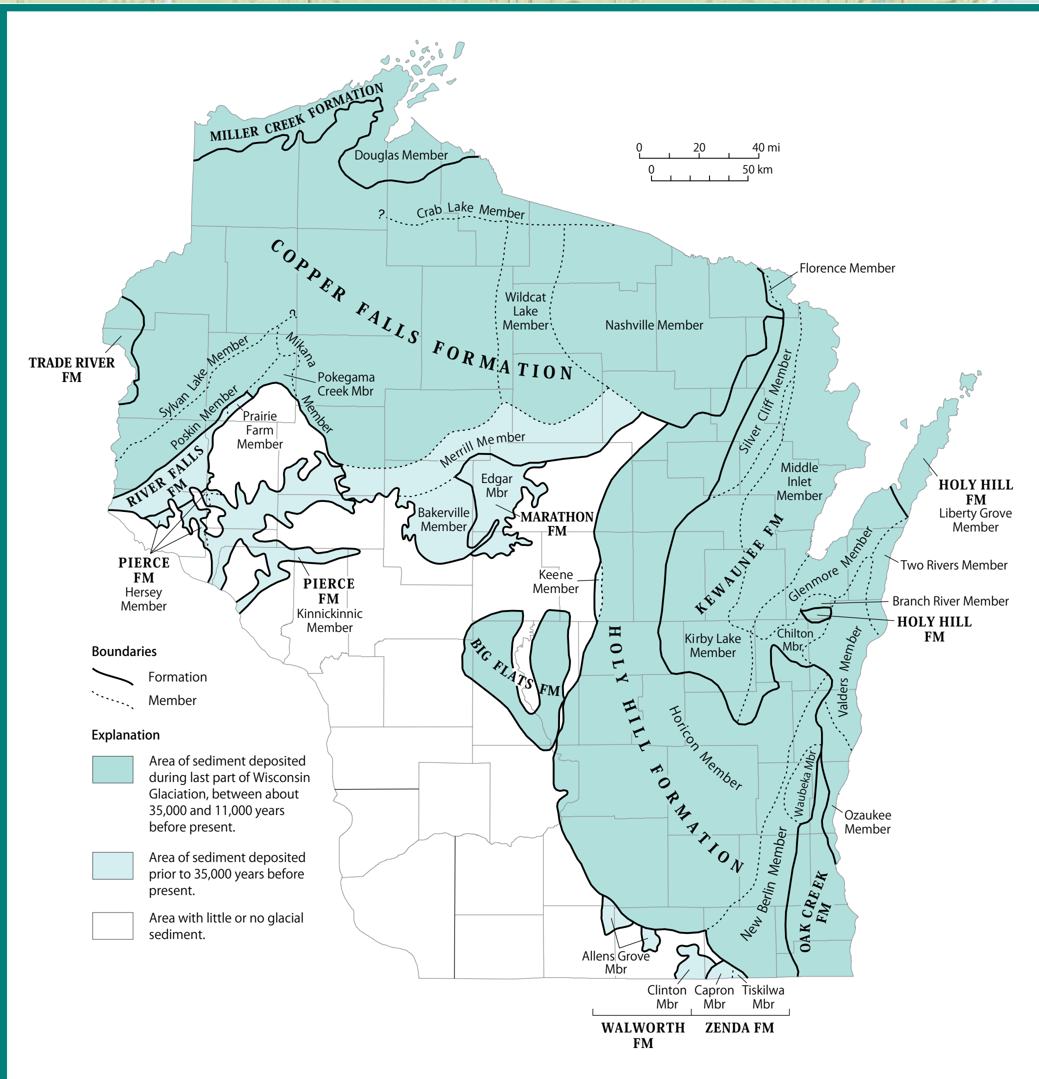
Lexicon of Pleistocene Stratigraphic Units of Wisconsin



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Wisconsin Geological and Natural History Survey
Technical Report 1 | 2011

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Organization of the Lexicon

In this book, formations and their members are arranged by age, from oldest to youngest. For a quick lookup by formation name, refer to the following:

Formations by name

- Big Flats Fm. 111
- Copper Falls Fm. 58
- Hayton Fm.. 88
- Holy Hill Fm. 96
- Kewaunee Fm. 123
- Kieler Fm. 157
- Marathon Fm. 29
- Miller Creek Fm. 145
- Oak Creek Fm. 115
- Pierce Fm. 18
- River Falls Fm. 37
- Rountree Fm. 152
- Trade River Fm.. 118
- Walworth Fm. 43
- Zenda Fm. 51

A note about outcrop descriptions

If you attempt to locate geologic type sections or other sediment exposures mentioned in this book, recognize that many have changed since the unit was named. Outcrop descriptions have NOT been updated in this version of the Lexicon; many outcrops are no longer present or have changed markedly. See the "Previous Usage" section for each unit to determine when it was formally defined and described.

Introduction: Classification principles and summary of non-loess lithostratigraphic units

David M. Mickelson, Lee Clayton, Robert W. Baker, William N. Mode, Allan F. Schneider, and Kent M. Syverson

Background

The Pleistocene deposits of Wisconsin consist of a complex sequence of deposits differing in origin, age, lithology, thickness, and extent (Syverson and Colgan, 2004, in press). This report presents additions and revisions to the original lithostratigraphic classification of deposits published in 1984 and the supplement published in 1988. We have decided not to significantly modify definitions of units defined in Mickelson and others (1984) and Attig and others (1988). Many of the Pleistocene deposits in Wisconsin were classified in these papers. We here publish or republish definitions of 15 formations that include 48 members. Some till deposits and most fluvial, lacustrine, and alluvial deposits remain to be defined, but the list of defined units has expanded substantially since the 1984 publication.

The framework for the classification of Pleistocene units is based on till stratigraphy. However, most members and formations named in this paper include not only till, but associated fluvial, eolian, and lacustrine deposits. Some formations and members are completely non-glacial.

We also provide guidelines for the formal definition and naming of lithostratigraphic units in Wisconsin. The classification scheme follows that of the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 2005). Each unit definition includes a discussion of the following: source of name, identification of the person naming the unit, type-section location and description, reference-section location and description, description of unit, nature of contacts, differentiation from other units, regional extent and thickness, origin, age and correlation, and previous usage. Although some type sections and reference sections have changed dramatically since the initial descriptions and some sections may not exist any longer, we have not named new ones. During the past several years, a number of Pleistocene lithostratigraphic units have been named formally in published reports and have been included here. A number of Pleistocene lithostratigraphic units have also been named informally in published reports and in theses. Some of these units are included here; others have not been included because they require more detailed study before they are formally defined. In addition, a number of formations and member names have been redefined or abandoned (see appendix). Here we bring together all formal Pleistocene lithostratigraphy information in a single publication for the convenience of the reader.

Although chronostratigraphic units, biostratigraphic units, and stratigraphic units based on interpreted geologic events are needed by Pleistocene geologists, we here concentrate on lithostratigraphic units because they form the foundation of any stratigraphic system. We hope that formal recognition of these other types of units will come later. The lithostratigraphic names introduced in 1984 and 1988 have been adopted by many consultants and others studying various aspects of the geology of Wisconsin. The standards set in this publication are those that will be followed in future publications of the Wisconsin Geological and Natural History Survey, and we hope that the use of lithostratigraphic names by consultants and agency personnel continues to grow.

In addition to time-stratigraphic considerations, which are mentioned only briefly in this paper, we have not done justice to the properties of all units. One purpose for developing a lithostratigraphic classification of Pleistocene deposits is to impose order on very complex deposits so properties of deposits in different places can be understood. A database called TILLPRO, which summarizes sample properties, is now available from the

Map Sales office of the Wisconsin Geological and Natural History Survey (WGNHS, 2004). It is primarily a summary of grain-size analyses performed on unlithified sediment samples collected from Wisconsin and analyzed in the Quaternary Laboratory at the Department of Geology and Geophysics, University of Wisconsin-Madison. Information is organized in a set of related tables in Microsoft® Access® format. Forms and queries allow a user to view, sort, select, and evaluate the information; users can perform searches on the records and customize the format for their particular use or interpretation. Records can be selected and exported to other software programs for further analysis. The TILLPRO database should be useful to planners, environmental consultants and regulators, and earth-science researchers. Note that the TILLPRO database includes samples other than till. The properties such as grain size provided in the unit definitions in this paper have not been updated for units defined in 1984 and 1988, because more up-to-date numbers can be obtained in the future from the TILLPRO database, which is periodically updated.

Explanation of ages presented in this report

In this report, authors have provided representative ages for lithostratigraphic units. Most of these ages are for wood and other organic materials, and are reported as originally published in uncalibrated radiocarbon years before present (^{14}C yr B.P.). In addition, radiocarbon ages younger than 50,000 ^{14}C yr B.P. have been converted to calendar years (cal. yr B.P.) using CalPal-2007online (Danzeglocke and others, 2010). Estimated ages originally reported in radiocarbon years (but not based on a specific date) also have been converted to calendar years using CalPal-2007online. These "calibrated" ages will be different than those calibrated using other programs such as CALIB v. 5.0 (Stuiver and Reimer, 1993). Thus, calibrated ages should be viewed as an approximation of the age in calendar years. In a few cases, authors have used remanent paleomagnetic signatures (for example, Baker and others, 1983, see Pierce Formation description) and OSL (optically stimulated luminescence) (Rawling and others, 2008, for example) to determine sediment ages. These dates have been reported in calendar years (cal. yr B.P.).

Acknowledgments

Many people have contributed to the compilation of this volume. Eric Carson used CalPal-2007online to convert radiocarbon ages into calendar years. Gene Leisz produced several figures in the introduction. Linda Deith collected topographic map figures, edited the final manuscript, and handled publication design. William N. Mode and Randall J. Schaetzl served as peer reviewers for newly defined lithostratigraphic units. We thank all of these people for their assistance.

Principles of lithostratigraphic classification in Wisconsin

The discussion below outlines the philosophy behind the classification system. It remains very similar to that described in 1984, but there have been minor changes. The definitions are generally in accordance with the requirements given in the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 2005). In particular, we have accepted the formation as the basic mapping unit. Formations have been defined so as to be recognizable in the field. Although not all potential formations in the state are defined in this report, it is our intention that all materials of Quaternary age, with the possible exception of man-made deposits, eventually will be included in some formation.

Formations are subdivided into members where clear-cut stratigraphic subdivisions are present within a formation. Members are formally defined with type sections, but need not be recognizable everywhere in the field. One of our ultimate goals is to interpret Quaternary history. Where it is clear, for example, that a certain till unit represents an ice advance of some significance, the unit should be distinguished from members above and below even though they may be indistinguishable in many outcrops in the field.

All units defined should be traceable laterally even though gradational changes occur away from the type section. In some units, in fact, the basis for recognition at the type section may not be usable in other areas. This is acceptable as long as the integrity of the unit remains. If at some point, however, it becomes indistinguishable from the unit above or below, an arbitrary vertical cutoff should be used.

In addition to the preceding points, our definitions are based on the following considerations:

1. Caution is needed in using names from adjacent regions. Admittedly, an overabundance of names may cause confusion because they are hard to remember, but the potential for confusion resulting from incorrect correlations is probably much greater. Therefore, Illinois (Lineback, 1979) and Minnesota (Patterson and Johnson, 2004) lithostratigraphic names are used only if they seem well established, if their relationship to units in Wisconsin seems clear, and if the units have only a limited distribution in Wisconsin. Later, when the stratigraphy becomes more firmly established, some of these new names may be abandoned in favor of previously defined equivalents.

2. In the glaciated area, the framework is built around sequences of till units (figs. 1, 2). These units are frequently the most distinctive, most laterally extensive, and least variable. In the last decade, the use of the descriptive term diamicton has been commonly used to include all poorly sorted sediments. Most grain-size data descriptions in this paper are for diamicton interpreted to be till. However, some of the diamicton associated with a till unit may be mudflow, landslide or other poorly sorted sediment that was not deposited directly by glacial ice. In unglaciated southwestern Wisconsin, where most Pleistocene and Holocene deposits are in valley bottoms physically separated by loess-covered uplands, till is absent and the stratigraphic framework is based on regionally extensive fluvial, eolian, and lacustrine units.

3. To reduce map complexity, formations should not intertongue at the field-mapping scale. However, lithologies do intertongue with each other, and an arbitrary decision is made on the placement of lateral boundaries between formations. Tongues of different grain size might be placed into one or the other formation on the basis of similarity in some characteristic other than grain size (color, for example), or they can be placed on the basis of a vertical-cutoff rule (American Commission on Stratigraphic Nomenclature, 1970, Article 5e), or on some other basis, as the individual situation requires. A vertical cutoff extending downward from the end of a tongue generally results in a less complex geologic map than one extending upward, and we suggest this should be standard procedure unless a good reason can be found for doing otherwise. For example, in figure 1 members 2B and 2C become indistinguishable at distance 1, and a vertical cutoff is drawn downward. This procedure prevents having a contact between identical units on a surface map as would happen if the contact were drawn upward, and eliminates the implication that they are distinguishable to the right as would be the case if a horizontal contact were drawn.

4. Because the stratigraphy is based primarily on till units in the glaciated part of the state, confusion may occur in the classification of other materials such as proglacial fluvial sediment and lacustrine sediment. There are many different ways these materials can be handled. The system we have adopted for units defined here is best illustrated by a discussion of figure 1.

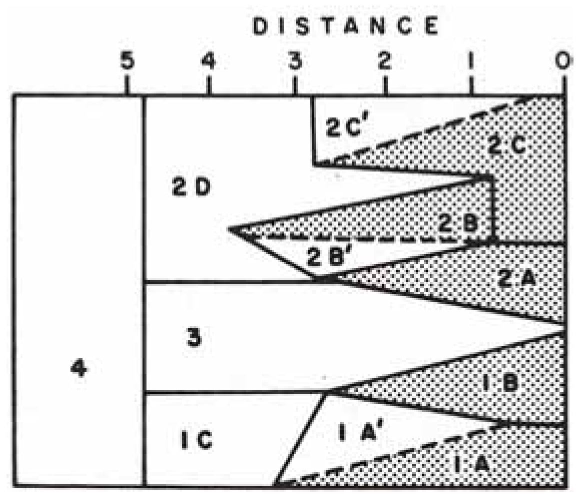

Figure 1. Hypothetical depth–distance stratigraphic diagram to illustrate the subdivision of units into formations and members (from Mickelson and others, 1984). Distances are arbitrary. Units with pattern are till. Others are fluvial, eolian, or lacustrine deposits. For purposes of discussion they are assumed to be gravel. See text for discussion.

Introduction: Classification principles and summary of non-loess lithostratigraphic units

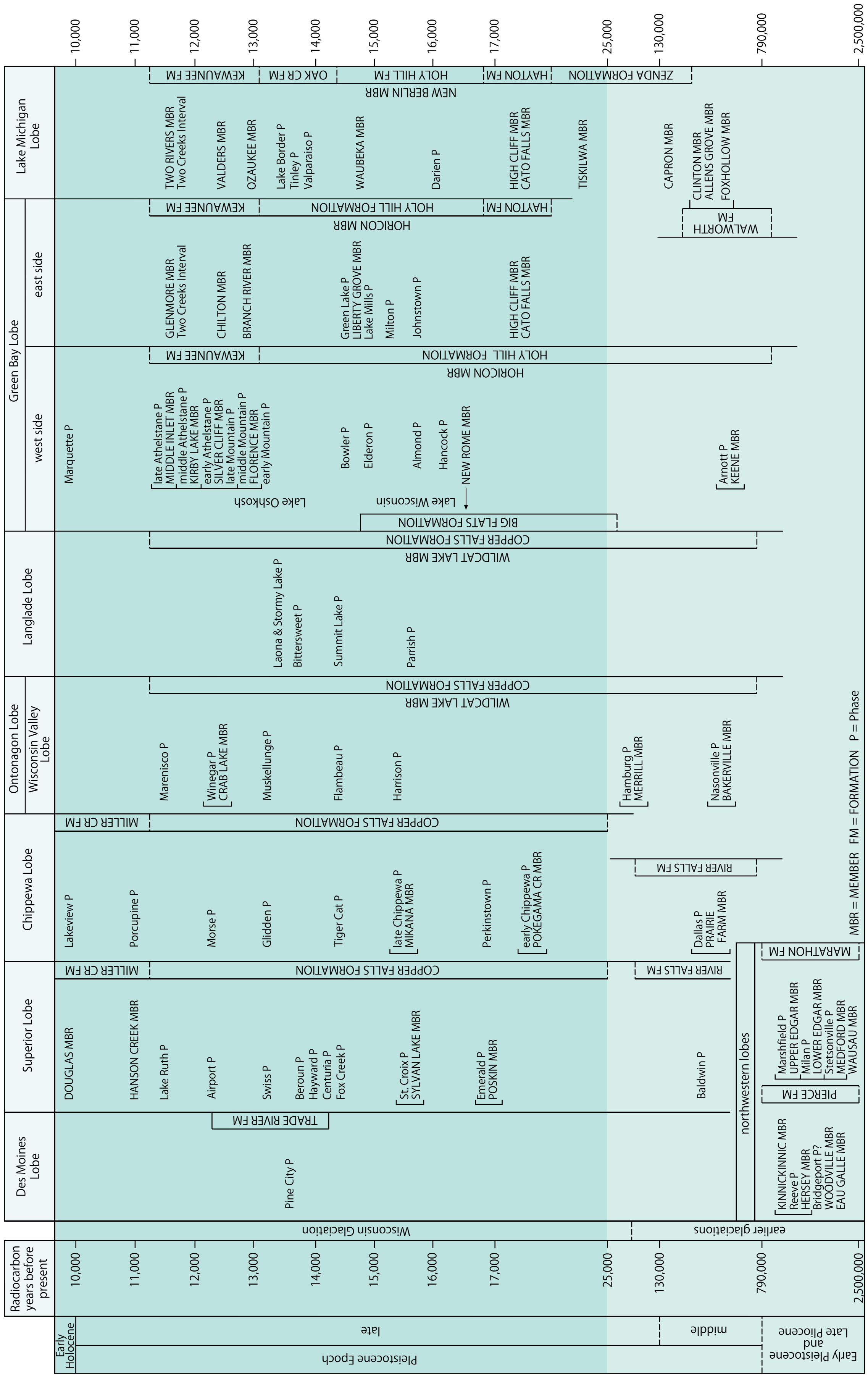

Figure 2. Organization of Pleistocene lithostratigraphic units of Wisconsin by glacial lobe (west to east) and approximate time of deposition. Modified from Clayton and others (2006).

Figure 1 shows till units and other units such as lacustrine or fluvial sediment. We will assume they are all gravel for the sake of discussion. Four formations are shown. Assume till units of formations 1 and 2 are distinguishable by clearly recognizable field criteria (presence or absence of some rock type, major textural difference, or major color difference). Starting at the base of the section, assume till units 1A and 1B are distinguishable from each other throughout the area of the cross section. These are defined as separate members of formation 1. The gravel unit 1A′ clearly is associated lithologically with the till of 1A. It is part of that member and is considered informally as a facies of the member (as are other associated deposits such as basal till, supraglacial diamicton, etc.). The contact between this gravel and gravel to the left is drawn as far left as the association between the gravel 1A′ and till 1A can be documented. If this contact cannot be found, an arbitrary cutoff is drawn as shown. To the left of 1A′, the gravel is clearly associated with formation 1, but not demonstrably associated with either member. This gravel is considered a third member of formation 1 (1C).

The system used here does not allow the intertonguing of formations, but does allow intertonguing of members. In figure 1, if the gravel above member 1B and below member 2A were clearly associated with either formation, the contact would be drawn accordingly. If the gravel between formations cannot be related to either formation, it could be defined as a new formation (3), which is bounded above and below by formations 2 and 1. Its left boundary is an arbitrary vertical cutoff at the point where units 2D and 1C become indistinguishable from formation 3. The gravel between till units 2A and 2B is a parallel case to that between 1A and 1B, and the same arguments hold for defining the units. The gravel between units 2B and 2C is not clearly associated with either member but is clearly associated with formation 2, so it is therefore made part of member 2D. The gravel above the till of unit 2C clearly is associated with unit 2C and is placed in that unit. Moving to the left, as soon as the association with 2C is lost, a contact is drawn and the gravel is considered to be unit 2D.

This may or may not coincide with the outer limit of a till sheet. Formation 4 (actually several formations if different materials are involved) consists of all of the material not clearly associated with a formation based on till lithology. Examples of formations with relationships similar to formation 4 are defined in this paper, and these include the Rountree and Kieler Formations.

(5) "Till" should not be used in the name of a lithostratigraphic unit, even though it seems to be permitted by Article 1e of the Code (American Commission on Stratigraphic Nomenclature, 1970), because lithostratigraphic units are descriptively rather than genetically defined (Articles 4a and 4c), and "till" is a genetic, not a descriptive, term. That is, "Douglas Clay," rather than "Douglas Till" or "Douglas Till Member," would be the correct name for a lithostratigraphic unit if the till is composed largely of clay. However, it seems more appropriate to use a lithostratigraphic name rather than a lithologic name for a lithostratigraphic unit (Douglas Member is most appropriate). Based on present usage, however, it would be acceptable to informally use the term "Douglas till" as shorthand for "till of the Douglas Member."

Summary of lithostratigraphic units defined in this paper

This section gives an overview of the units covered in the lexicon. Unit names are printed in bold.

Units deposited before and during the early part of the Wisconsin Glaciation

The **Rountree Formation** consists of clay and silt, generally very weathered, with some chert. It is composed primarily of weathering products from carbonate rock and loess. It is found primarily on carbonate rock, and is thickest and most continuous on flat to gently sloping uplands.

Older till and associated sediment deposited before the Wisconsin Glaciation (fig. 2) are present in the western, central, and southern parts of the state. No comprehensive study of all of these units has been undertaken, and units are defined locally. The distribution of surficial units is shown in figure 3, and surficial and subsurface units are itemized by county in figure 4. Other units without described type sections in Wisconsin will continue to be used informally. These units, not described in this report, include the Argyle, Janesville, Ogle, and Winslow tills of Bleuer (1971). Deposits in southern Wisconsin also were studied by Miller (2000), but his suggested units are not included in the definitions here because the units are discontinuous and difficult to correlate between sites.

In Pierce and adjoining counties, several units deposited before the Wisconsin Glaciation have been recognized. The **Pierce Formation** contains four members. The **Eau Galle Member** contains non-calcareous clayey lake sediment. This lies below the **Woodville Member**, which consists of gray calcareous till. The **Hersey Member** contains gray calcareous till and associated sand and gravel derived from a northwesterly source. The till of the Hersey Member is the "old gray" till of Chamberlin (1910) and Leverett (1932) and the basal till of Black (1959) and Black and Reed (1965). This is locally overlain by the **Kinnickinnic Member**, a thinly laminated sequence of silts and clays deposited in ice-marginal lakes. Based on soil development and paleomagnetic data, the Pierce Formation appears to be pre-Illinoian age (Baker and others, 1983).

Although "drifts" were mapped in central Wisconsin by Weidman (1907), Hole (1943), and others, the units were not defined in any formal sense, and this terminology has dropped from common usage. Perhaps correlative with deposits of the Pierce Formation, are deposits of the **Marathon Formation** in central Wisconsin (fig. 3). The oldest member of the Marathon Formation is the **Wausau Member**. This till was informally named the Wausau till by LaBerge and Myers (1971) and described in detail by Stewart (1973) and Mode (1976). It is generally thin, weathered, and discontinuous, and likely was mapped as undifferentiated Marathon Formation by Attig and Muldoon (1989). The till of the overlying **Medford Member** is dark gray and calcareous. The till of the **Edgar Member** is calcareous, brown and siltier than the till of the Wausau Member (Mode, 1976). Medford Member till contains more expandable clay than the Edgar Member till. The Marathon Formation is typified by a generally water-eroded landscape with thin till or sand and gravel over pre-Pleistocene rock. No glacial constructional topography has been recognized in the area of Marathon Formation deposits.

In northern Pierce and St. Croix Counties (fig. 3), the Pierce Formation is overlain by the **River Falls Formation**. This formation contains fluvial sand and gravel and reddish-brown sandy till typical of sediment derived from the Lake Superior basin. The till of the River Falls Formation is the "old red till" of Chamberlin (1910) and Leverett (1932), the superglacial drift of Black (1959) and Black and Reed (1965), and the Baldwin till of Baker and Simpson (1981) and Baker and others (1982). The River Falls Formation appears have been deposited either during the Illinoian Glaciation or the early part of the Wisconsin Glaciation based on the degree of erosion and weathering (Baker and others, 1983; Syverson, 2007). The **Prairie Farm Member** is at the surface in parts of Barron and Dunn Counties (Johnson, M.D., 1986). Its till is richer in Barron Quartzite fragments than other till in the River Falls Formation.

Farther east, in central Wisconsin, two members of the **Copper Falls Formation** overlie the Marathon Formation and probably were deposited before the last part of the Wisconsin Glaciation (Attig and Muldoon, 1989). The **Bakerville Member** and overlying **Merrill Member** both contain brown to reddish-brown, sandy till. Constructional glacial topography has been described in areas underlain by the Merrill Member till (Syverson, 2007), but not surfaces underlain by the Bakerville Member till.

The **Keene Member** of the **Holy Hill Formation** was deposited along the western side of the Green Bay Lobe (fig. 3). The Keene Member contains brown to reddish-brown, sandy till. Based on its degree of weathering and erosion, this unit was deposited before the last part of the Wisconsin Glaciation and may predate the Wisconsin Glaciation (Clayton, 1986b).

Introduction: Classification principles and summary of non-loess lithostratigraphic units

Figure 3. Distribution of surficial Pleistocene lithostratigraphic units in Wisconsin. Formations are separated by solid lines; members are separated by dashed lines. (Kieler Formation loess units are not shown on this diagram as it drapes much of the landscape in Wisconsin.) Modified from Clayton and others (2006) and Syverson and Colgan (in press).

Figure 4. Wisconsin Pleistocene lithostratigraphic units listed by county. Only till, lake sediment, and loess units are listed. Note: Although Kieler Formation loess drapes the landscape in many parts of Wisconsin, the Kieler Formation is only listed for counties where it is a mappable unit (typically near the Mississippi River). Units are listed from youngest (top) to oldest (bottom).

Adams
Kewaunee Fm.
(lake sediment)
Big Flats Fm.
Holy Hill Fm.,
Horicon Mbr.

Ashland
Miller Creek Fm.
Copper Falls Fm.

Barron
Copper Falls Fm.
River Falls Fm.
Pierce Fm.

Bayfield
Miller Creek Fm.
Copper Falls Fm.

Brown
Kewaunee Fm.
Holy Hill Fm.

Buffalo
Kieler Fm.
Rountree Fm.
Pierce Fm.

Burnett
Trade River Fm.
Copper Falls Fm.
River Falls Fm.

Calumet
Kewaunee Fm.
Holy Hill Fm.
Hayton Fm.

Chippewa
Copper Falls Fm.
River Falls Fm.
Pierce Fm.,
Kinnickinnic Mbr.

Clark
Copper Falls Fm.
Marathon Fm.

Columbia
Holy Hill Fm.

Crawford
Kieler Fm.
Rountree Fm.

Dane
Kieler Fm.
Rountree Fm.
Holy Hill Fm.
Walworth Fm.

Dodge
Holy Hill Fm.
Hayton Fm.

Door
Kewaunee Fm.
Holy Hill Fm., Liberty
Grove Mbr.

Douglas
Miller Creek Fm.
Copper Falls Fm.

Dunn
River Falls Fm.
Pierce Fm.

Eau Claire
Copper Falls Fm.
River Falls Fm.
Pierce Fm.,
Kinnickinnic Mbr.

Florence
Kewaunee Fm.
Copper Falls Fm.,
Nashville Mbr.

Fond du Lac
Kewaunee Fm.
Holy Hill Fm.
Hayton Fm.

Forest
Copper Falls Fm.
Holy Hill Fm.
Marathon Fm.

Grant
Kieler Fm.
Rountree Fm.

Green
Kieler Fm.
Rountree Fm.
Walworth Fm.

Green Lake
Holy Hill Fm.

Iowa
Kieler Fm.
Rountree Fm.

Iron
Miller Creek Fm.
Copper Falls Fm.

Jackson
Big Flats Fm.

Jefferson
Holy Hill Fm.

Juneau
Big Flats Fm.

Kenosha
Oak Creek Fm.
Holy Hill Fm.

Kewaunee
Kewaunee Fm.

La Crosse
Kieler Fm.
Rountree Fm.

Lafayette
Kieler Fm.
Rountree Fm.

Langlade
Copper Falls Fm.
Holy Hill Fm.,
Horicon Mbr.
Marathon Fm.,
Wausau Mbr.

Lincoln
Copper Falls Fm.
Marathon Fm.

Manitowoc
Kewaunee Fm.
Holy Hill Fm.
Hayton Fm.

Marathon
Copper Falls Fm.,
Merrill Mbr.
Bakerville Mbr.
Holy Hill Fm.
Marathon Fm.

Marinette
Kewaunee Fm.
Copper Falls Fm.
Holy Hill Fm.

Marquette
Holy Hill Fm.

Menominee
Kewaunee Fm.
Holy Hill Fm.

Milwaukee
Kewaunee Fm.,
Ozaukee Mbr.
Oak Creek Fm.
Holy Hill Fm.

Monroe
Kieler Fm.
Rountree Fm.

Oconto
Kewaunee Fm.
Copper Falls Fm.,
Nashville Mbr.
Holy Hill Fm.

Oneida
Copper Falls Fm.
Marathon Fm.

Outagamie
Kewaunee Fm.
Hayton Fm.

Ozaukee
Kewaunee Fm.,
Ozaukee Mbr.
Oak Creek Fm.
Holy Hill Fm.

Pepin
Kieler Fm.
Rountree Fm.
Pierce Fm.

Pierce
River Falls Fm.
Pierce Fm.

Polk
Trade River Fm.
Copper Falls Fm.
River Falls Fm.
Pierce Fm.

Portage
Big Flats Fm.
Holy Hill Fm.,
Horicon Mbr.
Keene Mbr.

Price
Copper Falls Fm.

Racine
Oak Creek Fm.
Holy Hill Fm.

Richland
Kieler Fm.
Rountree Fm.

Rock
Holy Hill Fm.
Walworth Fm.

Rusk
Copper Falls Fm.
River Falls Fm.

St. Croix
Copper Falls Fm.
River Falls Fm.
Pierce Fm.

Sauk
Big Flats Fm.
Holy Hill Fm.
Rountree Fm.

Sawyer
Copper Falls Fm.

Shawano
Kewaunee Fm.
Holy Hill Fm.

Sheboygan
Kewaunee Fm.
Oak Creek Fm.
Holy Hill Fm.
Hayton Fm.

Taylor
Copper Falls Fm.
Marathon Fm.

Trempealeau
Kieler Fm.
Rountree Fm.
Pierce Fm.,
Kinnickinnic Mbr.

Vernon
Kieler Fm.
Rountree Fm.

Vilas
Copper Falls Fm.
Marathon Fm.

Walworth
Oak Creek Fm.
Holy Hill Fm.
Zenda Fm.
Walworth Fm.,
Clinton Mbr.

Washburn
Copper Falls Fm.

Washington
Oak Creek Fm.
Holy Hill Fm.
Zenda Fm.,
Tiskilwa Mbr.

Waukesha
Oak Creek Fm.
Holy Hill Fm.

Waupaca
Kewaunee Fm.
Holy Hill Fm.

Waushara
Kewaunee Fm.
Holy Hill Fm.

Winnebago
Kewaunee Fm.
Holy Hill Fm.

Wood
Big Flats Fm.
Copper Falls Fm.,
Bakerville Mbr.
Marathon Fm.,
Edgar Mbr.

The **Walworth Formation** is present in south-central Wisconsin (fig. 3). It is distinguished by sandy, generally gray-to-brown tills and associated deposits. The Walworth Formation is subdivided into three members, stratigraphically from oldest to youngest, the Foxhollow, Allens Grove, and Clinton Members (Fricke, 1976). The till of the **Foxhollow Member** has been described only in drill holes in southern Rock County and southern and western Walworth County. The relationship with units in Illinois is not clear (Kempton and others, 1985). Stratigraphically above the Foxhollow Member is the **Allens Grove Member**. The till of this member appears to be correlative with the Argyle Member of the Winnebago Formation of Illinois (Fricke, 1976; Fricke and Johnson, 1983; Canfield and Mickelson, 1985). In eastern Rock and western Walworth Counties, the till is overlain by the **Clinton Member** as defined by Fricke (1976) near Clinton in eastern Rock County. This unit appears to extend only a short distance into Illinois (Canfield and Mickelson, 1985).

The **Zenda Formation** is present in south-central Wisconsin and includes two members, the older of which (the Capron Member) likely predates the Wisconsin Glaciation and the younger of which (the Tiskilwa Member) was deposited during the last part of the Wisconsin Glaciation (Willman and Frye, 1970; Curry and others, 1997). Both contain light reddish-brown, silty till, distinctly different from tills of the Walworth Formation below and the Holy Hill Formation above. We accept the definitions of the Capron and Tiskilwa Till Members of Willman and Frye (1970), but in Wisconsin drop the word "till" from the formal name. The **Capron Member** is present at the surface in a small area of southwestern Walworth County (fig. 3) (Fricke, 1976; Johnson, 1976; Ham and Attig, 2004), and its extent in the subsurface is unknown. This unit is correlative with the Capron Member of the Winnebago Formation in Illinois (Krumm and Berg, 1985). Recent OSL ages suggest the Capron Member was deposited during the Illinoian Glaciation (R. Berg, Illinois State Geological Survey, oral communication, 2009).

