Geoscience Wisconsin
Volume 7 July 1983

WISCONSINAN STRATIGRAPHY AND GLACIAL SEQUENCE IN SOUTHEASTERN WISCONSIN

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ABSTRACT

The Wisconsinan Stage is represented in southeastern Wisconsin by eleven formally named and defined rock-stratigraphic units of formation or member rank. These units are distinguished from one another by their stratigraphic position and lithologic characteristics, which are summarized in this paper. Particular emphasis is placed on the lithostratigraphy of late Wisconsinan units associated with the activity of the Lake Michigan Lobe during the Woodfordian Subage. Several unnamed, undifferentiated, and informal units of glacial, glaciofluvial, lacustrine, and eolian origin are also known to be present.

The Altonian Substage (Early Wisconsinan) is represented by the Walworth Formation, which consists of the Foxhollow Member, the Allens Grove Member, and the Clinton Member (in ascending order), and by the Capron Member of the Zenda Formation. These units are present in Rock and Walworth Counties, where they all occur in an area bounded by the Rock River on the west and by late Wisconsinan moraines on the north and east. Relatively little is known about the details of the ice advances responsible for the deposition of these units, however, partly because of their limited distribution and surface expression

The Woodfordian Substage (Late Wisconsinan) is represented by the Tiskilwa Member of the Zenda Formation, the Horicon Formation, the New Berlin Formation, the Oak Creek Formation, and the Ozaukee Member of the Kewaunee Formation. Except for the Tiskilwa Member, which occurs mainly in the shallow subsurface, all these units cover large areas of southeastern Wisconsin. All but the Horicon Formation were deposited by the Lake Michigan Lobe or its sublobes and by their associated meltwater streams. Till of the Horicon Formation was laid down by the Green Bay Lobe, which buried much of southeastern Wisconsin, formed the classical drumlin field of that area, and terminated at the Johnstown Moraine on the west and south and at the Kettle Interlobate Moraine on the east.

Both the New Berlin and Oak Creek Formations appear to represent several ice advances. The farthest advance to result in the deposition of sandy New Berlin till was that of the Delavan Sublobe, which shaped the Waukesha drumlin field and continued southwestward to its terminal Darien Moraine. The northwest side of the lobe terminated at the Kettle Moraine; thus, the Horicon and New Berlin Formations are considered to be age equivalents in southeastern Wisconsin.

A large proglacial lake, here called glacial Lake Milwaukee, is postulated for the Lake Michigan basin during stagnation and retreat of the Delavan Sublobe. When the Lake Michigan Lobe subsequently readvanced out of the basin, it incorporated large amounts of lacustrine silt and clay into the Oak Creek Formation. As the lobe pushed westward, it overran stagnant ice from the Delavan Sublobe and terminated along the Valparaiso Moraine. Later readvances reached the Tinley and Lake Border Moraines, and these were followed by still another advance that left red clay-rich till of the Ozaukee Member in a belt adjacent to the lake north of Milwaukee.

INTRODUCTION

This paper summarizes the lithostratigraphic record and the sequence of glacial events during the Wisconsinan Age in southeastern Wisconsin. In accord with the general theme of the field trip for which this is written, emphasis is placed on Late Wisconsinan (Woodfordian) stratigraphy and events. Emphasis is also placed on the activity of the Lake Michigan Lobe.

For nearly half a century following the publication of Alden's second U.S. Geological Survey professional paper on the Quaternary geology of southeastern Wisconsin in 1918, the glacial deposits of this area received virtually no attention until the studies of Ned Bleuer and Norman Lasca were initiated in the mid-1960s. The results of these investigations were incorporated in the guidebook prepared for the 1970 Annual Meeting of The Geological Society of America in Milwaukee (Black and others, 1970). Since that meeting, our knowledge of Wisconsinan stratigraphy and the glacial sequence of this area has been substantially supplemented, and thus it seems appropriate to review the subject for this 1983 meeting of the North-Central Section of the Society.

Five areas of activity have contributed to the acquisition of new knowledge during the past 13 years. They are as follows:

(1) Completion of graduate dissertations by Lawrence Acomb, Carl Fricke, Thomas Johnson, and G. Richard Whittecar under the direction of Professor David Mickelson at the University of Wisconsin-Madison.

(2) Surficial mapping by personnel of the Wisconsin Geological and Natural History Survey, mainly by David Hadley in Walworth County.

(3) Shore erosion and bluff stability studies along the Lake Michigan shoreline. The principal effort was a comprehensive project conducted during the summer of 1976 that was supported by a major grant to the State from the federal Office of Coastal Zone Management, National Oceanic and Atmospheric Administration, under the provisions of the Coastal Zone Management Act of 1972. Financial assistance was also provided by the Wisconsin Geological and Natural History Survey. Dave Hadley was Principal Investigator, Dave Mickelson and I were Co-Investigators, but many persons contributed to the success of the project (Mickelson and others, 1977).

(4) Continuing regional studies by myself of the glacial stratigraphy and landforms of southeastern Wisconsin. Commencing in 1971, these studies were supported initially by a research grant from the Wisconsin Alumni Research Foundation and subsequently by field expenses from the Wisconsin Geological and Natural History Survey and by research grants from the Committee on Research and Creative Activity of the University of Wisconsin--Parkside.

(5) Cooperative studies during the past two years with personnel of the Illinois State Geological Survey, including Ardith Hansel, Leon Follmer, Herbert Glass, and John Kempton.

A significant result of the increased attention to Quaternary studies in southeastern Wisconsin and throughout the State during the past decade has been the establishment of a formal, though as yet incomplete, rock-stratigraphic classification for deposits of the Quaternary Period (Mickelson and others, 1983). That classification is used in this paper.

ALTONIAN SUBSTAGE

Four early Wisconsinan (Altonian) till units are apparently present in southeastern Wisconsin (fig. 1). Working in the area south and west of the prominent Woodfordian moraines and east of the Driftless Area, Bleuer (1970) mapped three Altonian till units. The oldest of these he informally named the "Janesville till," which--with its associated ice-contact stratified drift called the "Janesville gravel"--Bleuer thought was probably deposited during Early Altonian time and correlated with one of the units in the lower part of the Winnebago Formation of Illinois. The two younger units were mapped by Bleuer as the Argyle and Capron tills, which he believed correlated directly with the Argyle Till Member and the Capron Till Member, respectively, of the Winnebago Formation of Illinois (Frye and others, 1969; Willman and Frye, 1970).

Fricke (Fricke and Johnson, in press), on the other hand, recognized four Altonian tills: in ascending stratigraphic order, the Foxhollow till, the Allens Grove till, the Clinton till, and the Capron till. From lithologic and drill-hole data, he concluded that the Allens Grove till is equivalent to the Argyle Till Member of Illinois and that the overlying Clinton till, previously correlated and mapped by Bleuer as the Argyle, is a separate and distinct unit between the Allens Grove (Argyle) till and the Capron till, both in Wisconsin and in northern Illinois (fig. 1). The Clinton has not been formally named in Illinois, however. Fricke's Foxhollow till, which in Wisconsin is known only from drill holes, appears to be present in exposures near Rockford, but like the Clinton it has not yet been accorded formal recognition by the Illinois State Geological Survey. The status of Bleuer's Janesville till is uncertain; Fricke (Fricke and Johnson, in press) inferred that it is equivalent to his Allens Grove till, but it might equate with the Foxhollow.

Because the lithologic characteristics of the Altonian tills differ from one another, it is assumed that each was deposited by a separate advance of the ice, probably all from the Lake Michigan basin. Very little is known, however, about the details of these advances, and most of the tills have little or no surface expression. Only a very sketchy interpretation of glacial history is possible, therefore.

Walworth Formation

Three mid-Altonian units constitute the Walworth Formation (Mickelson and others, 1983). In ascending order, they are the Foxhollow Member, the Allens Grove Member, and the Clinton Member (fig. 1). All three of these units are best known from southeastern Rock County and adjacent southwestern Walworth County in an area that is bounded on the west by the Rock River, on the north by the Johnstown Moraine, and on the east by the Darien Moraine and the Capron Ridge (fig. 2). Only the Clinton Member, however, is presently known to occur at the surface. All three units were likely deposited prior to 40 000 B.P. by glacier ice from the Lake Michigan basin.

Foxhollow Member

The Foxhollow Member (Mickelson and others, 1983) includes gray loam till that is present in the subsurface of southeastern Rock County, southwestern Walworth County, and part of northern Illinois. It occurs mainly as a fill in preglacial or early Pleistocene bedrock valleys, notably the Troy Valley (Alden, 1904, 1918; Green, 1968), which trends southwestward across southern Walworth County.

Foxhollow till is distinguished from the other two members of the Formation by having less sand (44 percent) and by a lower ratio (less than 0.8:1) of light to dark dolomite grains in the coarse-sand fraction. The Foxhollow is

