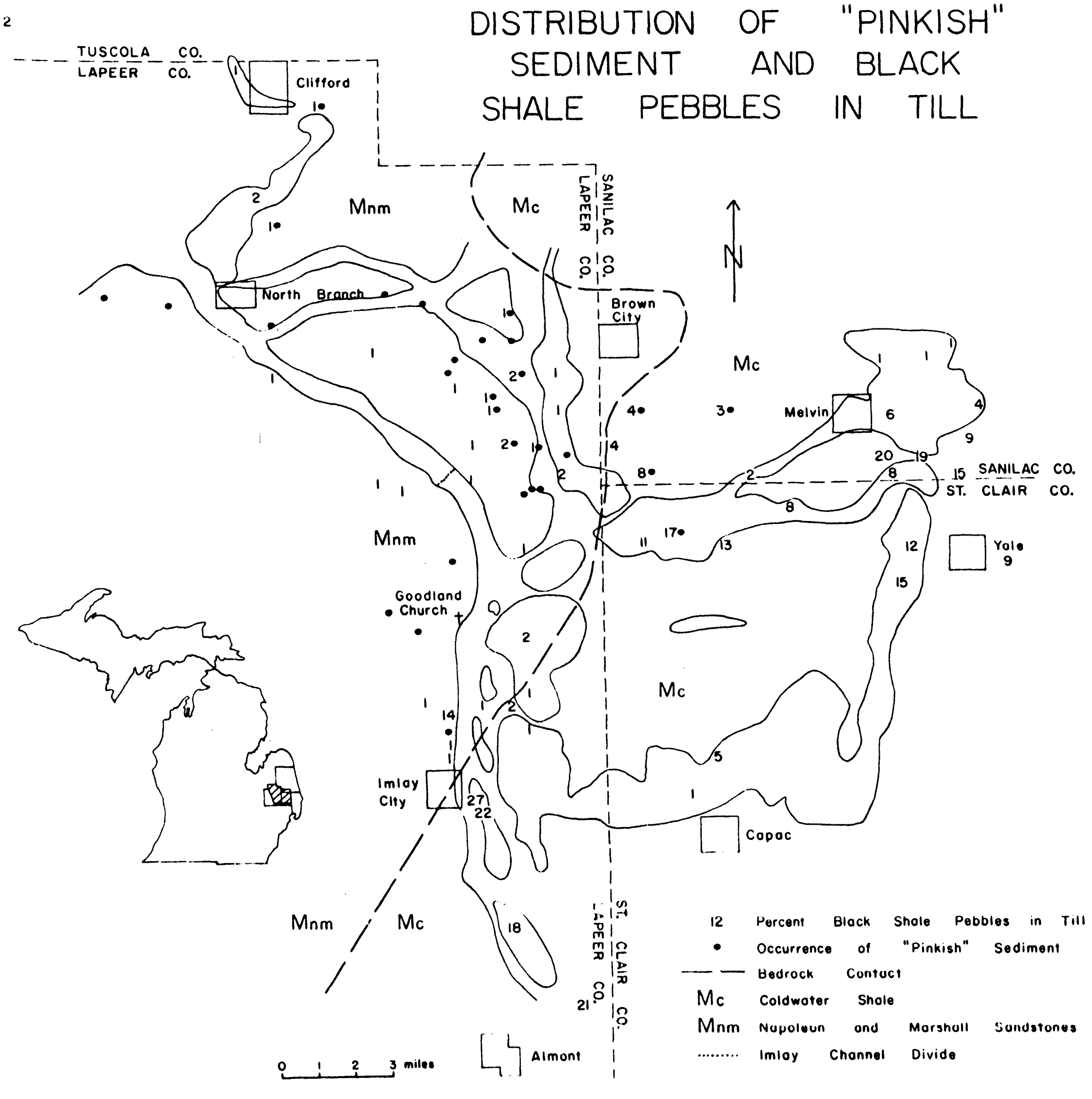


FIGURE 11.

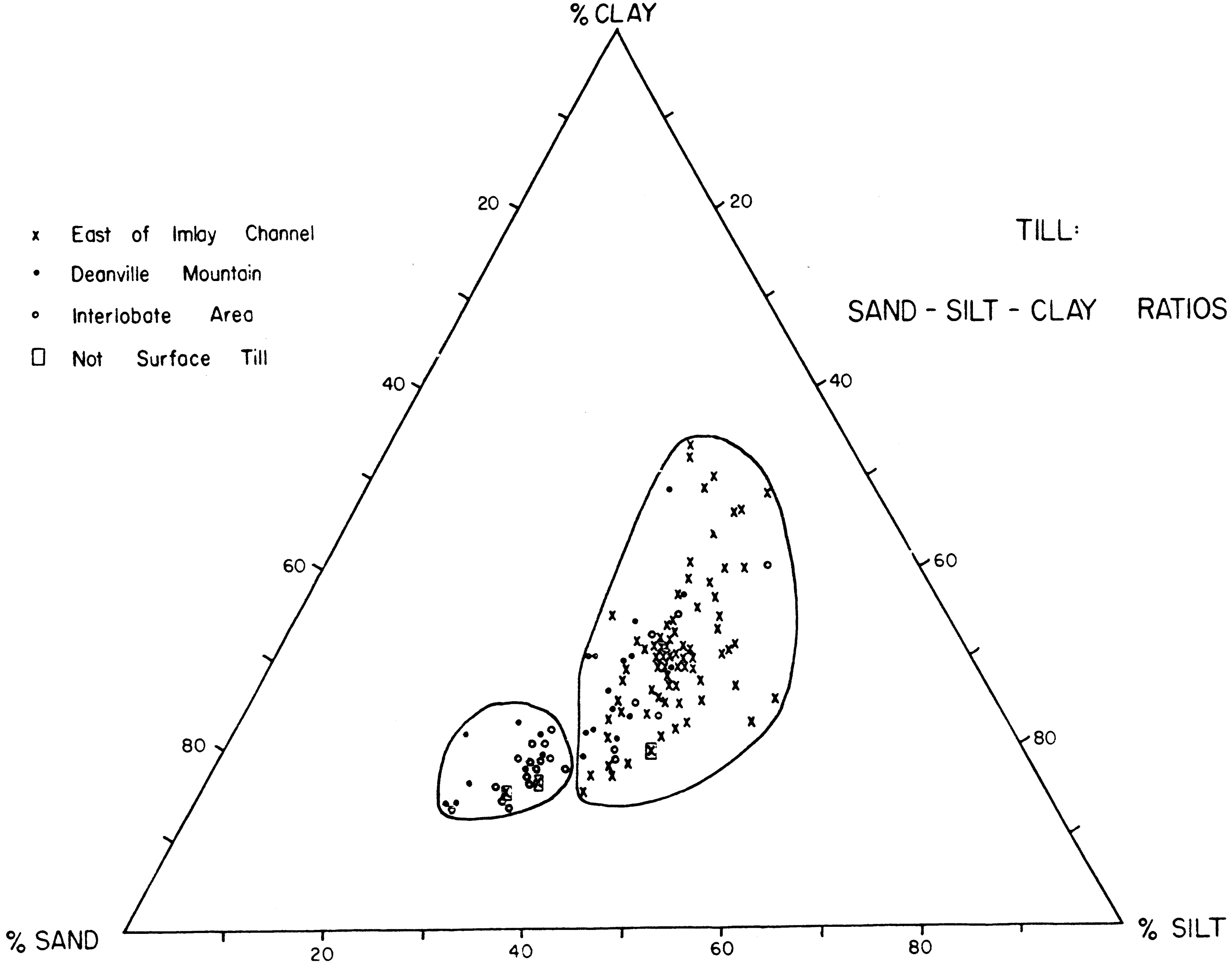
DISTRIBUTION OF "PINKISH" SEDIMENT AND BLACK SHALE PEBBLES IN TILL

TILL: SAND-SILT-CLAY RATIOS

As a single criterion for differentiating till sheets in the Imlay City, Michigan, area, sand-silt-clay ratios are less effective than till pebble composition. These ratios, however, do support the conclusion drawn from till pebble compositions that different tills lie on either side of the Imlay channel. Particles less than 2 mm and greater than 0.0625 mm in diameter were sieved, and hydrometer analysis was performed on particles less than 0.25 mm in diameter with readings at 40 seconds, 2 hours, and in some cases at 24 hours. The grain-size distributions of 122 samples were determined. Twelve samples studied for till pebble composition were not analyzed for grain-size distribution.