Units deposited during the last part of the Wisconsin Glaciation

Units deposited during the last part of the Wisconsin Glaciation are less eroded and underlie surfaces with relatively unmodified landforms. For these reasons, more information is known about the glacial lobes (fig. 5) and ice phases (fig. 6) that deposited the till units. Although the glacial lobe that deposited a given till is not, in itself, considered to be part of the definition of a lithostratigraphic unit, several significant lithostratigraphic breaks occur along former lobe boundaries. In other places, however, there appears to be little difference between deposits of adjacent lobes, and in those areas a single lithostratigraphic unit is mapped for deposits of both lobes (for example, the Kewaunee, Copper Falls, and Holy Hill Formations). In the following discussion, glacial lobes are discussed relative to the distribution of units, but are not considered part of the formal definition.

The surface occurrence of the **Tiskilwa Member** of the Zenda Formation is limited to a relatively small area in Walworth County (Alden, 1918; Johnson, 1976). The Tiskilwa Member contains light reddish-brown, silty till. It is present in the subsurface beneath the New Berlin Member of the Holy Hill Formation at least as far north as

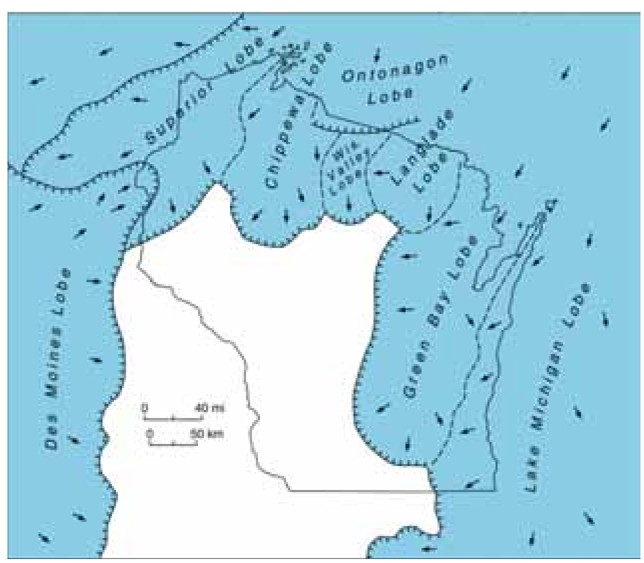

Figure 5. Glacial lobes in Wisconsin during the Wisconsin Glaciation. Arrows indicate the direction of ice movement. From Clayton and others (2006).

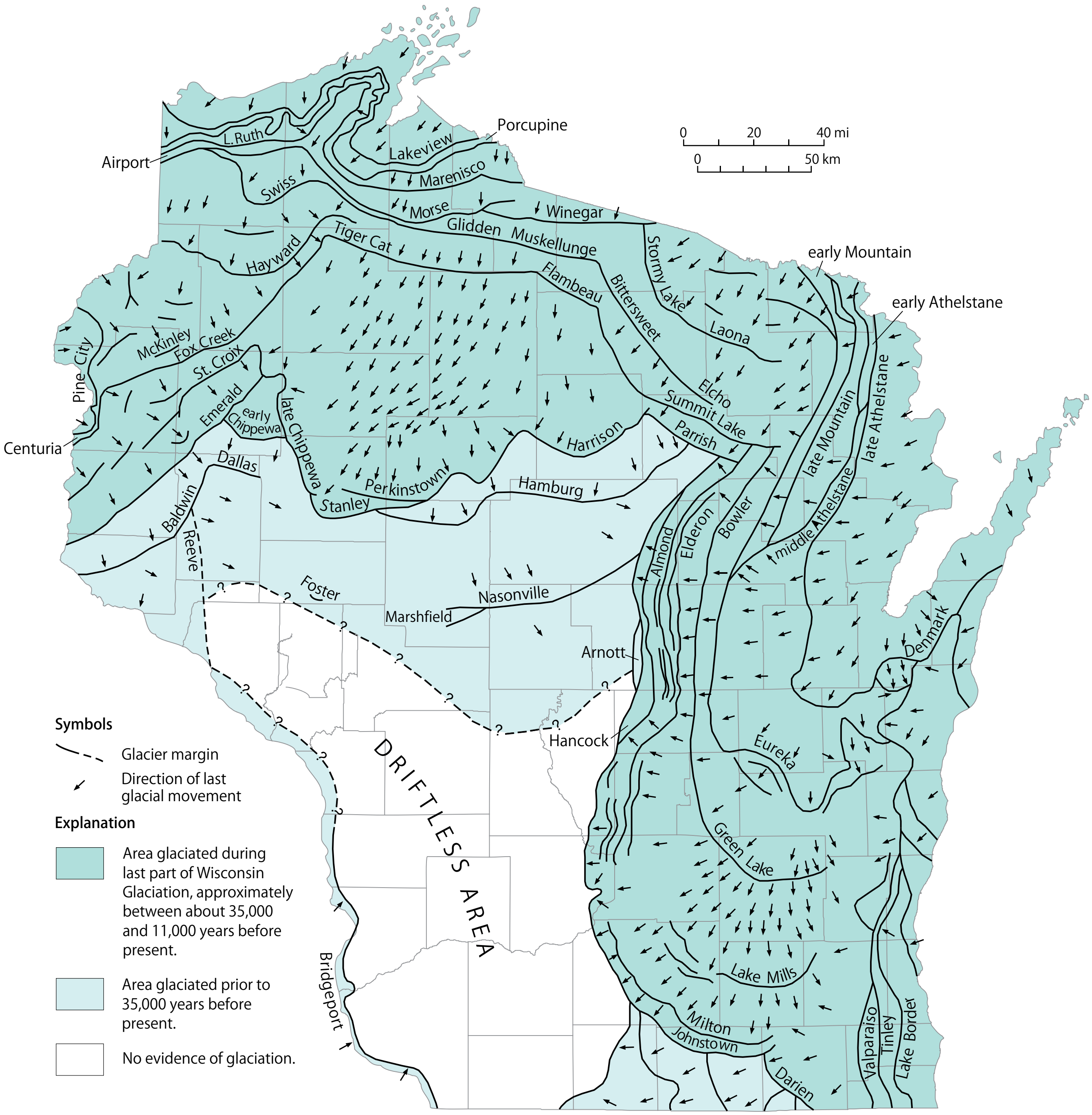

Figure 6. Glacial ice phases in Wisconsin. A phase is a geologic event rather than a period of time. Most phases represent at least a minor advance of the edge of the ice sheet. Each line marks the outermost edge of the ice sheet during a phase of glaciation. Modified from Clayton and others (2006) and Syverson and Colgan (in press).

Milwaukee and southern Washington County (Mickelson and Syverson, 1997). It is presumably the same unit as the Tiskilwa Formation in Illinois (Hansel and Johnson, 1996).

The **Hayton Formation** is found in the subsurface in much of northeastern and east-central Wisconsin. This unit, formally defined in this publication, was deposited by the Green Bay and Lake Michigan Lobes or possibly an undivided lobe that advanced from the north–northeast. The **Cato Falls Member** contains gray silty till. Gray silt and fine sand of the **High Cliff Member** is thought to be an eolian deposit.

Sediment of the **Holy Hill Formation** is present in southeastern and south-central Wisconsin. The formation was defined by Mickelson and Syverson (1997) to include what had been the Horicon and New Berlin Formations. Alden (1918) argued that deposits of the Lake Michigan Lobe (New Berlin) could be distinguished in the field from those of the adjacent Green Bay Lobe (Horicon) by its larger amount of Niagaran (Silurian) dolomite. These are now called the **Horicon Member** and **New Berlin Member** because they cannot be distinguished in the field, and only with great difficulty in the lab. The yellowish-brown till of both units has more sand than till of the Zenda Formation below and of the Oak Creek Formation above. Holy Hill Formation till is very sandy in Langlade County to the north and is more silt-rich in Dane and Rock Counties to the south. The grain-size change is gradational, however, and therefore sediment of the Mapleview Member, as defined in 1984, is clearly the same unit as the Horicon Member. Thus, the use of Mapleview Member has been discontinued. The **Liberty Grove Member** in Door County and the **Horicon** and **New Berlin Members** continue to be recognized and are described in this report. Till of the **Waubeka Member** is somewhat siltier than till of the underlying New Berlin Member in eastern Wisconsin and sandier than the overlying Oak Creek Formation (Mickelson and Syverson, 1997).

The **Big Flats Formation** is the surface unit in much of the Central Sand Plains. In most areas it contains sand deposited by lake and stream processes. The **New Rome Member** is composed of thinly laminated, commonly rhythmically bedded, glaciolacustrine silt and clay deposited in low-energy environments within glacial Lake Wisconsin.

Lacustrine silt and clay, fluvial sand and gravel, and till of the **Oak Creek Formation** overlie the Holy Hill Formation in Kenosha, Racine, Waukesha, Milwaukee, and Ozaukee Counties (fig. 3). Till of the Oak Creek Formation is generally gray (where unoxidized) and clayey, and is distinctly different from till of underlying and overlying formations. The till was deposited by ice of the Lake Michigan Lobe, and many lacustrine units associated with the till were deposited during early phases of the lobe. The formation contains at least three till informal units (2A, 2B, and 2C of Mickelson and others, 1977) and an unknown number of other members. These are not defined in this paper. This formation is largely correlative with the Wadsworth Formation of Illinois (Hansel and Johnson, 1996).

Sediment of the **Kewaunee Formation** overlies different members of the Holy Hill and Oak Creek Formations and pre-Pleistocene bedrock. The till included in this formation is typically more reddish brown than deposits of underlying formations, and it contains more silt and clay than till of the Holy Hill Formation. The Kewaunee Formation includes till and associated deposits, mostly lake sediment, of both the Lake Michigan and Green Bay Lobes (fig. 3). Initially, four members were recognized (Acomb, 1978; Acomb and others, 1982; Mickelson and others, 1984) in the area once covered by the Lake Michigan Lobe. The lowest member is the **Ozaukee Member**. Till of this member is present as the surface till along the shoreline of Lake Michigan from northern Milwaukee County into Sheboygan County. It is also present farther north in Manitowoc and Kewaunee Counties (Acomb, 1978; Dagle and others, 1980). Till of the Haven Member was described between those two sites (Acomb and others, 1982). The Haven Member is now thought to be Ozaukee Member (Carlson, 2002; Carlson and others, in press), so the name Haven Member has been discontinued. The Ozaukee Member is at least in part correlative with the Shorewood Member of the Kewaunee Formation in Illinois (Lineback and others, 1974; Hansel and Johnson, 1996) and with the Silver Cliff and Branch River Members of the Kewaunee Formation in the Green Bay lowland. The **Valders Member** of the Kewaunee Formation is distinguished from the overlying Two Rivers Member by its greater percentage of expandable clay and lower percentage of illite. It has less clay than the till of the Ozaukee Member. The Valders Member evidently is correlative with the Manitowoc Till Member of the Illinois State Geological Survey as defined in cores of Lake Michigan sediment (Lineback and others, 1974). The Valders Member appears to correlate with the Kirby Lake and Chilton Members of the Kewaunee Formation in the Green Bay lowland. Radiocarbon dates beneath Valders Member till at the type section range from 12,965 ± 200 ^{14}C yr B.P. (15,779 ± 540 cal. yr B.P.) to 14,210 ± 90 ^{14}C yr B.P. (17,434 ± 256 cal. yr B.P.) (Maher and others, 1998; Mickelson and others, 2007). The **Two Rivers Member**, defined by Evenson (1973), is the uppermost Lake Michigan Lobe deposit containing till. Clay mineralogy has been used to distinguish it from the till of the Valders Member, as has the presence of the Two Creeks Forest Bed between the two units. The Two Rivers Member appears to correlate with the Glenmore and Silver Cliff Members in the area covered by the Green Bay Lobe.

Green Bay, the Fox River, and the steep slope of the Silurian escarpment form a discontinuity across which no detailed stratigraphy has been completed. Properties of potentially correlative units differ significantly, and at this time it appears most logical to continue to have an arbitrary vertical cutoff at the Fox River (fig. 3) and use separate member names on either side of the river, as was done by McCartney and Mickelson (1982). East of the Fox River, the three members of the Kewaunee Formation, from oldest to youngest, are the Branch River, Chilton, and Glenmore Members as defined based on till units within each member. Till of the **Branch River Member** is redder and has more clay than the underlying till of the Holy Hill Formation. It is sandier than the overlying **Chilton** and **Glenmore Members** (Mickelson and Socha, in press), and is correlative with the Silver Cliff Member west of the Fox River. The Chilton and Glenmore Members are indistinguishable in the field except by measuring depth of carbonate leaching in the till at well-drained sites in the landscape (Mickelson and Evenson, 1975). Till of the Chilton Member is distinguished from till of the Glenmore Member in the laboratory by having higher magnetic susceptibility (McCartney and Mickelson, 1982). The Chilton Member is correlative with the Kirby Lake Member, and the Glenmore Member is correlative with the Middle Inlet Member west of the Fox River. A radiocarbon date beneath the Chilton Member of 13,370 ± 90 ^{14}C yr B.P. (16,302 ± 428 cal. yr B.P.) provides a maximum age for the Chilton Member (Mickelson and others, 2007).

West of the Fox River, informal names were given to the reddish-brown till by McCartney (1979) and McCartney and Mickelson (1982); their definitions serve as the basis for the formal lithostratigraphic definitions presented here. The **Florence Member** is the oldest member of the Kewaunee Formation west of the Fox River. It contains less sand than till of the underlying Holy Hill Formation and till of the overlying Silver Cliff Member. The **Silver Cliff Member** till contains more sand than till of the overlying Kirby Lake Member. Till of the **Kirby Lake Member** is typically thinner, redder, and finer grained than till of the overlying Middle Inlet Member, and correlates with the fine-grained till of the Chilton Member east of the Fox River. The **Middle Inlet Member** is the youngest lithostratigraphic unit containing till deposited by the western part of the Green Bay Lobe in Wisconsin. In the south (Brown and Outagamie Counties), the till is fine grained like the correlative Glenmore Member till east of the Fox River. To the north in Oconto, Marinette, and Florence Counties, till of the Middle Inlet Member is progressively sandier (McCartney, 1979; McCartney and Mickelson, 1982). The Two Creeks Forest Bed is here given informal lithostratigraphic recognition. It consists of organic material accumulated as forest floor litter or in shallow ponds and is dated about 11,200 to 12,400 ^{14}C yr B.P. (approximately 13,100 to 14,600 cal. yr B.P.) (Mickelson and others, 2007). It is present throughout much of the area covered by the Two Rivers, Glenmore, and Middle Inlet Members.

The **Copper Falls Formation** occurs across a broad area of northern Wisconsin. Till of the Copper Falls Formation is generally sandy and reddish brown, with a small proportion of Paleozoic sedimentary clasts. This till is derived from the Lake Superior basin and generally is distinctly different from deposits of the Lake Michigan and Green Bay Lobes. In some places, particularly in Florence County where the lobes overrode similar bedrock, the distinction between the Copper Falls Formation and the adjacent Holy Hill Formation is not clear. Till of the Copper Falls Formation can be distinguished from the underlying Marathon and Pierce Formation tills because it is sandier, redder, and less weathered. Copper Falls Formation till deposited during the last part of the Wisconsin Glaciation displays primary constructional glacial landforms, unlike the older Bakerville Member of the Copper Falls Formation.

The type section of the **Nashville Member** of the Copper Falls Formation is in southern Forest County, and the unit is recognizable in northern Langlade, most of Forest, Vilas, and Oneida Counties (fig. 3), corresponding to the extent of the Langlade Lobe. Till of the Nashville Member is reddish brown and sandy. It is distinguished from till of the underlying Merrill Member by an intervening sand unit in places and a somewhat different clay mineral content (Simpkins, 1979; Simpkins and others, 1987). It is distinguished in Langlade and southern Forest Counties from the Horicon Member of the Holy Hill Formation by its lower concentration of dolomite and other Paleozoic sedimentary clasts. The Nashville Member is probably time correlative with all or part of the Horicon Member of the Holy Hill Formation. In eastern Langlade and southern Forest Counties, the Nashville Member overlies the Horicon Member. Although detailed work to the northeast has not been completed, it seems likely that an unnamed member of the Holy Hill Formation lies above the Nashville Member. We recognize that this results in intertonguing of formations, but this seems unavoidable for practical classification of the units. The **Wildcat Lake** and **Crab Lake Members** were deposited by the Wisconsin Valley and Ontonagon Lobes, respectively. They were defined by Attig (1985) in Vilas County. Reddish-brown till of the Wildcat Lake Member is sandy and rich in Lake-Superior-derived clasts, and till of the Crab Lake Member is finer grained.

In western Wisconsin, several members of the Copper Falls Formation have been recognized (Johnson, M.D., 1986, 2000). The tills of each member are all quite similar, but there are differences in texture and composition. All are sandy and reddish brown. The **Pokegama Creek Member**, which is at the surface in east-central Barron County, is richer in locally derived quartzite fragments than the other members. Till of the **Mikana Member** contains less quartzite than till of the Pokegama Creek Member. Both units were deposited by ice of the Chippewa Lobe. Farther west in Barron, Polk and St. Croix Counties, the **Poskin** and **Sylvan Lake Members** were deposited by the Superior Lobe. Both contain gravelly, sandy till with little quartzite. Color is an important discriminator for these units. The **Sunrise Member** contains rhythmically laminated lacustrine sand, silt, and clay. The Sunrise Member was deposited in a glacial lake as the retreating Superior Lobe deposited till of the Copper Falls Formation. At this time, the Sunrise Member is known to exist only in western Wisconsin and eastern Minnesota (Johnson, 2000). It can be distinguished from the younger Falun Member of the Trade River Formation by its low carbonate content, reddish color, and stratigraphic position.

The **Trade River Formation** contains calcareous till, lake, and stream sediment derived from the Grantsburg Sublobe of the Des Moines Lobe. All deposits are calcareous and typically less red than those of the Copper Falls Formation. The **Falun Member** contains sand, silt and clay deposited in a lake in front of the Grantsburg Sublobe.

The **Miller Creek Formation** is the surface unit in parts of Douglas, Bayfield, Ashland, and Iron Counties (fig. 3) in northwestern Wisconsin. Till and lacustrine silt and clay in the formation have a distinctly red color. All till in the formation is more clayey than till in the underlying Copper Falls Formation. Two members are defined within the formation. The older, the **Hanson Creek Member**, contains till and laminated silt and clay (Need, 1980). Color is the main distinction between the Hanson Creek Member and till of the overlying, more reddish **Douglas Member**. Till of the Douglas Member has two distinct facies: a clay facies with textural properties similar to the till of the Hanson Creek Member, and a sandier facies.

Introduction:
Quaternary loess lithostratigraphy in Wisconsin

James C. Knox, David S. Leigh, Peter M. Jacobs, Joseph A. Mason, and John W. Attig

Loess is silt-dominated, wind-deposited sediment that is found throughout many areas of Wisconsin. The majority of Wisconsin's best agricultural soils occur in loess or loess-derived surficial sediments, so an understanding of loess distribution and characteristics is important. Rates of loess accumulations were generally greatest during past glaciations in the region. Sediment thickness and texture, as well as the number of recognizable units, vary locally and regionally because of differential proximities to source areas and differential erosion since deposition. The two most important sources of loess include (a) floodplains of sediment-laden rivers that carried outwash from former glacial ice sheets (Leigh and Knox, 1994), and (b) sparsely vegetated periglacial landscapes and the floodplains of the sediment-laden streams that drained them (Mason and others, 1994). Loess also was derived locally from smaller sources such as the exposed beds of recently drained glacial or ice-walled lakes, or freshly exposed glacial sediment (Schaetzl and others, 2009). Ongoing research in Vilas and Oneida Counties, Wisconsin, is showing that outwash plains also were important local sources of loess in that area (R.J. Schaetzl, 2009, written communication).

Major sources of loess in Wisconsin were the Mississippi River valley; the Wisconsin River valley, including the bed of Glacial Lake Wisconsin; and other outwash areas near former glacial margins. The greatest thickness and most complete record of loess in Wisconsin is in the Driftless Area of southwestern and western Wisconsin.

The Driftless Area, located along the eastern margin of the Mississippi River valley (fig. 6), was an area of major loess accumulation for several reasons. First, this river carried large sediment loads of gravel, sand, silt, and clay when it was a major meltwater outlet during past glaciations, and it exposed a large, broad floodplain. Thus, it was a major source of loess during more than one glaciation. Second, the glaciogenic loess in the Driftless Area was supplemented by loess carried eastward from periglacial landscapes of southeastern Minnesota and northeastern Iowa (Mason and others, 1994; Bettis and others, 2003). In addition, because there is no definitive evidence that the Driftless Area was ever covered by glacial ice, the area was always open for loess deposition and older loess units were not removed by glacial erosion.

Even though glacial ice was not present to erode loess, severe periglacial climatic conditions in the Driftless Area during times of nearby glaciation contributed to extensive erosion by mass wasting processes (Mason and Knox, 1997). Knox (1989) compared the volume of loess deposited and eroded during the last glacial advance into the region (marine isotope stage 2). In a small Grant County watershed, Knox found that the rate of soil loss during tundra climatic conditions between about 12,000 to 20,000 ^{14}C yr B.P. (approximately 14,000 to 24,000 cal. yr B.P.) was approximately double the rate of soil erosion associated with historical agricultural land use. Consequently, most remaining loess in the Driftless Area and elsewhere in Wisconsin is not older than the last glacial advance into the Midwest, about 33,000 cal. yr B.P.

Although the presence of loess in southwestern Wisconsin has been recognized since the late 1800s (Chamberlin, 1897), the first formal publication of separate stratigraphic loess units did not occur until the late 1900s (Leigh and Knox, 1994). We use the name **Kieler Formation** to represent the collective loess deposits of Wisconsin because deposits older than late Wisconsin (MIS 2) are too thin and dispersed to be mappable as separate units. The Kieler Formation is named for the Grant

County village of Kieler where nearby construction of new State Highway 151 in 1993 exposed numerous cuts with multiple loess units.

The Kieler Formation in the area of the type section commonly includes four loess units, which are from oldest to youngest: the Wyalusing Member (rarely seen, MIS 8?), the Loveland Member (MIS 6-8), the Roxana Member (MIS 3), and the Peoria Member (MIS 2). Nonetheless, evidence of additional loess units is present elsewhere in southwestern Wisconsin. For example, a vertical sequence of at least five loess units has been identified near Oil City in the central Driftless Area (Jacobs and Knox, 1994) and four loess deposits have been described in the lower Wisconsin River valley near Bridgeport (Leigh and Knox, 1994). Post-depositional weathering and erosion have either altered or removed evidence of most loess in the state deposited before the Wisconsin Glaciation (pre-MIS 2), although loess deposited during the Illinoian Glaciation (MIS 6-8) is common on many southwestern Wisconsin upland divides near the Mississippi River.

Leigh and Knox (1994) adopted the loess unit names of the Illinois State Geological Survey to represent Wisconsin's three youngest loess units because these units are stratigraphically equivalent to similar loess units in adjacent Illinois. The two older loess units noted by Jacobs and Knox (1994) and Leigh and Knox (1994) have not been named because their geographic occurrence is too limited for mapping and because post-depositional weathering typically has welded them into a complex pedogenic sequence. The members of the Kieler Formation are described from oldest unit to youngest unit below. See the Kieler Formation description and the individual member descriptions in this publication for details.

Wyalusing Member (MIS 8?). The Wyalusing Member's status is rather uncertain. It underlies the Loveland Member and typically is composed of non-calcareous, unbedded, brown (10YR 4/3 to 10YR 4/4) silt loam with faint reddish hue. It averages less than 5 percent sand, 75 to 90 percent silt, and less than 25 percent clay. The Wyalusing Member has been slightly to moderately altered by soil formation and displays weak to moderate platy to blocky pedogenic structure. The Wyalusing Member is lithologically similar to the Roxana Member, except that the Wyalusing lacks charred plant material and is in a lower stratigraphic position than the Roxana Member. It is uncommon outside of the lower Wisconsin River valley. This may be due to post-depositional erosion, weathering, or bioturbation (mixing of the sediment caused by organisms).

Leigh and Knox (1994) noted that soil/stratigraphic morphologies of the Wyalusing-Loveland and the Roxana-Peoria couplets are strikingly similar. They hypothesized that the two discrete sedimentary sequences may reflect the impact of global ice expansion and contraction on weathering and the extent and magnitudes of proglacial drainage. Broadly similar soil/stratigraphic morphology exists in eastern Nebraska between lower and upper Loveland Formation loess units and between Wisconsin age Gilman Canyon Formation and Peoria Formation loess units (Mason and others, 2007). The lower zone of the Loveland Formation loess has a slightly darker and redder color than most of the upper Loveland Formation. The sequence is classified entirely as Loveland Formation loess because no well-developed paleosol occurs between the upper and lower zones to denote an extended depositional hiatus (Mason and others, 2007). The similarity of physical properties between the two units of the Loveland Formation in eastern Nebraska is relatively similar to the Wyalusing and Loveland Member couplet in Wisconsin's Kieler Formation. The similarity might suggest that the Wyalusing Member is actually the initial component of Loveland Member loess deposition. Furthermore, the Gilman Canyon Formation loess, which overlies Loveland Formation loess and underlies Peoria Formation loess in Nebraska, is of similar age to the Roxana Member. Gilman Canyon Formation loess also has broadly similar physical appearance to the Roxana Member.

Loveland Member (MIS 6-8). The Loveland Member in southwestern Wisconsin generally consists of light brownish-gray (2.5Y 6/2) to yellowish-brown (10YR 5/4) silt loam that becomes darker and redder upward, largely due to pedogenic alteration. Strong blocky pedogenic structure characterizes the Sangamon Geosol, which exists in upper part of the Loveland Member, and evidence of weathering extends throughout the unit when it is less than 2 m thick. At the Kieler Formation type section, the unit averages 2 percent sand, 61 percent silt, and 37 percent clay in the lower Loveland Member, below the B horizon of the Sangamon Geosol. The relatively high clay fraction probably is a result of downward mixing and some weathering. Where thicker than 2 m, the lower Loveland Member appears more massive and shows minimal weathering. Most detrital carbonate minerals have been leached from the Loveland Member.

Post-depositional erosion has removed Loveland Member at most sites in Wisconsin. Only 7 percent of 60 drill cores contained Loveland Member loess on the crests of interstream divides in northwestern Illinois and southwestern Wisconsin along the Mississippi River (Leigh and Knox, 1994). Wisconsin's proximity to former margins of continental glaciers favored episodes of rapid mass wasting which greatly accelerated upland erosion rates.

Roxana Member (MIS 3). The Roxana Member is a common loess unit at many sites in southwestern Wisconsin. It averages less than 5 percent sand, 75 to 90 percent silt, and less than 25 percent clay. It probably contained detrital carbonates when deposited, but if so, these minerals subsequently have been removed by weathering; thus, the Roxana is usually non-calcareous. The Roxana Member commonly exhibits weak to moderate platy or blocky pedogenic structure throughout. Its common color is brown (10YR 4/3 to 10YR 4/4), and this contrasts sharply with the overlying Peoria Member, whose colors range from light brownish gray (2.5Y 6/2) to yellowish brown (10YR 5/4). Leigh and Knox (1993) found that another prominent characteristic of the Roxana Member is the abundance of spruce charcoal dispersed throughout the matrix, suggesting that a boreal forest extended across southwestern Wisconsin when this loess unit was accumulating between about 27,000 and 55,000 ^{14}C yr B.P. (32,000 and 60,000 cal. yr B.P.). These radiocarbon ages support the idea that Roxana loess mainly accumulated during MIS 3 in western and southwestern Wisconsin. However, farther south in Illinois where Lake Michigan Lobe tills and outwash contributed Roxana sediment, Johnson and Follmer (1989) suggested deposition of this unit may have begun during MIS 4 and continued through MIS 3.

Geochemical and mineralogical composition of the Roxana Member in southwestern Wisconsin indicates that detritus from regional hillslope erosion is not an important component of the sediment. These data support the idea that the Roxana Member here originated as loess blown from the floodplains of glacier-fed rivers, particularly the Mississippi (Leigh, 1994). Roxana Member grain size decreases westward from the Mississippi River valley in southeastern Minnesota (Mason and others, 1994), suggesting that periglacial sources west of the Mississippi were not important sources for the Roxana Member, as they were for the overlying Peoria Member.

The maximum observed thickness of the Roxana Member is about 1.5 m, but commonly it is only centimeters to a few tens of centimeters thick, presumably due to erosional truncation. The original thickness of the Roxana Member in the southwestern Wisconsin is difficult to determine with certainty because there is often evidence of erosional truncation before burial. The upper boundary typically is clear to abrupt with the overlying Peoria Member, whereas the lower boundary more commonly is gradational ("welded") with the underlying Sangamon Geosol.

Peoria Member (MIS 2). The Peoria Member is the youngest loess unit in Wisconsin, and it comprises the bulk of the loess in the Kieler Formation. The Peoria Member is the only member suitable for mapping in Wisconsin. Thick deposits of Peoria Member in the Driftless Area commonly consist of medium to coarse silt loam that is light brownish gray (2.5Y 6/2) in the basal part of the unit and yellowish brown (10YR 5/4) in oxidized upper horizons. The unweathered basal portion is massive and calcareous. The weathered upper portion is non-calcareous and displays moderate to strong blocky pedogenic structure (Leigh and Knox, 1994).

Leigh and Knox (1994) reported an accelerator mass spectrometer (AMS) age of 24,250 ± 970 ^{14}C yr B.P. (29,076 ± 1041 cal. yr B.P., GX-15888-AMS) for snail shells located 25 cm above the base of a 4.5 m thick Peoria Member unit on top of a Mississippi River valley bluff. This age suggests that Peoria Member deposition on uplands closely followed the advance of glacial ice into the headwaters of the upper Mississippi River during the last part of the Wisconsin Glaciation (MIS 2), as well as the associated development of periglacial environments outside the ice margins. Many Peoria Member deposits outside of the Driftless Area accumulated over a range of ages reflecting glacial retreat from the region. Schaetzl and others (2009) reports these deposits have various sources including moraines, drained lake plains, sediment associated with thawed or degraded permafrost, outwash plains, and other local exposed unstable land surfaces that emerged following deglaciation. Peoria Member loess with very localized sources is generally less than 25 cm thick (Schaetzl and others, 2009).

The maximum thickness of *in situ* Peoria Member loess in Wisconsin is about 7 m on broad upland divides in the Driftless Area near the Mississippi River. To the east, the average thickness of the Peoria Member loess thins rapidly to 1 m or less beyond a distance of about 30 to 40 km (20 to 25 miles) east of the Mississippi River valley (Leigh and Knox, 1994), although the thickness again increases to 1 m or more in some areas glaciated by the Green Bay Lobe. In these areas local conditions associated with moraines, lake plains, outwash plains, degrading permafrost, and other formerly unstable land surfaces became important loess sources (Hole, 1950; Jacobs and others, 2008, Schaetzl and others, 2009). Furthermore, loess from periglacial landscapes west of the Mississippi River almost certainly contributed to loess in southwestern Wisconsin as well, based on projection of loess thickness trends eastward from those nonglacial source areas (Mason and others, 1994). The Peoria Member is 3.8 m thick at the Kieler Formation type section, an area located about 4.1 km (2.5 miles) east of the Mississippi River source area. The Peoria Member is common throughout much of Wisconsin, but outside of the Driftless Area, Peoria Member loess ranges in thickness from a few cm to nearly 2 m. Textures of these "interior" deposits range from silt loam to fine sandy loam, generally coarsening toward source areas. Where thin (<35 cm), Peoria Member sediment typically is partially or wholly mixed into the underlying sediment.

On the glaciated land surface of the southern Green Bay Lobe, Peoria Member thickness is patchy, ranging from imperceptible in drumlin areas to 1 to 2 m on bedrock uplands or flat, well-drained outwash plains. Notable occurrences of Peoria Member occur on the outwash plain (Rock Prairie) of western Rock and eastern Walworth Counties, and on the backslope of the Oneota Cuesta of southern Columbia, northwestern Dodge, and southeastern Green Lake Counties (Jacobs and others, 2008). The probable source area for most loess on the southern Green Bay Lobe land surface was the bed of Glacial Lake Wisconsin, which, following drainage of the lake, was eroded by wind and reconstructed as a sand sheet and dune field, allowing dust deflation and subsequent accumulation on the uplands to the southeast. Dune construction largely occurred between 10,600 to 14,000 cal. yr B.P. (Rawling and others, 2008). In rolling terrain with drumlins, much of the loess was eroded off of the hillslopes and accumulated as colluvial deposits on footslopes or as lake sediment in the inter-drumlin lowlands. The fine-grained sediment filling the lowlands between drumlins has a grain-size distribution and clay mineralogy that better matches upland Peoria Member than the glacial sediment of the Green Bay Lobe (Jacobs and Mason, 2007).

Pierce Formation

Robert W. Baker

Source of name. Pierce County, in west-central Wisconsin.