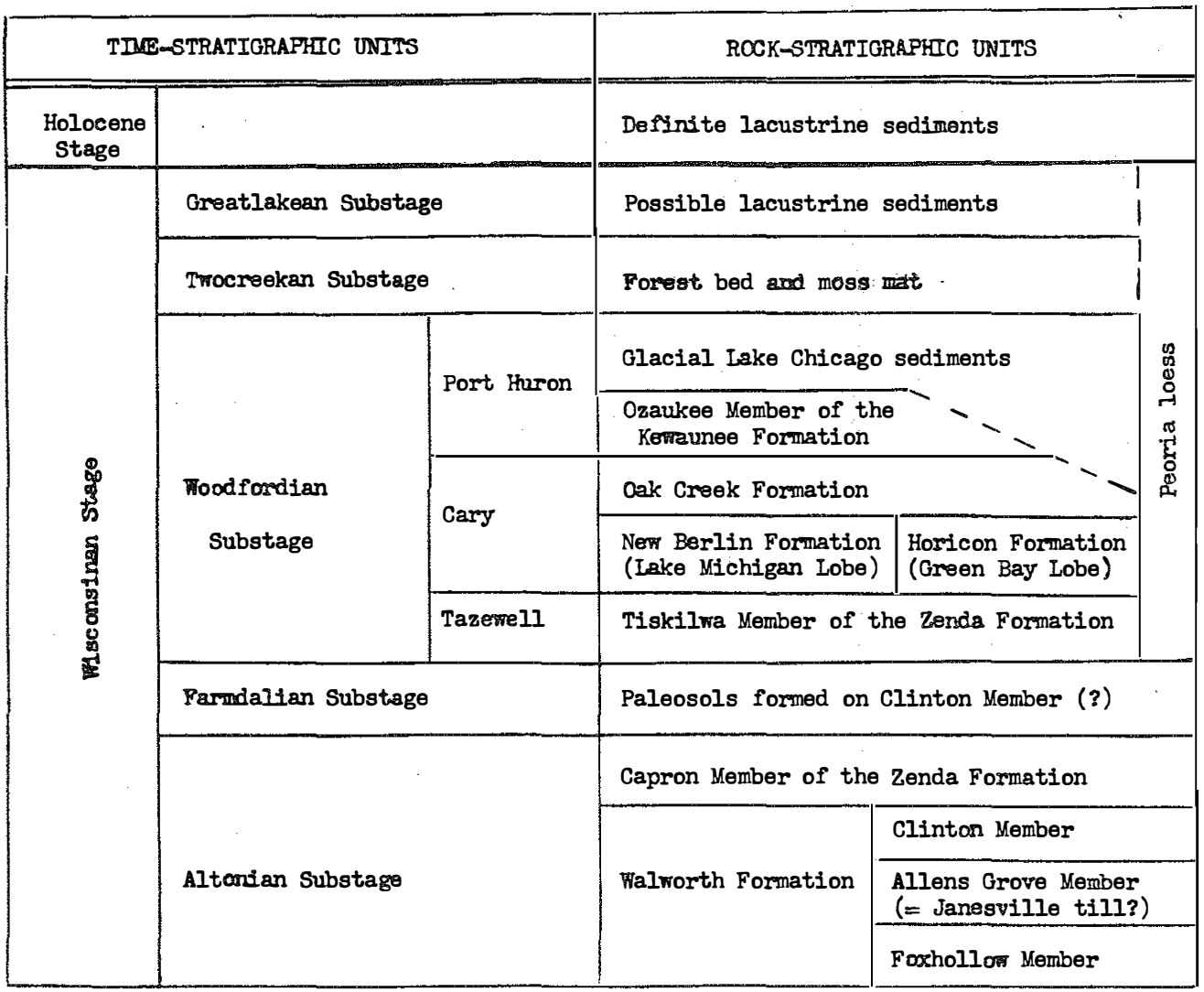


FIGURE 1.--Stratigraphic units of the Wisconsinan Stage in southestern Wisconsin.

also considered to have the lowest average illite content (53 percent) of all the tills in southeastern Wisconsin (Fricke and Johnson, in press; Mickelson and others, 1983), but in my opinion the X-ray diffraction data are not sufficiently different to distinguish the unit from other tills in the area (table 1).

Allens Grove Member

The middle unit of the Walworth Formation is the Allens Grove Member. It includes pink sandy till that lies beneath the Clinton Member in southeastern Rock County.

Allens Grove till has about 53 percent sand and thus is texturally intermediate between the less sandy Foxhollow till and the sandier Clinton till (table 1). It is also intermediate between the other two members of the Walworth Formation in the ratio of light-to-dark dolomite in the coarse-sand fraction. Two groups of samples from Allens Grove till have significantly different clay-mineral compositions (table 1), according to Fricke and Johnson (in press). Perhaps the most diagnostic characteristic of Allens Grove till is its pinkish-tan or salmon color.

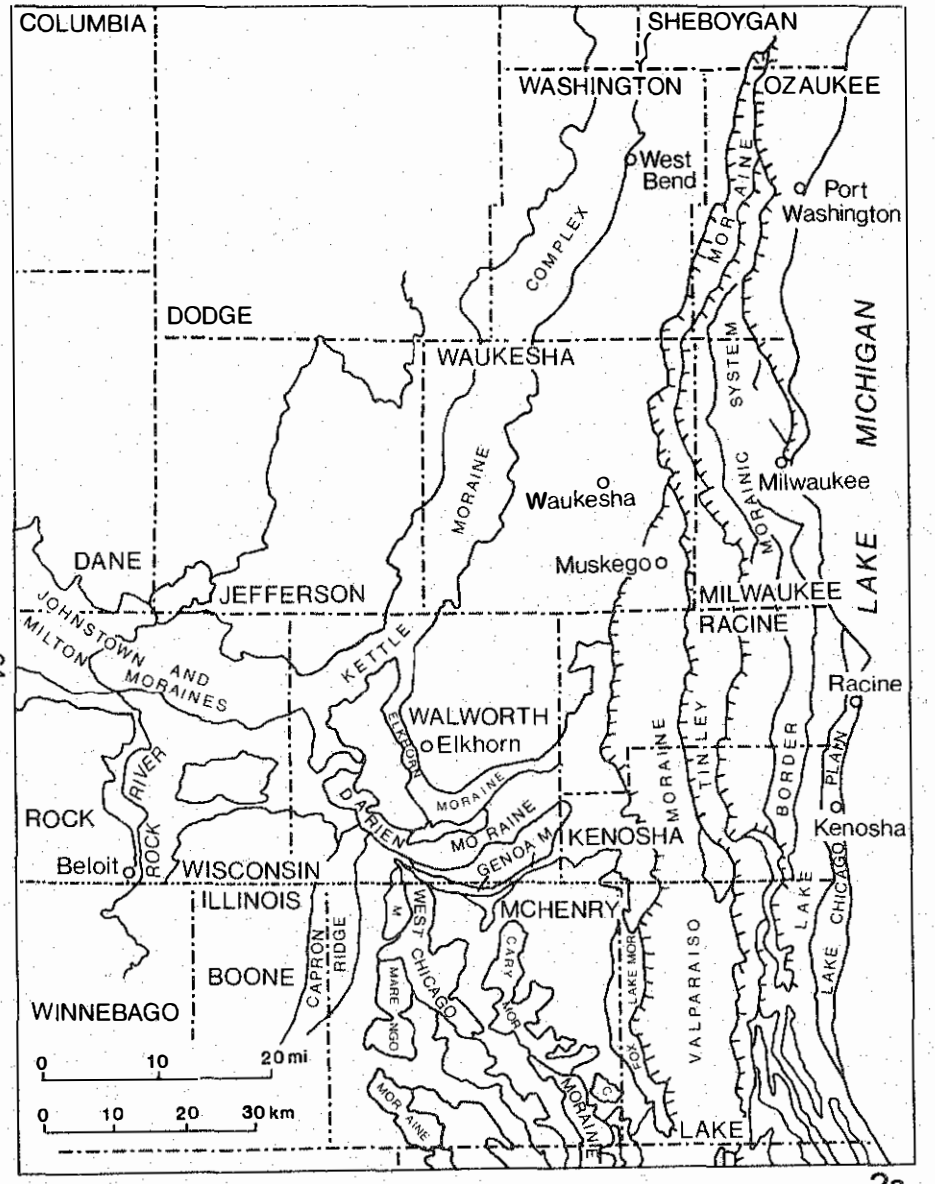
The Allens Grove till extends southward into northern Illinois, where it is called the Argyle Till Member of the Winnebago Formation (Frye and others, 1969; Willman and Frye, 1970). At some places in Illinois, the Argyle till is overlain by the Plano Silt Member of the Winnebago Formation (Kempton and Hackett, 1968), which consists of silt, organic silt, and peat. Finite radiocarbon dates on wood and other organic material range from 32 600 to 41 000 B.P. Other dates are greater than 40 000 B.P. (Willman and Frye, 1970, table 1).

Clinton Member

The youngest unit of the Walworth Formation is the Clinton Member (Fricke and Johnson, in press; Mickelson and others, 1983), which includes sandy loam till and associated sand and gravel that occurs at the surface in southern Rock and southwestern Walworth Counties. As already stated, the unit was mapped by Bleuer (1970) as the Argyle till on the assumption that it was equivalent to the Argyle till of Illinois. Its eastern surficial extent is the north-south-trending Capron Ridge, but Fricke and Johnson (in press) have confirmed that Clinton till is definitely present beneath the younger Capron till in the ridge. It is also present west of the Rock River; its distribution in this area is patchy, but it appears to extend westward in tributary valleys to the Sugar River, nearly 12.9 km west of the Rock-Green county line (Bleuer, 1970, p. J-18).

Clinton till has the most sand (61 percent) of the three members of the Walworth Formation (table 1). It also has the highest ratio of light-to-dark dolomite in the coarse-sand fraction (greater than 1.3 to 1), according to Fricke and Johnson (in press). Like the underlying Allens Grove Member, two groups of samples of Clinton till have significantly different percentages of clay minerals (table 1). Although the till is most commonly light yellowish brown (10YR 6/4) or light brown (7.5YR 6/4), a pink color (7.5YR 7/4 or 7.5YR 8/4) is also somewhat characteristic, particularly when the till is dry (Bleuer, 1970, p. J-14). Fricke and Johnson (in press) suggested that this may be due to the local incorporation of material from the underlying Allens Grove Member.

Bleuer was obviously puzzled by a less sandy till that he found beneath his Argyle (now Clinton) till at depths of 2 to 6 m below the upland