Limestone till samples from the interlobate area west of the Imlay channel have a mean matrix texture of 44.8 ± 4.7% sand, 34.3 ± 2.0% silt, and 20.8 ± 3.0% clay. Sandstone till samples from the area east of the Imlay channel have a mean matrix texture of 28.8 ± 1.8% sand, 40.3 ± 0.9% silt, and 30.9 ± 2.0% clay. Student's t-tests show that the means of each grain-size component for these two sediments differ significantly at the 0.05 level (Table 3). Therefore, the limestone and sandstone till types are differentiated not only by pebble composition but also by matrix texture. A scatter plot of sand-silt-clay ratios reveals this general separation of limestone and sandstone tills into two clusters (Figure 12).

If the limestone till is a stagnant ice ablation deposit, its coarse texture may result from extensive meltwater action which selectively removed silt and clay particles. In this case the



TILL:

SAND - SILT - CLAY RATIOS

FIGURE 12.

variability of the limestone till matrix texture would have been determined by the intensity range of meltwater activity. However, if the limestone till was deposited by active ice which readvanced over older kamic sand and gravel, its coarse texture may be attributed to incorporation of those older sediments by that ice. In this case the very high variance of limestone-till sand content relative to the variance of its silt and clay contents may be caused by varying degrees of sand incorporation. Texture alone is not sufficient evidence to pinpoint the stagnant or active ice origin of this till.

Sand-silt-clay ratios of Deanville Mountain till samples plot in both the limestone and sandstone matrix-texture clusters (Figure 12). Deanville Mountain till has an average matrix texture of 40.0 ± 4.4% sand, 33.8 ± 2.1% silt, and 26.2 ± 3.6% clay. Student's t-tests at the 0.05 level show that this texture differs significantly from the mean matrix texture of the sandstone till but that Deanville Mountain till does not differ significantly from the limestone till in sand and silt content (Table 3). Sandstone pebble content of Deanville Mountain till indicates that it was deposited by the same readvancing ice which deposited the sandstone till. Differences in matrix texture, however, identify Deanville Mountain till as a coarse facies of the sandstone till sheet. This facies was produced by the incorporation of older kamic sands and gravels by the sandstone-rich ice as it overrode Deanville Mountain. The sandstone till sheet as a whole, consisting of the sandstone till and Deanville Mountain till facies, has a matrix texture (31.3 ± 1.9% sand, 38.9 ± 1.0% silt, 29.8 ± 1.7% clay) which is significantly different at the 0.05 level in all size components from the mean limestone till texture (Table 3).

The percentage of black shale pebbles in a till sample is not correlated with the matrix texture, although the weak black shale could easily have been a ready source of fine particles. Ten sandstone till samples contain less than 10% sand, but only two of these contain more than 1% black shale pebbles. Sand-silt-clay ratios of sandstone till samples with high black shale pebble contents are close to the mean matrix texture for this till type.

Table 5. Results of Student's t-tests[+] of the significance of differences in pebble composition between gravels of the Imlay City area.

Interlobate Limestone Gravel vs. Sandstone-rich Gravel

Parameter	F-Test for Equal Variances	t-Test of Significant Difference
% LS_i	Equal	Significant
% SS_i + Sh	Not Equal	Significant
% Crystalline	Equal	Significant

Interlobate Limestone Gravel vs. Deanville Mountain Gravel

Parameter	F-Test for Equal Variances	t-Test of Significant Difference
% LS_i	Equal	Significant
% SS_i + Sh	Equal	Not Significant
% Crystalline	Equal	Not Significant

Sandstone-rich Gravel vs. Deanville Mountain Gravel

Parameter	F-Test for Equal Variances	t-Test of Significant Difference
% LS_i	Equal	Significant
% SS_i + Sh	Not Equal	Significant
% Crystalline	Equal	Significant

[+] See Appendix for tests performed at 0.05 level of significance.

GRAVEL: PEBBLE COMPOSITION

Pebble compositions of 48 gravel samples from the kames west of the Imlay channel and in Deanville Mountain and from kames and outwash channels east of Deanville Mountain were determined by counts of 100 pebbles 1 to 3 inches in maximum dimension.

Gravel from the interlobate kames is composed of 52.4 ± 3.0% LS_i, 17.2 ± 3.5% SS_i+ Sh, and 30.5 ± 3.6% crystalline rocks, and kamic gravel from Deanville Mountain consists of 57.3 ± 2.5% LS_i, 14.0 ± 2.2% SS_i+ Sh, and 28.3 ± 2.0% crystalline rocks. Student's t-tests show that the difference between mean sandstone and mean crystalline content of the two gravels is not significant at the 0.05 level, although the greater mean limestone content of the Deanville Mountain gravel is significantly different at the 0.05 level from the mean limestone content of the interlobate gravel (Table 5).

Gravel from kames and outwash channels east of Deanville Mountain is composed of 40.0 ± 6.1% LS_i, 38.3 ± 7.9% SS_i+ Sh, and 21.7 ± 4.4% crystalline rocks. Student's t-tests show that the three pebble component means of this gravel differ significantly at the 0.05 level from the corresponding means of the interlobate gravel and of the Deanville Mountain gravel (Table 5).

Thus two distinct gravel lithologies have been demonstrated: limestone-rich interlobate gravel and sandstone-rich gravel east of Deanville Mountain (Figure 13). Limestone-rich Deanville Mountain gravel differs significantly from the sandstone-rich gravel but displays very strong affinities to the interlobate gravel.