Location and description of type section. An exposure 10 m high on the west side of an abandoned gravel pit, 200 m north of Highway 12, and approximately 1 km (0.6 mile) southwest of Hersey. It is located in the SW¼SE¼ sec. 29, T. 29 N., R. 15 W., St. Croix County, an area shown on the Wilson 7.5-minute quadrangle (fig. 7). This type section also serves as the type section for the Hersey Member.

Location of reference sections. Type sections and reference sections of the Hersey and Kinnickinnic Members serve as reference sections for this formation.

Description of unit. The Pierce Formation includes gray calcareous till and associated yellowish-brown sand and gravel, as well as silt and clay of glacial lacustrine origin. At the present time, four members are recognized. The oldest unit, the Eau Galle Member, contains massive lacustrine sediment that averages 7 percent sand, 36 percent silt, and 57 percent clay (Attig and others, 1988). This is overlain by till of the Woodville Member, a gray calcareous till that averages 45 percent sand, 31 percent silt, and 24 percent clay. The Hersey Member overlies the Woodville Member and contains gray calcareous till of western provenance that averages 42 percent sand, 33 percent silt, and 25 percent clay. This, in turn, is overlain by the Kinnickinnic Member, a laminated lacustrine sediment deposited in ice-marginal lakes, which averages 14 percent sand, 66 percent silt, and 20 percent clay. To date, the sand and gravel in this formation have not been studied in detail.

Nature of contacts. The Pierce Formation is the surficial unit in southern Pierce and western Dunn, Pepin, and Buffalo Counties. In northern Pierce County and most of St. Croix County it is overlain by the River Falls Formation, which contains reddish-brown till and associated sand and gravel from the Lake Superior area. This contact is sharp and is commonly erosional in nature. The basal contact is unknown except where the Hersey Member lies directly on Paleozoic bedrock.

Differentiation from other units. Till of this formation is distinguished from till of the overlying River Falls Formation primarily on the basis of its gray color. Secondary differentiation can be made by the much higher sand content of the River Falls Formation and by the distinctive clay mineralogy of the Hersey and Woodville Members.

Figure 7. Part of the Wilson 7.5-minute quadrangle showing the location of the type section of the Pierce Formation and the Hersey Member.

Regional extent and thickness. The thickness of the Pierce Formation ranges from less than a meter on the tops of some bedrock highlands to at least 55 m in southern Pierce County. The Hersey Member extends to the east as the surface deposit into western Buffalo, Pepin, and Dunn Counties (fig. 3). The northern extent of the Pierce Formation beneath the River Falls Formation is unknown at this time. However, Pierce Formation till has been found in exposures in southwestern Barron County (Johnson, M.D., 1986) and in drill holes in southern Polk County (Johnson, 2000). It appears that the Hersey Member was deposited by the eastern edge of a large glacial lobe. The Kinnickinnic Member is confined to the present valleys of the Kinnickinnic, Rush, Trimbelle, Chippewa, and Buffalo Rivers (fig. 3). It is found at altitudes below about 366 m and was deposited in ice-marginal lakes on the east side of the glacier that deposited the Hersey Member. The Eau Galle and Woodville Members have only been recognized in the subsurface where they are 8 and 4.5 m thick, respectively.

Age and correlation. Five radiocarbon dates have been obtained from wood and peat from within the Hersey Member. Three of the dates are non-finite, ranging from greater than 38,000 ^{14}C yr B.P. (42,600 cal. yr B.P.) to greater than 45,000 ^{14}C yr B.P. (49,000 cal. yr B.P.), and two are finite dates of about 30,000 ^{14}C yr B.P. (34,200 cal. yr B.P., Black, 1959, 1974; Baker and Simpson, 1981). Paleomagnetic investigations, however, suggest that the finite radiocarbon dates are erroneous (Baker and others, 1983). Results of alternating field demagnetization show that both the lower Hersey and Kinnickinnic Members are reversely magnetized, whereas the upper portions of these members have normal remanent magnetization. The possible ages of this unit are discussed by Baker and others (1983). It probably was deposited before the Illinoian Glaciation.

Previous usage. First formalized in Mickelson and others (1984).

Pierce Formation: Eau Galle Member

Robert W. Baker

Source of name. The Eau Galle River in St. Croix, Pierce, and Dunn Counties, Wisconsin.

Location and description of type section. Drill hole at the reference section for the Hersey Member of the Pierce Formation at Woodville, Wisconsin, located in the SE¼NW¼NW¼ sec. 35, T. 29 N., R. 16 W., St. Croix County, an area shown on the Baldwin East 7.5-minute quadrangle (figs. 8, 9). Here the Eau Galle Member is overlain by 4.5 m of till of the Woodville Member, which is in turn overlain by 0.3 m of organic sediment, 3.8 m of till of the Hersey Member, and 8.3 m of till and sand and gravel of the River Falls Formation at the surface. The thickness and grain-size distribution of units at the type section are given in figure 10. This drill hole also serves as the type section for the Woodville Member.

Description of unit. The Eau Galle Member contains unbedded, noncalcareous silty and clayey glacial lake sediment. Its color ranges from yellowish brown (10YR 5/4) to gray (10YR 5/1). Samples from the Eau Galle Member average 7 percent sand, 36 percent silt, and 57 percent clay (fig. 11). The clay averages 65 percent montmorillonite, 20 percent mica (illite), 10 percent kaolinite, and 5 percent chlorite.

Nature of contacts. The upper contact with the Woodville Member of the Pierce Formation is abrupt and sharp. The nature of the lower contact is unknown.

Differentiation from other units. The lake sediment of the Eau Galle Member is readily distinguished from the till of the Hersey and Woodville Members by its conspicuous lack of clasts and its clayey texture. It can be distinguished from the Kinnickinnic Member by the abundance of clay (57 percent as compared to 20 percent) and montmorillonite, and by the scarcity of kaolinite.

Figure 8. Part of the Baldwin East 7.5-minute quadrangle showing the location of the type section for the Eau Galle and Woodville Members.

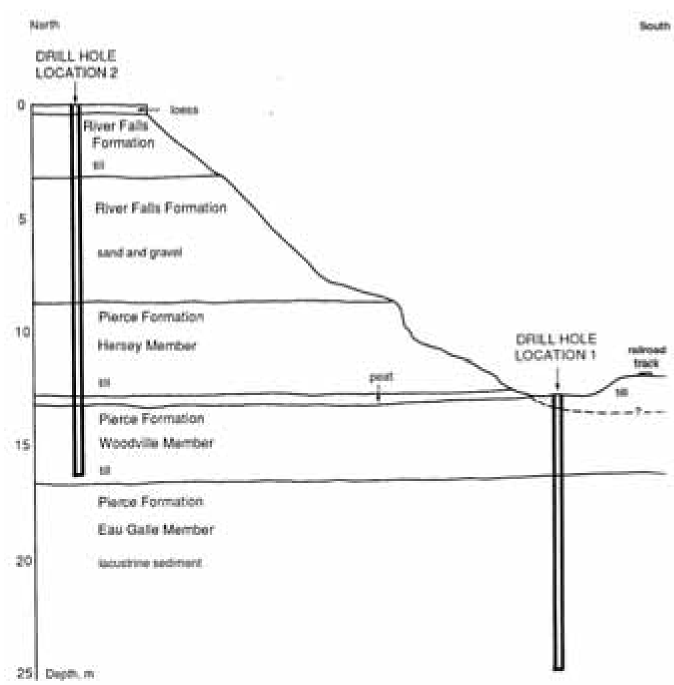

Figure 9. Diagram of the type section of the Eau Galle and Woodville Members showing the location of drill holes and stratigraphic units. From Baker (1984).

Pierce Formation: Eau Galle Member

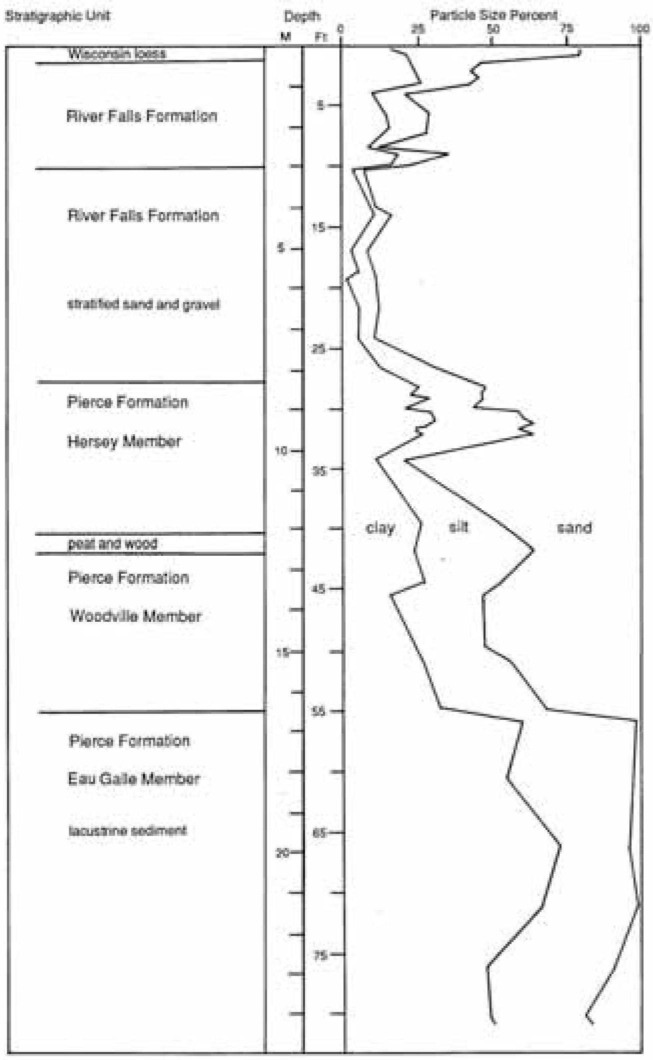

Figure 10. Thickness and grain-size distribution at the type section of the Eau Galle and Woodville Members. Modified from Baker (1984).

Regional extent and thickness. Because the Eau Galle Member has been found only in the subsurface, its distribution in western Wisconsin and its thickness are unknown. On the basis of sampling of a drill hole at Woodville, Wisconsin, the thickness of the Eau Galle Member is known to exceed 8 m.

Origin. The Eau Galle Member was probably deposited in glacial lakes dammed by the glacier that deposited the Woodville Member.

Age and correlation. The Eau Galle Member is thought to have been deposited before the Illinoian Glaciation on the basis of its position below the Hersey Member, which has reversed remanent magnetization. No correlative unit is known to exist in Wisconsin or Minnesota.

Previous usage. This name was first used by Baker (1984), and the unit was formalized in Attig and others (1988).

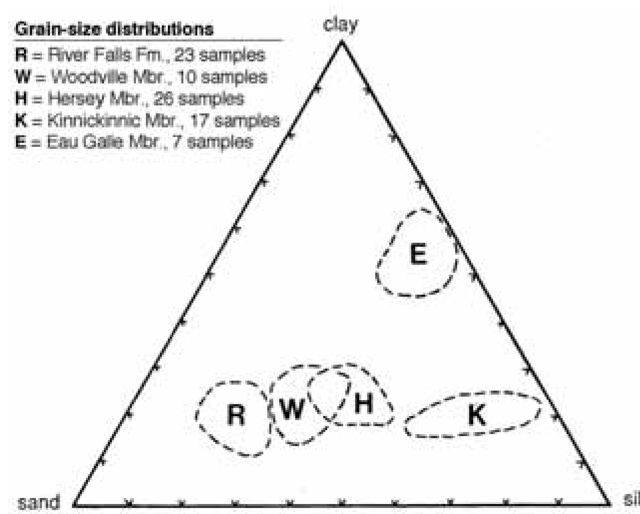

Figure 11. Diagram showing the grain-size distribution of material from units deposited before the Wisconsin Glaciation in west-central Wisconsin. From Baker (1984).

Pierce Formation: Woodville Member

Robert W. Baker

Source of name. The town of Woodville, eastern St. Croix County, Wisconsin.

Location and description of type section. Drill hole at the reference section for the Hersey Member of the Pierce Formation at Woodville, Wisconsin, located in the SE¼NW¼NW¼ sec. 35, T. 29 N., R. 16 W., St. Croix County, an area shown on the Baldwin East 7.5-minute quadrangle (see figs. 8 and 9 in the Eau Galle Member description). Here 8.3 m of till and sand and gravel of the River Falls Formation is present at the surface. This overlies 3.8 m of till of the Hersey Member, 0.3 m of organic sediment, 4.5 m of till of the Woodville Member, and 8 m of the Eau Galle Member. The thickness and grain-size distribution of units at the type section are given in figure 10 in the Eau Galle Member description.

Description of unit. The Woodville Member is an unbedded, structureless, and strongly calcareous till. Its color ranges from gray (5YR 5/1) to dark gray (10YR 4/1). Samples from the matrix of the Woodville Member average 45 percent sand, 31 percent silt, and 24 percent clay (fig. 11). The clay of the unweathered Woodville Member averages 64 percent montmorillonite, 22 percent kaolinite, and 14 percent illite; it does not contain vermiculite.

Nature of contacts. The upper contact with the organic horizon and the lower contact with the Eau Galle Member are abrupt and sharp.

Differentiation from other units. The Woodville Member is easily differentiated from the glacial lake sediment of the Kinnickinnic and Eau Galle Members by its coarse clasts and by its abundance of sand. It can be distinguished from the till of the Hersey Member by its more abundant montmorillonite and kaolinite and by its somewhat more abundant sand.

Regional extent and thickness. Like the Eau Galle Member, the Woodville Member has only been recognized in the subsurface. Consequently, its distribution and maximum thickness are unknown. However, at Woodville, Wisconsin, the Woodville Member is 4.5 m thick.

Origin. The carbonate content, color, grain size, clay mineralogy, and pebble abundance of the Woodville Member are similar to till units in Iowa and Minnesota, which have a northwestern source (Manitoba area).

Age and correlation. The Woodville Member is thought to have been deposited before the Illinoian Glaciation because the Woodville Member is below the Hersey Member, which has reversed remanent magnetization. The color, grain-size distribution, and pebble and clay mineralogy suggest that the Woodville Member correlates with the Aurora Member of the Wolf Creek Formation in eastern Iowa (Hallberg, 1980). No correlative units are recognized in Wisconsin or Minnesota.

Previous usage. This name was first used for this unit by Baker (1984). The unit was formalized in Attig and others (1988).

Pierce Formation: Hersey Member

Robert W. Baker

Source of name. The rural locality of Hersey, eastern St. Croix County, Wisconsin, in the northwest quadrant of the Wilson 7.5-minute quadrangle.

Location and description of type section. An exposure 10 m high on the west side of an abandoned gravel pit, 200 m north of Highway 12, and approximately 1 km (0.6 mile) southwest of Hersey. It is located in the SW¼SE¼SE¼ sec. 29, T. 29 N., R. 15 W., St. Croix County, an area shown on the Wilson 7.5-minute quadrangle (see fig. 7 in the Pierce Formation description). This type section also serves as the type section for the Pierce Formation.

Location and description of reference section. The 20 m-high Northwestern Railroad cut in the town of Woodville, SE¼NW¼NW¼ sec. 35, T. 29 N., R. 16 E., St. Croix County, an area shown on the Baldwin East 7.5-minute quadrangle (fig. 12). The Hersey Member till is located at the base of the railroad cut.

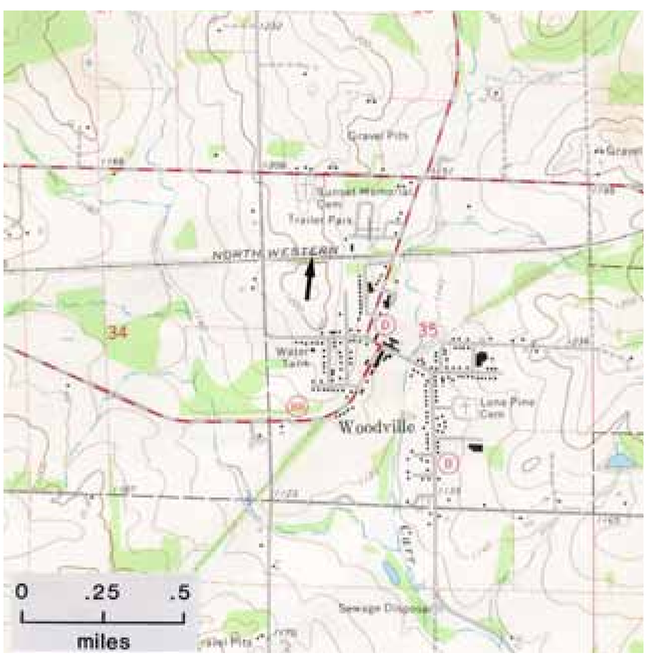

Figure 12. Part of the Baldwin East 7.5-minute quadrangle showing the location of the reference section of the Hersey Member.

Description of TYPE SECTION

Depth (m)	Horizon	Description
Kieler Formation (Peoria Member) loess		
0.0–0.20	Ap	Very dark grayish-brown (10YR 3/2) silt loam; weak granular structure; very friable; abrupt smooth boundary.
0.20–0.31	Bt1	Dark yellowish-brown (10YR 4/4) clay loam to silty clay loam; moderate subangular blocky structure; friable, clear wavy boundary.
Hersey Member till		
0.31–0.92	2Bt2	Brown to dark brown (7.5YR 4/4) clay loam; moderate prismatic breaking to strong subangular blocky structure; gradual wavy boundary.
0.92–1.13	2Bt3	Brown to dark brown (7.5YR 4/4) clay loam; strong subangular blocky structure; friable; clear wavy boundary.
1.13–1.38	2Bt4	Yellowish-brown (10YR 5/6) clay loam; strong subangular blocky structure; friable; gradual wavy boundary.
1.38–1.93	2BCK1	Yellowish-brown (10YR 5/6) loam; strong angular blocky structure; firm; strongly calcareous; gradual wavy boundary.
1.93–2.32	2BCK2	Yellowish-brown (10YR 5/4) loam; moderate, angular blocky structure; firm; strongly calcareous; gradual wavy boundary.
2.32–2.80	2C1	Yellowish-brown (10YR 5/4) loam; structureless; firm; calcareous; gradual wavy boundary.
2.80–3.18	2C2	Yellowish-brown (10YR 5/4) loam; structureless; massive; very firm; strongly calcareous; abrupt wavy boundary.
3.18+	2C3	Dark gray (10YR 4/1) loam; structureless; massive; very firm, strongly calcareous.

Description of REFERENCE SECTION

Depth (m)	Horizon	Description
Kieler Formation (Peoria Member) loess		
0.0–0.28	A	Very dark grayish-brown (10YR 3/2) silt loam; moderate granular structure; very friable; clear smooth boundary.
0.28–0.40	E	Brown (7.5YR 5/4) silt loam; weak and fine subangular blocky structure; friable; clear smooth boundary.
River Falls Formation till		
0.40–0.53	2Bt1	Yellowish-red (5YR 4/6) light sandy clay loam; fine and moderate subangular blocky structure; friable; slightly sticky and slightly plastic; gradual smooth boundary.
0.53–0.73	2Bt2	Yellowish-red (5YR 4/6) sandy loam; medium and moderate subangular blocky structure; friable; slightly sticky and slightly plastic; gradual smooth boundary.
0.73–1.20	2Bt3	Yellowish-red (5YR 4/6) heavy sandy clay loam; moderate subangular blocky structure; friable; sticky and plastic; common, distinct light brown (7.5YR 6/4) ped face coatings; gradual smooth boundary.
1.20–1.78	2Bt4	Yellowish-red (5YR 4/6) sandy clay loam; weak subangular blocky structure; friable to firm; sticky and plastic; common prominent light brownish-gray (10YR 6/2 and 7.5YR 6/4) mottles.
1.78–3.45	2C1	Yellowish red (5YR 4/6) sandy clay loam; structureless; massive; friable; sticky and plastic; few prominent (7.5YR 6/4) mottles.
3.45–5.15	2C2	Yellowish-red (5YR 4/6) sandy clay loam; structureless; massive; friable; sticky and plastic.
Sand and gravel		
5.15–12.27	3C3	Yellowish-brown (10YR 5/8) sand, coarse sand, and gravel; structureless; single grain; noncalcareous. Also contains brownish-yellow sand and gravel; structureless; single grain.
12.27–13.50	3C4	Pale brown (10YR 6/3) sand and gravel; structureless; single grain; calcareous.
Hersey Member till		
13.50–13.80	4Btb1	Dark yellowish-brown (10YR 4/4) clay loam; structureless; massive; very firm; sticky and plastic; noncalcareous.
13.80–14.00	4Btb2	Yellowish-brown (10YR 5/4) clay loam; structureless; massive; very firm; sticky and plastic; noncalcareous.
14.00+	4C	Dark gray (10YR 4/1) loam; structureless; massive; very firm; calcareous.

(continued)

Description of unit. The till of the Hersey Member is predominantly structureless and in the unweathered state, strongly calcareous. Its color varies vertically within the weathering profile from yellowish brown (10YR 5/4 to 6) in the oxidized zone to dark gray (10YR 4/1) in the unoxidized zone. The Hersey Member is deeply weathered, with a solum as much as 2.9 m thick and leaching to depths as much as 3.5 m. The unweathered Hersey Member is loam averaging 42 percent sand, 33 percent silt, and 25 percent clay rather consistently throughout Pierce and St. Croix Counties. The weathered Hersey Member is typically a clay loam with the particle-size distribution depending on the position in the solum. Pebble lithologies average 43 percent igneous, 16 percent metamorphic, and 41 percent sedimentary rock (samples counted at eight sites). The clay mineralogy of the Hersey Member is quite distinctive. In all profiles, vermiculite drops to 5 percent or less in the lower portion of the B horizon and is absent from the C horizon. Other minerals in the clay-mineral fraction average 50 to 60 percent montmorillonite, 25 to 30 percent kaolinite, 15 percent illite, 5 to 10 percent quartz, and 0 to 5 percent chlorite.

Nature of contacts. Because it is thick and deeply buried in northern Pierce and St. Croix Counties, the lower contact of the Hersey Member is generally unknown except where the member overlies Paleozoic bedrock. At the Woodville Member type section (fig. 8), the Hersey Member has a sharp contact with an underlying organic sediment layer. The upper contact, where it is buried by the River Falls Formation, is always sharp, with a truncated paleosol in the Hersey Member frequently observable. In the major river valleys of west-central Wisconsin, the Hersey Member is overlain by the Kinnickinnic Member, a glaciolacustrine deposit (fig. 3). The boundary between these members is commonly of a gradational, interfingering type. However, in several exposures in southern Pierce County, the boundary is quite sharp.

Differentiation from other units. The till of the Hersey Member is similar to gray Trade River Formation till deposited by the Grantsburg Sublobe in western Wisconsin during the last part of the Wisconsin Glaciation. However, the two are easily distinguishable on the basis of stratigraphic position, shale content, and by vastly different sola thicknesses; they are everywhere separated by one or more red till units and the solum thickness of the Hersey Member is on average five times thicker than the Trade River Formation till. The Hersey Member can be distinguished from the overlying River Falls Formation on the basis of its dark gray color, its lower sand but higher silt content, and its lower vermiculite and higher montmorillonite content. Compared to the underlying till of the Woodville Member, the Hersey Member has a somewhat lower sand percentage, lower montmorillonite percentage, and higher kaolinite percentage.

Regional extent and thickness. The Hersey Member is the surface unit in southern Pierce and western Buffalo, Pepin, and Dunn Counties. Its northern extent is unknown due to burial by the River Falls Formation and several units in the St. Croix moraine deposited during the last part of the Wisconsin Glaciation. However, deep exposures of Pierce Formation till, either the Hersey or Woodville Members, have been found in southwestern Barron and western Polk Counties. The Hersey Member is less than a meter thick over uplands to greater than 55 m thick in southern Pierce County. In many areas, however, its exact thickness is unknown.

Origin. The calcareous nature, color, texture, clay mineralogy, and pebble content of the Hersey Member are typical of glacial deposits in Iowa and Minnesota that have a northwestern source (Manitoba area). This is further supported by till fabric measurements and the distribution of the member, which suggest that it was deposited by the eastern edge of a large glacial lobe that advanced into Wisconsin from the northwest.

Age and correlation. The Hersey Member may have been deposited before the Illinoian Glaciation based on its reversed remanent magnetization (Baker and others, 1983). See the Pierce Formation description for details on age determination. The Hersey Member correlates with the "old gray drift" mapped by Ruhe and Gould (1954) in southeastern Minnesota and interpreted as "Kansan" in age. In addition, its color, particle-size distribution, pebble and clay mineralogy, and degree of soil development are nearly identical to the Wolf Creek Formation deposited before the Illinoian Glaciation (Hallberg, 1980) in eastern Iowa (Baker and others, 1983).

Previous usage. This name was first used for this unit by Baker and Simpson (1981), and the unit was formalized in Mickelson and others (1984).

Pierce Formation: Kinnickinnic Member

Robert W. Baker

Source of name. The Kinnickinnic River located in western St. Croix and Pierce Counties, Wisconsin, terminating in the St. Croix River about 10 km (6 miles) north of the town of Prescott.

Location and description of type section. A stream embankment about 400 m north of County Highway FF. The embankment is 11 m high and is located in the SE¼SW¼SW¼ sec. 12, T. 27 N., R. 19 W., Pierce County, an area shown on the River Falls West 7.5-minute quadrangle (fig. 13).

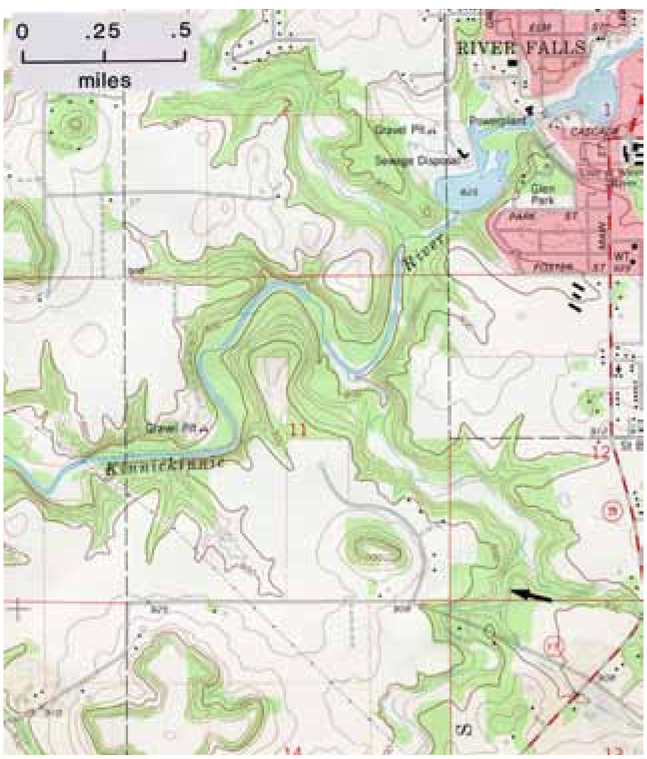

Figure 13. Part of the River Falls West 7.5-minute quadrangle showing the location of the type section of the Kinnickinnic Member.

Description of TYPE SECTION

Depth (m)	Horizon	Description
Colluvial material		
0.00–0.08	A1	Very dark grayish-brown (10YR 3/2) loamy sand; weak granular structure; very friable.
0.08–0.16	A2	Black (10YR 2/1) loamy sand; weak subangular blocky structure; very friable; clear wavy boundary.
0.16–0.24	C1	Yellowish-brown (10YR 5/6) loamy sand; weak subangular blocky structure; very friable; clear wavy boundary.
Kinnickinnic Member lake sediment		
0.24–0.46	2C2	Brown (10YR 5/3) sandy loam with many distinct mottles; platy structure; wavy boundary.
0.46–0.69	2C3	Yellowish-brown (10YR 5/6) silt loam; platy structure; clear, smooth boundary.
0.69–1.20	2C4	Yellowish-brown (10YR 5/4) silt loam with many faint yellowish-brown (10YR 5/6) mottles; platy structure; abrupt boundary.
1.20+	2C5	Dark gray (5YR 4/1) silty clay loam with dark yellowish brown (10YR 4/6) sandy laminae; platy structure.

Location of reference section. A stream embankment about 500 m north of County Highway FF, in an exposure on the east bank of an intermittent tributary to the Kinnickinnic River. The exposure is 17 m high and it is located in the SW¼NW¼ sec. 15, T. 27 N., R. 19 W., Pierce County, an area shown on the River Falls West 7.5-minute quadrangle (fig. 14).

Description of REFERENCE SECTION

Depth (m)	Horizon	Description
Colluvial material		
0.0–0.08	A	Dark grayish-brown (10YR 4/2) sandy loam; moderate granular structure; very friable; clear, wavy boundary.
0.08–0.20	AB	Dark grayish-brown (10YR 4/2) sandy loam; weak subangular blocky structure; very friable; clear, wavy boundary.
0.20–0.33	BA	Dark yellowish-brown (10YR 4/4) sandy loam; weak subangular blocky structure; friable; wavy boundary.
0.33–0.51	Bw	Strong brown (7.5YR 5/6) sandy loam; weak subangular blocky structure; friable, abrupt boundary.
Kinnickinnic Member lake sediment		
0.51–1.38	2C1	Yellowish-brown (10YR 6/8) silt loam; strong angular blocky structure; wavy boundary.
1.38–7.84	2C2	Dark gray (5YR 4/1) silty clay loam with dark yellowish-brown (10YR 4/6) laminae; platy structure.
7.84+	3C	Olive-yellow (2.5Y 6/8) sand.

Description of unit. The Kinnickinnic Member consists of thinly laminated calcareous glacial lacustrine sediment. Its color varies vertically within the weathering profile from very dark grayish brown (10YR 3/2) in the oxidized zone to dark gray (10YR 4/1) in the unoxidized zone. The Kinnickinnic Member is silt loam, averaging 14 percent sand, 66 percent silt, and 20 percent clay. Because of its high silt and clay content, the Kinnickinnic Member has a low permeability and consequently has undergone rather limited soil development; the solum generally is less than 2 m thick, and leaching rarely occurs to depths greater than 2.8 m. The Kinnickinnic Member averages 50 percent montmorillonite, 25 percent kaolinite, 15 percent illite, and 10 to 15 percent vermiculite.

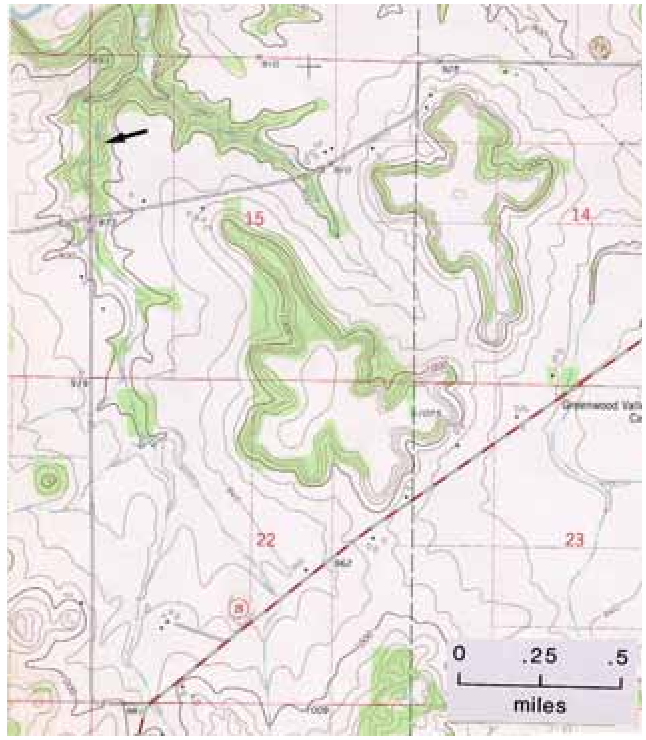

Figure 14. Part of the River Falls West 7.5-minute quadrangle showing the location of the reference section of the Kinnickinnic Member.

Nature of contacts. The lower contact between the Kinnickinnic Member and the Hersey Member, where visible, varies from sharp to interfingering. In areas where it is buried by the River Falls Formation, the upper contact of the Kinnickinnic Member is abrupt and sharp.

Differentiation from other units. The Kinnickinnic Member is readily distinguishable from other till units in western Wisconsin largely on the basis of its distinctive, thinly laminated nature. It can also be differentiated on the basis of its high silt and clay content (more than 80 percent) and its dark gray color. It can be distinguished from the Eau Galle Member by its stratigraphic position, by the lower clay content (20 percent as compared to 57 percent), by less montmorillonite (50 percent as compared to 65 percent), and by a greater amount of kaolinite (25 percent as compared to 10 percent).

Regional extent and thickness. The Kinnickinnic Member is found at elevations below about 365 m (1200 feet) in the valleys of the Kinnickinnic, Trimbelle, Rush, Chippewa, and Buffalo Rivers. Its distribution in these valleys is not uniform due to episodes of cutting and filling that have occurred since its deposition. In the Kinnickinnic River valley and in the upper Trimbelle and Rush River valleys, the Kinnickinnic Member is buried beneath the River Falls Formation. Because the lower contact of the Kinnickinnic Member is frequently not observable, its maximum thickness is unknown. Based on measurements made in vertical exposures, it is known to be at least 21 m thick.