COLUMBIA
SHEBOYGAN
WASHINGTON
OZAUKEE
West Bend
Port Washington
COMPLEX
MORAINE
DODGE
WAUKESHA
SYSTEM
MICHIGAN
MORAINE
Waukesha
MORAINIC
Milwaukee
LAKE
DANE
Muskego
JEFFERSON
MILWAUKEE
RACINE
JOHNSTOWN
MILTON
AND
MORAINES
KETTLE
Racine
WALWORTH
ELKHORN
Elkhorn
MORAINE
TINLEY
BORDER
PLAIN
RIVER
ROCK
DARIEN
MORAINE
MORAINE
KENOSHA
Kenosha
ROCK
Beloit
WISCONSIN
GENOA M
ILLINOIS
MCHENRY
WEST CHICAGO
LAKE
CHICAGO
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RIDGE
MORAINE
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CARY
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0 10 20 mi
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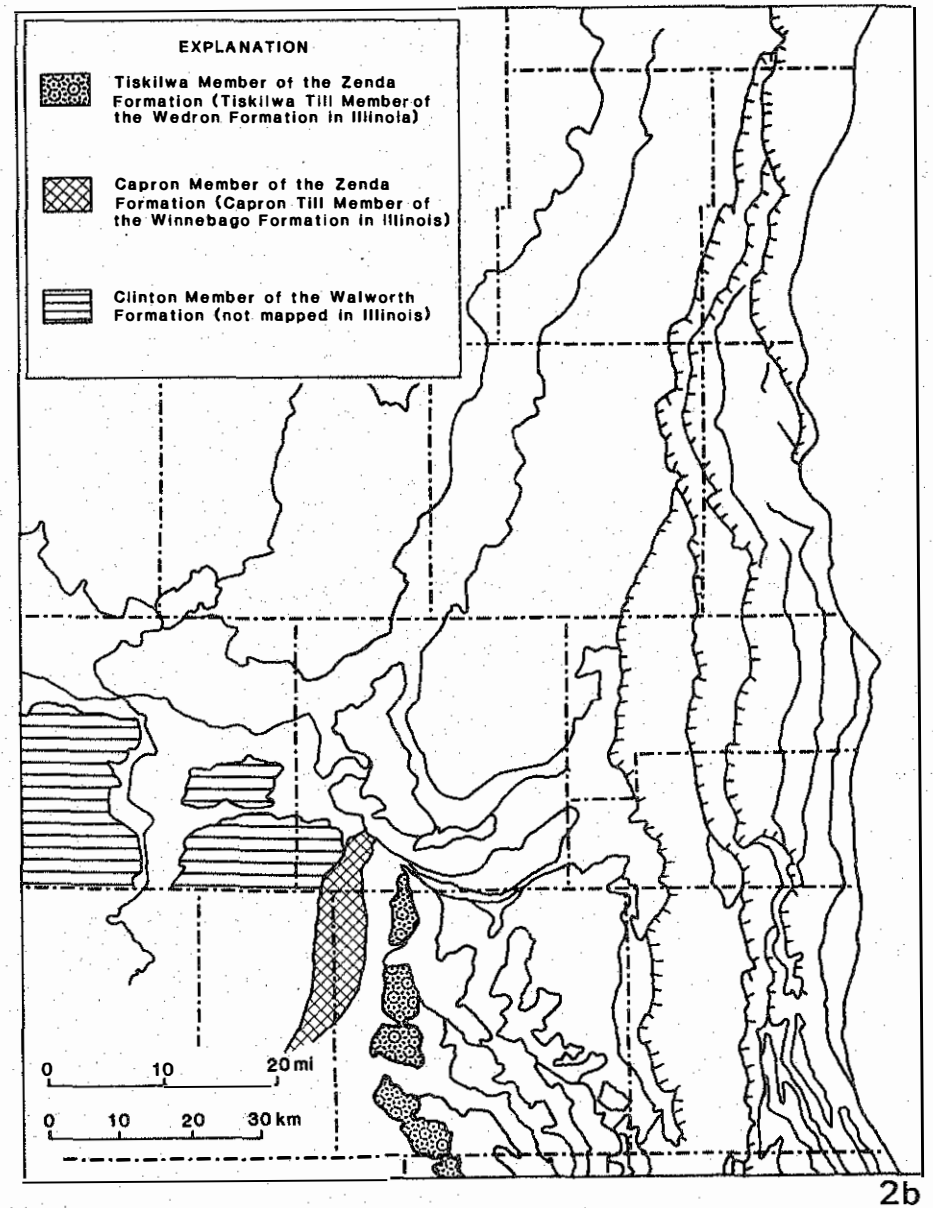
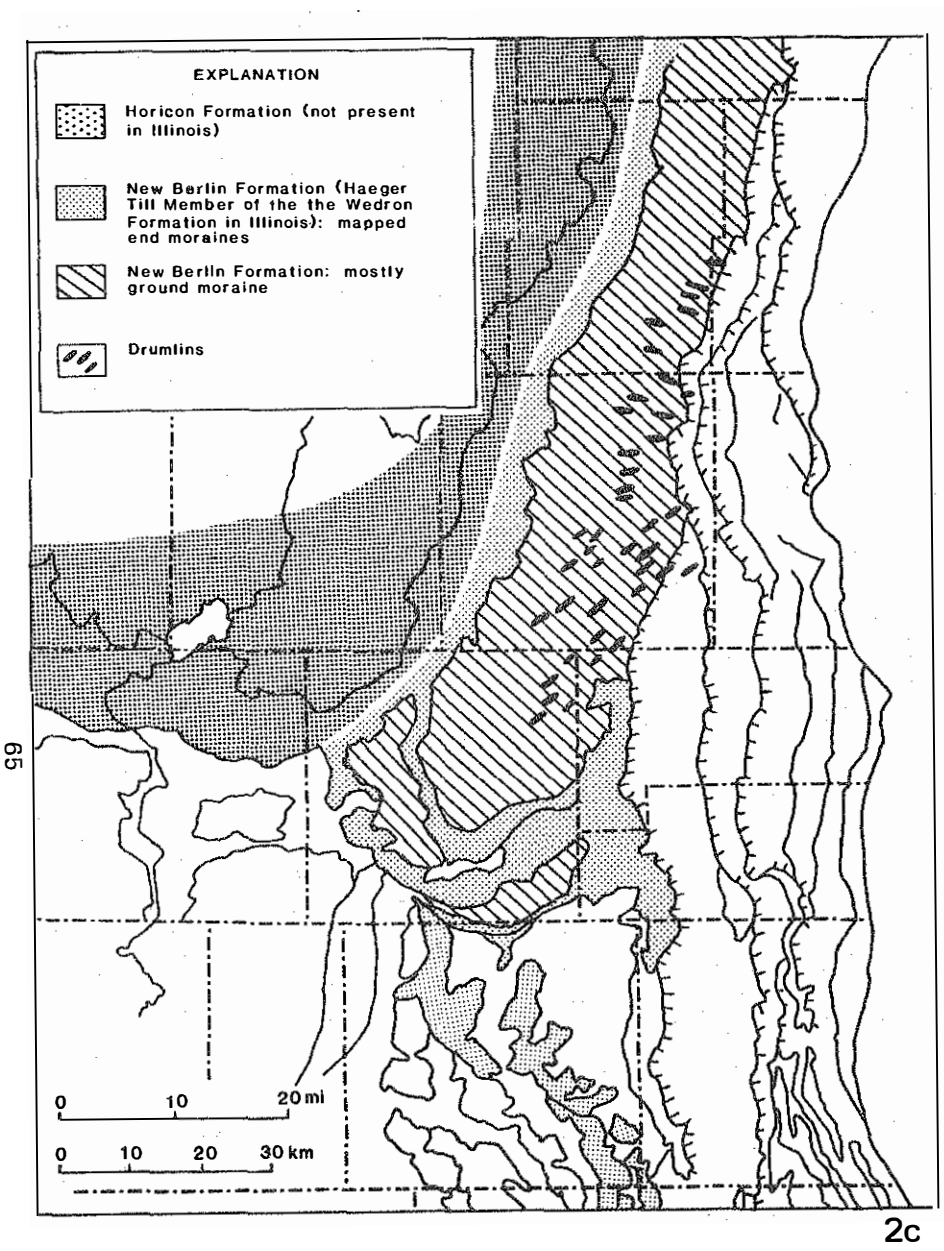

EXPLANATION
Tiskilwa Member of the Zenda Formation (Tiskilwa Till Member of the Wedron Formation in Illinois)
Capron Member of the Zenda Formation (Capron Till Member of the Winnebago Formation in Illinois)
Clinton Member of the Walworth Formation (not mapped in Illinois)
0 10 20 mi
0 10 20 30 km
2b



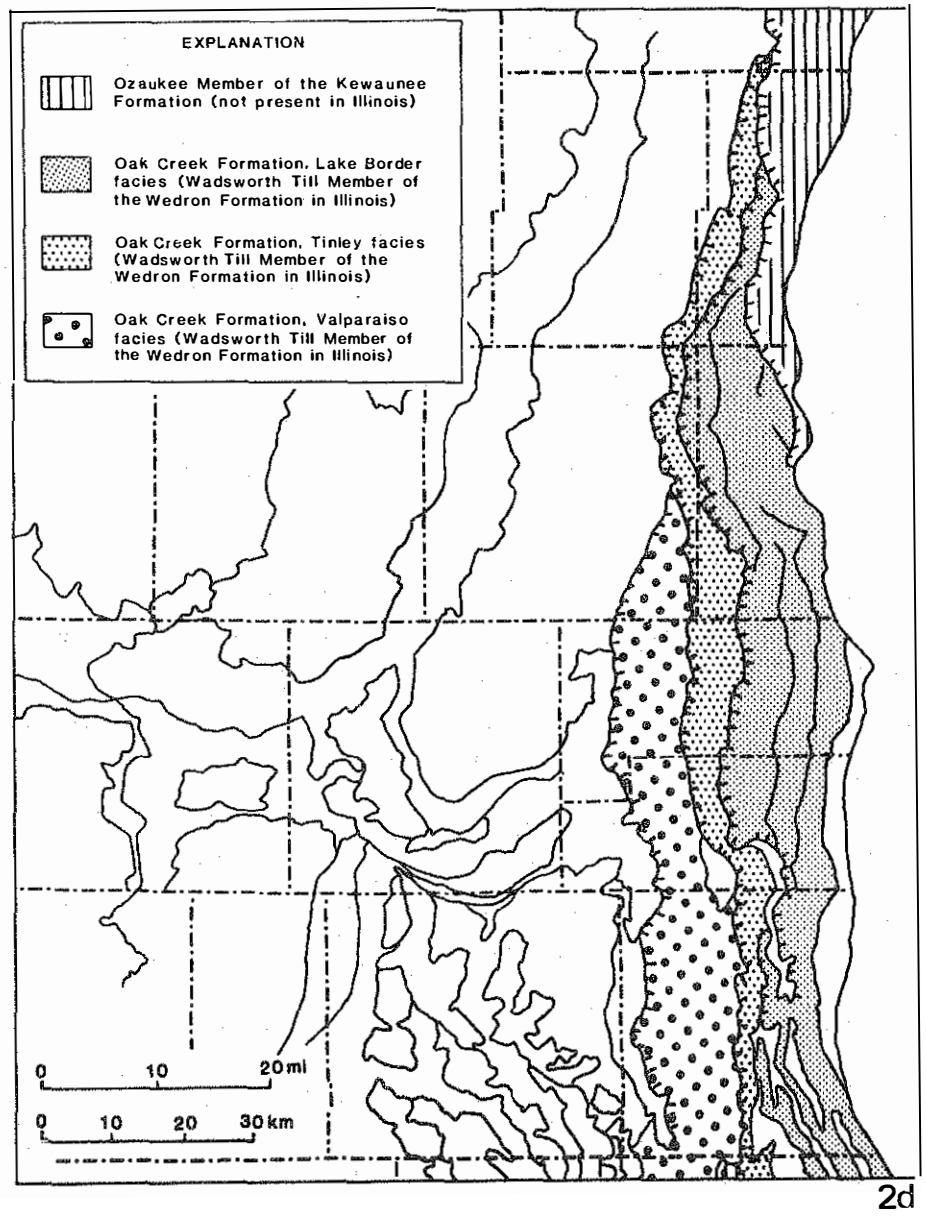


FIGURE 2.--Glacial geology of part of southeastern Wisconsin showing moraines and counties (2a) and distribution of Wisconsinan rock-stratigraphic units (2b, 2c, 2d). Moraines as shown do not necessarily represent the interpretations of the author; rather, an attempt is made to show relationships mapped by several workers. Hachured lines represent distal edges of younger rock-stratigraphic units. Wisconsin part compiled from Alden (1904, 1918), Thwaites (1956), Hadley and Pelham (1976), and the author's field maps; Illinois part compiled from Leighton and Willman (1953) and Willman and Frye (1970).