GRAVEL: PEBBLE COMPOSITION

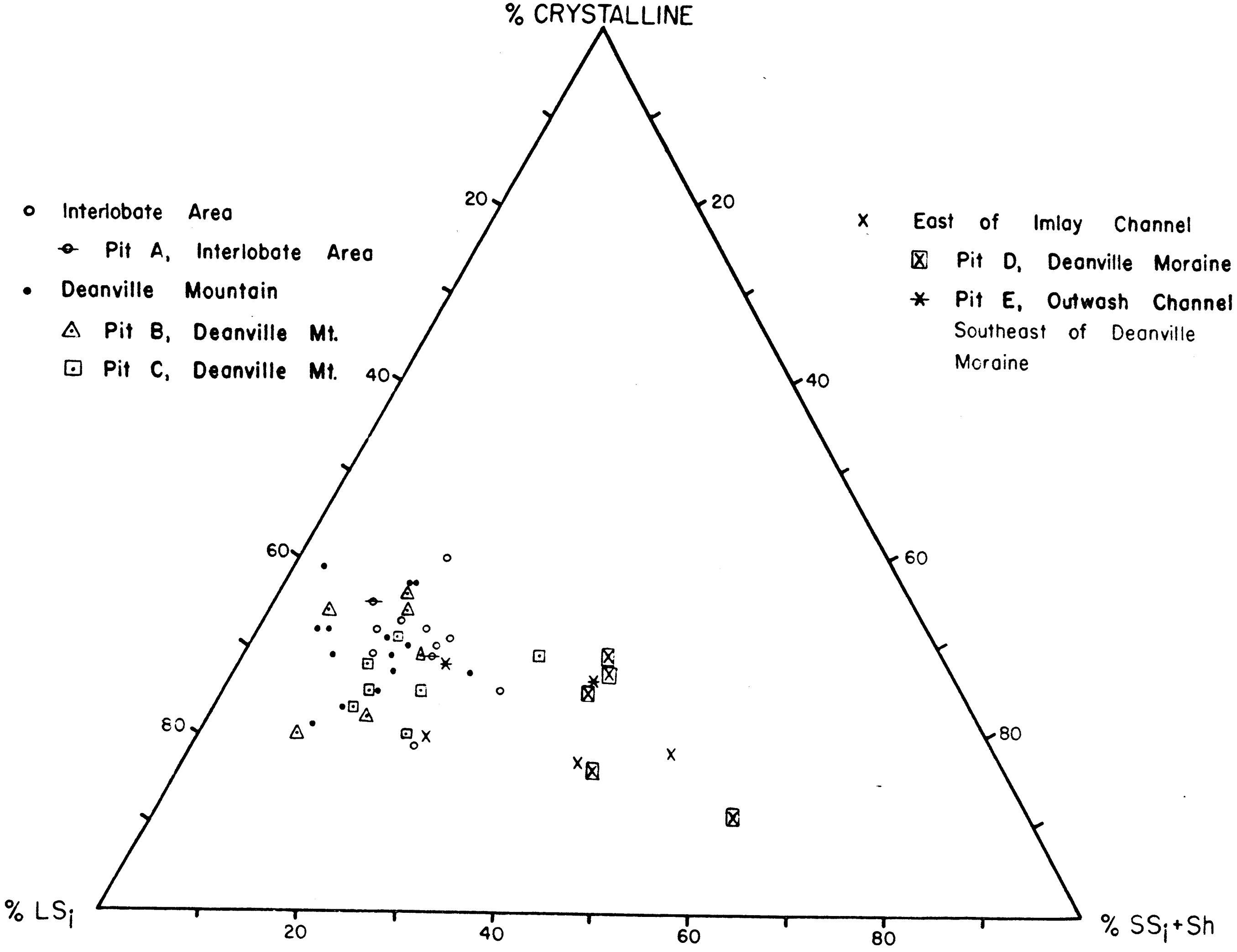


FIGURE 13.

The pebble composition of the limestone-rich interlobate gravel is statistically the same as that of the limestone till according to Student's t-tests at the 0.05 level of significance (Table 4). Deanville Mountain gravel contains the same amount of sandstone as the limestone till but differs significantly from that sediment in mean limestone and mean crystalline content (Table 4). In spite of the significant differences in some pebble components between the interlobate limestone gravel and Deanville Mountain gravel (Table 5) and between the limestone till and Deanville Mountain gravel (Table 4), their general compositional similarity, especially in contrast with the composition of the sandstone-rich till and gravel, suggests that the interlobate limestone gravel, Deanville Mountain gravel, and limestone till were derived from the same ice source.

The usefulness of gravel compositions in relating outwash channel and stagnant ice drainage events to the limestone or sandstone till sheet was questioned because of possible selective destruction of soft lithologies by stream transport. Large percentages of soft sandstone, siltstone, and black shale pebbles characterize deposits of the younger ice advance. If intensive selective destruction occurred, all gravels studied, whether derived from the limestone-rich or sandstone-rich ice, would contain large numbers of more resistant limestone and crystalline pebbles.

Gravel east of Deanville Mountain contains an average of 11.1% more sandstone pebbles than the interlobate limestone gravel, 14.3% more sandstone pebbles than the Deanville Mountain gravel, but 13.6% fewer sandstone pebbles than the sandstone till. This relatively sandstone-rich gravel east of Deanville Mountain was probably derived from the same ice source as the sandstone till: both the sandstone till and sandstone-rich gravel have very high variances in percent SS_i + Sh, intermediate variances in percent LS_i, and low variances in percent crystalline rocks; the Deanville Mountain gravel, interlobate limestone gravel, and limestone till are each characterized by approximately equal variances among their three pebble components. The statistically significant difference between the pebble components of the sandstone till and sandstone-rich gravel may be explained by destruction of sandstone and black shale during stream transport of the gravel. Such selective removal is demonstrated not only by the gravel's lower sandstone content but also by its higher content of more resistant limestone and crystalline rocks relative to the sandstone till. Selective destruction of soft lithologies did affect the average sandstone-rich gravel, but distance of transport and intensity of abrasion were not sufficient to remove a percentage of the characteristic soft lithologies large enough to produce confusion of this sediment with limestone-rich gravels derived from the limestone-rich ice.

Gravels at any location may be quite variable in pebble composition, but with only two exceptions all samples from a single site fall into the limestone-rich or sandstone-rich gravel category. Two gravel samples from a small outwash channel in front of the Deanville moraine's outer ridge near Yale were collected about ten feet apart at the same level in the section. One of these samples is a sandstone-rich gravel, clearly derived from the sandstone-rich ice which deposited the Deanville moraine, but the other has a composition characteristic of the limestone-rich gravels of the interlobate area and Deanville Mountain. Presumably this sharp contrast in pebble composition is a facies change induced by some very local process which selectively removed sandstone and other soft lithologies, but it sounds a note of caution in the interpretation of gravel pebble compositions. However, the occurrence of very coarse, sandstone-rich gravels over finer limestone-rich gravels on the high eastern edge of Deanville Mountain may be easily explained: younger, readvancing sandstone-rich ice discharged outwash gravel over the older kamic gravels as it met the steep eastern face of Deanville Mountain.

Sandstone-rich gravels occur in the topographically indistinct Weaver Drain channel between Deanville Mountain and the Deanville moraine. The gravel lithology associates some of the flow through this channel with discharge from the sandstone-rich ice, perhaps as it stood at the Deanville moraine during retreat from its maximum position along the eastern bank of the Imlay channel. This indistinct channel is parallel to the Imlay channel and drained northwestward to the Elm Creek channel. The poorly developed gradient (Figure 3) and faint topography of the Weaver Drain channel indicate that its life as an ice-border dischargeway was brief. The divide at the channel's southern end, which now stands at slightly over 840 feet above sea level, stood at slightly over 780 feet before uplift and therefore may have permitted small-volume discharge from Lake Maumee III through this channel at times of high water if that lake extended north to this divide.

Beds of unoxidized clay, silt, sand, and plant macrofossils overlie sandstone till in the Weaver Drain channel and record discharge from the retreating sandstone-rich ice front and possibly

location:-
SE1/4, SE1/4, Sec. 15, T9N, R12E

from Lake Maumee III. The macrofossils consist primarily of leaves and twigs of Dryas integrifolia, Salix herbacea, Salix spp., Vaccinium uliginosum, and other as yet unidentified species. Small pelecypod shells, probably Pisidium (Norton Miller, personal communication), and ostracodes also occur in these sediments. The organic matter is post-till in age, but the stratigraphy and topography of the Weaver Drain channel and the modern ecology and ranges of these boreal forest and tundra pioneer plant species suggest that any time lag between the deposition of the sandstone till and growth and deposition of these plants was very short. Deposition in this channel is presumed to have ceased at the latest with the drop in lake level from Maumee III to Glacial Lake Arkona. The C-14 age of plant material from this site is therefore expected to date the eastward retreat of the sandstone-rich ice during Maumee III time, i.e. to date the last phase of Glacial Lake Maumee and the approximate end of Cary time.