Origin. The Kinnickinnic Member was deposited in an extensive, interconnected network of glacially dammed lakes. The glacial advance that deposited the Hersey Member also blocked the drainage of the Kinnickinnic, Trimbelle, Rush, Chippewa, and Buffalo Rivers, forming a series of ice-dammed lakes. As the glacier retreated from its maximum position, these lakes lengthened to the southwest. Based on the distribution of the Kinnickinnic Member in these valleys, the lake complex covered an area of over 5800 km^2. Estimates of sedimentation rates by counting varves indicate that these lakes existed for a minimum of 1200 years (Baker, 1984).

Age and correlation. The deposition of the Kinnickinnic Member probably took place before the Illinoian Glaciation based on its reversed-to-normal remanent magnetism. See the Pierce Formation section for details about age determination. Till-like sediment deposited before the Illinoian Glaciation has been found on the Bridgeport Strath at the mouth of the Wisconsin River near Prairie du Chien. Associated fluvial-glacial sediment show eastward drainage and are likely age correlative with the Kinnickinnic Member. These sediments also have similar clay mineralogy with the Kinnickinnic Member. The Bridgeport sediments are possibly associated with the same glacial advance responsible for the Kinnickinnic Member (Knox, 1982; Knox and others, 1982; Knox and Attig, 1988; Baker and others, 1998).

Previous usage. This unit was formalized in Mickelson and others (1984).

Marathon Formation

William N. Mode

Source of name. Marathon County, Wisconsin.

Location and description of type section. Gravel pit off west side of Ryan Street, 2.4 km (1.5 miles) south of Highway 29. It is located in the SW¼SW¼NE¼ sec. 27, T. 28 N., R. 8 E., Marathon County, an area shown on the Wausau 15-minute quadrangle (fig. 15). This type section also serves as the type section for the Wausau Member.

The type section is located about 100 m west of Ryan Street in a gravel pit. In the west wall of the pit, about 1 to 2 m of till of the Wausau Member overlies deeply weathered granitic saprolite.

Location of reference sections. Type and reference sections of the Edgar Member and the reference section of the Wausau Member serve as reference sections for the Marathon Formation.

Description of unit. The Marathon Formation contains till and associated sand and gravel that are generally light gray, pale yellow, or pale brown depending on the amount of oxidation. Three members are recognized. The lowest is the Wausau Member, which contains brown loam till (mean grain size 43 percent sand, 34 percent silt, and 23 percent clay). Overlying the Wausau Member is the Medford Member containing somewhat siltier, gray loam to silt loam till (mean grain size 33 percent sand, 47 percent silt, and 20 percent clay). The uppermost unit, the Edgar Member, contains brown loam till (mean grain size 33 percent sand, 43 percent silt, and 24 percent clay). Sand and gravel units within the formation have not been described in detail.

Nature of contacts. The Marathon Formation overlies Precambrian bedrock in most of Marathon County. The bedrock is sometimes unweathered, but generally it is decomposed to depths of several meters. This formation is the surficial unit in most of Marathon County, except in the far northern and western parts, where it is overlain by the redder and sandier Copper Falls Formation, and in the far eastern part, where it is presumably overlain by the Horicon Member of the Holy Hill Formation.

Figure 15. Part of the Wausau 15-minute quadrangle showing the location of the type section of the Marathon Formation and the Wausau Member.

Differentiation from other units. Till of the Marathon Formation is finer textured and is yellower than till of the overlying Copper Falls Formation. Lithologically, the clay mineral assemblage of till of the Marathon Formation contains more smectite and less illite than does till of the Bakerville and Merrill Members of the Copper Falls Formation.

Regional extent and thickness. The thickness of the Marathon Formation is as much as 20 m. It is thinnest at its southern limit in Marathon, Wood, and Clark Counties. The formation is thickest where it fills buried valleys (Bell and Sherrill, 1974). It generally thickens northward and extends beneath the Copper Falls Formation to the north. The extent of this formation beneath the Copper Falls Formation and the Horicon Member of the Holy Hill Formation (to the east) is not known.

Age and correlation. Lithologic similarity, position in sequence, and mapped distribution suggest that the Marathon Formation is correlative with the Pierce Formation of western Wisconsin (Syverson and Colgan, 2004). The Hersey Member of the Pierce Formation (Baker and others, 1983) and the Medford Member of the Marathon Formation (Syverson and others, 2005) both have reversed remanent magnetism, suggesting deposition before the Illinoian Glaciation. If so, then the Wausau Member was deposited before the Illinoian Glaciation as well.

Previous usage. Formalized in Mickelson and others (1984).

Marathon Formation: Wausau Member

William N. Mode

Source of name. The city of Wausau, Marathon County, Wisconsin.

Location and description of type section. Gravel pit off west side of Ryan Street, 2.4 km (1.5 miles) south of Highway 29. It is located in the SW¼SW¼NE¼ sec. 27, T. 28 N., R. 8 E., Marathon County, an area shown on the Wausau 15-minute quadrangle (fig. 15). This type section also serves as the type section for the Marathon Formation.

The type section is located about 100 m west of Ryan Street in a gravel pit. In the west wall of the pit, about 1 to 2 m of till of the Wausau Member overlies deeply weathered granitic saprolite.

Location of reference section. Road cut on west side of North 57th Street, about 50 m north of its intersection with East Butternut Road, SE¼SE¼SE¼ sec. 4, T. 29 N., R. 8 E., Marathon County, an area shown on the Nutterville 7.5-minute quadrangle (fig. 16). The reference section is in a roadside ditch exposure which contains about 1 m of till of the Wausau Member capped by 10 to 20 cm of loess.

Description of unit. The Wausau Member typically contains a pebbly loam to clay loam till in which the less-than-2 mm fraction averages 43 percent sand, 34 percent silt, and 23 percent clay (15 samples). A high proportion (greater than 30 percent) of the pebbles are extensively weathered, and many of the intact clasts appear to have been mixed upward into the till from the underlying bedrock by frost action and tree throw. The field color of the till is predominantly brown (7.5YR 4/4). Coarse-sand fraction components are 75 percent igneous, 6 percent metamorphic, and 19 percent sedimentary rock. The clay minerals average 44 percent illite, 5 percent kaolinite plus chlorite, 18 percent vermiculite, and 32 percent smectite (Mode, 1976).

Nature of contacts. The Wausau Member typically is thin (less than 10 m) and rests directly on bedrock, on bedrock that has undergone granular disintegration, or on saprolite. These contacts are usually sharp, though some upward mixing of local bedrock into the till is usually apparent. No exposures of upper contacts of the Wausau Member with another unit are known.

Differentiation from other units. The Wausau Member is texturally distinct from the Merrill and Nashville Members of the Copper Falls Formation because it is finer grained, from the Bakerville Member of the Copper Falls Formation because it is less red in color, and from the Edgar Member because its modal grain size is not silt.

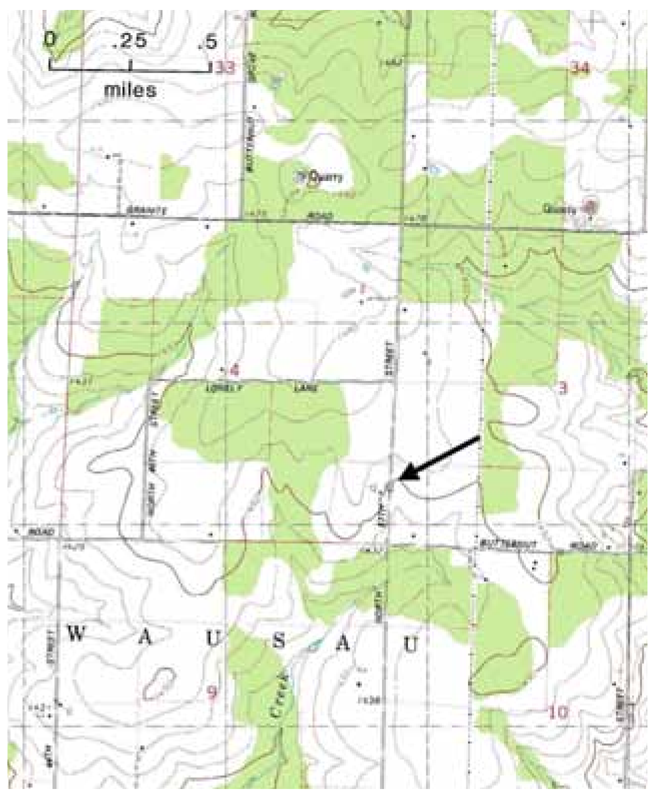

Figure 16. Part of the Nutterville 7.5-minute quadrangle showing the location of the reference section of the Wausau Member.

Regional extent and thickness. The Wausau Member is the surficial material over much of central Marathon and northern Wood Counties, and it is also present in the subsurface in western and north-central Marathon County. The till generally thins toward the south and toward the Wisconsin River.

Origin. Till of the Wausau Member was deposited by southeastward-flowing ice. The till has subsequently been altered considerably by weathering and erosion. The member also includes slopewash sediment and related sediments, but these may be recognized as a separate member in the future.

Age and correlation. The Wausau Member is older than 40,800 ± 2000 ^{14}C yr B.P. (44,741 ± 1735 cal. yr B.P., ISGS-256). This date is from organic deposits on top of the Merrill Member of the Copper Falls Formation, a unit that overlies the Wausau Member. Clay mineral studies by Stewart and Mickelson (1976) and Mode (1976) suggest deposition before the Wisconsin Glaciation. The overlying Medford Member has reversed remanent magnetism (Syverson and others, 2005), suggesting that the Wausau Member was deposited before the Illinoian Glaciation. The patchy distribution of till and lack of constructional topography make correlation difficult. The Wausau Member can be tentatively correlated with the lowest member of the Pierce Formation (the Woodville Member) of western Wisconsin based only on its basal position in the sequence.

Previous usage. First used as an informal unit name by LaBerge and Myers (1971) and subsequently by several writers including Stewart (1973), Mode (1976), and LaBerge and Myers (1983). Formalized in Mickelson and others (1984).

Marathon Formation: Medford Member

John W. Attig and Maureen A. Muldoon

Source of name. Town of Medford, Taylor County, Wisconsin.

Location and description of type section. A stream cut in the south bank of the Little Black River, southwest of the community of Medford. It is located in the SE¼NE¼SE¼ sec. 3, T. 30 N., R. 1 E., Taylor County, an area shown on the Stetsonville 7.5-minute quadrangle (fig. 17).

The stream bank is about 8 m high. In the uppermost 2 m of the bank, the reddish-brown, noncalcareous, sandy till of the Merrill Member of the Copper Falls Formation is exposed. Beneath the till of the Merrill Member, 3 m of dark gray, calcareous, silty till of the Medford Member of the Marathon Formation is exposed. There is a sharp contact between the two units. The sediment underlying the lower part of the bank is buried by slopewash sediment. In a drill hole (Mr-1146) about 15 m south of the type section, about 7 m of the Edgar Member of the Marathon Formation lies between the Merrill and Medford Members.

Location and description of reference sections. Two closely spaced power-auger holes (Wisconsin Geological and Natural History Survey numbers Mr-1138 and Mr-1169) near the crest of a hill, between two barns, on the north side of County Highway N, in the SE¼SW¼SW¼ sec. 17, T. 28 N., R. 2 E., Marathon County, an area shown on the Abbotsford 7.5-minute quadrangle (fig. 18).

Figure 17. Part of the Stetsonville 7.5-minute quadrangle showing the location of the type section of the Medford Member.

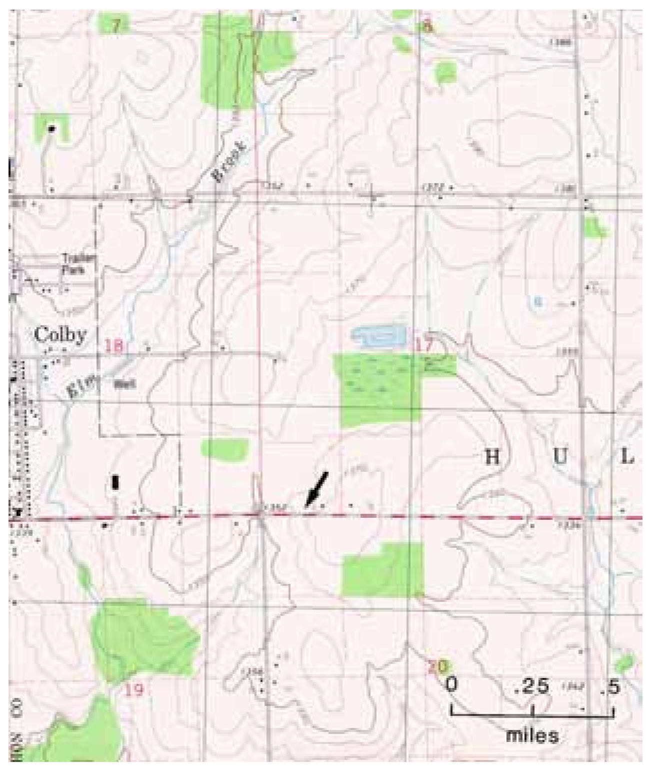

Figure 18. Part of the Abbotsford 7.5-minute quadrangle showing the location of the reference section of the Medford Member.

The auger penetrated 7.4 m of yellowish-brown to brown, calcareous loamy material that Attig and Muldoon (1989) interpreted as till of the Edgar Member; this material is leached to a depth of 2.6 m. The auger then penetrated 3.5 m of dark grayish-brown to gray, calcareous, loam to silt loam, and a 0.22 m layer of silty sand at 9.7 m. The loamy material was not leached; it is interpreted to be till of the Medford Member.

Description of unit. The Medford Member contains till and associated lake and stream sediment. Medford Member till is calcareous loam or silt loam. The less-than-2 mm fraction of the till averages 33 percent sand, 47 percent silt, and 20 percent clay (23 samples). Semiquantitative analysis of clay mineralogy of four samples averages 45 percent montmorillonite, 13 percent vermiculite, 26 percent illite, and 16 percent kaolinite plus chlorite. Average magnetic susceptibility is 1.4×10^{-3} (SI units, 23 samples). The average carbonate content of the coarse-silt fraction of six samples was 5.1 percent by weight, containing 1.8 percent calcite and 3.3 percent dolomite. Moist field color is typically very dark gray to gray (10YR 3/1 to 2.5Y 5/1). The pebble fabric in this unit (measured in four locations at the type section) is strongly developed; the long axes of most pebbles are oriented north-northwest to south-southeast and dip upglacier (north-northwest).

Nature of contacts. The lower contact of this unit has only been observed in three drill holes. In those holes the contact with undifferentiated Marathon Formation material is sharp. In many areas the Medford Member is overlain by till of the Edgar Member of the Marathon Formation. The contact with the overlying material is typically sharp.

Differentiation from other units. Till of the Medford Member is distinguished from the overlying till of the Edgar Member by color and clay mineralogy. Medford Member till is darker, grayer, and contains more shale fragments and more montmorillonite clay (45 percent) than Edgar Member till (33 percent).

Regional extent and thickness. Except at the type section, the Medford Member has been identified only in the subsurface. Drill-hole logs from northwestern Marathon County and southeastern Taylor County are the only record of this unit. It presumably extends into Clark County as well. Till of the Medford Member ranges in thickness from 4 to 7 m.

Origin. Till of the Medford Member was deposited by ice flowing from the north-northwest during the Stetsonville Phase (Attig and Muldoon, 1989).

Age and correlation. The age of the Medford Member is not known. The unit was deposited before the last part of the Wisconsin Glaciation. The Medford Member has reversed remanent magnetization (Syverson and others, 2005), as does the Hersey Member of the Pierce Formation in western Wisconsin (Baker and others, 1983). Both units were likely deposited before the Illinoian Glaciation and might be correlative units (Baker, 1984; Syverson and Colgan, 2004).

Previous usage. This name has been used by Muldoon (1987) and by Attig and Muldoon (1989). Formalized in Attig and others (1988).

Marathon Formation: Edgar Member

William N. Mode

Source of name. The village of Edgar, Marathon County, Wisconsin, which is located in the west-central part of the Edgar 7.5-minute quadrangle.

Location and description of type section. Railroad cut (Chicago and Northwestern) on south side of County Highway N. It is located in the NW¼NE¼NW¼ sec. 24, T. 28 N., R. 4 E., Marathon County, an area shown on the Edgar 7.5-minute quadrangle (fig. 19).

The deepest part of the Chicago and Northwestern Railroad cut is about 200 m south of County Highway N. The cut is thoroughly covered with vegetation so that a large exposure has never been examined. Samples for laboratory analysis and till fabric determination were obtained from a pit dug into the wall of the cut. An auger borehole just west of the type section revealed that the Edgar Member overlies more than 4 m of either organic colluvium or till of an unnamed member.

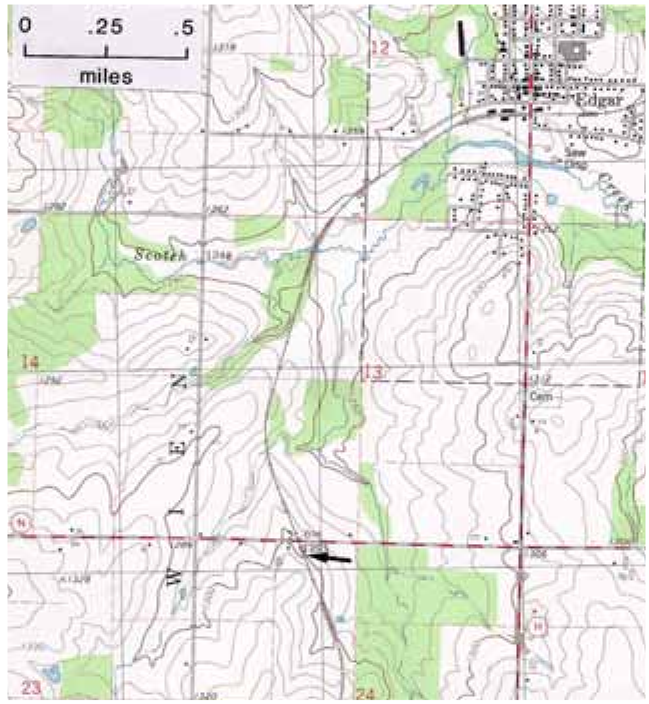

Figure 19. Part of the Edgar 7.5-minute quadrangle showing the location of the type section of the Edgar Member.

Location of reference section. Railroad cut (Minneapolis, St. Paul, and Sault Ste. Marie) on north side of Yellowstone Drive, about 0.5 km (0.3 mile) west of its intersection with Day Road, and about 0.9 km (0.6 mile) east of the village of Hewitt; located in the SE¼SW¼SE¼ sec. 13, T. 25 N., R. 3 E., Wood County, an area shown on the Hewitt 7.5-minute quadrangle (fig. 20). The reference section is well vegetated but contains at least 2 to 3 m of till of the Edgar Member at about the level of the track.

Figure 20. Part of the Hewitt 15-minute quadrangle showing the location of the reference section of the Edgar Member.

Description of unit. Till of the Edgar Member is typically pebbly loam to clay loam to silt loam; the less-than-2 mm fraction averages 33 percent sand, 43 percent silt, and 24 percent clay (17 samples). The field color of the till is variable, ranging from yellowish brown (10YR 5/6) to reddish brown (5YR 4/4). Unweathered till of the Edgar Member is calcareous, with up to 10 percent dolomite pebbles. The coarse sand fraction components are 72 percent igneous, 7 percent metamorphic, and 21 percent sedimentary. Average clay mineralogy is 44 percent illite, 6 percent kaolinite plus chlorite, 17 percent vermiculite, and 33 percent smectite (Mode, 1976).

Nature of contacts. The Edgar Member is generally thin (less than 10 m), and its lower contacts have never been observed in outcrop. In auger holes, it has a sharp upper contact with sandier materials overlying it and a sharp lower contact with bedrock, organic-rich sediment, or the Wausau or Medford Members.

Differentiation from other units. Till of the Edgar Member is distinguished from the Wausau Member by two characteristics: (1) it is calcareous (where unweathered) and (2) it is silty. Till of the Edgar Member is distinguished from the underlying till of the Medford Member by color and clay mineralogy. Edgar Member till is lighter in color and contains fewer shale fragments and less montmorillonite clay (33 percent) than Medford Member till (45 percent).

Regional extent and thickness. The Edgar Member has only been found in northern Wood, southwestern Marathon, and eastern Clark Counties, an area around the city of Marshfield. North and west of Marshfield, the Edgar Member is generally buried by the Bakerville Member of the Copper Falls Formation; south and east of Marshfield, it is exposed at the surface. The Edgar Member is generally less than 3 to 4 m thick except atop a low divide that extends east-southeastward from Marshfield, where it thickens to as much as 10 m.

Origin. Southward-flowing ice deposited the till of the Edgar Member (Mode, 1976) during the Milan Phase (Attig and Muldoon, 1989). Clayton (1991) observed fossils in stream sediment associated with the Edgar Member, and he proposed a source area in Manitoba.

Age and correlation. The Edgar Member underlies the Bakerville Member of the Copper Falls Formation, which in turn is older than or equivalent to the Merrill Member of the Copper Falls Formation. The Merrill Member is overlain by material radiocarbon dated at 40,800 ± 2000 ^{14}C yr B.P. (44,741 ± 1735 cal. yr B.P., ISGS-256); therefore, the Edgar Member is beyond radiocarbon range, presumably deposited before, or during the early part of, the Wisconsin Glaciation. The Medford Member, with reversed remanent magnetization, underlies the Edgar Member. If the Medford Member was deposited before the Illinoian Glaciation (Syverson and Colgan, 2004; Syverson and others, 2005), this provides a maximum age constraint for the Edgar Member. There are no known correlatives of the Edgar Member.

Previous usage. First used as an informal unit name by Mode (1976) and formalized in Mickelson and others (1984).

River Falls Formation

Robert W. Baker

Source of name. The city of River Falls, Pierce County, Wisconsin.

Location and description of type section. An exposure 13 m high on the south side of an abandoned gravel quarry, 300 m south of County Highway E, approximately 4 km (2.5 miles) northeast of Baldwin. It is located in the SE¼NE¼NE¼ sec. 18, T. 29 N., R. 16 W., St. Croix County, an area shown on the Emerald 7.5-minute quadrangle (fig. 21).

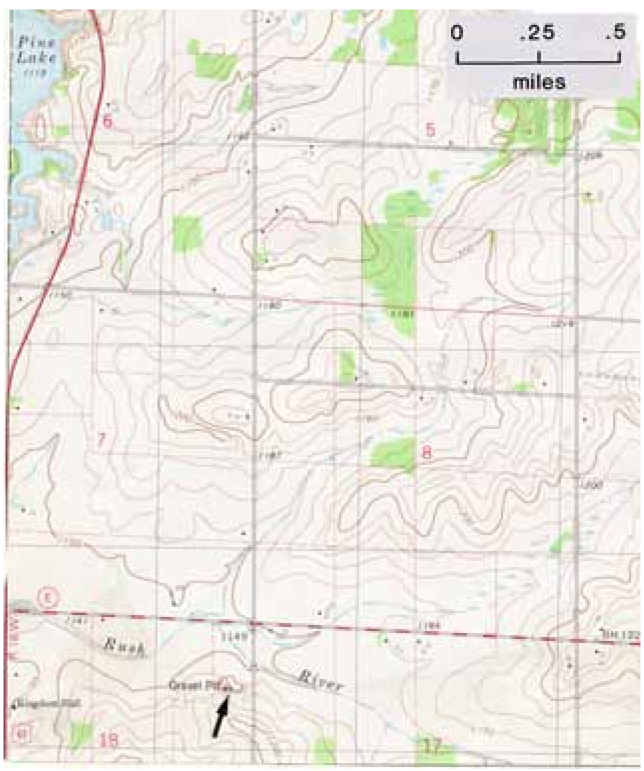

Figure 21. Part of the Emerald 7.5-minute quadrangle showing the location of the type section of the River Falls Formation.

Description of TYPE SECTION

Depth (m)	Horizon	Description
Kieler Formation (Peoria member) loess		
0.0–0.20	Ap	Dark brown (10YR 3/3) loam; weak, granular structure; very friable; clear smooth boundary.
0.20–0.38	E	Dark yellowish-brown (10YR 4/4) silty clay loam; moderate subangular blocky structure; friable; clear wavy boundary.
River Falls Formation till		
0.38–0.76	2Bt1	Dark reddish-brown (5YR 3/4) sandy loam to sandy clay loam; moderate subangular blocky structure; friable; gradual wavy boundary.
0.76–0.96	2Bt2	Reddish-brown (5YR 4/4) sandy clay loam; weak subangular blocky structure; friable; gradual wavy boundary.
0.96–1.40	2Bt3	Yellowish-red (5YR 4/6) sandy clay loam with grayish brown (10YR 5/2) inclusions; weak subangular blocky structures; friable; gradual wavy boundary.
1.40–2.16	2C	Yellowish-red (5YR 4/6) sandy clay loam with dark gray (10YR 4/1) and light brownish-gray (10YR 6/2) inclusions; weak subangular blocky structures; friable; abrupt wavy boundary.
Sand and gravel		
2.16–2.81	3Btb	Dark brown (7.5 YR 4/4) sandy clay loam; moderate subangular blocky structure; friable; gradual wavy boundary.
2.81–3.50	3C	Dark reddish-brown (5YR 3/4) sandy clay loam to sandy loam; strong medium and coarse angular to subangular blocky structure; slightly compact in places; a few lenses of gray till.

Location and description of reference section. An exposure 5 m high on the west side of an abandoned gravel pit about 50 m south of Pleasant Valley Road, approximately 8 km (5 miles) southeast of River Falls. It is located in the SW¼SW¼NE¼ sec. 28, T. 27 N., R. 18 W., Pierce County, an area shown on the River Falls East 7.5-minute quadrangle (fig. 22).

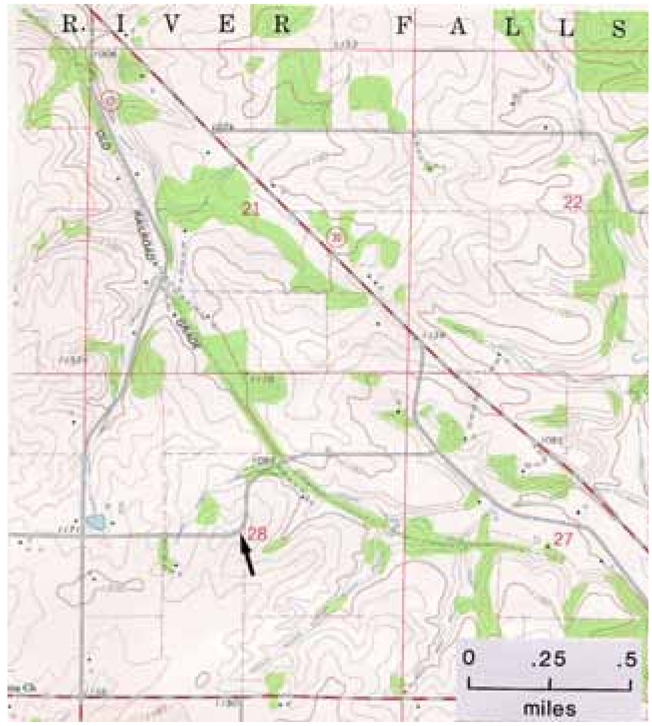

Figure 22. Part of the River Falls East 7.5-minute quadrangle showing the location of the reference section of the River Falls Formation.

Description of REFERENCE SECTION

Depth (m)	Horizon	Description
Kieler Formation (Peoria Member) loess		
0.0-0.23	Ap	Brown to dark brown (10YR 4/3) silt loam; weak granular structure; very friable; wavy boundary.
0.23-0.35	BA	Dark yellowish-brown (10YR 4/4) loam; weak subangular blocky structure; very friable; abrupt wavy boundary.
River Falls Formation till		
0.35-0.40	2Bt1	Reddish-brown (5YR 4/4) sandy clay loam; moderate subangular blocky structure; friable; clear wavy boundary.
0.40-0.94	2Bt2	Reddish-brown (5YR 4/4) sandy clay loam; moderate subangular blocky structure; friable; common patches of sand; diffuse wavy boundary.
0.94-1.35	2Bt3	Reddish-brown (5YR 4/4) sandy clay loam; moderate subangular blocky structure; friable; clear wavy boundary.
1.35-2.20	2BC	Yellowish-red (5YR 4/6) sandy loam; moderate subangular blocky structure; friable; clear wavy boundary.
2.20-2.54	2C1	Reddish-brown (5YR 4/4) sandy clay loam; structureless; very friable.
Pierce Formation sand and gravel		
2.54+	3C	Olive-yellow (2.5Y 6/8) sand.

Description of unit. Most of the till of the River Falls Formation is structureless basal till. However, locally in St. Croix County the upper portion of the unit is weakly stratified, containing discontinuous lenses of fine sand, and is probably of supraglacial origin. The color of the River Falls till varies vertically within the weathering profile from yellowish red (5YR 4/6) in the argillic horizon to reddish brown (5YR 4/4) in the C horizon. The River Falls Formation is deeply weathered with solum thicknesses of up to 2.8 m. The unweathered till is sandy clay loam averaging 60 percent sand, 15 percent silt, and 25 percent clay. The weathered River Falls Formation till is also sandy clay loam; however, the particle size varies somewhat depending on the position in the solum. Pebble lithologies average 64 percent igneous, 11 percent metamorphic, and 25 percent sedimentary rock (samples counted at nine sites). The clay-sized fraction of the River Falls Formation till averages 30 to 40 percent montmorillonite, 20 to 25 percent kaolinite, 15 to 20 percent vermiculite, 5 to 10 percent illite, and as much as 5 percent quartz.

Nature of contacts. The lower contact of the River Falls Formation with the underlying Hersey Member is everywhere sharp and abrupt. Likewise, where observable, the upper contact between the River Falls Formation and the till and associated sand and gravel of the Copper Falls Formation in the St. Croix moraine is also sharp and distinct.

Differentiation from other units. The till of the River Falls Formation is similar to reddish-brown Copper Falls Formation till of the St. Croix moraine. However, the two can easily be distinguished by their considerably different sola thicknesses. The solum thickness on till in the St. Croix moraine rarely exceeds 0.9 m, whereas in the River Falls Formation the solum thickness commonly exceeds 2.2 m. The River Falls Formation till can be distinguished from the underlying Hersey Member on the basis of its reddish-brown color, its higher sand and lower silt content, and its higher vermiculite and lower montmorillonite content.

Regional extent and thickness. The River Falls Formation is the surface unit in northern Pierce, eastern St. Croix, and western Dunn Counties. Its northern extent is unknown due to burial by the thick Copper Falls Formation sediment within the St. Croix moraine. In St. Croix County, the River Falls Formation ranges in thickness from less than 1 m on bedrock uplands to more than 10 m. In many areas, however, its exact thickness is unknown.

Origin. The color, texture, and clay and pebble mineralogy of the River Falls Formation are characteristic of sediment derived from the Lake Superior basin. This is supported by till fabric data, which suggest that till of the formation was deposited by a glacier that advanced from the north-northeast.

Age and correlation. The age of the River Falls Formation is unknown. Based on its thick solum, it is likely that the River Falls Formation was deposited before the Wisconsin Glaciation or during the early part of the Wisconsin Glaciation. Till of the River Falls Formation correlates with the "red drift" of the Hampton moraine of Minnesota, mapped by Ruhe and Gould (1954). It also appears to correlate with the Hawk Creek Till of western Minnesota (Matsch, 1972). Correlation with units to the east in Wisconsin that were deposited before the last part of the Wisconsin Glaciation is uncertain at this time.

Previous usage. This unit was called the Baldwin till by Baker and Simpson (1981). The River Falls Formation was formalized in Mickelson and others (1984).

River Falls Formation: Prairie Farm Member

Mark D. Johnson

Source of name. Community of Prairie Farm, Barron County, Wisconsin.

Location and description of type section. Road cut on south side of the east-west-trending 3½ Avenue. It is located in the NE¼NW¼SE¼ sec. 13, T. 32 N., R. 13 W., Barron County, an area shown on the Dority Creek 7.5-minute quadrangle (fig. 23). At this site, 0.2 to 0.4 m of loess overlies till of the Prairie Farm Member, which is exposed to a depth of 3 m. The upper part of the till contains stringers of sand that were intruded down into the till after its deposition. The sand occurs along root channels and may be the result of frost churning or tree tip. The pebble fabric, measured below the sand-stringer zone, indicates that the till was deposited by ice flowing S. 20° W. A transect of closely spaced samples shows that relative magnetic susceptibility increases with depth.

Location and description of reference sections. (1) Till in a road cut on the north side of the east-west-trending 8th Avenue. It is located in the SW¼SW¼SW¼ sec. 19, T. 33 N., R. 12 W., Barron County, an area shown on the Dority Creek 7.5-minute quadrangle (fig. 24). At this site, 0.3 to 0.4 m of loess overlies till of the Prairie Farm Member, which is exposed to a depth of 2 m. A pebble fabric at this site shows that the till was deposited by ice flowing S. 40° W.