Stratigraphic Unit	Grain Size of Matrix (< 2 mm)				Clay-mineral Composition (< .002 mm)				Source of Data
	Sand (%)	Silt (%)	Clay (%)	N	Expandable Clay Mins (%)	Illite (%)	Kaolinite + Chlorite (%)	N	
Ozaukee till	13	47	40	(19)[a]	20	60	20	(20)	Acomb and others, 1982
Oak Creek till	12	44	44	(68)[b]	15	72	13	(55)	ISGS, H.D. Glass
Horicon till	72	17	11	(24)[c]					Allan, 1967
New Berlin till	58	29	13	(15)[b]	17	66	17	(26)	ISGS, H.D. Glass
Tiskilwa till	42 39	35 39	23 22	(8)[b] (?)[d]	18	67	15	(24)	ISGS. H.D. Glass Fricke & Johnson, in press
Capron till									
Upper phase	41 40	35 42	24 18	(3)[b] (5)[d]	28	61	11	(3)	Fricke & Johnson, in press Bleuer, 1970
Lower phase	27 24	38 45	35 31	(2)[b] (3)[d]	28	61	11	(2)	Fricke & Johnson, in press Bleuer, 1970
Clinton till	61	27	12	(85)[b]	26 45	60 45	14 10	(85)	Fricke & Johnson, in press
Argyle till	62	28	10	(app 30)[d]					Bleuer, 1970
Allens Grove till	53	35	12	(40)[b]	26 39	61 47	13 14	(40)	Fricke & Johnson, in press
Janesville till	47	40	13	(app 40)[d]					Bleuer, 1970
Foxhollow till	44	37	19	(22)[b]	28	53	19	(22)	Fricke & Johnson, in press

N (00) = number of samples. Grain-size boundaries: [a]Boundaries are 2 mm, 0.062 mm, and 0.002 mm.

[b]Boundaries are 2 mm, 0.062 mm, and 0.004 mm. [c]Boundaries are 2 mm, 0.05 mm, and 0.002 mm.

[d]Precise boundaries not stated.

Table 1. Average grain-size distribution and clay-mineral composition of tills in southeastern Wisconsin.

surface. Ten samples of this lower till averaged 47 percent sand, 38 percent silt, and 15 percent clay. Whereas the surficial till is rich in Niagaran dolomite, the lower till is rich in local dolomite (Bleuer, 1970, p. J-16). A till with lithologic characteristics similar to this lower till was also found stratigraphically below the Argyle (Clinton) north of Turtle Creek. Bleuer tentatively correlated both this unit and the lower till south of Turtle Creek with his Janesville till. It seems reasonable to conclude that Bleuer's sub-Argyle (sub-Clinton) till units equate with Fricke's Allens Grove or Foxhollow tills.

Fricke (Fricke and Johnson, in press) reported the presence of a fossil B horizon formed on the Clinton till beneath flatter upland surfaces. At the type section of the Clinton Member in southeastern Rock County, the paleosol has a reddish-brown B2t horizon and a brown beta horizon formed in the upper 1.7 m of the Clinton till. At the type section of the Allens Grove Member, where it is overlain by about 8.2 m of Clinton till, a paleosol also occurs at the top of the Clinton Member. At both localities the section is capped by 1 to 2 m of loess, which is assumed to be Peoria loess. Although the paleosol has been stripped from steeper slopes by erosion, Fricke suggested that it may be present along the footslopes beneath a loess and colluvial cover.

Bleuer (1970, p. J-16) reported the discovery by Robert Engel of the Soil Conservation Service of an organic-rich, sandy A1 horizon overlying gleyed, leached sandy loam till. The soil is buried by 1.5 m of Peoria loess.

The Robein Silt, on which the Farmdalian Substage of Illinois is based, is not known to be present in southeastern Wisconsin. However, the paleosols described by both Fricke and Bleuer may well represent Farmdalian time in southeast Wisconsin.

The Clinton Member appears to be the oldest stratigraphic unit in southeastern Wisconsin about which ice-flow direction can be inferred from geomorphic evidence. Between the Capron Ridge and the Rock River outwash terrace, the upland is characterized by a distinctly drumlinoid topography. First recognized by Buell (1895) before the turn of the century, the landscape was nicely described by Bleuer (1970, p. J-15) in the following manner:

> "Drainage is deranged and youthful, and, except for those areas adjacent to Turtle Creek or the Rock River valley, the drainage is almost wholly controlled by the subdued constructional topography. Much of the area is a series of broad, imperfectly drained to poorly drained lineated lowlands between low, gently sloping lineated hills. Local relief is less than 60 feet within the area.
>
> "The lineations are not parallel everywhere east of the Rock River, contrary to Alden (1918, Pl. III) and Leighton and Brophy (1966, Fig. 2, p. 484). The topography south of Turtle Creek has a general west-southwest lineation, but individual ridges are oriented between this trend and east-west. Orientations of upland crests north of Turtle Creek are west-northwest and suggest a locally divergent flow. This diversity of orientation may be in part due to the effect of bedrock topography upon glacial deposition."

Bleuer correctly points out that the topography west of the Rock River valley is grossly different from that east of the river and that the surface morphology is bedrock controlled. Ice flow west of the Rock River was from the east-southeast, according to Bleuer

(1970, p. J-14), rather than from the east-northeast as in the area between the Rock River and the Capron Ridge. He recognizes the possibility, however, that the lineated landscape of this latter area may not be directly related to the surface till, but instead to an older till (Bleuer, 1970, p. J-16). This possibility seems to be unlikely.

Zenda Formation
Capron Member

The youngest Altonian unit known to be present in southeastern Wisconsin is named the Capron Member of the Zenda Formation (Mickelson and others, 1983). The Capron Member occurs at the surface only in a small area of southwestern Walworth County, where it is found in the north-south-trending Capron Ridge (fig. 2). The Capron Ridge enters Walworth County from Boone and McHenry Counties, Illinois, where the unit was named the Capron Till Member of the Winnebago Formation (Frye and others, 1969; Willman and Frye, 1970) for the village of Capron located on the ridge 10 km south of the Wisconsin-Illinois boundary.

The Capron till is generally a medium-grained till, although two distinct compositional phases have been recognized, both in Illinois (Frye and others, 1969; Willman and Frye, 1970) and in Wisconsin (Bleuer, 1970, p. J-11; Fricke and Johnson, in press)--a lower siltier phase and an upper sandier phase (table 1). In Illinois the more sandy unit has more expandable clay minerals and less illite, but in Wisconsin the clay-mineral composition of the two phases appears to be similar, as well as resembling the clay-mineral content of one group of samples from both the Allens Grove and Clinton tills (table 1). The till is moderately compact and calcareous, as in Illinois, and is light brown (7.5YR 6/4) to brown (7.5YR 4/4) in color. Capron till can be distinguished from till of the older Walworth Formation and the younger Horicon Formation by its distinctly finer grain size and its slightly darker or pinker color.

Like older Altonian till in southeastern Wisconsin, the Capron till was deposited by the Lake Michigan Lobe (Frye and others, 1969, p. 6; Bleuer, 1970, p. J-12). Nearly 80 percent of the pebbles are dolomite, and about half of the stones identified by Bleuer (1970, p. J-11) were Niagaran dolomite pebbles. Frye and others (1969, p. 6) concluded that the intermediate composition of the Capron till, in terms of both its illite and Devonian black shale content, indicates primary glacier scour along the western side of the Lake Michigan basin.

The Capron Member was apparently deposited between 30 000 and 35 000 years ago. Its age is established by stratigraphic relations in Illinois, where the unit overlies the Plano Silt Member of the Winnebago Formation and underlies the Robein Silt. The Plano Silt is at least 35 000 radiocarbon years old, and the Robein Silt has radiocarbon dates between 21 000 and 28 000 B.P. (Willman and Frye, 1970). Thus the Capron Member is Late Altonian.

About 7 km of the Capron Ridge occurs in Wisconsin. Near the state line the ridge has a maximum relief of about 27 m. It descends slightly from south to north and is apparently overlapped and truncated on the north by outwash deposits and by the northwest-southeast-trending Darien Moraine. The eastern toe of the ridge is buried by proglacial sand associated with the Darien-Marengo-West Chicago morainic belt. Along the western edge of the ridge, Capron till blankets the Clinton Member of the Walworth Formation (Fricke and Johnson, in press).

Although it is commonly thought to be an end moraine, very little is actually known about the origin of the Capron Ridge. According to Bleuer (1970,

p. J-12), drift thicknesses of more than 10.5 m were penetrated by power auger at several sites along the crest of the ridge. Near the north end of the ridge crest, however, bedrock was encountered at depths of only 0.6 to 1.8 m, and borings in the eastern part of the ridge indicate the presence of an older till at depths ranging from 1.5 to 6.1 m. He concluded, therefore, that some of the relief of the Capron Moraine is due to a core of older till or high bedrock.

WOODFORDIAN SUBSTAGE

Five Late Wisconsinan (Woodfordian) stratigraphic units are formally recognized in southeastern Wisconsin. These units range in age from about 18 000 or 20 000 years to 12 500 or 13 000 years. In ascending stratigraphic order, they are the Tiskilwa Member of the Zenda Formation, the New Berlin and Horicon Formations (age equivalents), the Oak Creek Formation, and the Ozaukee Member of the Kewaunee Formation (fig. 1 and Mickelson and others, 1983). Peoria loess and unnamed lacustrine deposits are also present.