12,770 ± 210 (I-4899)

The Imlay channel meets the floor of Lake Silverwood northwest of North Branch, Michigan. Leverett and Taylor feel that Lake Silverwood "... appears to have formed at the time of the Imlay or perhaps of the Goodland moraine. It stood at about 860 feet ... and received the Silverwood and Fostoria outwash aprons" (1915, p. 349). Recent topographic maps, however, show that the clay- and silt-mantled Lake Silverwood plain has an average present elevation of 790 feet above sea level. Where the Imlay channel meets the eastern and western edges of the Lake Silverwood plain, the channel and lake floors are accordant. The Imlay outlet river did not incise a channel into the Silverwood lacustrine plain. These morphological relationships suggest that the Imlay outlet river emptied into and flowed out of Lake Silverwood during at least part of the river's life.

Gravel from a pit 1½ miles north of the interlobate area in the Lake Silverwood floor is limestone-rich like the interlobate and Deanville Mountain gravels. The gravel in this pit is overlain by 3 to 4 feet of lacustrine clay and thus pre-dates Lake Silverwood. This limestone-rich gravel may be outwash from the limestone-rich ice which deposited the interlobate sediments.

The Silverwood outwash apron, a digitate sand and gravel plain, occupies the northeastern part of the Lake Silverwood floor (Figure 2). At one site 2 feet of sand and gravel with a grain-size distribution characteristic of the Silverwood outwash apron overlie lacustrine clay. This stratigraphy confirms Leverett and Taylor's (1915) belief that the Silverwood outwash apron extends southward over the clay-mantled Lake Silverwood plain; the outwash decreases slightly in grain size to the south. The ice front probably stood at the section of the Otisville moraine which trends northwestward through Clifford, Michigan, during deposition of the Silverwood outwash apron. The Otisville moraine, which outlines Lake Silverwood, is composed of sandstone till. Therefore, the Silverwood outwash apron was probably derived from the readvancing sandstone-rich ice.

The failure of the Imlay outlet river to incise a channel across the Lake Silverwood floor suggests that the river and lake were contemporaneous bodies of water. The main discharge through the Imlay channel flowed from Lake Maumee III. Therefore, Lake Silverwood seemingly did not pre-date Lake Maumee III but rather probably is Maumee III in age. Limestone-rich gravels derived from the melting of limestone-rich ice may have been deposited in the Lake Silverwood area prior to the lake's formation. Lake Silverwood was probably ponded in the re-entrant between the Huron-Erie and Saginaw lobes during the sandstone-rich ice advance to the Otisville moraine; this ice may have temporarily dammed any western outlet from the lake. The Silverwood outwash apron was deposited in Lake Silverwood during early Maumee III time as the sandstone-rich ice stood at the Otisville moraine.

MORPHOLOGY OF THE SANDSTONE TILL SHEET

The sedimentological contrast between the limestone and sandstone till sheets outlines the sequence of ice advance, retreat, and readvance in the Imlay City, Michigan, area. These events coincide with Leverett and Taylor's (1915) concept, based strongly on morphology, of deposition in the interlobate area during Maumee I time, ice retreat during Maumee II time, and ice readvance in Maumee III time. Therefore, deposition of limestone-rich sediments west of the Imlay channel and in Deanville Mountain occurred primarily during the life of Lake Maumee I; the Huron-Erie lobe then retreated northeastward and opened the low Maumee II outlet; and the ice which readvanced to close the Maumee II outlet caused a rise in lake level, incorporated large amounts of local bedrock, and deposited sandstone till during the life of Lake Maumee III.

Leverett and Taylor (1915) concentrate upon correlation of Huron-Erie and Saginaw lobe moraines around the "thumb" reentrant. They overlook and misinterpret some topographic features indicative of the ice-lobation pattern during the Maumee III ice retreat from the Imlay to Yale moraines. Leverett and Taylor describe main morainic trends in the study area as roughly parallel to the edge of the interlobate area. They call ridges which cut across those main trends "problematical transverse ridges."

> "The origin of the transverse ridges can not be fully explained at present. It seems clear, however, that they are related in some way to strong lines of drainage in or under the ice, and are therefore in a certain sense analogous to eskers, although not of typical esker form." (Leverett and Taylor, 1915, p. 267)

Leverett and Taylor identify the east-west section of the Deanville moraine and the crescentic portion of the Otisville moraine between North Branch and Clifford, Michigan, as transverse ridges (Figure 2). The present study, however, shows that these ridges are moraines representative of ice stillstands: they are composed of the same sandstone till as the moraines with which they connect, are morphologically continuous with those moraines, and show no evidence of water action during their deposition.

Although Leverett and Taylor interpret their origin incorrectly, they are right in noticing the pattern of these "transverse ridges." The configuration of the Imlay and Goodland moraines, which are composed of sandstone till, suggests that these moraines were built by a small ice lobe which flowed almost due south (Figure 14). This hypothesis of southerly ice motion is supported by the pebble composition of the sandstone till. The major upglacier source of Marshall sandstone is a broad bedrock band which trends almost directly north in the "thumb." The direction of ice motion with respect to the bedrock pattern seems to have controlled the pebble composition of the sandstone till. The pattern of the Deanville-Yale system west of Yale, Michigan, suggests that this moraine represents a stillstand of the southward-moving ice lobe after its pauses at the Imlay and Goodland moraines.

The westward convexity of the Otisville moraine between Clifford and North Branch, Michigan, indicates that ice movement there was to the west or west-southwest (Figure 14). The contrast of ice-movement direction in the Imlay City and North Branch areas may result from primary differences in ice motion around the inter-

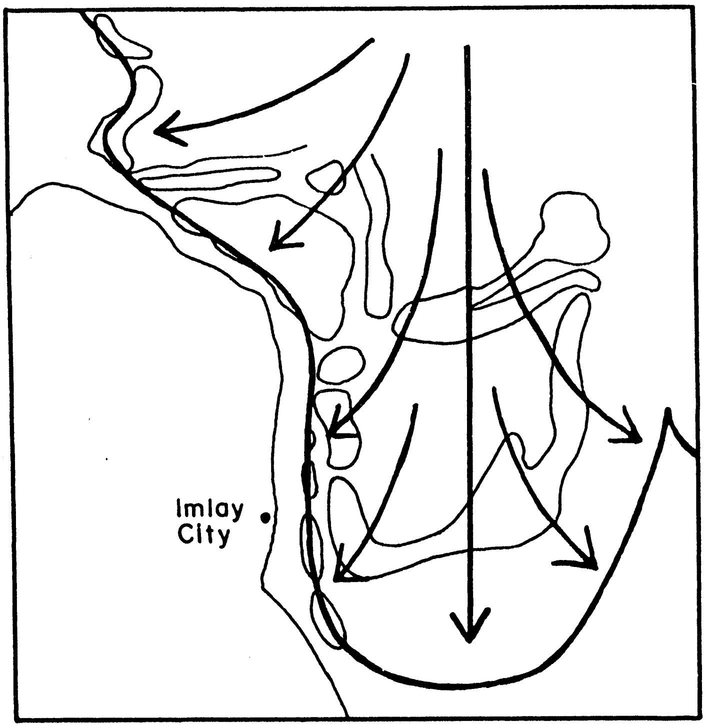


Figure 14. Arrows show hypothesized directions of ice movement during maximum of the sandstone-rich ice advance. The Goodland and Deanville moraines were deposited during the retreat of this southward flowing ice lobe.

lobate re-entrant or from deflection of the south-flowing ice lobe by the older kamic mass of Deanville Mountain.

Leverett and Taylor (1915) assign deposition of the Imlay through Yale moraines to Maumee III time. On the other hand, Bergquist and MacLachlan (1951) feel that the Imlay and Goodland moraines were built by ice retreating from the interlobate area during late Maumee I time. If Bergquist and MacLachlan are correct, any major contrast in till petrologies should occur between the Goodland moraine and next younger Deanville moraine, which they identify as the oldest moraine of Maumee III age. However, the Imlay and Goodland moraines are composed of the sandstone till characteristic of the Deanville and Yale moraines, not of limestone-rich sediments associated with the interlobate area; the contrast in till petrologies occurs between the Imlay moraine and interlobate area (Figure 9). If the sandstone till is of Maumee III age, then the Imlay and Goodland moraines must represent the maximum Maumee III advance of the sandstone-rich ice which deposited the Deanville and Yale moraines during its retreat.