(2) Sand in a pit (1982) located in the SW¼SW¼NE¼ sec. 5, T. 31 N., R. 9 W., Chippewa County, an area shown on the New Auburn 7.5-minute quadrangle (fig. 25). At this site loess overlies 3 m of sand of the Prairie Farm Member, which in turn overlies till. The sand at this site is crudely bedded horizontally and no sedimentary structures are apparent within beds. The sand contains up to

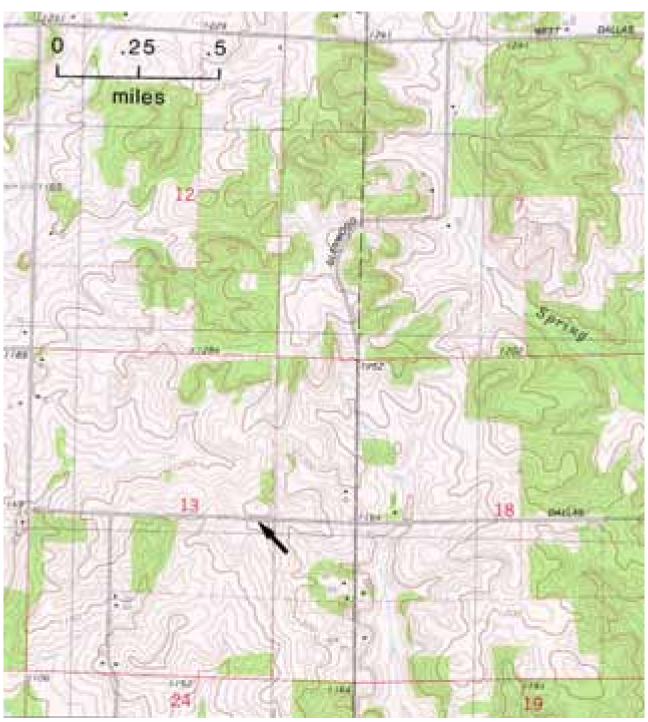

Figure 23. Part of the Dority Creek 7.5-minute quadrangle showing the location of the type section of the Prairie Farm Member.

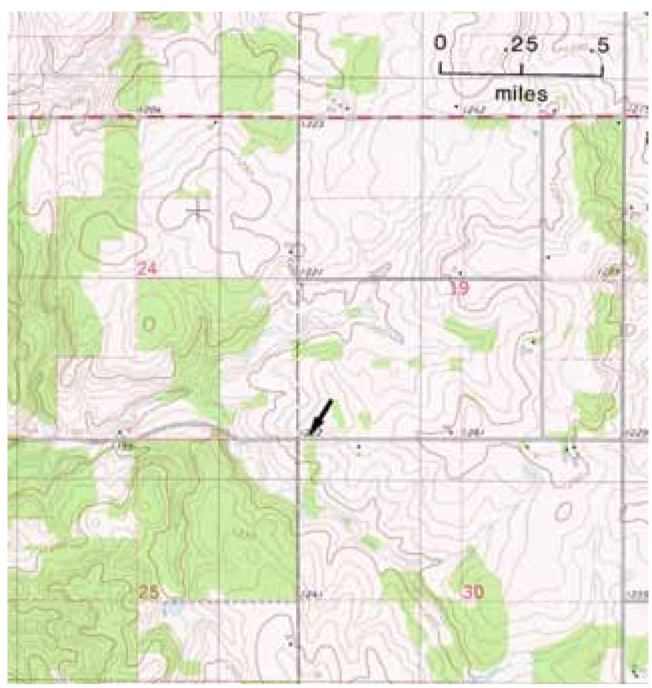

Figure 24. Part of the Dority Creek 7.5-minute quadrangle showing the location of reference section 1 of the Prairie Farm Member.

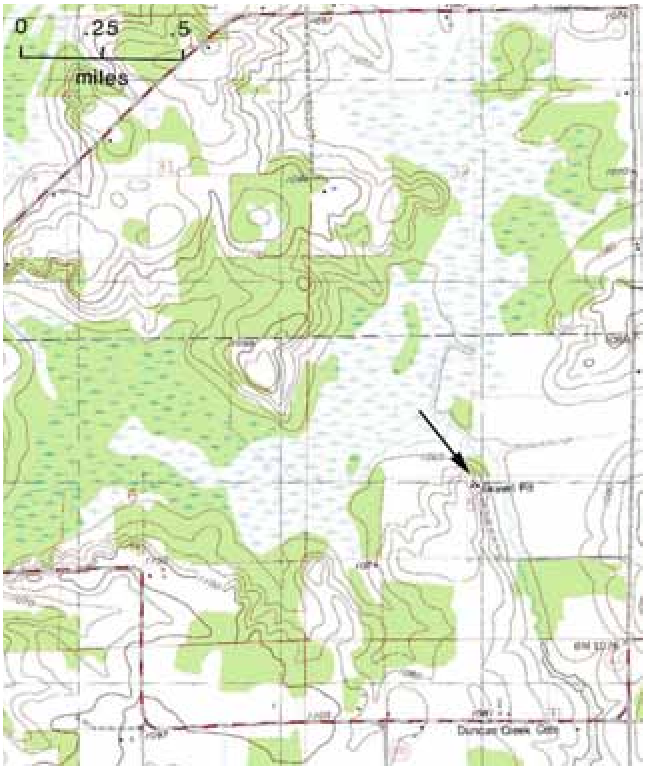

Figure 25. Part of the New Auburn 7.5-minute quadrangle showing the location of reference section 2 of the Prairie Farm Member.

8 percent clay, presumably illuviated into the sand, and this gives the sand a sticky feeling. The sand was probably deposited by streams, but the origin is not clear. A large channel-shaped deposit of cobble gravel truncates the sand in the west face of the pit, and an ice-wedge cast is visible in the south face. Illuviated clay coats the gravel in the channel but is not present in the sand of the ice-wedge cast. In the sand, magnetic susceptibility increases with depth.

Description of unit. Till of the Prairie Farm Member is unbedded and contains slightly gravelly to gravelly sandy loam with some slightly gravelly to gravelly loamy sand. The less-than-2 mm matrix averages 73 percent sand, 16 percent silt, and 11 percent clay. It is yellowish red to strong brown (5YR 4/6 to 4/8 to 7.5YR 4/8). The clay-mineral composition is variable; it averages 21 percent kaolinite, 53 percent illite, and 26 percent expandable clay. The very-coarse-sand fraction contains about 59 percent quartz, 5 to 6 percent fine-grained mafic rock, 4 to 5 percent granite, 10 percent coarse-grained mafic rock, 1 to 2 percent quartzite, 5 percent red sandstone, 2 percent other sandstone, and 11 to 12 percent other lithologies. The pebble fraction contains 22 percent fine-grained mafic rock, 15 percent coarse-grained mafic rock, 6 percent rhyolite, 9 percent granite and gneiss, 9 percent Barron quartzite, 17 percent Precambrian sandstone, 14 percent Cambrian sandstone, and 8 percent other lithologies. The relative magnetic susceptibility of the till is typically 4.9 (arbitrary units of the University of Wisconsin–Madison, Department of Geology and Geophysics Pleistocene laboratory). The unit is leached of carbonates to an unknown depth.

Nature of contacts. In the region where the till of the Prairie Farm Member crops out, it has a sharp contact with the underlying Cambrian sandstone. The contact with the overlying loess tends to be either sharp or gradational over a few centimeters.

Differentiation from other units. Till of the Prairie Farm Member contains more Barron quartzite in the pebble fraction (9 percent) than other till of the River Falls Formation (less than 1 percent), or the till of the Poskin (1 percent) or Sylvan Lake (1 or 2 percent) Members of the Copper Falls Formation. The till of the Prairie Farm Member has a lower relative magnetic susceptibility (4.9, arbitrary units) than till of the Copper Falls Formation (8 to 12, arbitrary units). Prairie Farm Member till is easily distinguishable from the till of the Pierce Formation, which is olive black, slightly gravelly loam. The kaolinite:illite ratio (Johnson, 1984) is higher in the till of the Prairie Farm Member (1.7:1) than in the till of the Poskin (1.4:1), Pokegama Creek (1.2:1), Sylvan Lake (1.1:1), and Mikana (1.0:1) Members of the Copper Falls Formation.

Regional extent and thickness. Till of the Prairie Farm Member occurs at the surface in a triangular-shaped area in southern Barron County (fig. 3). Its southern limit in Dunn County is not known. To the northeast, it extends to the southern margin of the Pokegama Creek Member; to the northwest, to the margin of the Poskin Member. In southwestern Barron County, till of the Prairie Farm Member lies adjacent to till of an unnamed member of the River Falls Formation. The till is less than 2 m thick in most surface exposures, although well logs show thicknesses as great as 10 m.

Origin. Till of the Prairie Farm Member was deposited during the Dallas Phase of the Chippewa Lobe (fig. 6, Johnson, M.D., 1986) by ice flowing to the south and southwest.

Age and correlation. The age of the Prairie Farm Member is unknown, but it probably was deposited before the Wisconsin Glaciation and prior to the last interglacial (MIS 5). Some of its characteristics (clay minerals, magnetic susceptibility) have been affected by weathering. This weathering suggests that the Prairie Farm Member is much older than the Copper Falls Formation, which was deposited during the last part of the Wisconsin Glaciation in the western part of the state. Baker and others (1983) concluded that the River Falls Formation was deposited in its type area either during the Illinoian Glaciation or the early part of the Wisconsin Glaciation. The Prairie Farm Member till is probably older than the till of the Merrill Member of the Copper Falls Formation (in north-central Wisconsin) because the till of the Merrill Member does not show similar weathering characteristics. Stewart and Mickelson (1976) concluded that the till of the Merrill Member was deposited during the early part of the Wisconsin Glaciation because of dates older than 40,800 ^{14}C yr B.P. (44,700 cal. yr B.P.). The till of the Prairie Farm Member is included with other till units in the River Falls Formation because it has similar grain size, color, magnetic susceptibility, and clay-mineral content. Prairie Farm Member till was probably deposited at about the same time as the River Falls Formation in St. Croix County as described by Baker and others (1983). It may be similar in age to the Edgar Member of north-central Wisconsin (Mode, 1976). The Edgar Member appears to be similarly weathered because it has lower magnetic susceptibility near the surface.

Previous usage. First used by M.D. Johnson (1984, 1986). Formalized in Attig and others (1988).

Walworth Formation

David M. Mickelson

Source of name. Walworth County, southern Wisconsin.

Location and description of type section. Road cut and test hole along new Highway 15 (the Beloit-Milwaukee Road), 3.2 km (2 miles) northeast of Clinton. It is located in the NE¼SW¼ sec. 3, T. 1 N., R. 14 E., Rock County, an area shown on the Clinton 7.5-minute quadrangle (fig. 26). This road cut and test hole also serve as the type section for the Clinton Member of the Walworth Formation.

Loess 2.1 m thick overlies a truncated B horizon 1.5 m thick developed in Clinton Member till. Clinton Member till extends to the bottom of the cut 8 m below the surface. A drill hole penetrates Clinton Member till to a depth of 14.6 m below the top of the cut.

Location of reference sections. Type sections of the Foxhollow and Allens Grove Members serve as reference sections for this formation. In addition, all reference sections of the Foxhollow, Allens Grove, and Clinton Members serve as reference sections for the Walworth Formation

Description of unit. The Walworth Formation includes till and associated sand and gravel which are generally sandy and gray (unoxidized) to brown (oxidized). Fricke (1976) recognized three members. The oldest, the Foxhollow Member, contains gray (unoxidized), loamy till which averages 44 percent sand, 37 percent silt, and 19 percent clay. This is overlain by the somewhat sandier Allens Grove Member till which averages 53 percent sand, 35 percent silt, and 12 percent clay. The uppermost unit, the Clinton Member, contains sandier till with an average grain size of 61 percent sand, 27 percent silt, and 12 percent clay. Sand and gravel within the formation has not been described in detail.

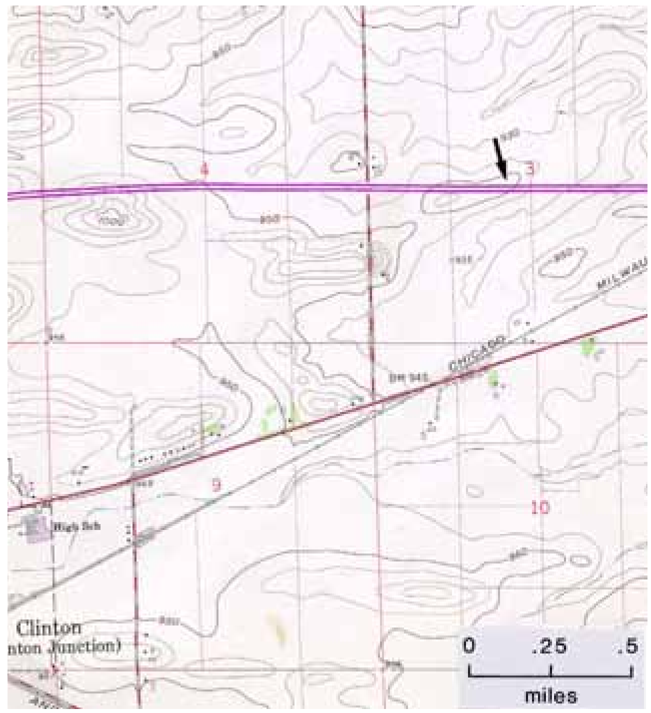

Figure 26. Part of the Clinton 7.5-minute quadrangle showing the location of the type section of the Walworth Formation and the Clinton Member.

Nature of contacts. The Walworth Formation is the surficial unit in eastern Rock and western Walworth Counties. In eastern Walworth County it is overlain by the Zenda Formation, which contains more silt and clay and is distinctly red or pink in outcrop. The basal contact is generally not known except where members lie on pre-Pleistocene rock.

Differentiation from other units. Till of the Walworth Formation can be distinguished from till of the overlying Zenda Formation by the greater sand percentage and the lack of the reddish color typical of the Zenda Formation (Fricke, 1976; Johnson, 1976). The extent of the Walworth

Formation to the west and its differentiation from older units described by Bleuer (1971) and Miller (2000) are not known at this time.

Regional extent and thickness. The Walworth Formation ranges in thickness from only a few meters on top of bedrock highs in eastern Rock County to approximately 80 m in the Rock River valley in western Rock County. Its extent eastward beneath the Zenda Formation (fig. 3) and northward beneath the Horicon Member of the Holy Hill Formation (fig. 3) is unknown. It extends as a surficial unit from western Walworth County (Ham and Attig, 2004) to the valley of the Rock River in central Rock County where it abuts sand and gravel of the Horicon Member. It extends at least into western Rock County, but the western edge of the formation is not mapped. Miller (2000) mapped units west of the Rock River, but these units are not formally defined.

Age and correlation. The age of the Walworth Formation is unknown. Correlative deposits in Illinois were assumed to have been deposited during the early part of the Wisconsin Glaciation (the Altonian Glaciation of Willman and Frye, 1970), but all of these are older than 130,000 cal. yr B.P. based on OSL dates; thus, they are older than the last interglacial (R. Berg, Illinois State Geological Survey, oral communication, 2009). The Foxhollow Member probably has an unnamed correlative in Illinois, but correlatives in Wisconsin are unknown. The Allens Grove Member is evidently equivalent to the Argyle Till Member of Illinois. The Clinton Member extends as the surficial unit into Illinois but it has not been formally named there. Clinton Member till has been correlated with the Argyle Till Member of Illinois in the past, but this correlation has not been reviewed in the light of recent work in Illinois (R. Berg, oral communication, 2009).

Previous usage. Formalized in Mickelson and others (1984).

Walworth Formation: Foxhollow Member

Carl Fricke and David M. Mickelson

Source of name. The locality of Foxhollow, Rock County, Wisconsin.

Location and description of type section. Test hole drilled approximately 5 km (3 miles) east of Beloit on the east side of Town Hall Road and north of State Highway 67 (formerly part of County Highway P). It is located in the center of the NE¼SE¼NE¼ sec. 33, T. 1 N., R. 13 E., Rock County, an area shown on the Shopiere 7.5-minute quadrangle (fig. 27).

The type section is test hole 671 of Fricke (1976). Here the Foxhollow Member is overlain by 5.5 m of Allens Grove Member, which is in turn overlain by 4.3 m of Clinton Member till at the surface. The boring penetrated 3.0 m of gray till of the Foxhollow Member before refusal. The Foxhollow Member here contains abundant wood chips.

Description of unit. The Foxhollow Member contains a pebbly, silty, and clayey till. Its overall color is gray, ranging from silver to brownish gray and purplish gray. In the type section test hole, the upper 0.6 m of the Foxhollow Member till is oxidized and red in color. The till also contains wood fragments. Numerous dolomite pebbles and igneous stones are found in the till. The ratio of light-colored to dark-colored dolomite in the very coarse sand (1 to 2 mm) size range is equal to or less than 0.8:1. Semiquantitative clay mineral analyses average 28 percent montmorillonite, 53 percent illite, and 19 percent kaolinite plus chlorite.

Nature of contacts. The upper contact with the Allens Grove Member is sharp and easily recognized. The basal contact is generally not known except where the Foxhollow Member rests on pre-Pleistocene rock.

Differentiation from other units. The Foxhollow Member can easily be distinguished from other tills in the area (the Allens Grove and Clinton Members, the Capron Member of the Zenda Formation, and the Horicon and New Berlin Members of the Holy Hill Formation) by its lower sand and higher silt and clay content, small light-to-dark dolomite ratio, low illite content, and gray color.

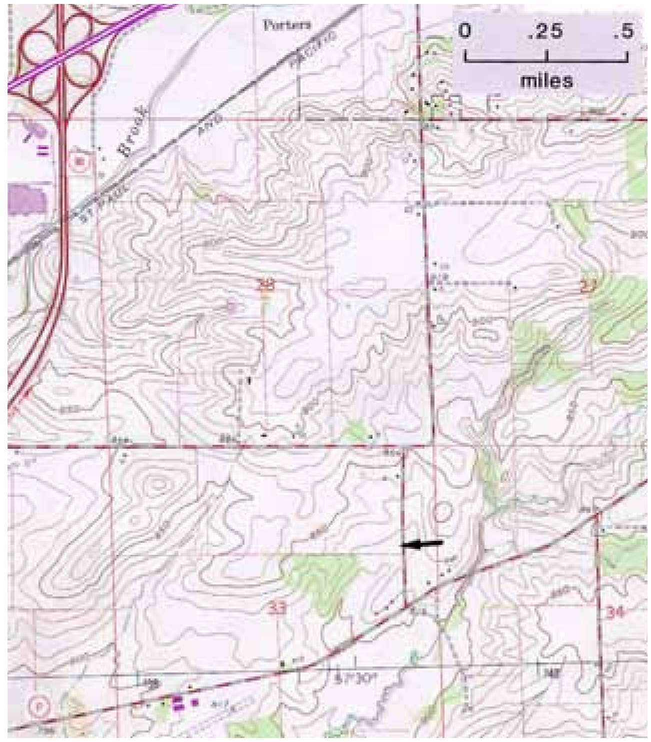

Figure 27. Part of the Shopiere 7.5-minute quadrangle showing the location of the type section (a drill hole) of the Foxhollow Member.

Regional extent and thickness. The Foxhollow Member is known to underlie most of Wisconsin east of the Rock River, south of Turtle Creek, in and west of the buried Troy Valley, and part of northern Illinois. In places the till is greater than 3.6 m thick.

Origin. The Foxhollow Member consists largely of till, most likely deposited by glacial ice that advanced from the Lake Michigan basin.

Age and correlation. Initially, it was thought that the Foxhollow Member was deposited during the middle part of the Wisconsin Glaciation or earlier (before 40,000 ^{14}C yr B.P., which is about 44,000 cal. yr B.P., Mickelson and others, 1984). Recent OSL ages from the Illinois State Geological Survey now suggest that the Foxhollow Member was deposited during the Illinoian Glaciation (R. Berg, Illinois State Geological Survey, oral communication, 2009). Stratigraphically, the Foxhollow Member lies below the younger Allens Grove Member.

Previous usage. First used informally as a unit name by Fricke (1976). Formalized in Mickelson and others (1984).

Walworth Formation: Allens Grove Member

Carl Fricke and David M. Mickelson

Source of name. The rural locality of Allens Grove, Walworth County, Wisconsin.

Location and description of type section. Base of the west wall of a borrow pit, 0.8 km (0.5 mile) east of Allens Grove, approximately 4 km (2.5 miles) west of the Capron Ridge, and just north of old Highway 15. It is located in the NW¼SE¼SW¼ sec. 32, T. 2 N., R. 15 E., Walworth County, an area shown on the Sharon 7.5-minute quadrangle (fig. 28).

The top of the section (fig. 29) contains 0.6 m of yellowish-red (5YR 4/6) truncated B horizon developed on 8 m of Clinton Member till and sand. An unnamed sand unit separates the Clinton Member from the underlying Allens Grove Member. The Allens Grove Member at the type section is about 5 m thick and consists of compact, grayish till oxidized at the surface (Fricke, 1976, p. 22). A drill hole adjacent to the section penetrates Clinton Member till (2 m), gray lacustrine silt (14 m), and 7 m of what is presumably Foxhollow Member.

Description of unit. The Allens Grove Member contains a yellowish-brown to light yellowish-brown (7.5YR to 10YR 5/4 to 6/4), sandy, pebbly till and associated deposits. The till is hard and compact, both when dry and wet, and commonly has a pinkish tint. Numerous dolomite and igneous pebbles are present in the till. The till averages 53 percent sand, 35 percent silt, and 12 percent clay.

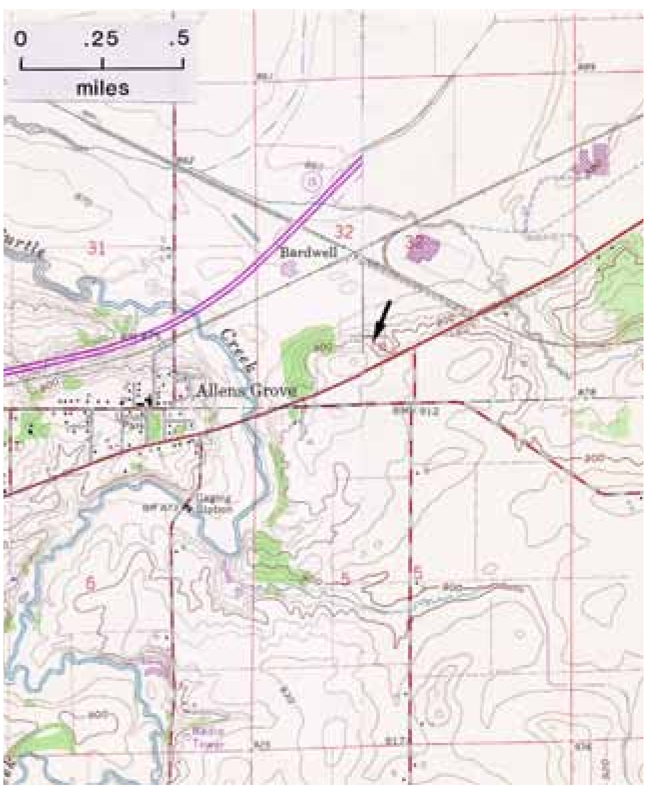

Figure 28. Parts of the Clinton and Sharon 7.5-minute quadrangles showing the location of the type section of the Allens Grove Member.

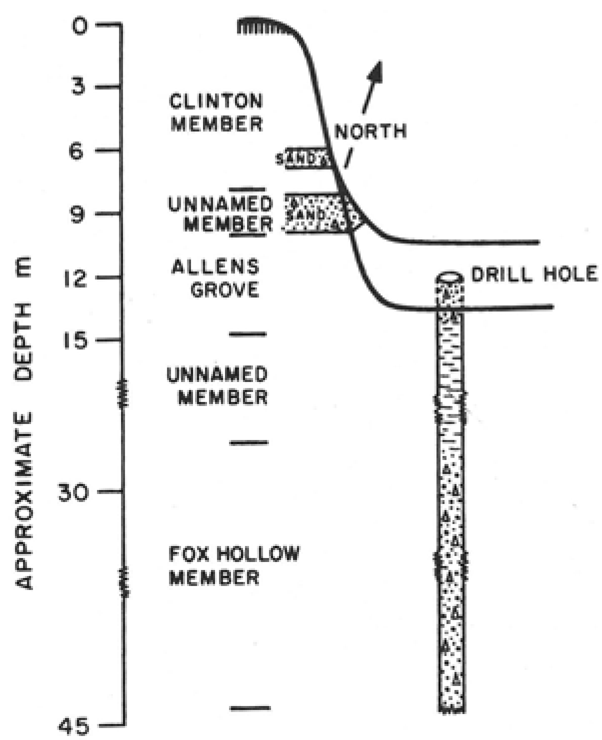

Figure 29. Sketch of stratigraphy in drill hole at the type section of the Allens Grove Member.

Semiquantitative clay mineral analyses show two distinct groups: one averaging 26 montmorillonite, 61 percent illite, and 13 percent kaolinite plus chlorite; and the other averaging 39 montmorillonite, 47 percent illite, and 14 percent kaolinite plus chlorite.

Nature of contacts. The upper contact with the Clinton Member varies from sharp to diffuse. The lower contact with the Foxhollow Member is sharp.

Differentiation from other units. The Allens Grove Member is less sandy than the Clinton Member and till in the Horicon and New Berlin Members of the Holy Hill Formation, but is more sandy than the Foxhollow Member and the Capron Member of the Zenda Formation. The Allens Grove Member has a light-to-dark dolomite ratio of between 0.8:1 and 1.3:1, intermediate between the Clinton Member and the Foxhollow Member. Its salmon-pink color can sometimes be used as a distinguishing feature.

Regional extent and thickness. The Allens Grove Member underlies the Clinton Member east of the Rock River in Rock County, Wisconsin, south of the Johnstown moraine and west of the Capron Ridge. The till extends south into northern Illinois. The till is as much as 3.9 m thick.

Origin. Glacial till deposited by ice from the Lake Michigan basin.

Age and correlation. The Allens Grove Member was deposited before 40,000 ^{14}C yr B.P. (44,000 cal. yr B.P.). The Allens Grove Member is equivalent to the Argyle Till Member in Illinois, a unit interpreted to have been deposited during the Illinoian Glaciation (R. Berg, Illinois State Geological Survey, oral communication, 2009).

Previous usage. First used as an informal unit name by Fricke (1976). Formalized in Mickelson and others (1984).

Walworth Formation: Clinton Member

Carl Fricke and David M. Mickelson

Source of name. The village of Clinton, Rock County, Wisconsin.

Location and description of type section. Road cut and test hole along new Highway 15 (the Beloit-Milwaukee Road), 3.2 km (2 miles) northeast of Clinton. It is located in the NE¼SW¼ sec. 3, T. 1 N., R. 14 E., Rock County, an area shown on the Clinton 7.5-minute quadrangle (fig. 26). This road cut and test hole also serve as the type section for the Walworth Formation.

Loess 2.1 m thick overlies a truncated B horizon 1.5 m thick developed in Clinton Member till. Clinton Member till extends to the bottom of the cut 8 m below the surface. A drill hole penetrates Clinton Member till to a depth of 14.6 m below the top of the cut.

Location of reference section. Turtle Town Quarry located in the NW¼SW¼NW¼ sec. 22, T. 1 N., R. 13 E., Rock County, an area shown on the Shopiere 7.5-minute quadrangle (fig. 30). The reference section has been described by Bleuer (1971) and briefly by Fricke (1976).

Description of unit. The Clinton Member contains a pebbly, sandy till containing little clay. In outcrops, its color most often is light yellowish brown (10YR 6/4), although at times it has a pink tint. When dry, the till is hard and crumbly. Numerous dolomite pebbles and a few cobbles are found in the till, along with smaller amounts of igneous rock clasts. In the very coarse sand fraction (1 to 2 mm), the light-to-dark dolomite ratio is greater than 1.3:1. The unit averages 61 percent sand, 27 percent silt, and 12 percent clay. Semiquantitative clay mineral analyses generally average 26 percent montmorillonite, 60 percent illite, and 14 percent kaolinite plus chlorite. However, a second group of samples averages 45 percent montmorillonite, 45 percent illite, and 10 percent kaolinite plus chlorite (Fricke, 1976).

Nature of contacts. The contacts between the Capron Member (above) and Allens Grove Member (below) are generally sharp, although the contact with the Allens Grove Member is diffuse in places.

Differentiation from other units. The Clinton Member can be distinguished from the Capron Member, the Allens Grove Member, and the Foxhollow Member by its very sandy texture, buff color, clay mineralogy, and its ratio of light-to-dark dolomite in the sand fraction. It is nearly indistinguishable from till in the Johnstown moraine (the Horicon Member of the Holy Hill Formation) except possibly for the Clinton Member's lower concentration of weathered minerals.

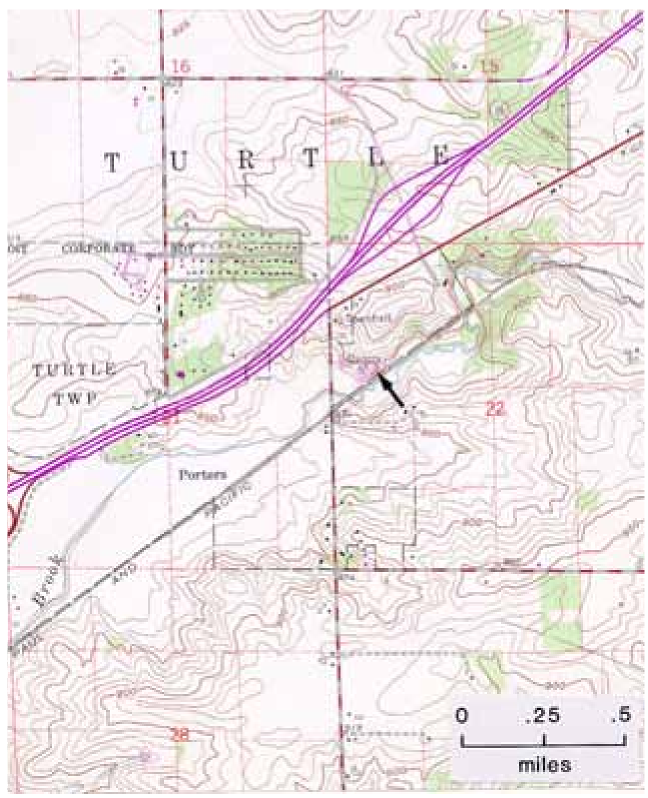

Figure 30. Part of the Shopiere 7.5-minute quadrangle showing the location of the reference section of the Clinton Member.

Regional extent and thickness. South and west of the Darien and Johnstown moraines, the Clinton Member is the uppermost (surficial) till in eastern Rock County and western Walworth County. It extends westward at least as far as 4.8 km (2.9 miles) west of the Rock River in Rock County, Wisconsin, with the possible exception of the upland west of Janesville, north of Bass Creek, and south of the Johnstown moraine. It extends south into northern Illinois and east beneath the Capron Ridge. The till ranges in thickness from less than 1 m along the Rock River and in the shallow bedrock uplands north of Turtle Creek to more than 12.6 m south of Turtle Creek.

Origin. Till and associated sediment deposited by ice flowing westward from the Lake Michigan basin.

Age and correlation. No precise age can be given to the Clinton Member till. When first defined, Mickelson and others (1984) proposed it was probably deposited during the middle part of the Wisconsin Glaciation (before 40,000 ^{14}C yr B.P., which is about 44,000 cal. yr B.P.) The Clinton Member was formerly correlated with the Argyle Till Member of the Winnebago Formation in northern Illinois. However, the Clinton Member is a separate, distinct unit that lies above the Allens Grove Member (the Argyle Till Member in Illinois) and below the Capron Member. The Capron Member was recently dated using the OSL method at about 130,000 cal. yr B.P., so the Clinton Member was deposited before the last part of the Illinoian Glaciation (R. Berg, Illinois State Geological Survey, oral communication, 2009).

Previous usage. First used as an informal unit name by Fricke (1976). Formalized in Mickelson and others (1984).

Zenda Formation

Allan F. Schneider

Source of name. The locality of Zenda, south-central Walworth County, Wisconsin.

Location and description of type section. Road cut on south side of County Highway B, immediately east of intersection with Hillside Road, 1.8 km (1.1 miles) northeast of Zenda. It is located in the NW¼NW¼SW¼ sec. 26, T. 1 N., R. 17 E., Walworth County, an area shown on the Lake Geneva 7.5-minute quadrangle (fig. 31).

Approximately 2.5 m of the Tiskilwa Member is well exposed at the type section of the Zenda Formation; the Capron Member is not present. Two facies of Tiskilwa Member till occur in the cut; one facies contains about 42 percent sand, 36 percent silt, and 22 percent clay, and the other about 65 percent sand, 24 percent silt, and 11 percent clay. The finer-grained till is more typical of the Tiskilwa Member in southern Wisconsin than the sandier phase. No significant difference in the clay mineral content of the two facies is apparent (H.D. Glass, Illinois State Geological Survey, written communication, 1982); analyses of the finer facies average 24 percent expandable clay minerals, 66 percent illite, and 10 percent kaolinite plus chlorite (3 samples), whereas the sandier facies averages 22 percent expandables, 65 percent illite, and 14 percent kaolinite plus chlorite (2 samples). Both facies have the 5YR hue that is typical of Tiskilwa Member till in northern Illinois and southern Wisconsin.