Almost certainly, further field and laboratory investigations will result in the subdivision of some of these units and thus lead to refinements of our current rock-stratigraphic framework for this area. The New Berlin Formation, for example, is known to consist of two principal members, a lower sand and gravel unit and an upper till unit, but neither is formally defined at this time. The Oak Creek Formation very likely represents two, three, or possibly even four advances of the Lake Michigan Lobe that left deposits that may eventually be distinguished from each other lithologically and correlated with specific morainic ridges. For a more detailed treatment than presented in this paper of the Oak Creek Formation and its correlative unit in northeastern Illinois, the Wadsworth Till Member of the Wedron Formation, the reader is referred to accompanying papers in the guidebook by Hansel (1983) and Need (1983).

Zenda Formation
Tiskilwa Member

The earliest incursion of ice into southeastern Wisconsin during the Woodfordian Subage occurred about 18 000-20 000 B.P. It is represented by till of the Tiskilwa Member of the Zenda Formation (Mickelson and others, 1983). This unit was named the Tiskilwa Till Member of the Wedron Formation (Willman and Frye, 1970) from a road cut in Bureau County, Illinois, 8 km northwest of Tiskilwa in the Bloomington Moraine (Frye and Willman, 1965, p. 95).

Tiskilwa till in Illinois is "sandy, pink-tan to reddish tan-brown, and generally is described as pink till" (Willman and Frye, 1970, p. 68). Tiskilwa till in Wisconsin is similar. Typically it has a 5YR hue, but ranges in color from reddish brown (5YR 4/3, 5YR 4/4, or 5YR 5/4) or yellowish red (5YR 4/6) to brown (7.5YR 5/4) where it is oxidized. Where unoxidized, it is commonly dark reddish gray (5YR 4/2) or weak red (2.5YR 4/2).

Till of the Tiskilwa Member is slightly to moderately stony. Grain-size analyses indicate that the matrix of the till contains an average of about 42 percent sand, 35 percent silt, and 23 percent clay (table 1). In some places a more sandy phase of the till is present. A single sample from one of the formally designated Wisconsin reference sections for the Tiskilwa Member contains 65 percent sand, 24 percent silt, and 11 percent clay; in contrast, three samples of the more typical till from the same exposure average 42 percent sand, 36 percent silt, and 22 percent clay. To date it has not been possible to determine the distribution of the more sandy facies,

partly because of the similarity in both color and texture between the sandier Tiskilwa till and till of the younger New Berlin Formation that has been contaminated with Tiskilwa till as a result of erosion and assimilation. In fact, the two are virtually indistinguishable, even in relatively deep, fresh cuts.

The more typical Tiskilwa till is lithologically similar to till of the older Capron Member of the Zenda Formation. Both are pink, medium-textured tills with approximately the same grain-size distributions (table 1). Capron till is less red, however, according to Bleuer (1970, p. J-11 to J-13) and normally has a 7.5YR hue rather than the 5YR hue that is typical of Tiskilwa till. Tiskilwa till is readily distinguished from both the older Clinton till and the younger (uncontaminated) New Berlin till by its pinkish color and distinctly finer grain size. New Berlin till also has more pebbles than the Tiskilwa till.

In McHenry County, Illinois, just south of the Wisconsin state line, Tiskilwa till composes the Marengo Moraine, a prominent north-south-trending end moraine. According to Willman and Frye (1970, p. 108), the Marengo Moraine represents the outermost moraine of the Harvard Sublobe of the Lake Michigan Lobe. It is one of the higher and more prominent end moraines in Illinois, being about 65 km long and 5 km wide; it generally rises 45 to 60 m above the outwash plain in front (to the west) of the moraine. Although it has been correlated in the past with the Bloomington Moraine, the exact relationship between the moraines now appears to be somewhat uncertain (Willman and Frye, 1970, p. 108).

Less than a kilometer north of the Wisconsin-Illinois boundary the Marengo Moraine is overlapped from the east by the northwest-southeast-trending Darien Moraine, the terminal moraine of the Delavan Sublobe of the Lake Michigan Lobe (Alden, 1904, 1918; Schneider, 1982), and its proglacial outwash deposits. It can be traced northward, however, chiefly by mapping the distribution of pink Tiskilwa till, which is exposed at or near the surface in a belt roughly 10 to 18 km wide that extends from the state line northward through Walworth County to the Kettle Moraine. The high topography north and south of Lake Geneva is certainly part of the Marengo Moraine, irregularly blanketed with a thin veneer of younger drift. Very probably, Tiskilwa till forms the core of much of the Elkhorn Moraine, which Alden (1904, 1918)) considered to be a recessional moraine of the Delavan Sublobe but which we now believe is largely the northward continuation of the Marengo Ridge, partially buried beneath a thin cover of New Berlin till. It is in this latter area that Tiskilwa till and contaminated New Berlin till are difficult or impossihle to distinguish in many exposures. Yet in many others sharp contacts of apparently pure tills establish the relative age of the two units.

The Tiskilwa Member is also known to be present at many localities farther east, where it is normally buried beneath thick drift of the New Berlin and Oak Creek Formations. It has not been observed, however, in bluff exposures along the Lake Michigan shoreline.

In summary, pink Tiskilwa till was deposited by the Harvard Sublobe from the Lake Michigan hasin sometime between 18 000 and 20 000 B.P. The Harvard Sublobe advanced westward to the location of the Marengo Moraine--a prominent landscape feature in northern Illinois that may be traced northward as a buried topographic high beneath deposits of a later advance.

New Berlin Formation

The New Berlin Formation was named by Schneider (Mickelson and others, 1983) for coarse-grained drift of the Delavan Sublobe of the Lake Michigan Lobe (Alden, 1904, 1918; Schneider, 1982). As previously stated, the formation consists of two principal members, a lower sand and gravel unit and an upper unit that is mostly till. Neither unit has been formally defined.

Both members of the New Berlin Formation are commonly present where the formation is at or near the surface in southeastern Wisconsin. This area includes much of Waukesha and Walworth Counties and smaller parts of Kenosha, Racine, Milwaukee, Washington, and Ozaukee Counties. Geomorphologically, the formation covers the area in and behind (northeast of) the Darien Moraine, between the Kettle Interlobate Moraine on the west and either the Valparaiso or Tinley Moraine on the east (fig. 2). It extends eastward in the subsurface to Lake Michigan, at least in some places, because it is exposed near the base of the bluff as far south as Sheridan Park in southern Milwaukee County. Whether the New Berlin Formation is present beneath thick deposits of the Oak Creek Formation in eastern Racine and eastern Kenosha Counties is not known, but it seems probable that it was at least deposited in that area.

The New Berlin Formation takes its name from the city of New Berlin in eastern Waukesha County, where the formation is well exposed in numerous gravel pits in the Waukesha drumlin field (fig. 2). Its type section, in fact, is a compound gravel pit in the heart of the drumlin field. The formation is also well exposed in road cuts and in gravel pits farther to the southwest in southern Waukesha, northwestern Racine, and Walworth Counties.

The lower (sand and gravel) unit is commonly the thicker of the two members; it ranges in thickness from 0 to about 12 m. The upper member of the formation is generally thinner, ranging up to about 10 m in thickness; in some places, however, it is only a meter or two thick. The full thickness of the formation is exposed in several gravel pits in Waukesha and Walworth Counties, where the sharp contact between the top of the Tiskilwa Member of the Zenda Formation and the base of the New Berlin Formation defines the floors of the pits.

The lower member of the New Berlin Formation is interpreted as outwash sediment deposited in front of and around the margins of the advancing Delavan Sublobe. The upper member is interpreted as basal till. Whittecar and Mickelson (1979) have postulated that both an "advance" till and a "retreat" till are present in the Waukesha drumlin field, based upon a study of internal structures in the drumlins. The formation also includes thick, coarse ice-contact stratified deposits, which reach their greatest extent adjacent to the Fox River in western Kenosha, western Racine, and eastern Walworth Counties.

The upper member of the New Berlin Formation is typically gravelly sandy loam till, averaging about 58 percent sand, 29 percent silt, and 13 percent clay in the matrix (table 1). The grain size is variable, however, and in some places the till is considerably more sandy, containing as much as 70 or 72 percent sand. In other places it is less sandy and is gravelly loam.

Oxidized till is yellowish brown (10YR 5/4 to 7.5YR 5/4 or 7.5YR 4/4) or, less commonly, brown (10 YR 5/3); unoxidized till is grayish brown (10 YR 5/2 or 2.5Y 5/2). The till everywhere, except of course where leached, is strongly calcareous and has a pH of about 8. The characteristics of New Berlin till are due to the presence of very high amounts of crushed dolomite in all size fractions. Dolomite also

dominates the stone assemblage, which includes a wide variety of igneous and metamorphic rock types.

Illite is the most abundant clay mineral of New Berlin till, constituting about 66 percent of the clay-mineral complex; expandable clays and kaolinite plus chlorite are nearly equal in abundance, each accounting for 17 percent of the total, as determined by H. D. Glass of the Illinois State Geological Survey (table 1).

Till of the New Berlin Formation is readily identified, therefore, by its high and diversified pebble content, sandy texture, brown to yellowish-brown color, and high carbonate content. Where New Berlin till is thin and contains assimilated till from the underlying Tiskilwa Member of the Zenda Formation, as in and near the area of Alden's (1918) Elkhorn Moraine in Walworth County, it has a distinct pinkish cast, contains less sand, more clay and is difficult to distinguish from the Tiskilwa.

Moraine Relations

The New Berlin Formation is correlated with the Horicon Formation of the Green Bay Lobe and is also considered to equate with the Haeger Till Member of the Wedron Formation of Illinois (Willman and Frye, 1970). The Haeger till and associated sand and gravel deposits cover many square kilometers in northeastern Illinois, particularly in McHenry County, where they constitute the West Chicago Moraine. In northwestern McHenry County, 16 km south o the Wisconsin state line, the northwest-southeast-trending West Chicago Moraine climbs onto the proximal (east) side of the north-south-trending Marengo Moraine (fig. 2). The morphological relationship is clear, especially when it is tied to the lithostratigraphic evidence. The overlap of the West Chicago Moraine across the Marengo Moraine is completed a kilometer or so north of the state line, but neither the morphologic nor the stratigraphic evidence is so clear as farther south.

The terminus of the Delavan Sublobe was clearly the Darien Moraine, which trends northwest-southeast across Walworth County and which is generally conceded to be equivalent to the West Chicago (Fricke and Johnson, in press). The possibility is raised here that the two moraines may not be so related. This possibility is suggested by a reentrant along the moraine front and by a slightly different trend on opposite sides of the reentrant. This possibility is further suggested by the presence of aligned depressions southeast of Walworth, which continue the trend of the front of the Darien Moraine northwest of Walworth and which are clearly transverse to the orientation of the West Chicago Moraine immediately to the south. The low area conceivably represents an ice-marginal trough at the snout of the Delavan Sublobe.