Leverett and Taylor (1915) maintain that ice retreat, which allowed the lake to expand eastward, was oscillatory during Maumee III time, but they cite no evidence for this conclusion. Sandstone-rich gravels in the eastern end of the outer Deanville moraine are, however, overlain by sandstone till, and the kamic portion of the Yale moraine northeast of Melvin, Michigan, is mantled by sandstone till. The overlying till in both areas may be ablation till, although matrix textures there are quite fine; or may be flowtill; or may be basal till deposited by sandstone-rich ice readvancing over its own outwash or kamic sediments. The last interpretation seems most satisfactory for the stratigraphy observed and would support Leverett and Taylor's concept of Maumee III oscillatory ice retreat, but the evidence now at hand is insufficient to prove its validity.

CORRELATION OF "THUMB" MORAINES

The ages assigned to Huron-Erie lobe moraines in this paper and to Saginaw lobe moraines by Bretz (1953) require tentative revision of Leverett and Taylor's (1915, p. 30) correlation of "thumb" moraines.

Leverett and Taylor separate moraines relevant to Lake Maumee history into Huron-Erie lobe moraines, Saginaw lobe moraines from the west slope of the "thumb," and moraines from the east limb of the Saginaw lobe (Table 6). The moraines comprising this last group may more appropriately be assigned to the axial portion of the Saginaw lobe (Table 7). Leverett and Taylor feel that the Otisville, Deanville, and Yale moraines were deposited by the Saginaw lobe (Table 6). However, the Deanville and Yale moraines and the eastern portion of the Otisville moraine lie on the Huron-Erie side of the "thumb" re-entrant; along with the Defiance, Birmingham, Imlay, and Goodland moraines, they were deposited by the Huron-Erie lobe (Table 7).

Leverett and Taylor's (1915) assignment of Maumee I age to the Defiance and Birmingham moraines is generally accepted (Table 7). This paper confirms their belief that the Imlay, Goodland, Deanville, and Yale moraines are Maumee III in age (Table 7). It also correlates the Otisville moraine with the Imlay moraine and identifies them as the maximum position of the readvancing Huron-Erie ice which caused lake level to rise to Maumee III (Table 7). Correlation of the Imlay and Otisville moraines contradicts Leverett and Taylor's interpretation in which the Otisville moraine is two moraines younger than the Imlay moraine (Table 6).

Table 6.

Correlations of "Thumb" Moraines
by Leverett and Taylor (1915, p. 30).

SAGINAW LOBE (East Limb)	SAGINAW LOBE (West slope of "thumb")	HURON-ERIE LOBE
West Haven moraine	Juniata moraine	Transverse Ridges
Henderson moraine	Yale moraine . . .	. . Adair moraine
Owosso moraine . .	. . Owosso moraine	
		Emmett moraine
	Mayville moraine	
		Mount Clemens moraine
	Deanville moraine	
Flint and Otisville moraines	Otisville moraine .	. . Berville moraine
St. Johns moraine .	. . Otter Lake moraine	Goodland moraine
Fowler moraine . .	. . . Fowler moraine	Imlay moraine
Lyons moraine . . .	. Lyons (?) moraine . .	. Birmingham moraine
Portland moraine . .	. Portland (?) moraine	. . Defiance moraine

Bretz (1953) feels that during ice retreat from the Saginaw lobe Fowler moraine water from Lake Maumee II first began to flow westward to the Glacial Grand River. Therefore, deposition of the Fowler moraine occurred in Maumee I time (Table 7), and the subsequent retreat from it correlates with retreat from the eastern edge of the interlobate area in the vicinity of Imlay City in Maumee II time. Bretz thus believes that the Fowler moraine is older than the Imlay moraine (Table 7) and contradicts Leverett and Taylor (1915) who correlate those moraines (Table 6).

Bretz (1953) also feels that readvance of the Saginaw lobe to the Flint moraine marked the end of Maumee II and the beginning of Maumee III time. The Flint moraine occupies the maximum position of this readvance, is of early Maumee III age, and is therefore analogous to the Huron-Erie lobe Imlay moraine. Assuming readvance in the Saginaw and Huron-Erie lobes to have been generally synchronous, the Flint, Imlay, and Otisville moraines are correlative and outline the maximum ice readvance of both lobes around the "thumb" in early Maumee III time. Leverett and Taylor (1915) recognize the Imlay moraine as the oldest Maumee III moraine, but they do not correlate it with the Flint moraine, which they feel is two moraines younger. Bretz (1953) assigns a Maumee III age to the Owosso and Henderson moraines but their direct correlation with the Goodland, Deanville, or Yale moraines is not yet possible (Table 7).

Table 7 presents the revisions suggested above of Leverett and Taylor's (1915, p. 30) correlation of "thumb" moraines. This new correlation is based upon the logical synthesis of individual studies from different areas, not upon continuous tracing of moraines in the field. Further field studies may alter or extend this corre-

Table 7. Correlations of "thumb" moraines suggested in this paper. Stage of Glacial Lake Maumee correlative with each moraine given by Roman numerals. Probable correlations of individual moraines shown by dotted lines.

SAGINAW LOBE (Axial Portion)	SAGINAW LOBE (West slope of "thumb")	HURON-ERIE LOBE
		Yale moraine (III)
Henderson moraine (III)		Deanville moraine (III)
Owosso moraine (III)		Goodland moraine (III)
Flint moraine . . (III)	Flint and Otisville moraines . (III)	. . Otisville and Imlay moraines (III)
Fowler moraine . . (I)	. Fowler moraine (I)	
		Birmingham moraine (I)
		Defiance moraine (I)

lation and answer questions such as whether the Deanville and Yale moraines were deposited simultaneously or consecutively during retreat of the Huron-Erie lobe.

POSSIBLE LOCATIONS OF THE MAUMEE II OUTLET

The classical and most probable area for the location of the unknown outlet of Lake Maumee II is mantled by sandstone till of Maumee III age; this outlet has been overridden by the sandstone-rich ice, and suggestions about its actual position can only be speculative.

The prominent valley at the southern tip of Deanville Mountain now occupied by the underfit North Branch of Mill Creek (Figure 2) stands at less than 800 feet above sea level, slightly less than the elevation of the adjacent Imlay channel floor (Figure 3). Before uplift the Mill Creek channel stood at approximately 740 feet, 20 feet below the level of Lake Maumee II. Was this valley a northeastward-flowing part of the Maumee II outlet here not obliterated by the Maumee III ice advance which deposited sandstone till on the Mill Creek channel banks? Or did the Mill Creek valley originate as an outwash channel draining the sandstone-rich ice front during Maumee III time? Was the Weaver Drain channel between Deanville Mountain and the Deanville moraine a northward-flowing section of the Maumee II outlet (Figure 2)? Does it owe its irregular gradient (Figure 3) to partial filling of a pre-existing channel by sediments derived from the sandstone-rich ice which advanced over it? Or is the Weaver Drain channel simply a poorly developed outwash channel of Maumee III age?