Figure 31. Part of the Lake Geneva 7.5-minute quadrangle showing the location of the type section of the Zenda Formation and reference section 1 of the Tiskilwa Member.

Location of reference sections. The type sections of the Capron and Tiskilwa Members serve as reference sections for the Zenda Formation.

Description of unit. The Zenda Formation includes two members, the older Capron Member and the younger Tiskilwa Member. Both consist mainly of till that is pink, calcareous, and loamy. Till of the Tiskilwa Member is, however, sandier and more pink, commonly having a 5YR hue, in contrast to the 7.5YR hue of the Capron Member till (Bleuer, 1970, p. J-11 to J-13). Both members appear to have sandier and siltier facies, and also contain some outwash sand.

Nature of contacts. Little is known about the contact relationship of the Zenda Formation with the older Clinton Member of the Walworth Formation. The contact of the Zenda Formation with the younger New Berlin Member of the Holy Hill Formation ranges from very sharp to gradational.

Differentiation from other units. Till of the Zenda Formation is distinguished from those of the older Walworth Formation and the younger New Berlin Member of the Holy Hill Formation by its pinker color and lower sand content. However, in some places where till of the New Berlin Member directly overlies the Tiskilwa Member, it is difficult to distinguish between them; the sandy facies of the Tiskilwa Member is, in fact, almost indistinguishable in the field from New Berlin Member till that contains assimilated Tiskilwa Member till. This is particularly the case in much of Alden's (1918) Elkhorn moraine, where a thin discontinuous blanket of New Berlin Member till overlies the Tiskilwa Member. Generally, however, New Berlin Member till has a higher pebble and sand content than the Tiskilwa Member till.

Regional extent and thickness. The Zenda Formation has a very limited distribution. It occurs at the surface only in Walworth County in the southeastern part of the state (Ham and Attig, 2004; fig. 3). To the north and east it is overlapped by the New Berlin Member of the Holy Hill Formation; Zenda Formation till is exposed at a number of isolated localities east of this boundary in eastern Walworth and western Racine Counties, but its precise geographic distribution in the subsurface is not well known.

Origin. The Zenda Formation was deposited by glacier ice and associated meltwater of the Lake Michigan Lobe.

Age and correlation. The Zenda Formation contains members with distinctly different ages. The Capron Member was deposited during the last part of the Illinoian Glaciation in Illinois based on three OSL ages averaging around 130,000 cal. yr B.P. (R. Berg, Illinois State Geological Survey, oral communication, 2009). The Tiskilwa Member was deposited during the last part of the Wisconsin Glaciation, or about 18,500 to 26,000 ^{14}C yr B.P. (22,100 to 30,900 cal. yr B.P., Hansel and Johnson, 1996). Correlation of the Zenda Formation with other stratigraphic units in Wisconsin is unclear.

Previous usage. Formalized in Mickelson and others (1984).

Zenda Formation: Capron Member

H.B. Willman and John C. Frye. Description written by Allan F. Schneider.

Source of name. Village of Capron, northeastern Boone County, northern Illinois.

Location and description of type section. Capron North Section, a road cut 5 km (3 miles) north of Capron, Illinois. It is located in the NE¼SE¼SE¼ sec. 23, T. 46 N., R. 4 E., Boone County, Illinois, an area shown on the Capron 7.5-minute quadrangle (fig. 32).

The Capron North Section exposes about 0.9 m of Capron Member till sandwiched between 0.7 m of loess (above) and 1.1 m of calcareous sand (below). Both the till and the sand are parts of the Capron Member. The upper third of the till is leached, and the lower part is pink and calcareous (Willman and Frye, 1970, p. 64).

Location of reference section. Borrow pit in the SE¼SW¼SE¼ sec. 5, T. 1 N., R. 15 E., Walworth County, an area shown on the Sharon 7.5-minute quadrangle (fig. 33). According to Bleuer (1971, p. J-12, J-13), Capron Member till overlies medium-grained outwash sand with a tectonically deformed, almost vertical contact. Bleuer described apparent inclusions of a leached, dark brown, loamy material similar to the Bt horizon of an older till, possibly from the Clinton Member of the Walworth Formation. The inclusions were located in a zone near the contact and in places along an adjacent roadside exposure.

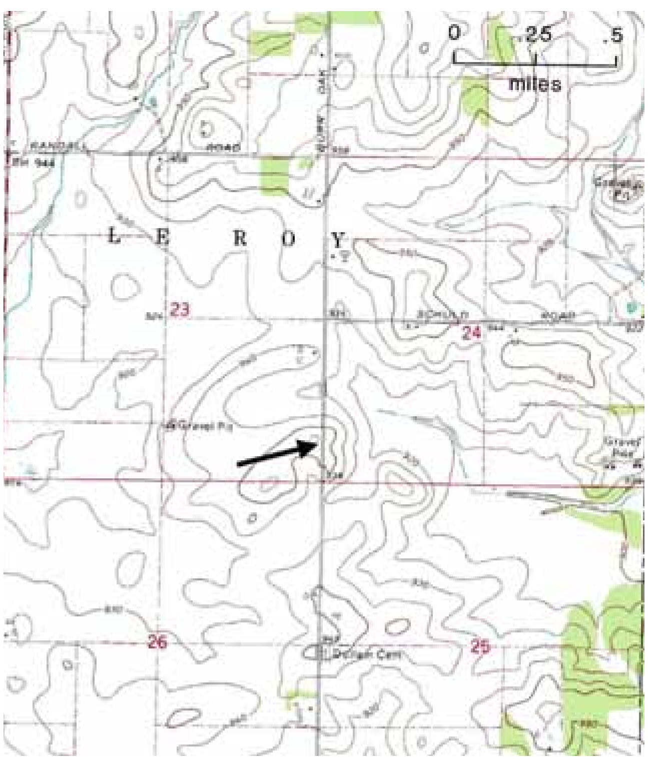

Figure 32. Part of the Capron (Wisconsin/Illinois) 7.5-minute quadrangle showing the location of the type section of the Capron Member.

Figure 33. Part of the Sharon 7.5-minute quadrangle showing the location of the reference section of the Capron Member.

Description of unit. In Illinois the Capron Till Member of the Winnebago Formation consists of calcareous pink till and calcareous sand (Willman and Frye, 1970, p. 64). Two compositional facies of the till are recognized, a lower silty facies and an upper sandy facies. The sandy facies contains more expandable clay minerals and less illite than the silty facies, whereas the silty facies contains somewhat more calcite in the clay fraction (Frye and others, 1969, p. 26). Capron Member till has an intermediate cobble and pebble content; it is pinkish gray to reddish brown in color and is loamy, compact and blocky (Frye and others, 1969, p. 26). According to Bleuer (1970, p. J-11), two phases of the till also can be recognized in Wisconsin. The lower phase contains 24 percent sand, 45 percent silt, and 31 percent clay in the matrix; the upper phase has 40 percent sand, 42 percent silt, and 18 percent clay (Bleuer, 1970, p. J-11). Fricke and Johnson (1983) observed both a silty facies and a sandy facies of Capron Member till in Wisconsin, but the textural difference is not so marked as in Illinois; the lower silty facies contains 27 percent sand, 38 percent silt, and 35 percent clay, whereas the upper sandy facies has 41 percent sand, 35 percent silt, and 24 percent clay. The clay-mineral composition of both facies averages 28 percent montmorillonite, 61 percent illite, and 11 percent kaolinite plus chlorite (Fricke and Johnson, 1983). The till is moderately compact and calcareous, as in Illinois, and is light brown (7.5YR 6/4) to brown (7.5YR 4/4). Nearly 80 percent of the pebble assemblage is dolomite, and about half of the stones identified by Bleuer (1970, p. J-11) were Niagaran dolomite.

Nature of contacts. Little is known about the character of either the lower contact with the older Clinton Member of the Walworth Formation or the upper contact with the Tiskilwa Member of the Zenda Formation.

Differentiation from other units. Till of the Capron Member is distinguished from till of both the older Clinton Member of the Walworth Formation and the younger Horicon Member of the Holy Hill Formation by its finer texture and slightly darker or pinker color. It is lithologically similar to till of the Tiskilwa Member of the Zenda Formation, but its color (7.5YR hue) is normally less red than the color (5YR hue) of the Tiskilwa Member (Bleuer, 1970, p. J-12, J-13).

Regional extent and thickness. The Capron Member is present at the surface only over a small area in southwestern Walworth County in the southeastern part of Wisconsin (Ham and Attig, 2004; fig. 3). Here it is found in the north-south-trending Capron Ridge, which enters Wisconsin at the junction of Walworth County with Boone and McHenry Counties, Illinois. The ridge rises above an outwash plain on the east and is apparently overridden and truncated by the Darien moraine on the north. Along the western margin of the Capron Ridge, the Capron Member blankets the Clinton Member of the Walworth Formation, which occurs at the surface just west of that margin (Fricke and Johnson, 1983). Borings on the Capron Ridge indicate that the Capron Member ranges in thickness from less than 2 m to more than 10 m (Bleuer, 1970, p. J-12).

Origin. Till of the Capron Member was deposited by the Lake Michigan Lobe (Frye and others, 1969, p. 6; Bleuer, 1970, p. J-12). Fricke and Johnson (1983) have suggested that the upper sandy facies may be ablation till and thus imply that the siltier facies might be its basal till equivalent.

Age and correlation. Three new OSL dates on sand associated with the Capron Member till average about 130,000 cal. yr B.P. (R. Berg, Illinois State Geological Survey, oral communication, 2009). Thus, the Capron Member is thought to have been deposited near the end of the Illinoian Glaciation. It is not possible to correlate the Capron Member with other Pleistocene lithostratigraphic units in Wisconsin at this time.

Previous usage. Name first used by Frye and others (1969) and defined formally in Willman and Frye (1970). (This description is from Mickelson and others (1984)).

Zenda Formation: Tiskilwa Member

H.B. Willman and John C. Frye. Description written by Allan F. Schneider.

Source of name. Village of Tiskilwa, southern Bureau County, Illinois.

Location and description of type section. Buda East Section, a road cut 8 km (5 miles) northwest of Tiskilwa, Illinois, and 5.4 km (3.4 miles) east of Buda, Illinois, on County Road 1200N. It is located in the SE¼SE¼SW¼ sec. 31, T. 16 N., R. 8 E., Bureau County, Illinois, an area shown on the Wyanet 7.5-minute quadrangle (fig. 34).

The type section of the Tiskilwa Till Member of the Wedron Formation is a road cut, designated as the Buda East Section, in the Bloomington moraine of northern Illinois (Willman and Frye, 1970, p. 68-69). At the base of this cut, 1.2 m of massive calcareous pinkish-tan sandy till of the Tiskilwa Till Member containing cobbles and small boulders is exposed. This till is overlain by 1.2 m of sand and gravel recognized in Illinois as part of the Henry Formation, which is overlain in turn by 2.4 m of Richland Loess (Frye and Willman, 1965, p. 95; Willman and Frye, 1970, p. 68).

Figure 34. Part of the Wyanet (Illinois) 7.5-minute quadrangle showing the location of the type section of Tiskilwa Member. Contours are in meters.

Location of reference sections. (1) Road cut on south side of County Highway B immediately east of intersection with Hillside Road, 1.8 km (1.1 miles) northeast of Zenda. It is located in the NW¼NW¼SW¼ sec. 26, T. 1 N., R. 17 E., Walworth County, an area shown on the Lake Geneva 7.5-minute quadrangle (fig. 31). This section also serves as the type section of the Zenda Formation. (2) Road cut on south side of Lovers Lane Road, immediately east of intersection with Bowers Road, 5.2 km (3.3 miles) northwest of Spring Prairie. It is located in the northwesternmost part of sec. 13, T. 3 N., R. 17 E., Walworth County, an area shown on the Springfield 7.5-minute quadrangle (fig. 35). About 3 m of reddish-brown (5YR 4/4) Tiskilwa Member till is exposed here on the south side of the deep Sugar Creek valley. Local relationships along the valley strongly suggest that this exposure is in the upper part of the Tiskilwa Member, not far below the contact with the overlying New Berlin Member of the Holy Hill Formation.

Description of unit. Till of the Tiskilwa Member in Illinois, where the unit was named, is sandy, pink-tan to reddish tan-brown, and generally is described as pink till (Willman and Frye, 1970, p. 68). Till of the Tiskilwa Member in Wisconsin is similar. Typically it has a 5YR hue, but it varies from reddish brown (5YR 4/3, 5YR 4/4, 5YR 5/4) or yellowish red (5YR 4/6) to brown (7.5YR 5/4), where oxidized. In a number of places it is about midway between 5YR 4/4

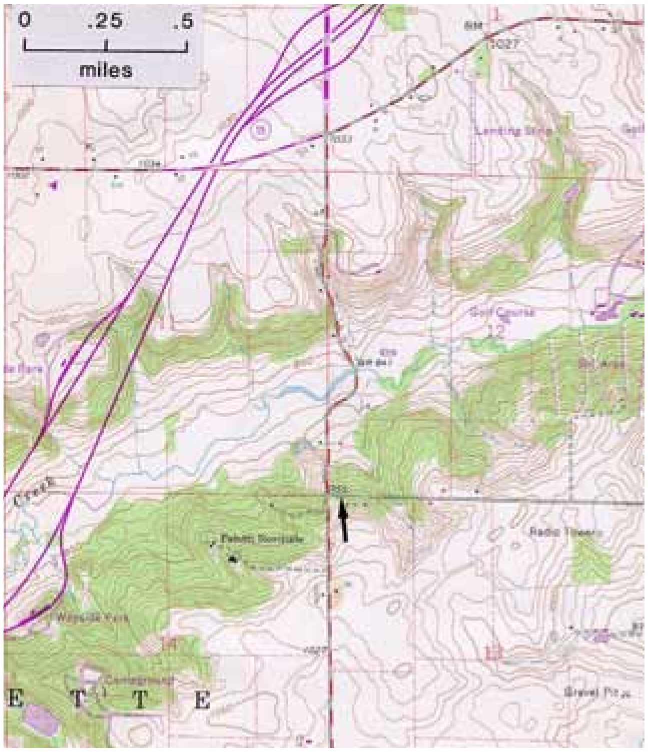

Figure 35. Part of the Springfield 7.5-minute quadrangle showing the location of reference section 2 of the Tiskilwa Member.

and 7.5YR 4/4. Where unoxidized, it is commonly dark reddish gray (5YR 4/2) or weak red (2.5YR 4/2). The till is slightly to moderately stony. Grain-size analyses indicate that the matrix of the till is loam, averaging 42 percent sand, 35 percent silt, and 23 percent clay. At reference section 1, listed above, a sandier facies of the Tiskilwa Member is present, in addition to the more typical till. The sandier facies contains 65 percent sand, 24 percent silt, and 11 percent clay (1 sample); in contrast, the more typical till averages 42 percent sand, 36 percent silt, and 22 percent clay (3 samples). It is not known if the sandy facies is present elsewhere in the area—Tiskilwa Member till is very similar to till of the New Berlin Member that has been "contaminated" with Tiskilwa Member till through glacial erosion and assimilation. The clay minerals average about 18 percent expandable clays, 67 percent illite, and 15 percent kaolinite plus chlorite (H.D. Glass, Illinois State Geological Survey, written communication, 1982).

Nature of contacts. Contacts of the Tiskilwa Member with the overlying New Berlin Member of the Holy Hill Formation are much better known than contacts with the older Capron Member. In fact, little is known about the nature of the boundary between the Tiskilwa and Capron Members. The contact of the Tiskilwa Member with the overlying New Berlin Member is generally sharp. In most places, it involves the lower sand and gravel facies of the New Berlin Member; the contact commonly coincides with or occurs just below the floors of gravel pits where the sand and gravel unit is mined. In places, this sand and gravel facies of the New Berlin Member is absent, and till of the Tiskilwa Member is directly overlain by till of the New Berlin Member; the contact is generally sharp. In other places, however, notably where much Tiskilwa Member till has been incorporated into the New Berlin Member, the contact is gradational and possibly unrecognizable. Where these tills are similar in texture and color, the contact can be identified only when the moisture content of both tills is moderately high.

Differentiation of other units. Till of the Tiskilwa Member is lithologically similar, though not identical, to till of the older Capron Member. Both are pink, loamy till units with approximately the same grain-size distributions. Capron Member till is less red, according to Bleuer (1970, p. 512), normally having a 7.5YR hue rather than the 5YR hue that is more typical of the Tiskilwa Member. Tiskilwa Member till is readily differentiated from both the older Clinton Member till and the younger New Berlin Member till by its pinkish color and distinctly finer texture.

Regional extent and thickness. In northern Illinois (McHenry County), the Tiskilwa Member is the dominant constituent of the prominent north-south-trending Marengo moraine, which is the outermost moraine of the Harvard Sublobe (Willman and Frye, 1970, p. 108). Just north of the Wisconsin state border, the Marengo moraine is overlapped by the northwest-southeast-trending Darien moraine, the terminal moraine of the Delavan Sublobe (Alden, 1904, 1918; Schneider, 1983), and its glacial outwash deposits. Thus, the Tiskilwa Member extends into Wisconsin from Illinois in south-central Walworth

County (Ham and Attig, 2004). It is exposed at the surface or beneath a blanket of the New Berlin Member in a belt roughly 11 to 18 km (7 to 11 miles) wide extending from the state line northward to the Kettle Moraine or its associated outwash deposits. It probably is the principal till of Alden's (1918) Elkhorn moraine, which comprises part of this belt for a considerable distance northwest of Lake Geneva. The Tiskilwa Member is also present at many localities farther east, where it is normally buried beneath thick sediment of the New Berlin Member of the Holy Hill Formation and the Oak Creek Formation. Typical or maximum thickness figures for the Tiskilwa Member are not known at this time.

Origin. Till of the Tiskilwa Member in Wisconsin was most likely deposited as a basal till by the Harvard Sublobe of the Lake Michigan Lobe, which in northern Illinois terminated at the Marengo moraine (Willman and Frye, 1970).

Age and correlation. The Tiskilwa Member was deposited during the last part of the Wisconsin Glaciation, probably between 18,500 and 26,000 ^{14}C yr B.P. (22,100 to 30,900 cal. yr B.P., Hansel and Johnson, 1996). Correlation of the Tiskilwa Member with other lithostratigraphic units in Wisconsin is problematic. The unit may correlate with the Pokegama Creek Member, Poskin Member, or other younger members of the Copper Falls Formation in the northwestern part of the state.

Previous usage. Unit was first named by Willman and Frye (1970) and formalized in Mickelson and others (1984).

Copper Falls Formation

Lee Clayton

Source of name. Copper Falls in Copper Falls State Park, Ashland County, Wisconsin.

Location and description of type section. Cut bank on west side of Bad River, about 0.8 km (0.5 mile) northwest of Copper Falls, in Copper Falls State Park. It is located in the SW¼SE¼NW¼ sec. 17, T. 45 N., R. 2 W., Ashland County, an area shown on the High Bridge 7.5-minute quadrangle (fig. 36). A sketch of units present is shown in figure 37.

All sediment in the type section is part of the Copper Falls Formation. The till members have not been formally defined because they have not yet been successfully correlated beyond the type section. There is considerable lateral variability in the type section, and the column in figure 37 was measured in the middle part of the cut bank, north of its highest point, where it is about 45 m high. The units at the type section are listed here from top to bottom (see fig. 37 for graphic representation of the type section).

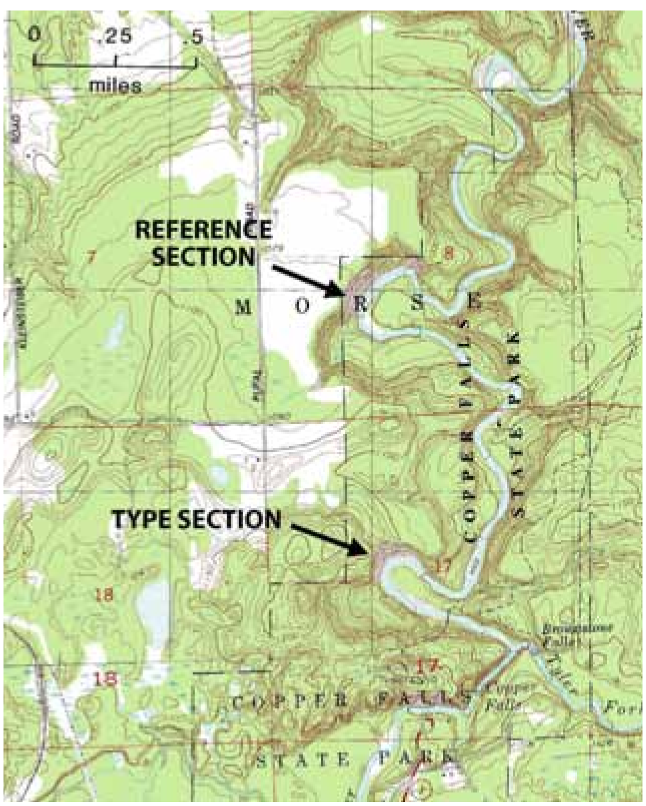

Figure 36. Parts of the High Bridge and Mellen 7.5-minute quadrangles showing the locations of the type section and reference section of the Copper Falls Formation.

Unit L: Sand at the top of the cut bank, 2 m thick.

Unit K: Reddish-brown till, 2 m thick, with 38 percent sand, 55 percent silt, and 7 percent clay (1 sample).

Unit J: Sand, 2 m thick, poorly exposed.

Unit I: Reddish-brown till (more bouldery than till unit G), averaging 43 percent sand, 45 percent silt, and 12 percent clay (3 samples).

Unit H: Fine sand and silt, 1 m thick, probably of offshore origin.

Unit G: Reddish-brown till (similar in color to till unit D), 5 m thick, averaging 35 percent sand, 53 percent silt, and 12 percent clay (5 samples); small inclusions of greenish calcareous till and a thin bed of sand occur near the top of the unit. The greenish gray till also occurs as a layer about 2 cm thick, about 17 m above river level, in the reference section located 1.3 km (0.8 mile) to the north of the type section.

Unit F: Fine sand with silt beds, 5.5 m thick, probably of offshore origin.

Unit E: Covered interval, 2 m thick, with water seeps.

Unit D: Reddish-brown till (but darker and redder than underlying unit C), 9.5 m thick, averaging 51 percent sand, 39 percent silt, and 10 percent clay (6 samples), sharp contact with underlying Unit C.

Unit		Description	Sample	Sand:Silt:Clay
Copper Falls Formation	L	Sand		50%
	K	Till, silt loam, reddish brown.	As-4:01-9-15-79	
	J	Sand, largely covered.		
	I	Till, loam and silt loam, reddish brown, bouldery.	As-4:02-9-15-74 As-4:03-9-15-79 As-4:04-9-15-79	
	H	Fine sand and silt (offshore?).		
	G	Till, reddish brown (like D), loam and silt loam, small inclusions of greenish-gray calcareous till near top.	As-4:05-9-15-79 As-4:06-9-15-79 As-4:07-9-15-79 As-4:08-9-15-79 As-4:09-9-15-79	
	F	Sand, with silt beds (offshore?).		
	E	Covered, seeps.		
	D	Till, loam and sandy loam, reddish brown, widely- spaced joints.	As-4:10-9-15-79 As-4:11-9-15-79 As-4:12-9-15-79 As-4:13-9-15-79 As-4:14-9-15-79 As-4:15-9-15-79	
	C	Till, loam and sandy loam, reddish brown, closely-spaced joints; lighter and browner than D.	As-4:16-9-15-79 As-4:17-9-15-79 As-4:18-9-15-79	
	B	Clay, silt, sand, and gravel (lacustrine or fluvial).		
	A	Covered interval. River Level	5 metres 0	50%

Figure 37. Stratigraphy of the type section of the Copper Falls Formation. Bottom of the section (river level) is near an elevation of 290 m (950 feet). The location is shown in figure 36.

Unit C: Reddish-brown till, 2.5 m thick, with closely spaced columnar joints, averaging 52 percent sand, 39 percent silt, and 9 percent clay (3 samples).

Unit B: Clay, silt, sand, and gravel, 4.5 m thick, probably of lacustrine or fluvial origin, or both.

Unit A: Slumped material rising 6 m up from the river level.

Most likely the upper three till layers (units G, I, and K) consist of flow till and represent several supraglacial debris flows. They are part of a collapse hummock and probably represent a single glacial advance. The lower two till units (C and D) may have been deposited during the same advance or during separate advances.

Location of reference section. Cut bank on west side of Bad River, about 1.3 km (0.8 mile) north of the type section, in Copper Falls State Park. It is located in the SW¼NE¼SW¼ sec. 8, T. 45 N., R. 2 W., Ashland County, an area shown on the High Bridge 7.5-minute quadrangle (fig. 36). A sketch of the units present is shown in figure 38. Till units may have been removed by shore erosion above Unit I. Correlation with the type section is unclear, but the greenish till near the bottom of Unit D of the reference section may correlate with the greenish till near the top of unit G of the type section; if so, it seems likely that units C and D of the type section occur below unit B of the reference section.

Description of unit. The Copper Falls Formation consists largely of fluvial sand and gravel and till. The composition of the till is highly variable, ranging from 35 to 80 percent sand, 15 to 50 percent silt, 2 to 15 percent clay, and a few percent pebbles, cobbles, and boulders. The till deposited by the Superior Lobe in Douglas County averages about 70 percent sand, 25 percent silt, and 5 percent clay, whereas the till deposited by the Chippewa Lobe in Bayfield, Ashland, and Iron Counties averages about 60 percent sand, 35 percent silt, and 5 percent clay. In all four counties the proportion of sand increases southward; sand averages 45 percent in the type area. Copper Falls Formation till is commonly reddish brown, ranging from 2.5YR to 7.5YR 3/4 to 4/4 to 4/6; it is generally redder to the north and browner to the south in Douglas, Bayfield, Ashland, and Iron Counties. It is slightly calcareous in most areas; in northern Douglas County the coarse silt fraction is between 0.5 and 1.5 percent carbonate, predominantly calcite.

Nature of contacts. The base of the formation is ill defined. It rests on pre-Pleistocene rock in the few places its base has been seen in Douglas, Bayfield, Ashland, and Iron Counties (Clayton, 1984), but presumably older Pleistocene units occur below the Copper Falls Formation. In northern Wisconsin the Copper Falls Formation is overlain by the Miller Creek Formation. In western Wisconsin, stream and lake sediment of the Copper Falls Formation is overlain by till of the Trade River Formation with a sharp contact (Johnson, 2000).

Differentiation from other units. Till of the Copper Falls Formation is sandier and browner than the till of the Miller Creek Formation, which contains as much as 35 percent sand only in the few places where it overlies sand and gravel. Till of the Copper Falls Formation is redder and less calcareous than till of the Trade River Formation.

Regional extent and thickness. The Copper Falls Formation is at the surface as far north as the Miller Creek Formation (fig. 3). It occurs as far east as the dolomitic Holy Hill Formation till of the Green Bay Lobe, and as far west as the Minnesota border. Its southern limit extends to the Chippewa moraine and 10 to 20 km southeast of the St. Croix moraine as shown in figure 3 (Johnson, 2000). It also extends into southern Clark County. The Copper Falls Formation is several tens of meters thick in many parts of Douglas, Bayfield, Ashland, and Iron Counties, and is more than 100 m thick in parts of Chippewa County.

Origin. Roughly half, or perhaps more, of the Copper Falls Formation consists of fluvial sediment deposited by meltwater streams in front of the glacier, on stagnant ice, or beneath the glacier in the form of eskers. Most of the rest of the formation is till deposited by the Superior, Chippewa, Wisconsin Valley, and the Langlade Lobes.

Copper Falls Formation

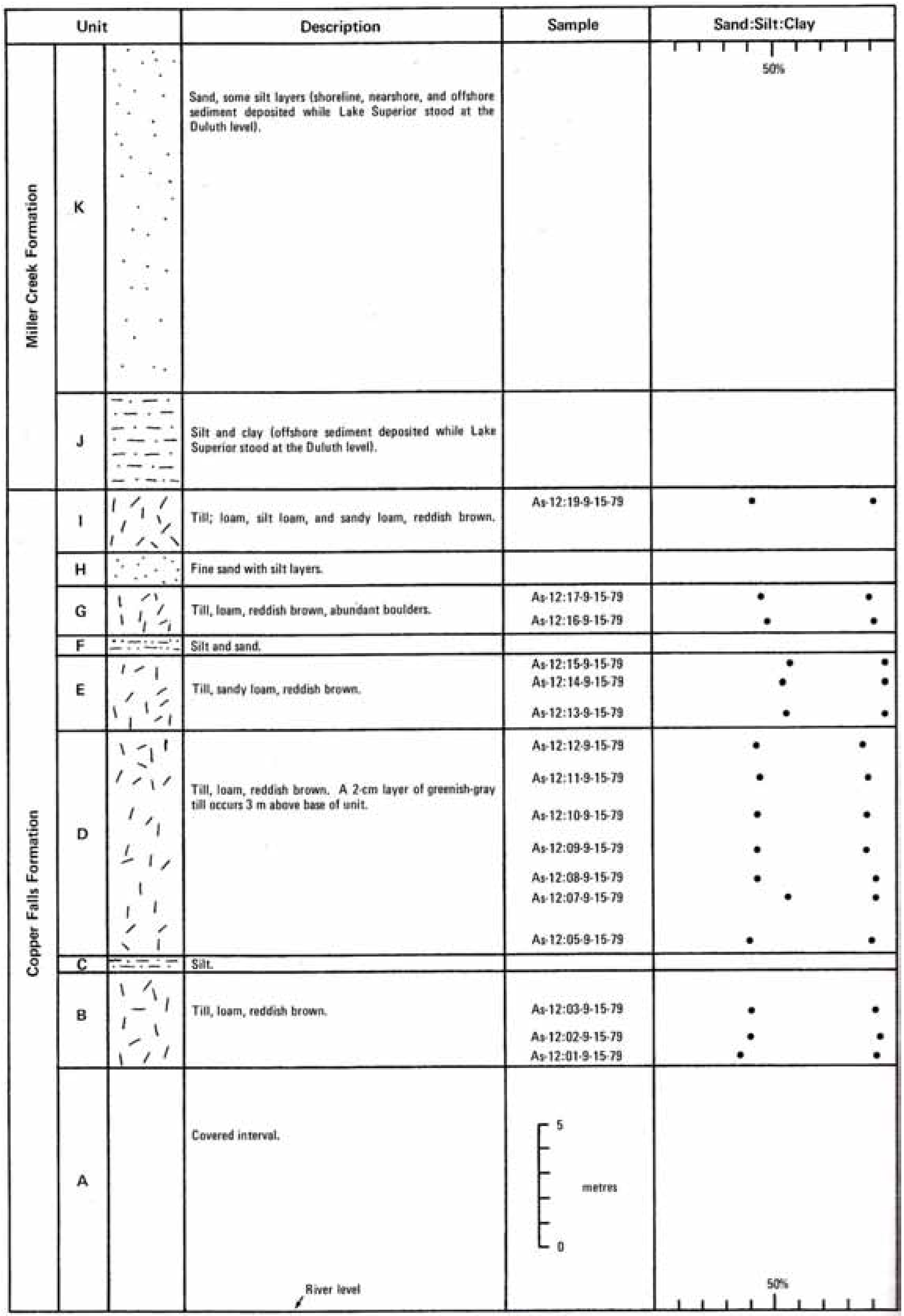

Figure 38. Stratigraphy of the reference section of the Copper Falls Formation. Bottom of the section (river level) is near an elevation of 273 m (895 feet). The location is shown in figure 36.

Age and correlation. The bulk of the Copper Falls Formation (and the youngest part) was likely deposited during the last part of the Wisconsin Glaciation. It is probably equivalent, at least in part, to the Cromwell Formation of Minnesota (Wright and others, 1970). The Jardine Creek till of Need (1980), Johnson (1980), and Need and others (1981) is either equivalent to, or a subdivision of, the Copper Falls Formation. The ages of the older Bakerville and Merrill Members have not been worked out in detail. The Merrill Member is overlain by an organic silt and clay unit with a date of 40,800 ± 2000 ^{14}C yr B.P. (44,741 ± 1735 cal. yr B.P., ISGS-256) (Stewart and Mickelson, 1976), so the Merrill Member was deposited during, or before, the middle part of the Wisconsin Glaciation. The Bakerville Member is eroded and does not exhibit any primary glacial topography. Based on its eroded nature and stratigraphic position, the Bakerville Member might correlate with the River Falls Formation in western Wisconsin, a unit thought to have been deposited during the Illinoian Glaciation (Syverson and Colgan, 2004; Syverson, 2007).

Previous usage. Formalized in Mickelson and others (1984).

Copper Falls Formation: Bakerville Member

William N. Mode

Source of name. The rural locality of Bakerville, located at the intersection of County Highways B and BB, northwestern Wood County, Wisconsin.

Location and description of type section. Gravel pit located 200 m east of Robin Road and about 250 m south of its intersection with Highway B, 1.7 km (1 mile) west of Bakerville. It is located in the SE¼NW¼NW¼ sec. 26, T. 25 N., R. 2 E., Wood County, an area shown on the Lake Manakiki 7.5-minute quadrangle (fig. 39).