The exact morphologic relationship of the Darien to the West Chicago Moraine is obscure because the two moraines meet in the same area as the transgression of the West Chicago Moraine across the Marengo Moraine is completed (fig. 2). Despite the fact that the West Chicago Moraine overlaps the Marengo Moraine, its north end descends into the bedrock valley of Lake Geneva (Green, 1968, p. C137). Thus, the West Chicago Moraine could, in turn, be overlapped by the Darien. If this is indeed the case, the age difference does not appear to be substantial, however.

Waukesha Drumlin Field

The Delavan Sublobe (called the Delavan lobe by Alden) probably entered southeastern Wisconsin from the Lake Michigan basin sometime between 16 000 and 14 000 years ago. The central part

of the ice mass crossed the area headed about S. 45 to 50° W., as indicated by striae (Chamberlin, 1877, p. 204) and by the orientation of drumlin axes in the Waukesha drumlin field, the lobe terminated on the southwest in the northwest-southeast oriented Darien Moraine, as postulated by Alden (1904, 1918).

More than 600 drumlins and associated elongate ridges are present in the Waukesha drumlin field, which was first described and mapped by Alden (1918, p. 30; pl. 1) and which was more recently described and figured by Whittecar and Mickelson (1979). In the main part of the drumlin field in eastern and south-central Waukesha County, the features are typically 0.8 to 1.3 km long and 15 to 30 m high. Nearly all of the drumlins appear to be cored with gravel of the lower member of the New Berlin Formation.

Like those of the Green Bay Lobe and other drumlin fields, the drumlins of the Waukesha area show a radiating or fan-shaped pattern (fig. 2). Most of the features in the main part of the field are oriented between S. 40° W. and S. 60° W. North of the latitude of Waukesha, however, the trend becomes more westerly, so that in north-central Waukesha County many of the drumlins are oriented east-west. Still farther north, as in southeastern Washington County, the features assume a northwest-southeast orientation (fig. 2). It seems abundantly clear from the morphologic evidence that the Delavan Sublobe radiated to the west and northwest as it approached its terminal position along the Kettle Interlobate Moraine. Much mor field work is needed in this area and farther north, however, in order to determine and confirm the stratigraphic and areal relations of the several lithologic units known to be present between the Kettle Moraine and the western limit of red till assigned to the Ozaukee Member of the Kewaunee Formation.

To the southwest along the main flow direction, the strong linear pattern grades into weakly fluted topography, which in turn gradually deteriorates in the down-ice direction as the terminal position of the lobe is approached. Whittecar and Mickelson (1979, p. 360) have stated that the density of drumlins decreases from about six drumlins per km^2 nearly 50 km from the terminal moraine to almost no drumlins about 10 km from the moraine; they observed that it is nearly the same decrease as in the drumlin field of the adjacent Green Bay Lobe. The southwesterly flow of the Delavan Sublobe may well have been impeded by the north-south-trending Marengo Moraine, which was overridden and blanketed with grayish brown till but which contributed its pink Tiskilwa till to the basal load of the Delavan glacier.

Southern and Eastern Extent of the Delavan Sublobe

The southern and eastern limits of the Delavan Sublobe are unknown. Alden (1904, 1918) considered the southern limit of the ice to be the Genoa Moraine (fig. 2), a general east-west-trending moraine but with distinct convexity to the south, which he mapped adjacent to the state line between the junction of the Marengo and Darien Moraines on the west and the Valparaiso Moraine on the east. The Darien Moraine was continued eastward by Alden (fig. 2) from the junction as a recessional moraine a few kilometers behind the Genoa Moraine. The recessional Elkhorn Moraine was likewise continued eastward, north of the recessional Darien position. All three of these Delavan Sublobe moraines merge on the east with the Valparaiso Morainic System, according to Alden's interpretation.

Although I concur with Alden that the areas in southeastern Walworth and western Kenosha Counties mapped by him as the Genoa and Darien Moraines were covered by the Delavan Sublobe, I have

been unable to identify and trace his end moraines. This entire area, including southwestern Racine County as well, is underlain almost exclusively by stratified drift and is characterized by a complex of kettle lakes, small kames, pitted outwash, ice-contact slopes, remnants of unpitted outwash surfaces, eskers, and other stagnant-ice features. In a few places the crests of northeast-southwest-oriented hills composed of New Berlin till and similar linear hills apparently made entirely of gravel rise some 5 to 15 m above their surroundings. The origin of this interesting area is not wholly clear, but it is currently interpreted as stagnation moraine. The linear features composed of till are believed to be drumlins formed by the Delavan Sublobe flowing to the southwest, but they were subsequently buried beneath supraglacial debris let down during a period of massive stagnation. This topography likely extended some unknown distance to the east and was subsequently overrun by later advances of the Lake Michigan Lobe, so that it is now largely concealed beneath fine-grained till belonging to the Oak Creek Formation.

Horicon Formation

The Horicon Formation (Mickelson and others, 1983) consists of till and associated sediment of the Green Bay Lobe, which covered much of eastern Wisconsin in late Woodfordian time. North of Lake Winnebago the formation is buried beneath red till of the Kewaunee Formation, but to the west and south of the red-till area the Horicon Formation is at the surface throughout a multi-county area that covers much of the southeastern part of the state, including the Wisconsin drumlin field. The deposits of the formation are bounded on the west and south by the Johnstown Moraine and on the east by the Kettle Interlobate Moraine (fig. 2).

Till of the Horicon Formation in southeastern Wisconsin is very similar to that of the New Berlin Formation, from which it is areally separated by deposits of the Kettle Moraine. Typically it is calcareous, yellowish-brown stony sandy loam. The matrix of the till from twenty-four drumlins in Jefferson County in the south-central part of the Green Bay Lobe average 72 percent sand, 17 percent silt, and 11 percent clay (table 1; Allan, 1967). The average gravel content of the same twenty-four samples was 27 percent. Calcium-carbonate equivalent ranged from less than 25 percent to more than 45 percent, averaging 34 percent (Allan, 1967). Till of the Green Bay Lobe (Horicon Formation) can be distinguished from till of the Lake Michigan Lobe (New Berlin Formation) presumably by its fewer Niagaran dolomite pebbles and its proportionally more abundant Ordovician dolomite clasts.

Although subunits of the Horicon Formation are formally recognized on the west side of the Green Bay Lobe in Langlade and Marathon Counties (Mapleview Member) and on the east side of the Green Bay Lobe in Door and Kewaunee Counties (Liberty Grove Member), the formation is undifferentiated in southeastern Wisconsin.

The Horicon Formation is correlated with the New Berlin Formation of the Delavan Sublobe and with the Haeger Till Member of the Wedron Formation in Illinois (Willman and Frye, 1970). Maher (1981) recently presented evidence from Devils Lake to show that retreat of the Green Bay Lobe from the Johnstown Moraine began about 12 500 years B.P. Two wood dates of 12 800 $\pm$ 220 B.P. (WIS-48; Black and Rubin, 1968, p. 104, 111) and 13 120 $\pm$ 130 B.P. (WIS-431; Black, 1976, p. 97) attest to the growth of a spruce forest in the deglaciated area of the Green Bay Lobe somewhat earlier, however.

Thus, the Horicon Formation appears to be at least 13 500 years old; it was probably deposited in southeastern Wisconsin about 14 000-15 000 years ago.

Oak Creek Formation

The coarse-grained New Berlin Formation is overlain by a much finer textured unit named by Schneider (Mickelson and others, 1983) the Oak Creek Formation. The unit takes its name from the City of Oak Creek south of Milwaukee; the type section is a Lake Michigan bluff exposure just north of the Oak Creek Power Plant in the southeastern corner of Milwaukee County.

The Oak Creek Formation includes fine-grained till, lacustrine clay, silt, and sand; and some glaciofluvial sand and gravel. The lacustrine and glaciofluvial sediments seem to be more characteristic of the formation near Lake Michigan than farther west, where the unit is predominantly till. Although its maximum thickness is unknown, bluff exposures alsong the Lake Michigan shoreline in southern Milwaukee County show that the Oak Creek Formation reaches a thickness of at least 35 m in some places.

The Oak Creek Formation occurs as the surface drift in a north-south belt that extends from the Illinois state line northward through Kenosha, Racine, Milwaukee, and eastern Waukesha Counties into Ozaukee and Washington Counties (fig. 2). The eastern boundary of the formation from the state line northward to Racine is the lacustrine plain of glacial Lake Chicago. Between Racine and Milwaukee the formation extends to Lake Michigan, and from Milwaukee northward it is overlapped by the Ozaukee Member of the Kewaunee Formation, which borders the lake in this area and farther north. The western limit of the Oak Creek Formation, at least through Kenosha, Racine, and southeastern Waukesha Counties, is the Valparaiso Moraine, whose distal margin is followed, in general, by the southward-flowing Fox River (fig. 2). North of here, in the Muskego area, the Valparaiso Moraine becomes subdued and is apparently overridden by the Tinley Moraine, which carries the Oak Creek Formation northward for another 50 km or so.

In addition to being the surface drift in the Valparaiso Moraine, the Oak Creek Formation is the principal component of the Tinley Moraine and the several ridges of the Lake Border Morainic System. It also, of course, underlies the ground moraine areas between the end moraines. East of the front of the Tinley Moraine, which Alden (1918) considered to be the outermost member of the Lake Border system, Oak Creek till is generally much thicker than farther west.

Oak Creek till everywhere is strongly calcareous and fine grained, normally containing between 80 and 95 percent silt and clay in the matrix. The texture of the till ranges from silty clay through clay loam and silty clay loam to silt loam. Most commonly, however, the deposit is either a silty clay or silty clay loam till. The average composition is about 12 percent sand, 44 percent silt, and 44 percent clay (table 1). Stones are small and not terribly abundant. Dolomite dominates the pebble assemblage, but the till contains a considerable variety of igneous and metamorphic rock types from the Canadian Shield; basalt is particularly common. The igneous and metamorphic rock assemblage is neither so rich nor so varied as in the New Berlin Formation, however. Perhaps the most diagnostic item is the presence of dark gray shale chips, which presumably were derived from the Lake Michigan basin.

Illite is the dominant clay mineral in the less-than-2-μm fraction of the till; it averages 72 percent of the

clay-mineral composition. Expandable clay minerals and kaolinite plus chlorite are about equal--15 and 13 percent, respectively, according to analyses made by H. D. Glass of the Illinois State Geological Survey.