The Weaver Drain channel descends into another valley which splits into the North Branch Transverse channel and the Elm Creek channel; these last two channels slope westward as tributaries to the Imlay channel (Figure 2). Leverett and Taylor (1915) describe the North Branch Transverse channel as well-developed, but instead it is topographically indistinct, has a very slight gradient, and its mouth is restricted by hills (Figure 3). The Elm Creek channel, however, is a distinct valley with sharp walls, is floored by sand and gravel, and has a clearly defined gradient. The Elm Creek and Imlay channel gradients are now identical (Figure 3), indicating possible mutual adjustments of their rivers and probably simultaneous discharge through both channels before uplift. There is no evidence to indicate that the depression occupied by the Elm Creek channel could not be pre-Maumee III in age, but its most recent use and topographic evolution date from Maumee III time. The North Branch Transverse channel, however, seems to be unrelated to Maumee III discharge through the Imlay channel. Was this faint North Branch Transverse channel a westward-flowing section of the Maumee II outlet which was buried by the sandstone-rich ice advance, its mouth blocked by construction of the Otisville moraine? Did filling of the North Branch Transverse channel cause meltwater from the sandstone-rich ice to seek a lower route to the Imlay channel through the Elm Creek channel?

Thus, the channel of the North Branch of Mill Creek, the Weaver Drain channel, and the North Branch Transverse channel may represent sections of or, linked together, the complete Maumee II outlet after alteration during Maumee III time, but any evidence to support such a conclusion is at best circumstantial.

COLOR VARIATIONS IN THE LIMESTONE AND SANDSTONE TILLS

Anomalous color variations consisting of "pinkish" zones in the buff (2.5Y 4/4 moist, olive brown) oxidized zone of the limestone and sandstone till sheets occur throughout the study area (Figure 11). Although the Munsell color of these zones varies (5YR 4/4 moist, reddish brown; 7.5YR 5/4 moist, brown; 10YR 5/3 moist, brown), the color contrast with the buff till is marked in all cases. These "pinkish" zones occur as horizontal streaks up to six inches thick and hundreds of feet long, as vertical streaks less than an inch thick and less than a foot long, and as large, irregular lenses with a maximum thickness of four feet. "Pinkish" streaking is fairly common; "pinkish" lenses are rare.

Three samples from "pinkish" lenses indicate that these lenses consist of a "pinkish" till petrologically different from the buff sandstone till. The "pinkish" till has a much higher limestone pebble content and sandier matrix than the sandstone till which encloses it (Figure 15, Locality A; Figure 16). Where limestone till contains lenses of "pinkish" till, the contrast in till pebble composition is slight (Figure 15, Locality B). The petrological data collected are insufficient to characterize "pinkish" till occurrences or to decide whether all of them consist of the same till. For the few samples examined, however, the sedimentological and color contrast of the "pinkish" and buff tills suggests that late Cary ice in the "thumb" entrained blocks of one or more older "pinkish" tills, moved these blocks <u>en masse</u>, and deposited them along with the younger buff till. The occurrence of petrologically distinct orange till masses in post-Cary buff till in east-

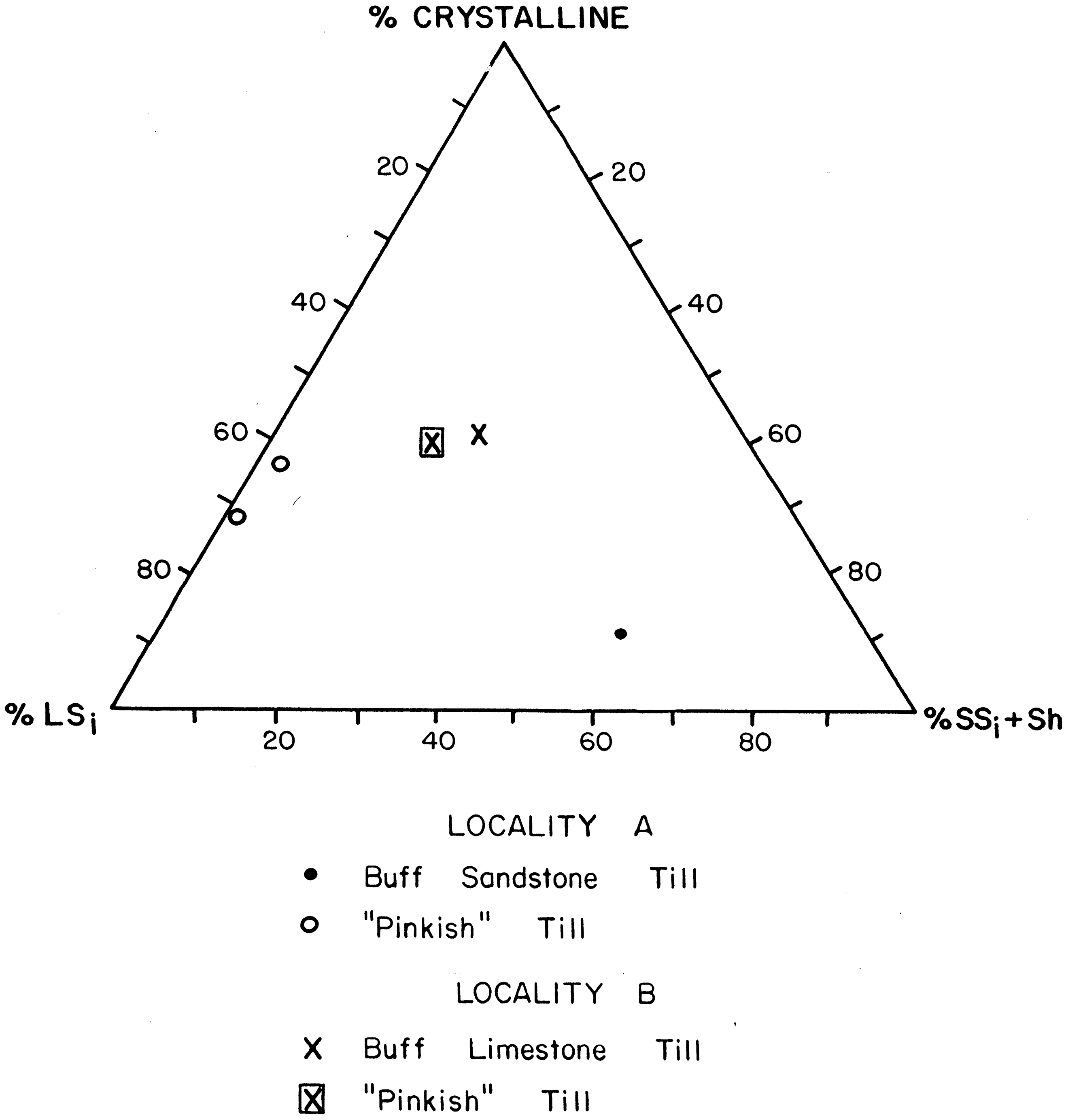


Figure 15. Pebble composition of buff limestone, buff sandstone, and "pinkish" tills.