The type section quarry is an active one (in 1984), and at different times up to 10 m of subglacial till and the same amount of supraglacial till have been exposed in different faces. The gravel is intimately associated with the supraglacial till. Also exposed under the Bakerville Member is stratified, calcareous silt and sand, which has been thrust faulted and drag folded. Underlying this stratified material in an auger hole, but not exposed, is calcareous till of the Edgar Member of the Marathon Formation.

Location and description of reference section. Road ditch exposure on the northwest side of the junction of Grant York Road and Romadka Road, about 1 km (0.6 mile) north of the village of Granton. It is located in the SE¼SE¼SE¼ sec. 35, T. 25 N., R. 1 W., Clark County, an area shown on the Granton 7.5-minute quadrangle (fig. 40). The exposure contains 10 cm of loess over about 2 m of till of the Bakerville Member. The Bakerville Member is underlain by sandstone.

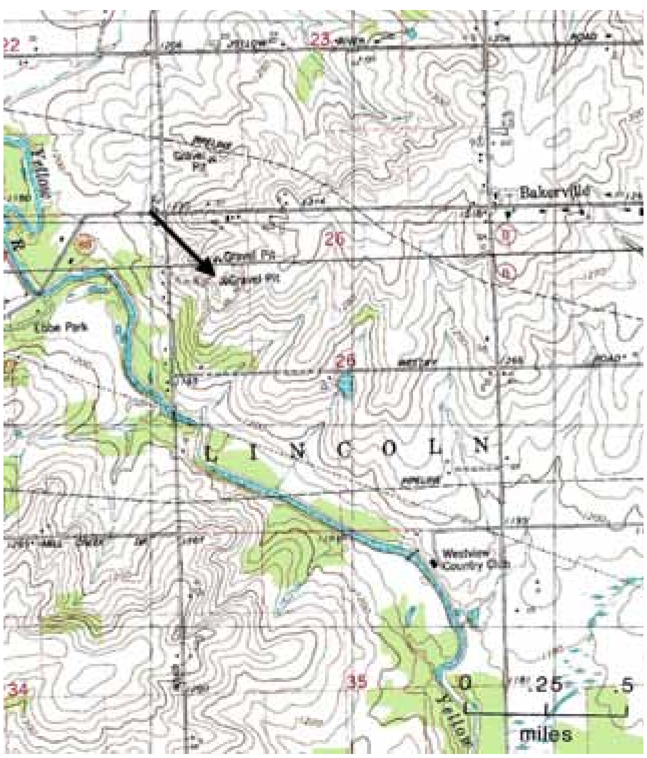

Figure 39. Parts of the Marshfield and Lake Manakiki 7.5-minute quadrangles showing the location of the type section of the Bakerville Member.

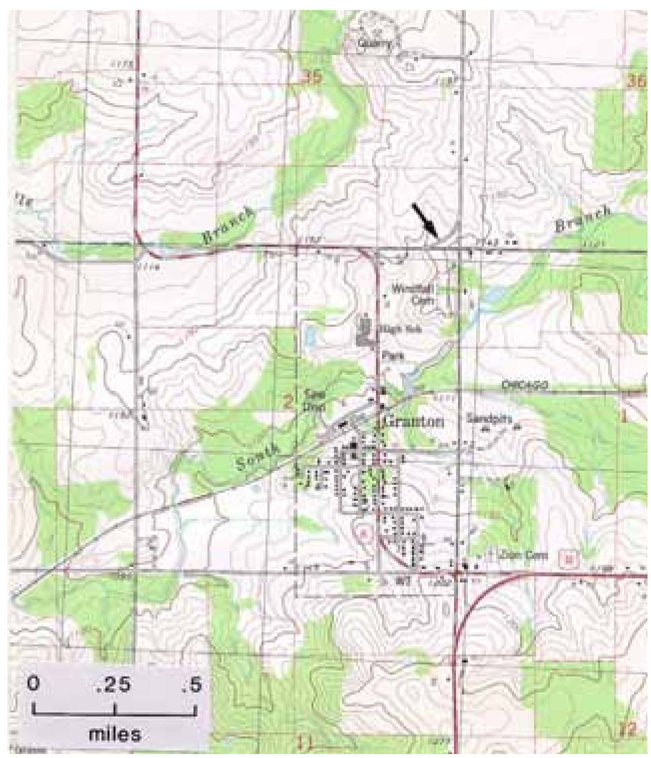

Figure 40. Part of the Granton 7.5-minute quadrangle showing the location of the reference section of the Bakerville Member.

Copper Falls Formation: Bakerville Member

Description of unit. Till of the Bakerville Member is a cobbly, pebbly sandy loam; the less-than-2 mm fraction averages 62 percent sand, 25 percent silt, and 13 percent clay (15 samples). Its field color is typically reddish brown (5YR 4/4). The coarse-sand fraction averages 60 percent igneous, 11 percent metamorphic, and 28 percent sedimentary rock types. Clay minerals average 53 percent illite, 8 percent kaolinite plus chlorite, 14 percent vermiculite, and 25 percent smectite (Mode, 1976).

Nature of contacts. No multiple till exposures including the Bakerville Member have been found, but the lower contact of the Bakerville Member over bedrock is sharp. In boreholes, its lower contact with the Edgar Member of the Marathon Formation is sharp.

Differentiation from other units. The Bakerville Member is typically redder and sandier than the Wausau, Medford, and Edgar Members of the Marathon Formation. It is quite similar to the Merrill Member, and may be equivalent to it, except that it has more than 20 percent sandstone and siltstone clasts, whereas the Merrill Member has less than 10 percent. The clay mineralogy of the Bakerville Member is intermediate between that of the Wausau and Edgar Members (which are similar) and the Merrill Member.

Regional extent and thickness. The Bakerville Member is the surface unit and reaches its greatest thickness (about 10 m) in the Marshfield moraine of southwestern Marathon, northwestern Wood, and southeastern Clark Counties. Behind this moraine, the Bakerville Member is considerably thinner (usually less than 5 m) or absent, so its distribution is very difficult to map. Complicating matters is the influence of local substrates on the till composition. Near the Marshfield moraine, the Bakerville Member commonly overlies Cambrian sandstone, whereas behind the moraine it generally overlies Precambrian rock. This difference is reflected in the texture of the Bakerville Member because samples from the sandstone area are generally sandy loam, whereas samples from the Precambrian bedrock area tend toward loam and sandy loam textures and are also more yellow (less red) in color.

Origin. The till of the Bakerville Member was deposited by southward-flowing ice from the Superior region, which terminated at the Marshfield moraine during the Nasonville Phase (fig. 6) of Attig and Muldoon (1989) and Clayton (1991).

Age and correlation. The Bakerville Member, whether it underlies or is equivalent to the Merrill Member, was deposited before 40,800 ± 2000 ^{14}C yr B.P. (44,741 ± 1735 cal. yr B.P., ISGS-256); thus, it was deposited during, or before, the middle part of the Wisconsin Glaciation. Its position in sequence and its mapped distribution suggest that the Bakerville Member may be equivalent to the River Falls Formation of western Wisconsin; however, the difficulty in demonstrating the age relationship of the Bakerville and Merrill Members, which are adjacent to one another, is a caution against such a long-distance correlation.

Previous usage. First used as an informal unit name by Mode (1976), and the name was originally formalized as a member of the Lincoln Formation in Mickelson and others (1984). It is formally reclassified here as a member of the Copper Falls Formation.

Copper Falls Formation: Merrill Member

William N. Mode

Source of name. City of Merrill, Lincoln County, Wisconsin.

Location and description of type section. Northwest corner of gravel pit located north of Duginski Road, about 500 m west of the intersection of Duginski Road with old Highway 51 and about 1.6 km (1 mile) north of the City of Merrill. It is located in the SE¼SE¼NW¼ sec. 1, T. 31 N., R. 6 E., Lincoln County, an area shown on the Merrill 7.5-minute quadrangle (fig. 41).

The gravel pit contains till of the Merrill Member in several stratigraphic settings. The northwestern corner of the pit exposes two till layers, each 2 to 3 m thick, separated by a thin sand bed (fig. 42). Two till fabrics were measured here (Stewart, 1973), and the fabric strength and uniformity suggest subglacial deposition even though the gravel pit is located in an area of hummocky terrain.

Figure 41. Part of the Merrill 7.5-minute quadrangle showing the location of the type section of the Merrill Member.

Location and description of reference section. Road cut on east side of County Highway S, about 100 m south of its intersection with Lincoln Drive. It is located in the NW¼NW¼NW¼ sec. 29, T. 30 N., R. 5 E., Marathon County, an area shown on the Hamburg 7.5-minute quadrangle (fig. 43). The reference section is a roadside ditch exposure, which contains about 1.5 meters of Merrill Member till overlying Precambrian bedrock and capped with about 20 cm of loess.

Description of unit. Till of the Merrill Member is a cobbly, pebbly sandy loam in which the less-than-2 mm fraction averages 62 percent sand, 28 percent silt, and 10 percent clay (21 samples). It is generally dark reddish brown (5YR 3/4 to 2.5YR 3/4), and the coarse sand lithology averages

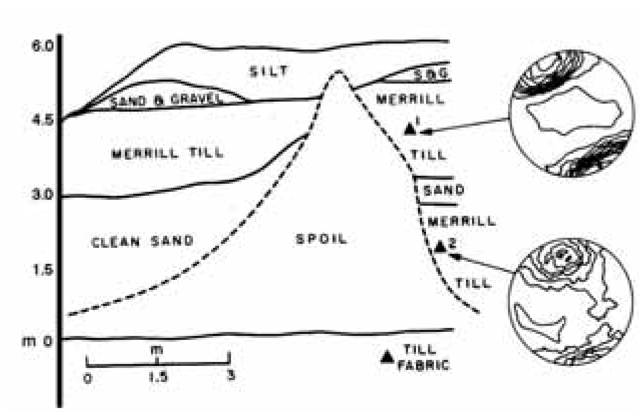

Figure 42. Sketch showing the stratigraphy at the type section of the Merrill Member. Fabric diagrams are lower hemisphere, equal-area stereonet plots of till-clast fabric. First contour is 1 sigma; contour interval is 2 sigma. From Stewart (1973).

Figure 43. Part of the Hamburg 7.5-minute quadrangle showing the location of the reference section of the Merrill Member.

71 percent igneous, 14 percent metamorphic, and 14 percent sedimentary rock types. The clay mineralogy averages 53 percent illite, 9 percent kaolinite plus chlorite, 22 percent vermiculite, and 16 percent smectite (Stewart, 1973; Mode, 1976).

Nature of contacts. The Merrill Member is thin near its southern limit in northern Marathon County; it can be seen in road cuts overlying the Wausau Member of the Marathon Formation with a relatively sharp contact. No exposures have been found showing the upper contact of the Merrill Member with the overlying Nashville Member of the Copper Falls Formation.

Differentiation from other units. Till of the Merrill Member has finer texture than till of the Nashville Member of the Copper Falls Formation, and coarser texture than the tills of the Wausau, Medford, and Edgar Members of the Marathon Formation. The Merrill Member is also redder than any of the Marathon Formation till units. The color and texture of the Merrill Member are similar to those of the Bakerville Member, although the Bakerville Member can be distinguished by its greater content of sandstone and siltstone clasts and smectite. The surface of the Merrill Member has preserved constructional glacial topography in areas such as southeastern Chippewa County (Syverson, 2007); whereas, such landforms are not seen on surfaces underlain by the Bakerville Member.

Regional extent and thickness. The Merrill Member is the surficial till outside of the outermost moraines deposited during the last part of the Wisconsin Glaciation in Chippewa, Langlade, Lincoln, eastern Marathon, and Taylor Counties. It is generally less than 10 m thick, is thickest in several discontinuous, hummocky moraines (Weidman, 1907; Stewart, 1973), and is thinnest toward its southern boundary.

Origin. Subglacial and supraglacial till of the Merrill Member was deposited by south-southeastward-flowing ice during the Hamburg Phase (fig. 6, Attig and Muldoon, 1989).

Age and correlation. A date of 40,800 ± 2000 ^{14}C yr B.P. (44,741 ± 1735 cal. yr B.P., ISGS-256) was obtained from organic silt and clay overlying the Merrill Member at Schelke Bog (Stewart and Mickelson, 1976). Therefore, the Merrill Member was deposited before or during the middle part of the Wisconsin Glaciation. Because the River Falls Formation of western Wisconsin is found in a position similar to that of the Merrill Member, it is hypothesized that these units are correlative.

Previous usage. First used as an informal unit name by LaBerge and Myers (1971). Subsequently used by Stewart (1973), Mode (1976) and others. The name was formalized as a member of the Lincoln Formation in Mickelson and others (1984). This unit is formally reclassified here as a member of the Copper Falls Formation.

Copper Falls Formation: Pokegama Creek Member

Mark D. Johnson

Source of name. Pokegama Creek, which heads in the Blue Hills of Barron County, Wisconsin.

Location and description of type section. Gravel pit located in the NW¼NE¼SW¼ sec. 1, T. 34 N., R. 11 W., Barron County, an area shown on the Rice Lake South 7.5-minute quadrangle (fig. 44). At this site, loess overlies till of the Pokegama Creek Member, which in turn overlies several meters of coarsening-upward gravelly sand of the Copper Falls Formation. Ventifacts (wind-abraded stones) occur on the till and beneath the loess, and the till contains several ice-wedge casts. A pebble fabric at this site shows that ice flowing S. 15° W. deposited the till. Magnetic susceptibility does not vary with depth.

Figure 44. Part of the Rice Lake South 7.5-minute quadrangle showing the location of the type section of the Pokegama Creek Member.

Location and description of reference section. Gravel pit located in the SW¼SE¼SW¼ sec. 1, T. 35 N., R. 10 W., Barron County, an area shown on the Mikana 7.5-minute quadrangle (fig. 45). More than 2 m of till of the Pokegama Creek Member is exposed at this site. A pebble fabric shows that ice flowing S. 25° W. deposited the till.

Description of unit. Till of the Pokegama Creek Member is slightly gravelly to gravelly sandy loam; part is slightly gravelly to gravelly loamy sand. The less-than-2 mm till matrix averages 69 percent sand, 20 percent silt, and

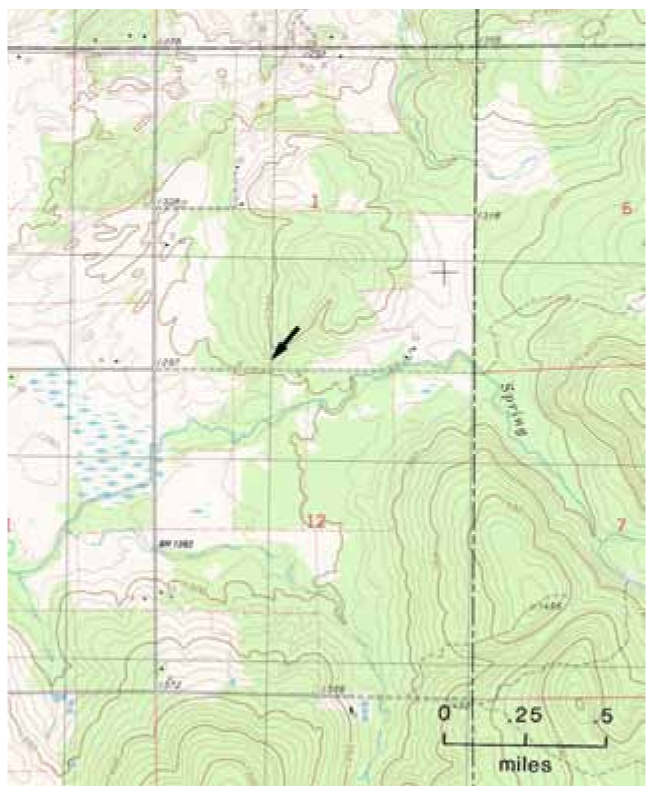

Figure 45. Part of the Mikana 7.5-minute quadrangle showing the location of the reference section of the Pokegama Creek Member.

11 percent clay. The till is yellowish red to strong brown (5YR 4/6 to 7.5YR 4/6). The clay in till samples averages about 13 percent kaolinite, 41 percent illite, and 45 percent expandable clay, but individual samples differ greatly from these figures. The very-coarse-sand fraction averages 51 percent quartz, 9 percent fine-grained mafic rock, 5 percent granite, 13 percent coarse-grained mafic rock, 2 percent Barron quartzite, 5 percent red sandstone, 1 percent other sandstone, and 14 percent other lithologies. The pebble fraction averages 26 percent fine-grained mafic rock, 23 percent coarse-grained mafic rock, 7 to 8 percent rhyolite, 11 percent granite and gneiss, 19 percent Barron quartzite, 6 percent Precambrian sandstone, 3 percent Cambrian sandstone, and 4 percent other lithologies. All samples analyzed were leached of carbonate.

Nature of contacts. Till of the Pokegama Creek Member has a sharp contact with underlying materials, such as sand and gravel, as at the type section, or with Barron quartzite or Cambrian sandstone. The upper contact with loess is gradational in places but is generally sharp. In places, the till is at the surface. Near Cameron, till of the Pokegama Creek Member is buried by stream sediment.

Differentiation from other units. Till of the Pokegama Creek Member can be readily distinguished from the till of the Pierce Formation by color and grain size, and from till of the River Falls Formation by magnetic susceptibility and the kaolinite:illite ratio. The Pokegama Creek Member has a relative magnetic susceptibility of 8.3 (arbitrary units of University of Wisconsin–Madison, Department of Geoscience Pleistocene laboratory) and a kaolinite:illite ratio of 1.2:1. Respective values for the till of the River Falls Formation are 4.0 (arbitrary units) and 2.3:1. The till of the Pokegama Creek Member has a fabric that indicates ice flow to the southwest and a relatively large amount of Barron quartzite compared to the till of the Poskin and Sylvan Lake Members. Till of the Pokegama Creek Member is most similar to the till of the Mikana Member, but it contains more quartzite than Mikana Member till, probably because Pokegama Creek till commonly rests on Barron quartzite. In the Blue Hills, till of the Mikana Member presumably overlies Barron quartzite. Here, Mikana Member till may be similar to the till of the Pokegama Creek Member, although the fabric of the two till units is different. Till of the Pokegama Creek Member has a fabric whose mode is oriented S. 10° E. to S. 20° W.; till of the Mikana Member has a fabric whose mode is oriented S. 20° W. to N. 45° W.

Regional extent and thickness. Till of the Pokegama Creek Member occurs at the surface beneath a few centimeters of loess in a triangle-shaped area in east-central Barron County (fig. 3). To the east, it is overlain by till of the Mikana Member deposited during the late Chippewa Phase of the Chippewa Lobe (fig. 6; Johnson, M.D., 1986). To the northwest, it is overlain by till of the Poskin Member. The southern extent is marked by an outwash head (secs. 9, 10, 11, T. 32 N., R. 10 W.) and ice-marginal ridges (sec. 7, T. 32 N., R. 10 W. and NE¼ sec. 14 T. 32 N., R. 11 W.). The thickness is variable: 1 m of till commonly is exposed in the south-central part of the county where sandstone is close to the surface; elsewhere the till is 4 to 7 m thick.

Origin. The till of the Pokegama Creek Member was deposited during the early Chippewa Phase of the Chippewa Lobe (fig. 6; Johnson, M.D., 1986) by ice flowing to the south and south-southwest.

Age and correlation. The Pokegama Creek Member was deposited during the latter part of the Wisconsin Glaciation, but prior to deposition of the Poskin Member of the Copper Falls Formation. Ice left by this advance did not melt until after the St. Croix and late Chippewa Phases (fig. 6). M.D. Johnson (1986) suggested that the till was deposited sometime between approximately 18,000 to 30,000 cal. yr B.P. No age equivalent is known in Wisconsin.

Previous usage. This name was first used by M.D. Johnson (1986) and formalized in Attig and others (1988).

Copper Falls Formation: Poskin Member

Mark D. Johnson

Source of name. Community of Poskin, Barron County, Wisconsin.

Location and description of type section. Gravel pit on west side of 18th St., west-southwest of the City of Rice Lake. It is located in the NE¼NE¼SE¼ sec. 25, T. 35 N., R. 12 W., Barron County, an area shown on the Barron 7.5-minute quadrangle (fig. 46). At this site, the till is overlain by stream sediment and loess. The till is up to 6 m thick and overlies stream sediment. The till contains beds that differ slightly in color and grain size. In places, the beds are folded. A pebble fabric indicates ice flowing S. 35° E. deposited the till (fig. 47).

Location and description of reference section. Gravel pit on north side of State Highway 48, accessed from 16½ St. It is located in the SE¼SW¼ sec. 14, T. 35 N., R. 12 W., Barron County, an area shown on the Haugen 7.5-minute quadrangle (fig. 48). At this site, 2 m of collapsed stream sediment of the Poskin Member overlies 3 m of till of the Poskin Member. Part of the till contains

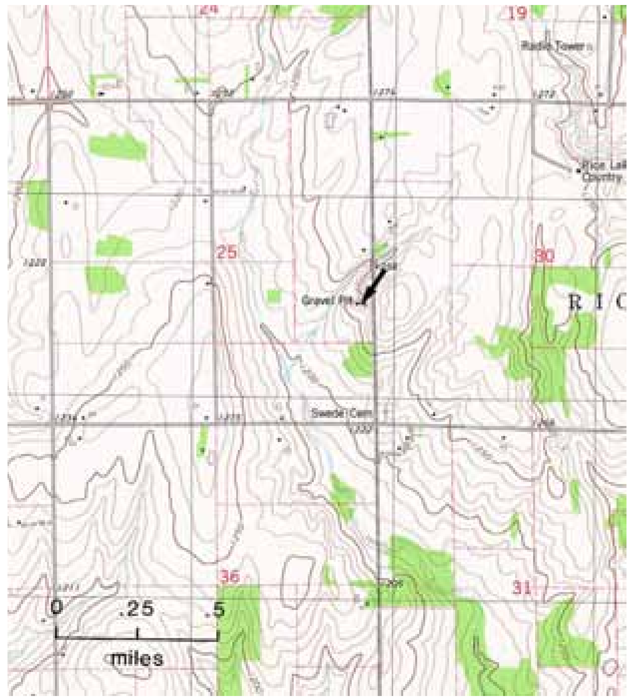

Figure 46. Part of the Barron 7.5-minute quadrangle showing the location of the type section of the Poskin Member.

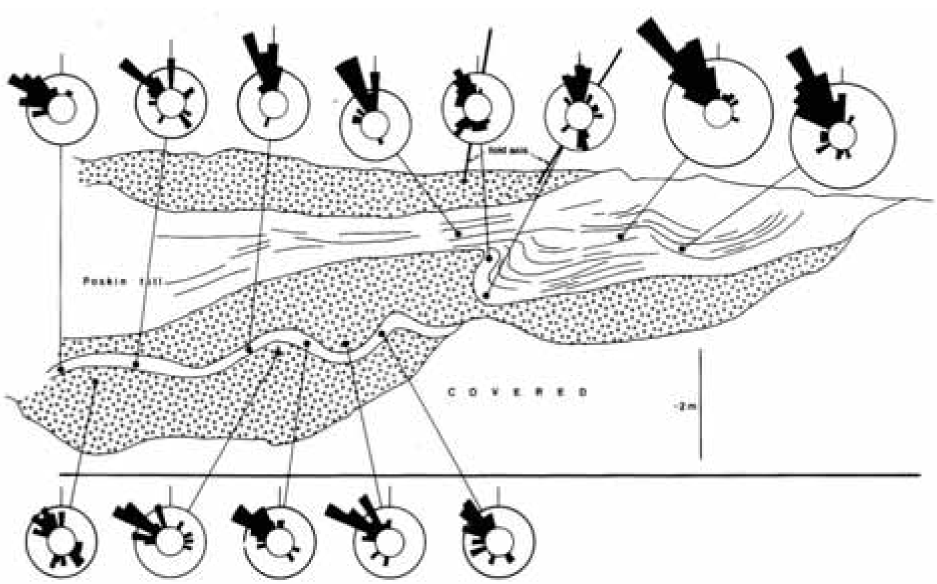

Figure 47. Diagram of the north wall of the excavation at the type section of the Poskin Member. The patterned area is stream-deposited gravelly sand; the lines represent stratification in the till. The sinuous bed in the stream sediment is till that may have been injected as a clastic dike. The pebble fabric diagrams are based on 25 measurements (50 in the two in the upper right) at each location. The enclosing circle has a radius of 10 percent of the pebbles counted. From Johnson (1984).

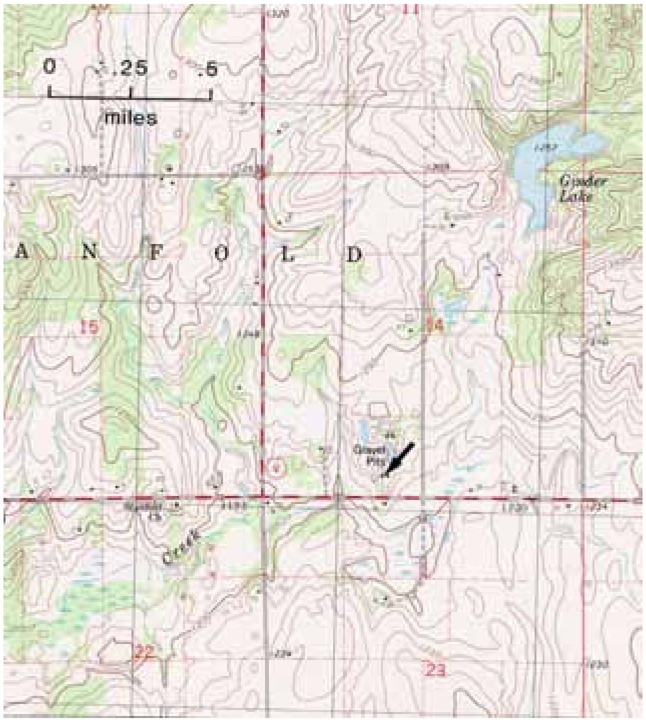

Figure 48. Part of the Haugen 7.5-minute quadrangle showing the location of the reference section of the Poskin Member.

sand stringers and is interbedded with the collapsed stream sediment. Unbedded till occurs beneath the till with sand stringers. These two types of till have similar color and grain size. The till with the sand stringers contains pebbles with widely scattered orientations; the unbedded till contains pebbles dipping predominantly to N. 60° W. The till with sand stringers is interpreted as supraglacial in origin; the unbedded till is interpreted as meltout or lodgement till.

Description of unit. Till of the Poskin Member is slightly gravelly to gravelly sandy loam with a less-than-2 mm matrix averaging 71 percent sand, 20 percent silt, and 9 percent clay. It is yellowish red (5YR 4/6) and has a typical clay-mineral composition of about 10 percent kaolinite, 30 percent illite, and 60 percent expandable clay. The very-coarse-sand fraction averages 47 percent quartz, 12 percent fine-grained mafic rock, 6 percent granite, 16 percent coarse-grained mafic rock, 2 percent Barron quartzite, 5 percent red sandstone, less than 1 percent other sandstone, and 11 to 12 percent other lithologies. The pebble fraction averages 35 percent fine-grained mafic rock, 21 percent coarse-grained mafic rock, 8 percent rhyolite, 11 percent granite and gneiss, 1 percent Barron quartzite, 10 percent Precambrian sandstone, 4 percent Cambrian sandstone, and 10 percent other lithologies. All samples analyzed were leached of carbonates. The till is generally unbedded but is stratified in places, as at the type section. Most exposures are not large enough to show stratification.

The character and distribution of stream sediment of the Poskin Member is not well known. The composition is predominantly slightly gravelly sand. Pebbles from a sample of stream sediment from the Poskin Member along Dority Creek include 39 percent fine-grained mafic rock, 40 percent coarse-grained mafic rock, 9 percent granite and gneiss, 4 percent rhyolite, 3 percent Precambrian sandstone, 4 percent Cambrian sandstone, and 1 percent other lithologies.

Nature of contacts. Where exposed, the lower contact of the till is sharp. The till typically overlies sand and gravel, but it overlies sandstone in southwest Barron County. The upper contact is generally sharp with the overlying loess. Till buried beneath sand and gravel of the Copper Falls Formation northwest of Cameron may be part of either the Poskin or Pokegama Creek Members.

Differentiation from other units. Till of the Poskin Member can be easily distinguished from the till of the Pierce Formation by grain size and color; from till of the River Falls Formation by magnetic susceptibility and kaolinite:illite ratio. The respective values for the Poskin Member are 9.3 (arbitrary units) and 1.4:1, and for the River Falls Formation, 4.0 (arbitrary units) and 2.3:1. Till of the Poskin Member contains less quartzite (1 percent) than till of the Pokegama Creek Member (19 percent) or till of the Mikana Member (4 percent). Till of the Poskin Member is brighter colored (5YR 4/6) than till of the Sylvan Lake Member (5YR 4/4).

Regional extent and thickness. Till of the Poskin Member occurs in a band parallel to, and 10 to 20 km in front of, the limit of the Sylvan Lake Member of the Copper Falls Formation (fig. 3). The southeastern limit is not well marked geomorphically but can be placed confidently where it abuts surface till units showing characteristics of the Pokegama Creek Member and River Falls Formation. It occurs southwest of Barron County in St. Croix County (Kostka and others, 2004). Till of the Poskin Member is very thick (an average thickness of 15 m is indicated in well reports). In places it may be as thick as 50 m or as thin as 1 m where it overlies sandstone.

Origin. Till of the Poskin Member was deposited by ice of the Superior Lobe flowing to the southeast during the Emerald Phase (fig. 6; Johnson, 2000). This phase was formerly called the early St. Croix Advance by M.D. Johnson (1986).

Age and correlation. The Poskin Member was deposited during the last part of the Wisconsin Glaciation. Ice left by the Poskin Advance was buried by outwash and did not melt until after ice of the St. Croix and late Chippewa Phases deposited the Sylvan Lake and Mikana Members (figs. 3, 6). The Poskin Member is older than the Sylvan Lake Member (deposited approximately 18,000 cal. yr B.P.) and younger than the Pokegama Creek Member (deposited between about 18,000 to 30,000 cal. yr B.P.).

No previously defined units in Wisconsin are known to correlate with the till of the Poskin Member. However, Berg (1960) described till in what he referred to as the "Emerald moraine" near Emerald, Wisconsin. This feature, though not clearly a moraine form, coincides geographically with the sampled limit of the Poskin till. Johnson (2000) later referred to the glacial phase that deposited the till as the Emerald Phase. "Extramorainic drift" has been reported flanking the St. Croix moraine in Wisconsin and Minnesota (Leverett, 1928; Schneider, 1961; Hobbs, 1983) and may have been deposited at nearly the same time as the Poskin Member.

Previous usage. This name was first used by M.D. Johnson (1984, 1986) and formalized in Attig and others (1988).

Copper Falls Formation: Mikana Member

Mark D. Johnson

Source of name. Community of Mikana, Barron County, Wisconsin.

Location and description of type section. Road cut through a hummock on west side of a 24 ½ St., north of County Highway V. It is located in the NE¼SE¼SW¼ sec. 7, T. 36 N., R. 10 W., Barron County, an area shown on the Rice Lake North 7.5-minute quadrangle (fig. 49). At this site, several centimeters of loess overlie 3 m of till of the Mikana Member. A drill hole at this site penetrated 20 m of uniform Mikana Member till. The hole was abandoned before reaching the base of the unit. A pebble fabric shows that ice flowing S. 40° W. deposited the till.

Location and description of reference sections. (1) Till exposed in a road cut on the inside of a curve on County Highway W. It is located in the SW¼NW¼SW¼ sec. 15, T. 33 N., R. 9 W., Rusk County, an area shown on the Chain Lake 7.5-minute quadrangle (fig. 50). At this site, 0.5 m of silt overlies at least 5 m of Mikana Member till. A pebble fabric at this site shows that ice flowing S. 75° W. deposited the till.

(2) Several gravel pits in northeastern Barron County contain stream sediment, predominantly slightly gravelly sand to gravelly sand, of the Mikana Member. A reference section of typical stream sediment is exposed in a pit on the north side of State Highway 48. It is located in the SE¼ sec. 5, T. 35 N., R. 10 W., Barron County, an area shown

Figure 49. Part of the Rice Lake North 7.5-minute quadrangle showing the location of the type section of the Mikana Member.

Figure 50. Part of the Chain Lake 7.5-minute quadrangle showing the location of reference section 1 of the Mikana Member.

Figure 51. Part of the Mikana 7.5-minute quadrangle showing the location of reference section 2 of the Mikana Member. This reference section displays typical Mikana Member stream sediment.

on the Mikana 7.5-minute quadrangle (fig. 51). At this site, silt 0.2 to 0.3 m thick overlies several meters of gravelly sand.

Description of unit. Till of the Mikana Member is slightly gravelly to gravelly sandy loam with a less-than-2 mm matrix averaging 71 percent sand, 21 percent silt, and 8 percent clay. It is dark reddish brown (5YR 3/6) in the upper oxidized and leached zone, and reddish brown (5YR 4/4) below 3.5 to 5.0 m. Where it is unoxidized and not leached of carbonate, the clay-mineral composition averages 11 percent kaolinite, 35 percent illite, and 54 percent expandable clay. The very-coarse-sand fraction typically contains 50 percent quartz, 11 percent fine-grained mafic rock, 7 percent granite, 13 percent coarse-grained mafic rock, 2 percent Barron quartzite, 4 percent red sandstone, less than 1 percent other sandstone, and 12 to 13 percent other lithologies. Where not leached of carbonate, the very-coarse-sand fraction contains 1 to 2 percent limestone. The pebble fraction contains about 35 percent fine-grained mafic rock, 22 percent coarse-grained mafic rock, 13 percent rhyolite, 10 percent granite and gneiss, 4 percent Barron quartzite, 7 percent Precambrian sandstone, 1 percent Cambrian sandstone, and 8 percent other lithologies. The relative magnetic susceptibility of the till is 9.7 (arbitrary units of University of Wisconsin–Madison, Department of Geoscience Pleistocene laboratory). The till is unbedded and contains unimodally oriented pebbles.