Oak Creek till normally has a 10YR hue. The color of the oxidized till nearly everywhere is brown (10YR 4/3 to 10YR 5/3), yellowish brown (10YR 5/4 to 10YR 5/6), or dark yellowish brown (10YR 4/4). In a few places it has a 7.5YR hue (7.5YR 4/4, brown). Where the till is unoxidized, it is gray (10YR 5/1).

During the several advances of the Lake Michigan Lobe that were responsible for the Oak Creek till, the ice moved out of the Lake Michigan basin with a more westerly heading than marked the advance of the Delavan Sublobe. Whereas ice of the Delavan Sublobe flowed S. 45° W. across southeastern and south-central Waukesha County, northwestern Racine County, and eastern Walworth County, later movements appear to have been almost due west. This is suggested in Kenosha and Racine Counties by the general north-south orientation of all end moraines that are made of Oak Creek till. Farther north, in Milwaukee, northeastern Waukesha, southeastern Washington, and southern Ozaukee Counties, most of these ridges show a distinctly westward bulge, but the nature of their convexity still suggests ice flow from east to west.

East-west flow of the Lake Michigan Lobe is supported by the orientation of glacial striae. At the Vulcan Materials Company new quarry on the north side of Racine, for example, striations strike about S. 80° W. At the old Horlick quarry on the Root River in Racine, now known as Quarry Lake Park, Alden (1918, p. 203) observed striae trending S. 83 to 93° W. At the old Moody quarry on the north slope of the Menomonee Valley in mid-Milwaukee, striations oriented S. 86° W. were reported by Chamberlin (1877, p. 201).

Valparaiso Moraine

Many of the concepts presented in this paper differ significantly from those presented elsewhere. Some of these differences arise from correlation and nomenclature problems; others are the obvious result of differences in interpretation from other workers and from state to state. Among these differences are the temporal and spatial relations of the Valparaiso Moraine, and it seems desirable to discuss these relations briefly at this point.

In northern Illinois as many as nine named moraines are recognized within the Valparaiso Morainic System (Willman and Frye, 1970, p. 111-113; pl. 1; Willman, 1971, p. 47, 54-55; fig. 16), although some of the moraines that may be contemporaneous are given different names in different areas (Willman, 1971, p. 47). Three of these named moraines are mapped by the Illinois State Geological Survey to the Wisconsin state line (Willman and Frye, 1970, pl. 1; Willman, 1971, fig. 16); the outermost of these is the West Chicago Moraine, and east of the West Chicago are the Cary and Fox Lake Moraines (fig. 2). Behind (east of) the Fox Lake Moraine, the Valparaiso is undifferentiated.

The relationship of the West Chicago Moraine to the Darien Moraine has already been discussed. The continuation of both the Cary and Fox Lake Moraines in Wisconsin is obscure or unrecognizable. Thus only the undifferentiated Valparaiso can be carried northward into Wisconsin with certainty. For this reason and also because the distal edge of the undifferentiated Valparaiso closely coincides with the western limit of the Oak Creek Formation, I recognize only this moraine as

the Valparaiso. Such recognition is in virtual accord with the nomenclature used by Alden (1904; 1918, p. 231; pl. 4). Thus, the distal edge of the Valparaiso in Wisconsin is offset from the distal edge of the Valparaiso system in Illinois by about 32 km at the state line.

My interpretation of the age relationship of the Valparaiso Moraine to the Darien Moraine is not in agreement with Alden's interpretation, however. According to Alden (1918, p. 231), the moraines of the Delavan Sublobe are ". . . the correlatives and direct continuations of the Valparaiso morainic system of southern Kenosha County"--a relationship that Alden reiterated in many statements. "It appears that the main front of the glacier continued at the broad morainal belt bordering the Fox River in Kenosha County and for some distance to the southward during the whole time of the Delavan lobe and of its melting back to eastern Waukesha County" (Alden, 1918, p. 231).

My own investigations indicate that southeastern Wisconsin was covered by the Delavan Sublobe prior to the advance of the Lake Michigan Lobe to the position of the Valparaiso Moraine and that the Valparaiso Moraine is younger than the Darien, rather than correlative with it (Schneider, 1982). These conclusions are based upon (1) the lithologic difference between the till units of the New Berlin and Oak Creek Formations, (2) stratigraphic superposition of the Oak Creek Formation above the New Berlin Formation, and (3) topographic unconformity between the northeast-southwest-oriented landforms formed by the Delavan Sublobe and the north-south orientation of the Valparaiso and younger end moraines, which truncate the obliquely trending features.

Glacial Lake Milwaukee

Wastage of the Delavan Sublobe prior to the deposition of the Oak Creek Formation was apparently accompanied by general withdrawal of the ice from eastern Wisconsin into the Lake Michigan basin. Although there is strong evidence to indicate that the duration of this withdrawal was fairly short, the distance of the withdrawal must have been substantial. The ice front probably receded to a position relatively far north in the Lake Michigan basin--at least sufficiently far to allow the formation of a sizable proglacial lake in the southern part of the basin. The existence of such a lake, here called glacial Lake Milwaukee, is inferred from the fact that when the Lake Michigan Lobe readvanced into southeastern Wisconsin and northeastern Illinois, it laid down a much finer grained deposit (Oak Creek till in Wisconsin, Wadsworth till in Illinois) than that of the underlying New Berlin Formation. Oak Creek till is not only much less stony than New Berlin till, but the matrix contains nearly 50 percent less sand and therefore a total of 50 percent more silt and clay than New Berlin till (table 1). This drastic difference in grain size can best be explained by the erosion and incorporation of fine-grained lake sediment. Scouring of the bedrock floor of the lake and assimilation of shale does not appear to be a wholly adequate explanation, though this certainly must also have occurred, as indicated by the abundance of shale chips in the till. If a proglacial lake was in fact present in the southern part of the Lake Michigan basin between the Valparaiso and Tinley advances, as postulated initially by Bretz (1951, p. 404-406; 1955, p. 107) and subsequently accepted by Hough (1958, p. 164-165; 1963, p. 90), surely a much larger lake existed immediately prior to the advance of the Lake Michigan Lobe to its Valparaiso position.

The extent and level of glacial Lake Milwaukee are unknown. No significant sequence of fine-grained lacustrine sediments between the New Berlin and Oak Creek Formations has yet been discovered to verify the existence of the lake. Nearly all of the area between the Fox River and the Lake Michigan shoreline is underlain by thick post-New Berlin till, particularly east of the distal margin of the Tinley Moraine. Thus, the stratigraphic record of Lake Milwaukee would only be seen in the subsurface, if indeed the level of the lake was sufficiently high to permit transgression very far inland beyond the modern shoreline. This possibility seems very unlikely, inasmuch as the highest known subsequent stages in the southern part of the lake basin (Glenwood I and Glenwood II) attained levels only 18 m higher than the present lake. The stratigraphic record of Lake Milwaukee, therefore, may be present only in the lake basin proper, and most of that record could well have been removed by the deep scouring of the basin that is attested by the abundance of shale in the Oak Creek till. Thus, it is unlikely that the extent of glacial Lake Milwaukee can be accurately determined. It does seem probable, however, that all or much of the southern Lake Michigan basin was occupied by the lake, in order to account for the high percentage of fine-grained materials in the tills that comprise much of the Valparaiso, Tinley, and Lake Border Moraines, which enclose the south end of the lake basin in southeastern Wisconsin, northeastern Illinois, and northwestern Indiana.

Valparaiso and Tinley Advances

Despite its apparent size, Lake Milwaukee appears to have had a relatively short life, because stagnant masses of the Delavan Sublobe had not completely melted before being overrun during the earliest advance of the Lake Michigan Lobe to deposit fine-grained till of the Oak Creek Formation. The ice pushed westward to the longitude of the Fox River, where it terminated at the Valparaiso Moraine on the east side of the Fox River valley in Kenosha, Racine, and southeastern Waukesha Counties (fig. 2). Except for part of southern Kenosha County, however, Oak Creek till in and behind the Valparaiso Moraine is relatively thin. Much of the relief within the moraine reflects an older stagnation topography, presumably related to the Delavan Sublobe, that is veneered with a thin, irregular blanket of Oak Creek till. Kames and similar topographic elements composed of ice-contact stratified drift are responsible for much of the relief of the moraine.

From its Valparaiso terminus the ice either backwasted to the Tinley Moraine or retreated some unknown distance and then readvanced to the Tinley position (fig. 2). Morphologic evidence and limited data on grain-size distribution strongly suggest that retreat and readvance is the more likely possibility. The greater thickness of Oak Creek till east of the Tinley margin has already been mentioned. Palimpsest landforms such as those in the Valparaiso belt are absent east of the Tinley front, and windows of pre-Oak Creek drift are unknown.

The most visible expression of the differential thickness of the Oak Creek Formation east and west of the Tinley front can be seen in the ditribution of ice-block depressions. From the Tinley Moraine eastward to the Lake Michigan shoreline, in a belt 19 to 25 km wide through eastern Kenosha, eastern Racine, and Milwaukee Counties, not a single natural lake marks the landscape. West of the Tinley front, by contrast, the topography is characterized by numerous kettle lakes. About 30 named lakes of moderate to large size occur in a belt that extends from the Illinois state line northward through western Kenosha and western Racine Counties into southeastern Wauke-

sha County; there the lakes terminate in the Muskego area, where the Valparaiso Moraine is subdued and overlapped by the Tinley front. Even a casual examination of a state highway map reveals the approximate boundary between the lake belt to the west and the lake-deficient zone on the east. U.S. Highway 45 roughly parallels the distal edge of the Tinley Moraine; in some places the road and the morainic front are nearly coincident, in other places the highway is about 3 km east of the front. Only a single lake is present east of the highway, and this occurs between the moraine and the highway, where the latter is west of the distal margin.

While it is true that many of these lakes are in the Valparaiso Moraine, many ocur west of the moraine in association with pitted outwash and stagnant-ice features. Thus it appears that their occurrence within the Valparaiso Moraine is related to the kames and other stagnation features that predate the deposition of Oak Creek till. I conclude, therefore, that although the eastern edge of the lake belt is clearly limited by the distribution of thick Oak Creek till in the Tinley Moraine, the western extent is totally unrelated to the western edge of the Oak Creek till sheet.