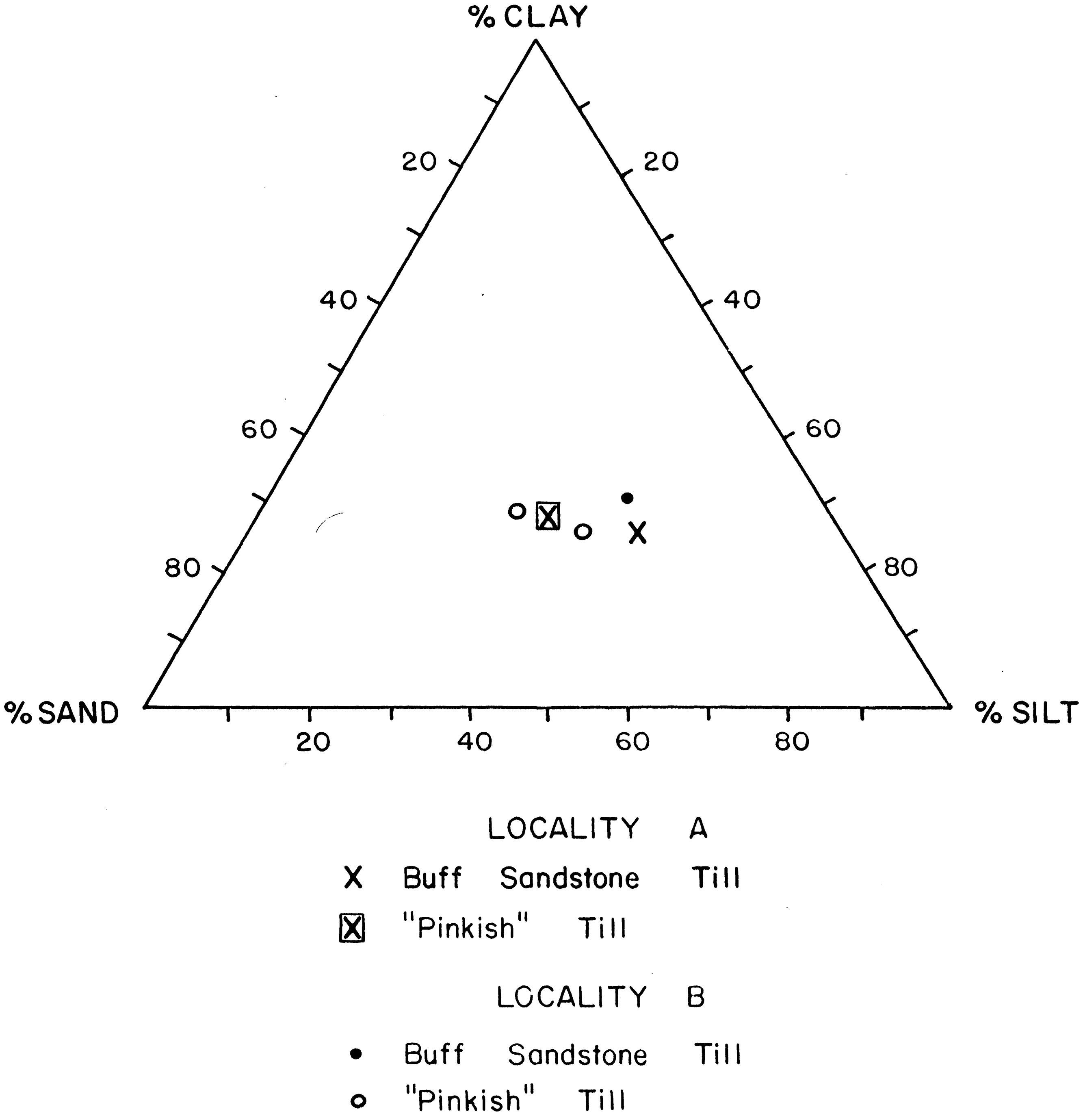


Figure 16. Sand-silt-clay ratios of buff sandstone and "pinkish" tills.

central North Dakota has been explained by this mechanism (Kelly and Baker, 1966).

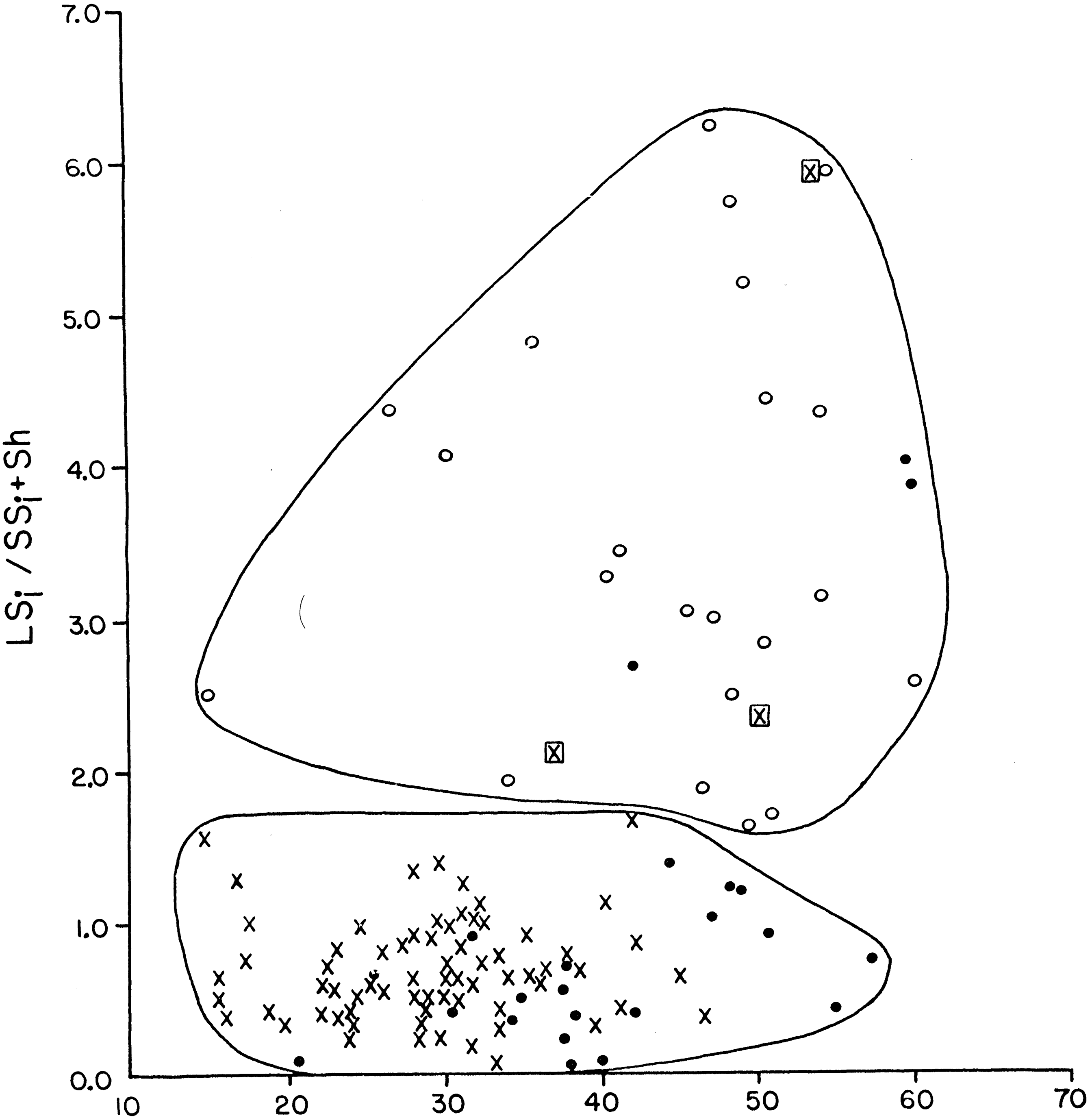
No systematic study of the pebble-free, silty and clayey sediment in the "pinkish" vertical and horizontal streaks has been made. These streaks may, however, consist of older "pinkish" lacustrine sediments which, like the "pinkish" till or tills to which they may be related, were also incorporated by late Cary ice.

CONCLUSIONS

Sedimentological analysis of till in the vicinity of Imlay City, Michigan, has led to the differentiation of two till sheets on the basis of pebble composition and matrix texture (Figure 17). The older of these tills, its relative age established by knowledge of the general direction of ice retreat in the Huron-Erie and Saginaw lobes, is characterized by higher limestone pebble content and a sandier matrix than is the younger sandstone-rich, more clayey till. Surface exposure of the older limestone till is restricted to the interlobate area west of the Imlay channel, while the younger sandstone till sheet occurs eastward from the eastern bank of the Imlay channel at least to the vicinity of Yale, Michigan. This contrast in till petrology along a clearly defined topographic boundary, the Imlay channel, indicates that two distinct drift sheets do occur in the study area.

The high percentage of Huron basin carbonate pebbles and relatively low percentage of local pebbles in the limestone till suggest that the older limestone-rich ice picked up the bulk of its sediment load some distance east and northeast of the study area; this ice incorporated relatively little of the local "thumb" sandstone and shale bedrock as it moved westward and southwestward across these lithologies. The younger sandstone till, however, is characterized by a high percentage of local bedrock pebbles and a low percentage of Huron basin carbonate pebbles: the sandstone-rich ice readvanced southward and derived the bulk of its load from local sandstone and shale sources, thus diluting the more distantly derived limestone and crystalline pebble components

DIFFERENTIATION OF TILL SHEETS



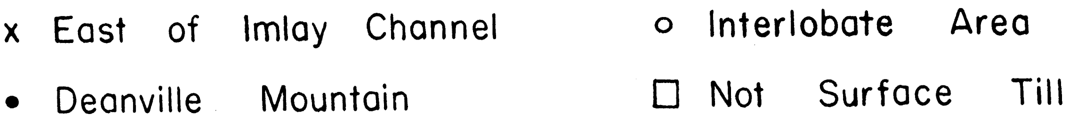


Figure 17. Differentiation of limestone (upper cluster) and sandstone (lower cluster) till sheets on the basis of pebble composition and matrix texture of 117 samples. Till type at each sample point in Figure 9 was determined from this scatter plot.

to produce the sandstone till. The petrologic difference between the limestone and sandstone tills reflects the dominance first of a more distant sediment source and later of a local sediment source. The high sandstone pebble content of the Deanville Mountain and sandstone tills is derived from the same local bedrock source area. Deanville Mountain till is a coarse facies of the sandstone till sheet and was produced by overriding and incorporation of older limestone-rich kamic sands and gravels by the sandstone-rich ice.

The similar pebble compositions of the interlobate limestone gravel, limestone till, and Deanville Mountain gravel indicate that these sediments are deposits of the same limestone-rich ice source. The layer of limestone till which overlies the interlobate limestone gravel may be ablation till or basal till. Deanville Mountain is a northeastern extension of the interlobate area. It was built before the advance of the sandstone-rich ice which flowed over this massive kamic obstacle to the eastern bank of the Imlay channel.

The petrologic contrast between the limestone and sandstone tills records ice advance, retreat, and readvance in the Imlay City area during Lake Maumee time. This sequence coincides with the general pattern of ice movement which Leverett and Taylor (1915) deduced from morphology. The following history of Glacial Lake Maumee is based upon sedimentological, stratigraphic, and morphological data:

1) Lake Maumee I formed upon ice retreat from the newly-built Fort Wayne moraine and discharged through the Fort Wayne outlet. During Maumee I time the Defiance and Birmingham moraines were constructed south of Imlay City, and in the Imlay City-North Branch area limestone-rich kamic gravels and limestone till were deposited in the interlobate area which included

Deanville Mountain. If the topographic low now occupied by the Imlay channel stood below lake level in Maumee I time, it may have served as an infant Imlay channel. Because elevations in the vicinity of the present Imlay channel divide during Maumee I time are unknown, Maumee I discharge through an infant Imlay channel is an unproven possibility.

2) Retreat of the limestone-rich ice opened a still unidentified outlet northeast of Imlay City; this outlet was lower than the Fort Wayne outlet and any possible infant Imlay channel. Lake level fell to Maumee II, and the outlet or outlets of Lake Maumee I were abandoned. If the topographic low now occupied by the Imlay channel stood at the same elevation in Maumee II time as it did at the end of Maumee III time, only intermittent, small-volume discharge during periods of high water could have flowed through that depression from Lake Maumee II. However, the floor of the depression probably stood higher during Maumee II time than at the end of Maumee III time, so that even intermittent discharge from Lake Maumee II via the Imlay channel would have been impossible. All lake discharge was probably carried by the unknown Maumee II outlet.

3) The ice readvanced southward along the Marshall sandstone bedrock band and picked up large amounts of this rock. It overrode the unknown Maumee II outlet, and consequently lake level rose to Maumee III. This sandstone-rich ice flowed over Deanville Mountain, incorporating older kamic sediments as it advanced. At its maximum the ice stood at the western edge of Deanville Mountain, built the Otisville and Imlay moraines, and ponded Lake Silverwood. The Imlay channel divide was low enough relative to lake level for the Imlay channel to have been a main Maumee III outlet. Lake Maumee III drained simultaneously through both the Imlay and Fort Wayne outlets, which have divides with very similar late Maumee III elevations. The Goodland, Deanville, and Yale moraines were deposited during northward retreat of the sandstone-rich ice. Retreat from the Yale moraine exposed ground lower than the Imlay and Fort Wayne outlets; those channels were permanently abandoned, and lake level fell to Glacial Lake Arkona.

The stratigraphic and sedimentological approach to the late Cary history of the Imlay City area requires revisions of some of Leverett and Taylor's (1915) morphological interpretations. Stratigraphy shows that Deanville Mountain is significantly older than the Maumee III ice advance, not of early Maumee III age as Leverett and Taylor claim, and that it is kamic with a thin layer of superposed till rather than morainic with superposed kames; that the interlobate area west of the Imlay channel is kamic, not morainic; and that the "problematical transverse ridges" are moraines which may provide information about ice lobation, not subglacial or englacial fluvial deposits related to eskers. These changes in Leverett and Taylor's interpretation of the glacial features of the Imlay City, Michigan, area do not, however, contradict their concept of the outlets used by each of the three Glacial Lake Maumee stages. Indeed, the new data presented in this paper point to their 1915 concept of Lake Maumee drainage as the correct one, with the exception of their omission of probable Maumee III discharge through the Fort Wayne outlet.

SUGGESTIONS FOR FURTHER STUDY

The limestone and sandstone till sheets should be mapped to outline the major late Cary ice advances onto the "thumb" and to determine whether the western portion of the Imlay channel also marks a major contrast in till petrologies. Variations in pebble composition and matrix texture within each till sheet around the "thumb" re-entrant should be examined for characteristics which distinguish Huron-Erie and Saginaw lobe deposits. Such distinguishing criteria would be useful in estimating the degree and chronology of interaction of the two lobes in the Huron-Erie-Saginaw interlobate area. The Port Huron moraine till should be studied petrologically, and the relationship of the younger border of the sandstone till sheet to the Port Huron moraine should be examined to determine whether the outer border of this moraine marks a strong petrologic contrast in tills. The classical belief that the Port Huron moraine is the product of an ice readvance of sufficient magnitude to subdivide late Wisconsin time suggests that such a contrast in tills should occur at the moraine's outer border.

APPENDIX

Student's t-Test Used in This Paper

Definitions:

$\bar{X}_1$ = Mean of first group

$\bar{X}_2$ = Mean of second group

s_1^2 = variance of first group, larger mean square

s_2^2 = variance of second group, smaller mean square

n_1 = sample size of first group

n_2 = sample size of second group

F-Test for Equal Variance:

$$F = \frac{s_1^2}{s_2^2}, \quad df = (n_1 - 1), (n_2 - 1)$$

Equal Variances:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\left(\frac{1}{n_1} + \frac{1}{n_2}\right)\left(\frac{s_1^2(n_1 - 1) + s_2^2(n_2 - 1)}{D}\right)}},$$

where $D = \max(n_1 - 1, 0) + \max(n_2 - 1, 0)$ and $df = D$.

Unequal Variances:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}},$$

where

$$df = \frac{1}{\frac{1}{n_1 - 1}\left(\frac{s_1{}^2/n_1}{s_1{}^2/n_1 + s_2{}^2/n_2}\right)^2 + \frac{1}{n_2 - 1}\left(\frac{s_2{}^2/n_2}{s_1{}^2/n_1 + s_2{}^2/n_2}\right)^2}$$

round to nearest integer.

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