In summary, then, a large area of stagnant ice of the Delavan Sublobe was overrun from the east by the Lake Michigan Lobe, which was carrying a rich subglacial (and englacial?) load of fine-grained lacustrine sediment derived from glacial Lake Milwaukee. The ice pushed westward to the Valparaiso Moraine, but in doing so it left only a thin blanket of basal Oak Creek till--perhaps because the ice was thin or perhaps because the time of deposition was short, as suggested by Willman (1971, p. 55). In any event, the thickness of the deposit was insufficient in most places to alter significantly the general character of the landscape. The ice front then withdrew an unknown distance to the east, perhaps into the lake basin, and then readvanced to its Tinley Moraine position. During this readvance, however, a much thicker layer of basal Oak Creek till was laid down, sufficiently thick to bury and obscure the stagnant-ice topography beneath. Only that part of the older terrain west of the Tinley front was thus preserved for the geomorphic record.

Retreat and readvance of the Lake Michigan Lobe to the Tinley Moraine--rather than simple recession of the ice front to that position--is supported by preliminary grain-size studies, which indicate that till of the Tinley advance is finer grained than that of the Valparaiso. Samples of Oak Creek till from the Tinley Moraine contain, on the average, about 8 percent less sand and 14 percent more clay than Valparaiso samples. The lower clay content of the Valparaiso facies is partially compensated by a higher silt content, however, so that total silt and clay in the Tinley samples averages only 8 percent greater than in the Valparaiso. Nevertheless, the ratio of silt and clay to sand in till of the Tinley Moraine (12 to 1) is more than twice that in the till of the Valparaiso advance (5.5 to 1). Only three of the 21 samples of presumed Tinley till that were analyzed contained less than 90 percent total silt and clay; two of these samples were collected at the edge of the Tinley Moraine, and the value for the third sample was 89 percent. Only two of 25 samples of Valparaiso till analyzed contained more than 90 percent silt and clay, although many values were in the mid to high 80s.

Although it has been stated (Hough, 1963, p. 90) that Tinley till contains a higher percentage of silt and clay than the Valparaiso due to the incorporation of lake deposits from Early Lake Chicago, an actual difference in grain-size distribution has never been

demonstrated. Deposits in the two moraines have been considered to be indistinguishable, both in northeastern Illinois (Bretz, 1955, p. 81) and northwestern Indiana (Schneider, 1968, p. 275), as well as in Wisconsin. "To the eye and hand, the Valparaiso till is indistinguishable from the Tinley," Bretz stated, but added "it is possible that mechanical analyses may someday show differences between the two . . ."

Whether the finer texture of the Tinley facies described above can be attributed to the assimilation of additional fine-grained lacustrine sediments from the Lake Michigan basin (Early Lake Chicago?) is unknown. The Valparaiso facies may simply be more sandy due to the incorporation of sand from the underlying New Berlin Formation. In either case or in both, however, the difference in grain size argues for a distinct retreat of the ice following its Valparaiso phase and a subsequent readvance to the Tinley position. Hopefully, this difference can be substantiated by additional analytical data.

Lake Border Advances

Evidence for subsequent activity of the Lake Michigan Lobe that resulted in the deposition of Oak Creek till is not so convincing and therefore will be only briefly outlined in this paper. At least five (post-Tinley) moraines of the Lake Border Morainic System can be recognized in southeastern Wisconsin, but all are not present in a given area. The general features of the Lake Border system were well described by Alden (1918, p. 301), who stated that "although, in large part, these ridges are clearly marked and are distinctly separated, so as to give the peculiar north-south trend to the drainage lines, they are cut through at intervals by streams, and in some places contiguous ridges coalesce, so that there may be differences of opinion as to their exact correlation." Correlation of these ridges with the five named moraines of the Lake Border system in Illinois (Park Ridge, Deerfield, Blodgett, Highland Park, and Zion City) is indeed virtually impossible except for the Highland Park Moraine, which can be traced across the state line.

The number of actual readvances of the ice represented by these five recessional moraines is unknown, but it appears probable that there were at least two. The first is represented by the outermost moraine of the system, which is bordered on the west by a distinct ice-marginal trough floored with outwash sand and gravel. In some places the trough is ditched; in other places it is partially used by underfit natural streams, including segments of the Root and Des Plaines Rivers (fig. 2). The second moraine that appears to represent a distinct retreat and readvance is informally called the Petrifying Springs moraine, which in Kenosha, Racine, and southeastern Milwaukee Counties is the innermost ridge of the Lake Border system (fig. 2). Farther north, in the City of Milwaukee, at least one additional (younger) moraine is present. The Petrifying Springs moraine has the greatest relief and is the most distincve moraine of the system. It correlates with the Highland Park Moraine of northern Illinois.

Analyses of five Oak Creek samples from the outermost Lake Border moraine suggest that the texture of the matrix of the till is similar to the Tinley facies. Analyses of a larger number of samples (17) from the Petrifying Springs moraine south of Milwaukee suggest that the till in this ridge is somewhat coarser grained than that of the Tinley and Lake Border phases, but not so coarse as that of the Valparaiso. The statistical validity of these data has not been tested, and thus it is recognized that these statements of possible differences may be unwarranted.

For a more thorough discussion of the texture and clay mineralogy of the Oak Creek till and its Illinois equivalent (Wadsworth Till Member of the Wedron Formation), the reader is referred to a companion paper in this volume by Hansel (1983).

Kewaunee Formation
Ozaukee Member

Stratigraphically above the Oak Creek Formation is the Ozaukee Member of the Kewaunee Formation (Mickelson and others, 1983). The Ozaukee is one of the eastern Wisconsin red clay tills that were formerly mapped as a single unit called the "Valders till" (Thwaites, 1943; Thwaites and Bertrand, 1957); the Valders till has recently been subdivided into many stratigraphic units based on lithologic characteristics and stratigraphic relations (Evenson, 1973; Mickelson and Evenson, 1975; Acomb and others, 1982; McCartney and Mickelson, 1982; Mickelson and others, 1983).

The Ozaukee is the southernmost and oldest of the late Wisconsinan red clayey tills of the Lake Michigan Lobe, having been deposited about 12 500 to 13 000 years ago. Because of lithologic similarity and because it overlies the Oak Creek Formation, the Ozaukee Member probably correlates with the Shorewood Till Member of the Wedron Formation, which was named and mapped from core samples under Lake Michigan by Lineback and others (1974). The correlation of lake-bottom tills with onshore tills remains somewhat uncertain, despite the acquisition of considerable data on deposits from both environments (Lineback and others, 1974; Acomb, 1978; Acomb and others, 1982; Hansel, 1983).

The Ozaukee Member occurs at the top of the Lake Michigan bluff in a belt that extends from the City of Milwaukee northward through Milwaukee and Ozaukee Counties to about the Sheboygan County line (fig. 2). It extends inland from the lakeshore to Alden's (1918) red-till boundary, which roughly parallels the ice-marginal Milwaukee River. Distinctive end-moraine topography marks the western limit of the unit in some places.

Till of the Ozaukee Member is easily distinguished from all other tills in southeastern Wisconsin by the combination of its fine-grained texture and its reddish color. The till is typically silty clay or silty clay loam; grain-size analyses of the till matrix indicate average composition of 13 percent sand, 47 percent silt, and 40 percent clay (table 1; Acomb and others, 1982). In terms of its mechanical composition, therefore, Ozaukee till is similar to Oak Creek till (table 1), particularly to the Valparaiso facies of Oak Creek till. Its reddish brown (5YR 4/3) to light reddish brown (5YR 6/3) color, however, serves to distinguish it from the yellowish-brown to brown Oak Creek till.

X-ray analyses (Acomb and others, 1982, p. 292-293) indicate that approximately 60 percent of the clay-mineral fraction is illite; the expandable clay minerals and kaolinite plus chlorite both average about 20 percent (table 1). The high illite content is believed to be an important parameter in distinguishing the Ozaukee Member from other members of the Kewaunee Formation farther north (Mickelson and others, 1983), but based on a limited number of analyses of my own samples by H. D. Glass 60 percent illite appears to be somewhat high for average Ozaukee till.

Peoria Loess

In addition to the five rock-stratigraphic units of the Woodfordian Substage described above, deposits of Peoria loess are also present in southeastern Wisconsin (fig. 1). Behind the Woodfordian ice boundary, the loess is relatively thin and difficult to identify. Where present, it is typically between 0.3 and 0.6 m thick, and thus it does not normally extend below the bottom of the solum.

Beyond the Woodfordian moraines, as in southwestern Walworth County and farther west where Peoria loess overlies older tills of the Altonian Substage, the loess blanket is considerably thicker. On many upland surfaces it is typically 1.2 to 1.5 m thick, and in some places it is undoubtedly thicker. Its maximum thickness, which is probably on the east side of the Rock River valley train, has not been determined.

The Peoria loess is not recognized as a formal rock-stratigraphic unit in Wisconsin at this time. Although the bulk of the deposit is considered to be Woodfordian in age, some is no doubt younger, as in Illinois (Willman and Frye, p. 61, fig. 8; p. 65-66).

Lacustrine Deposits

Whereas the Ozaukee Member overlies the Oak Creek Formation along the Lake Michigan shoreline north of Milwaukee, south of Milwaukee the Oak Creek Formation is overlain by various lacustrine and some eolian deposits that range in age from very late Woodfordian to Holocene (fig. 1). The lacustrine sediments include deeper water silt and clay--consisting of both massive and rhythmic deposits, and shallow water or beach sand and gravel. Some of these sediments were deposited in and around glacial Lake Chicago about 12 500 to 10 000 years ago. Younger lake sediments associated with the Algonquin, Nipissing, and Algoma stages are also present, as well as modern shoreline deposits. (Schneider, Edil, and Haas, 1977a,b; Schneider, Sander, and Larsen, 1979).

ACKNOWLEDGMENTS

Many Pleistocene friends have contributed to my understanding of the glacial stratigraphy and history of southeastern Wisconsin. Among the friends who have accompanied me in the field and have provided valuable observations and ideas are Ned Bleuer, Leon Follmer, David Hadley, Ardith Hansel, David Mickelson, and Paul Stoelting. I am particularly grateful to Herbert D. Glass of the Illinois State Geological Survey for providing clay-mineral analyses of my till samples. The Illinois Survey also made many grain-size analyses. Financial assistance during the past 12 years, mainly in the form of field expenses, has been provided by the Wisconsin Alumni Research Foundation, the National Oceanic and Atmospheric Administration's Office of Coastal Zone Management, the Committee on Research and Creative Activity of the University of Wisconsin-Parkside, and the Wisconsin Geological and Natural History Survey. Student field assistants have been Clifford Brandon, Rubin Guzman, John Hay, and Gordon Morris. The manuscript was reviewed by Robert Baker, Lee Clayton, and David Mickelson, all of whom made many helpful suggestions.

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