The character of the stream sediment of the Mikana Member is not well known. It generally contains sand with gravel lenses. Two sites contain pebbles that average 33 percent fine-grained mafic rock, 29 percent coarse-grained mafic rock, 12 percent rhyolite, 7 percent granite and gneiss, 2 to 3 percent Barron quartzite, 9 percent Precambrian sandstone, less than 1 percent Cambrian sandstone, and 5 percent other lithologies. The stream sediment is cross-bedded and horizontally bedded, and contains imbricated gravel.

Nature of contacts. The lower contact of the till is rarely seen in surface exposures. In drill holes, the till generally overlies sand and gravel. The upper contact is generally sharp with the overlying loess. For several square kilometers south of Mikana, the Mikana Member is overlain by sand and gravel.

Differentiation from other units. The color and grain size of the till of the Mikana Member distinguish it from the till of the Pierce Formation. The till of the River Falls Formation has a smaller relative magnetic susceptibility (4.0, arbitrary units) and a larger kaolinite:illite ratio (2.3:1 compared to 1.0:1 for the Mikana Member). Quartzite is more abundant in the Mikana Member (4 percent) than in the Poskin (1 percent) and Sylvan Lake (1 to 2 percent) Members. It is most similar to the Pokegama Creek Member, which has slightly more quartzite and a pebble fabric that indicates ice flow to the south.

Regional extent and thickness. In Barron County, till of the Mikana Member occurs in the northeasternmost township and along the eastern margin south of the Blue

Hills (fig. 3). The till is usually thin where it overlies Barron quartzite, but it is as thick as 20 m elsewhere.

Mikana stream sediment is present throughout the region behind the former ice-margin position and in plains that slope away from the ice-margin position in the northern and central parts of Barron County. Thickness is generally at least 10 m.

Origin. Till of the Mikana Member was deposited during the late Chippewa Phase of the Chippewa Lobe (fig. 6; Johnson, M.D., 1986).

Age and correlation. Till of the Mikana Member was deposited during the latter part of the Wisconsin Glaciation, which occurred approximately 18,000 cal. yr B.P. (Clayton and Moran, 1982). Mikana Member till is correlative with the till of the Chippewa moraine to the south in Chippewa County (Cahow, 1976; Syverson, 2007). These tills were deposited at about the same time as the Sylvan Lake Member of the Copper Falls Formation and the till of the St. Croix moraine in western Wisconsin and Minnesota.

Previous usage. This name was first used by M.D. Johnson (1986) and formalized in Attig and others (1988).

Copper Falls Formation: Sylvan Lake Member

Mark D. Johnson

Source of name. Sylvan Lake, Barron County, Wisconsin.

Location and description of type section. Road cut on south side of the east-west-trending 27 ½ Avenue. It is located in the SE¼SW¼NW¼ sec. 14, T. 36 N., R. 13 W., Barron County, an area shown on the Lower Vermillion Lake 7.5-minute quadrangle (fig. 52). At this site, silt and 2 m of interbedded till and stream sediment of the Sylvan Lake Member overlie 4 m of unbedded till of the Sylvan Lake Member. The interbedded till and stream sediment is supraglacial sediment, and the unbedded till is lodgement or meltout till. A pebble fabric within the unbedded till shows that ice flowing S. 35° E. deposited the till.

Location and description of reference sections. (1) Till in a small borrow pit on east side of the north-south-trending 13th Street. It is located in the NW¼SW¼SW¼ sec. 20, T. 36 N., R. 12 W., Barron County, an area shown on the Lower Vermillion Lake 7.5-minute quadrangle (fig. 53). At this site, 1.5 m of till of the Sylvan Lake Member, with a pebble fabric showing S. 10° E. ice flow, overlies at least 1.0 m of till of the Poskin Member. At the contact, a stone line has striations and a fabric parallel to the pebble fabric in the till of the Sylvan Lake Member.

(2) Gravel is mined from several northwest Barron County gravel pits that contain stream sediment of the Sylvan Lake Member, which is typically gravelly sand. Reference

Figure 52. Part of the Lower Vermillion Lake 7.5-minute quadrangle showing the location of the type section of the Sylvan Lake Member.

Figure 53. Part of the Lower Vermillion Lake 7.5-minute quadrangle showing the location of reference section 1 of the Sylvan Lake Member. This is reference section displays typical till of the Sylvan Lake Member.

Figure 54. Part of the Lower Vermillion Lake 7.5-minute quadrangle showing the location of reference section 2 of the Sylvan Lake Member. This reference section displays typical Sylvan Lake Member stream sediment.

Figure 55. Part of the Clayton 7.5-minute quadrangle showing the location of reference section 3 of the Sylvan Lake Member. This is reference section displays typical coarse-grained lake sediment of the Sylvan Lake Member.

section 2 containing typical Sylvan Lake Member stream sediment is located in the NE¼SE¼SE¼ sec. 36, T. 36 N., R. 13 W., Barron County, an area shown on the Lower Vermillion Lake 7.5-minute quadrangle (fig. 54). At this site, 0.6 m of silt overlies several meters of gravelly sand. This site is less than 1 km (0.5 mile) from the St. Croix Phase ice limit (fig. 6).

(3) The reference section for coarse-grained Sylvan Lake Member lake sediment is a gravel pit in the SE¼NW¼SE¼ sec. 6, T. 33 N., R. 14 W., Polk County, an area shown on the Clayton 7.5-minute quadrangle (fig. 55). At this site a small delta, which formed on the edge of an ice-walled lake, is exposed. Slightly gravelly sand occurs in topset, foreset, and bottomset beds. Silt units deposited by turbidity currents and a subaqueous debris flow also are exposed in the pit. Sediment is faulted near the ice-contact face; folds, which developed shortly after deposition by sediment flow, deform sediment at the delta top.

(4) The reference section for fine-grained lake sediment of the Sylvan Lake Member is a drill hole 1.6 km (1 mile) south of State Highway 8 on ½ St. It is located in the SW¼NW¼SE¼ sec. 31, T. 34 N., R. 14 W., Barron County, an area shown on the Turtle Lake 7.5-minute quadrangle (fig. 56). At this site several meters of silt loam overlies till of the Sylvan Lake Member.

Description of unit. Till of the Sylvan Lake Member is slightly gravelly to gravelly sandy loam; however, part is slightly gravelly to gravelly loamy sand. The less-than-2 mm till matrix averages 71 percent sand, 21 percent silt, and 8 percent clay. It is dark reddish brown (5YR 3/4 to 3/6) at the surface where it is oxidized and leached of carbonate. Below 2.5 to 5.0 m, the till is unoxidized, unleached, and is reddish brown (5YR 4/4). The clay minerals generally average 12 percent kaolinite, 31 percent illite, and 57 percent expandable clay. The very-coarse-sand fraction contains 44 percent quartz, 16 percent fine-grained mafic rock, 6 percent granite, 14 percent

Figure 56. Part of the Turtle Lake 7.5-minute quadrangle showing the location of reference section 4 of the Sylvan Lake Member. This reference section, a drill hole, displays typical fine-grained lake sediment of the Sylvan Lake Member.

coarse-grained mafic rock, 2 percent Barron quartzite, 5 percent red sandstone, less than 1 percent other sandstone, and 12 to 13 percent other lithologies. Below the leached zone, the very-coarse-sand fraction of the till contains less than 1 percent limestone. The pebble fraction contains 42 percent fine-grained mafic rock, 25 percent coarse-grained mafic rock, 9 percent rhyolite, 11 percent granite and gneiss, 1 or 2 percent Barron quartzite, 6 percent Precambrian sandstone, 3 percent Cambrian sandstone, and 1 percent other lithologies. The average relative magnetic susceptibility is 11.8 (arbitrary units of University of Wisconsin–Madison, Department of Geoscience Pleistocene laboratory).

Stream sediment of the Sylvan Lake Member is generally slightly gravelly sand, gravelly sand, and sand with beds of gravel. A pebble sample of stream sediment collected near the community of Turtle Lake has 48 percent fine-grained mafic rock, 25 percent coarse-grained mafic rock, 8 percent rhyolite, 9 percent granite and gneiss, 9 percent Precambrian sandstone, 2 percent Cambrian sandstone, and 2 percent other lithologies. The stream sediment is cross-bedded and horizontally bedded and contains imbricated gravel.

Lake sediment of the Sylvan Lake Member is generally coarse (sandy) near former lake margins and fine (silty) beneath former lake centers. Deltas at former lake-margin positions contain slightly gravelly sand and sand in topset and foreset beds. In places, foreset beds have been draped by silty fallout sediment. Bottomset beds are composed of sand and silty sediment in beds that are 1 to 30 mm thick. Debris-flow sediment composed of gravelly sandy loam is interbedded with bottomset beds in places. Near the centers of ice-walled-lake plains, the sediment consists of silt and sand deposited by fallout and turbidity currents. The fine-grained lake sediment in the lake-plain centers is 10 m thick in places. Coarse-grained sediment, which occurs below the silt and above till in places, is probably supraglacial sediment deposited by debris flows in the lake as ice melted during the formation of the ice-walled-lake basin.

Nature of contacts. The lower contact of the till unit is seldom exposed at the surface but is commonly found over sand and gravel in drill holes. The upper contact with loess is generally sharp. Stream sediment of the Sylvan Lake Member is overlain by a thin layer of loess. The lower contact of the stream sediment is seldom observed and may overlie till of the Sylvan Lake or Poskin Members or stream sediment of the Poskin Member. The lower contact of the lake sediment with till of the Sylvan Lake Member is sharp; the upper contact with the loess is sharp but difficult to identify where the lake sediment is silty.

Differentiation from other units. The color and grain size of Sylvan Lake Member till readily distinguish it from till of the Pierce Formation. The till of the River Falls Formation has a lower relative magnetic susceptibility (4.0 compared to 11.8 in till of the Sylvan Lake Member, arbitrary units) and higher kaolinite:illite ratio (2.3:1 compared to 1.1:1 in till of the Sylvan Lake Member). The Sylvan Lake Member has a lower quartzite percentage, a higher fine-grained mafic rock percentage, and a different fabric than till of the Prairie Farm, Pokegama Creek, and Mikana Members.

Regional extent and thickness. Till of the Sylvan Lake Member is located behind the former ice-margin position of the St. Croix Phase in St. Croix, Polk, and Barron Counties (fig. 6, Johnson, M.D., 1986). Sylvan Lake Member till is commonly exposed in the hummocky topography of that region. The till is 5 to 45 m thick.

Stream sediment of the Sylvan Lake Member underlies pitted plains behind and in front of the St. Croix ice-margin position. Thickness varies, but it is commonly greater than 10 m.

Lake sediment of the Sylvan Lake Member is found in ice-walled-lake plains in northwest Barron County and in Polk County. Sediment ranges in thickness from 10 to 15 m at the edges of plains to 7 to 10 m at the centers.

Origin. Till of the Sylvan Lake Member was deposited by the Superior Lobe during the St. Croix Phase (fig. 6). Much of the till was probably deposited by meltout or lodgement because it is unbedded and has a regionally consistent pebble fabric. Sediment interpreted as flow till is rarely exposed and most likely does not compose a large part of this member. Sand and gravel was deposited by supraglacial and proglacial streams. Lake sediment was deposited in ice-walled lakes.

Age and correlation. The Sylvan Lake Member was deposited during the latter part of the Wisconsin Glaciation about 18,000 cal. yr B.P. (Clayton and Moran, 1982). Till of the Sylvan Lake Member was deposited at about the same time as the till in the St. Croix moraine southwest of Barron County and in Minnesota, the till of the Mikana Member of the Copper Falls Formation, and most likely the till of the Nashville Member in eastern Wisconsin.

Previous usage. This name was first used by M.D. Johnson (1986) and formalized in Attig and others (1988).

Copper Falls Formation: Wildcat Lake Member

John W. Attig

Source of name. Wildcat Lake, Vilas County, Wisconsin.

Location and description of type section. A gravel pit on the southeast side of County Highway M, about 0.5 km (0.3 mile) southwest of the intersection of County Highways B and M. It is located in the NW¼NW¼NE¼ sec. 34, T. 43 N., R. 7 E., Vilas County, an area shown on the Tenderfoot Lake 7.5-minute quadrangle (fig. 57).

The type section is in the southeast corner of the gravel pit mentioned above. Three types of material crop out in what was a fresh face in 1982. Till of the Wildcat Lake Member crops out in the bottom 1 m of the section. The till is a uniform, compact, yellowish-red (5YR 5/6), slightly gravelly loamy sand. The till has a strongly developed pebble fabric; the long axes of most pebbles are parallel to ice flow and plunge upglacier. Debris-flow and stream sediment overlie the till.

Location and description of reference section. A power-auger hole near the crest of a drumlin on the south side of North Creek Road in the NW¼NW¼NW¼ sec. 36, T. 42 N., R. 6 E., Vilas County, an area shown on the Boulder Junction 7.5-minute quadrangle (fig. 58).

Figure 57. Part of the Tenderfoot Lake (Wisconsin/Michigan) 7.5-minute quadrangle showing the location of the type section of the Wildcat Lake Member.

The auger penetrated 1.5 m of gravelly sand to slightly gravelly loamy sand that is interpreted to be debris-flow sediment. The auger then penetrated 5.7 m of uniform, compact, yellowish-red (5YR 5/6) slightly gravelly loamy sand. The material below 1.5 m is interpreted to be till of the Wildcat Lake Member.

Description of unit. Till of the Wildcat Lake Member is slightly gravelly loamy sand to sandy loam. The till averages 71 percent sand, 21 percent silt, and 8 percent clay (16 samples). Clay minerals average 44 percent expandable clay, 41 percent illite, and 15 percent kaolinite plus chlorite (11 samples). Average relative magnetic susceptibility is 14.8 (16 samples, arbitrary units of University of Wisconsin–Madison, Department of Geoscience Pleistocene laboratory). Moist field color is typically yellowish red (5YR 5/6). The pebble lithologies in this unit average 8 percent sandstone, 14 percent unaltered volcanic rock (probably Keweenawan), 14 percent argillic and slaty metasedimentary rock, and 64 percent other igneous and metamorphic rock. A pebble fabric in this unit (measured at only one location) is strongly developed with the long axis of most pebbles oriented parallel to regional ice flow (north-northeast to south-southwest) and dipping upglacier (north-northeast) (Attig, 1984, 1985).

Figure 58. Part of the Boulder Junction 7.5-minute quadrangle showing the location of the reference section of the Wildcat Lake Member (a power-auger hole).

Nature of contacts. The lower contact of this unit has only been observed in drill holes. In those holes the contact with underlying sand and gravelly sand is abrupt. In many areas the till of the Wildcat Lake Member is overlain by debris-flow sediment and stream-deposited sand and gravel. The contact with the overlying material is typically sharp.

Differentiation from other units. Till of the Wildcat Lake Member has not been observed in contact with the till of any other named member. Wildcat Lake Member till has a higher magnetic susceptibility than till of the Nashville or Crab Lake Members. It is redder, contains more pebbles of sandstone and Keweenaw volcanic rock, and contains more expandable clay than the Nashville Member. It has a higher percentage of sand in the less-than-2 mm fraction, has a higher relative magnetic susceptibility, a lower percentage of expandable clay, and a higher percentage of illite than the Crab Lake Member.

Regional extent and thickness. The Wildcat Lake Member is the surface unit in western Vilas County south of the Winegar moraine. It presumably extends southward to the terminal moraine of the Wisconsin Valley Lobe, where it is equivalent to Bass Lake till that was informally named by Nelson (1973). The thickness of Wildcat Lake Member till is not well known. Several drill holes show the till of this unit is up to 6 m thick.

Origin. The Wildcat Lake Member contains till and associated debris-flow sediment and stream sediment. Till of the Wildcat Lake Member was deposited during the Harrison Phase (fig. 6; Ham and Attig, 1997) as the Wisconsin Valley Lobe flowed southwest across Vilas, and presumably Oneida, Lincoln, and Langlade Counties.

Age and correlation. The Wildcat Lake Member was deposited during the last part of the Wisconsin Glaciation. It is probably nearly equivalent in age to the Nashville Member and is older than the Crab Lake Member (Attig, 1984, 1985; Attig and others, 1985).

Previous usage. This member name was first used by Attig (1984, 1985) and by Attig and others (1985). Formalized in Attig and others (1988).

Copper Falls Formation: Nashville Member

William W. Simpkins

Source of name. Nashville Township, Forest County, Wisconsin.

Location and description of type section. Gravel pit in a drumlin located in the SE¼SW¼SE¼ sec. 7, T. 35 N., R. 12 E., southwestern Forest County, an area shown on the Nashville 7.5-minute quadrangle (figs. 59, 60).

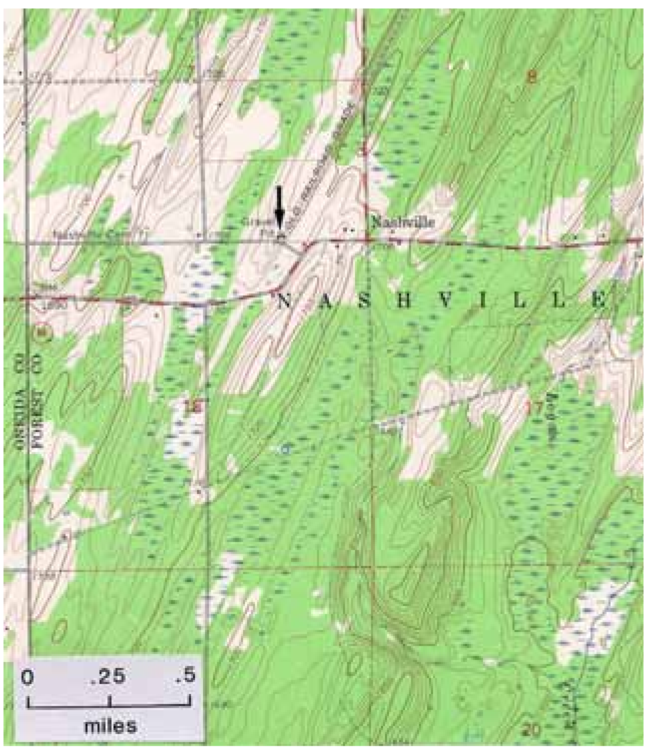

Figure 59. Part of the Nashville 7.5-minute quadrangle showing the location of the type section of the Nashville Member.

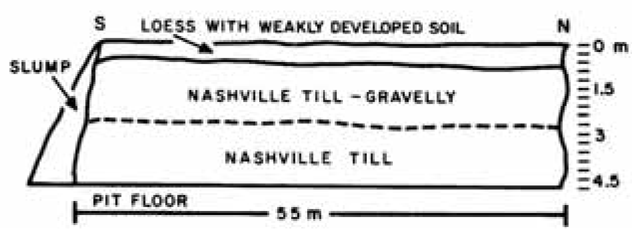

Figure 60. Sketch showing the stratigraphy of the west face of the gravel pit that is the type section of the Nashville Member.

A sketch of the west face of the gravel pit is shown in figure 60. All material exposed in the upper part of the pit is Nashville Member till, and supraglacial (gravelly) and subglacial facies are probably present. Gravel, presumably of the Nashville Member, is present at the base of the pit.

Location of reference sections. (1) Upper till unit (and probably the sand beneath) in the Pine Lake gravel pit, located in the SW¼NE¼NW¼ sec. 26, T. 37 N., R. 12 E., Forest County, an area shown on the Argonne 7.5-minute quadrangle (fig. 61). (2) Gravel pit in a drumlin on the west side of State Highway 55. It is located in the NW¼NW¼NW¼ sec. 31, T. 36 N., R. 12 E., Forest County, an area shown on the Crandon 7.5-minute quadrangle

Figure 61. Part of the Argonne 7.5-minute quadrangle showing the location of reference section 1 of the Nashville Member.

(fig. 62). About 2 m of Nashville Member till overlies more than 25 m of sand and gravel of the Horicon Member of the Holy Hill Formation.

Description of unit. Till of the Nashville Member is a pebbly, cobbly sandy loam, averaging 77 percent sand, 16 percent silt, and 7 percent clay in the less-than-2 mm fraction, and contains numerous sand lenses within it. The percentage of sand increases slightly in the northern part of Forest County. Moist field colors of the till range from reddish brown (5YR 4/4) to yellowish red (5YR 4/6) to brown and strong brown (7.5YR 4/4 to 7.5YR 4/6), with more reddish hues apparent in areas near the Michigan border. Clay mineral percentages determined using a semiquantitative analysis (Stewart, 1973) show the till to have approximately 80 percent illite, 12 percent kaolinite plus chlorite, 5 percent vermiculite, and 3 percent smectite (Simpkins, 1979). The pebble lithologies in the unit average 95 percent igneous and metamorphic rocks and 5 percent sedimentary rocks. The percentage of sedimentary clasts presumably increases towards the east.

Nature of contacts. The Nashville Member is generally underlain by sand, gravel, or till derived from the Green Bay Lobe (Horicon Member of the Holy Hill Formation). Unless it is at the surface, the Nashville Member is overlain by sand and gravel of the Langlade Lobe (Copper Falls Formation). The contacts are generally sharp, although some clasts of till can be found in stratified sediment overlying the till.

Differentiation from other units. Where the Nashville Member directly overlies till of the Horicon Member of the Holy Hill Formation, differentiation of the units is made by the high percentage of dolomite or sedimentary pebbles in the Horicon Member.

Regional extent and thickness. The Nashville Member is the surficial unit in southern Forest and northern Langlade Counties. The till is also present in eastern Vilas and Oneida Counties. The Nashville Member ranges in thickness from 2 to 17 m and averages 6.1 m.

Origin. The Nashville Member contains subglacial till deposited by glacial ice of the Langlade Lobe. Subglacial till in exposures may be overlain by thin supraglacial till. Associated deposits of sand and gravel are also included.

Figure 62. Part of the Crandon 7.5-minute quadrangle showing the location of reference section 2 of the Nashville Member.

Age and correlation. The Nashville Member was deposited during the last part of the Wisconsin Glaciation. It is the stratigraphic equivalent of the informally named Kempster and Moccasin Lake tills described by Nelson (1973) in the Parrish and Summit Lake moraines of the Langlade Lobe, respectively. It is the stratigraphic equivalent of the Horicon Member of the Holy Hill Formation, although till of the Nashville Member is known to overlie the Horicon Member in eastern Langlade County (Mickelson and others, 1974). Complex intertonguing of these units also occurs in an interlobate area in eastern Langlade County and northward to northern Florence County. Nashville Member till is also the approximate stratigraphic equivalent of the informally named Bass Lake till of the Wisconsin Valley Lobe, although the Bass Lake till crosscuts the informally named Kempster till in the Parrish moraine (Nelson, 1973).

Previous usage. This unit name was first used informally by Simpkins (1979); it was formalized in Mickelson and others (1984).

Copper Falls Formation: Crab Lake Member

John W. Attig

Source of name. Crab Lake, Vilas County, Wisconsin.

Location and description of type section. A road cut on the east side of Crab Lake Road about 75 m south of County Highway B. The type section is located in the NW¼NW¼NW¼ sec. 2, T. 43 N., R. 6 E., Vilas County, an area shown on the Presque Isle 7.5-minute quadrangle (fig. 63).

The type section is a fresh (1981) road cut that is 2 m high. At the base of the section, 1.5 m of compact, uniform, yellowish-red (5YR 5/6) slightly gravelly, sandy, silty, clayey till crops out. This till contains a well-developed pebble fabric indicating ice flow from the north. The till is overlain by 0.5 m of poorly compacted, variable yellowish-red (5YR 5/6 to 4/6), gravelly, sandy, silty, clayey till and debris-flow sediment.

Figure 63. Part of the Presque Isle (Wisconsin/Michigan) 7.5-minute quadrangle showing the location of the type section of the Crab Lake Member.

Location and description of reference section. A small gravel pit on the west side of a dirt road 1 km (0.6 mile) northwest of the intersection of Helen Creek and County Highway B. A fresh face was exposed in this pit in 1981. The site is located in the NE¼SE¼NW¼ sec. 19, T. 43 N., R. 9 E., Vilas County, an area shown on the Thousand Island Lake 7.5-minute quadrangle (fig. 64).

Figure 64. Part of the Thousand Island Lake (Wisconsin/Michigan) 7.5-minute quadrangle showing the location of the reference section of the Crab Lake Member.

The reference section is a fresh (1982) gravel pit exposure that is 3.5 m high. The lower 1.0 m consists of stratified coarse and fine sand. This material is overlain by 1.0 to 1.5 m of compact, uniform, yellowish-red (5YR 5/6) slightly gravelly, sandy, silty, clayey till. The till contains a well-developed pebble fabric indicating ice flow from the north. It also contains a 10 cm thick bed of yellowish-red (5YR 5/6) fine sand that has been deformed. The upper meter of the exposure consists of poorly compacted, variable yellowish-red (5YR 5/6 to 4/6), gravelly, sandy-loam debris-flow sediment. The pebble fabric in this upper unit is poorly developed and not related to regional ice flow.

Description of unit. Till of the Crab Lake Member is slightly gravelly sandy loam. The till averages 61 percent sand, 30 percent silt, and 9 percent clay (19 samples). Clay minerals average 64 percent expandable clay, 26 percent illite, and 9 percent kaolinite plus chlorite (16 samples). Average relative magnetic susceptibility is 8.5 (19 samples, arbitrary units). Moist field color is typically reddish brown (5YR 4/4). Pebble lithologies in this unit average 11 percent sandstone, 11 percent unaltered volcanic rock (probably Keweenawan), 16 percent argillic and slaty metasedimentary rock, and 62 percent other igneous and metamorphic rock. Till of this unit has a strongly developed pebble fabric; the long axes of most pebbles are oriented parallel to ice flow (north-south) and plunge upglacier (north). Attig (1984) interpreted the till of this member as lodgement or meltout till.

Nature of contacts. The lower contact of this unit has been observed at few places. Where the contact has been observed, till of the Crab Lake Member overlies stratified sand and gravel and the contact is sharp. In some places, the stratified sand and gravel underlying the Crab Lake Member is interpreted as part of the Nashville Member. In other areas, the underlying sand and gravel is undifferentiated.

Differentiation from other units. Till of the Crab Lake Member is not known to be in contact with the till of any other named member. Crab Lake Member till has a higher percentage of silt in the less-than-2 mm fraction than the tills of the Nashville and Wildcat Lake Members. It has a higher relative magnetic susceptibility, is redder, contains more pebbles of sandstone and Keweenawan volcanic rock, and has more expandable clay than the Nashville Member. It has lower relative magnetic susceptibility and more expandable clay than the Wildcat Lake Member.

Regional extent and thickness. The Crab Lake Member is the surface unit in Vilas County and adjacent Iron County in, and north of, the Winegar moraine. It presumably extends northward into Michigan at least as far as the Marenisco moraine. The maximum known thickness of the till of the Crab Lake Member is 8.5 m, but thickness is typically 1 to 3 m.

Origin. The Crab Lake Member contains till and associated supraglacial debris-flow sediment and stream sediment. The till of the Crab Lake Member was deposited during the Winegar Phase of the Ontonagon Lobe (fig. 6, Attig, 1985).

Age and correlation. The Crab Lake Member was deposited during the last part of the Wisconsin Glaciation (fig. 6). It is younger than the Wildcat Lake and Nashville Members of the Copper Falls Formation, and is equivalent to the informally named Morse till in Iron County (Clayton, 1984). It is also equivalent to the sediment in the Winegar moraine in adjacent Michigan described by Peterson (1982). Regional correlation (Clayton and Moran, 1982; Mickelson and others, 1983; Attig and others, 1985) suggests that the Crab Lake Member was deposited between about 14,000 to 16,000 cal. yr B.P.

Previous usage. This member name was first used by Attig (1984, 1985) and Attig and others (1985). Formalized in Attig and others (1988).

Copper Falls Formation: Sunrise Member

Mark D. Johnson

Source of name. Community of Sunrise in Chisago County, Minnesota.

Location and description of type section. The type section is in the east bank of the North Branch Sunrise River, on the outside of a meander bend. It is located in the NW¼NE¼NW¼ sec. 19, T. 35 N., R. 20 W., Chisago County, Minnesota, an area shown on the North Branch 7.5-minute quadrangle (fig. 65).

Slightly pebbly sand 4.7 m thick overlies the Sunrise Member at the type section. Many pebbles and some cobbles lie at the contact and represent a lag gravel truncating the top of the Sunrise Member. The laminated silt and clay beds of the Sunrise Member are 10.0 m thick below the sand. The base of the silt and clay lies below river level and is not exposed, and some of the silt and clay is covered. Detailed observations at the site reveal 776 exposed varves ranging in thickness from 0.7 to 2.5 cm. Varve 536 above river level in the sequence is 30 cm thick and could represent a mud-flow deposit rather than a varve.

Location and description of reference sections. Reference section A is exposed in a ravine on the north side of Benson Road. It is located in the N½NE¼SE¼ sec. 7, T. 38 N., R. 19 W., Burnett County, Wisconsin, an area shown on the Bass Creek 7.5-minute quadrangle (fig. 66). Reference section A contains several meters of sand overlying 6.5 m of Sunrise Member varved silt and clay; a gravel lag marks the contact. This cut contains 250 varves. Interbedded with the varved silt and clay are five thick (40 to 60 cm) silt and clay beds that are massive to graded. In places, these thick beds have discontinuous, convoluted silt beds. The thickness of these beds changes markedly when traced across the outcrop. Such characteristics suggest that they represent mud-flow or slump units.

Reference section B is exposed along the south bank of the Snake River. It is located in the SE¼NE¼NW¼ sec. 30, T. 39 N., R. 20 W., Pine County, Minnesota, an area shown on the Pine City 7.5-minute quadrangle (fig. 67). Reference section B exposes several meters of sandy Sunrise Member sediment that is interpreted to represent sedimentation close to the western shore of glacial Lake

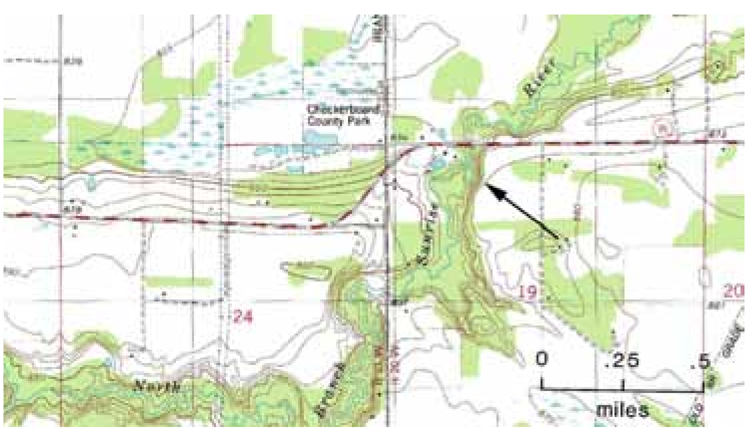

Figure 65. Part of the North Branch (Minnesota) 7.5-minute quadrangle showing the location of the type section of the Sunrise Member.

Figure 66. Part of the Bass Creek (Minnesota/Wisconsin) 7.5-minute quadrangle showing the location of reference section A of the Sunrise Member.

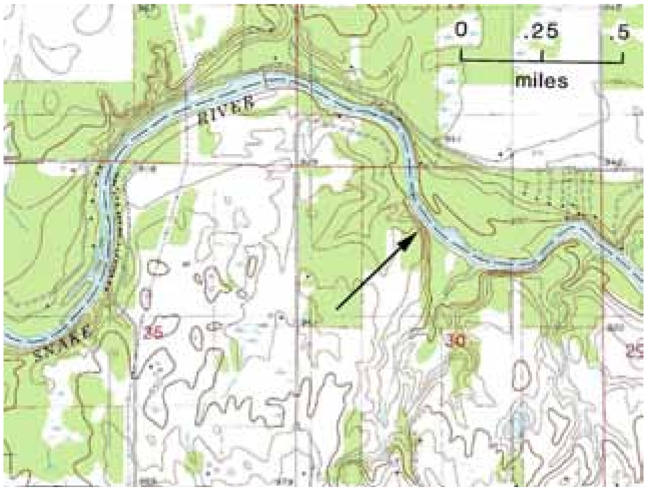

Figure 67. Part of the Pine City (Minnesota) 7.5-minute quadrangle showing the location of reference section B of the Sunrise Member.

Lind. From top to bottom the exposure contains 2.5 m of fine to coarse sand, 1.2 m of rippled sand with clay drapes, 0.3 m of red till-like material, 1.0 m of medium to coarse sand, and 3.0 m of red sandy till with some interbeds of sand. The rippled sand layer contains 50 clay drapes that are interpreted to be winter layers. In places the clay is truncated and present only in ripple troughs. The overlying sand is not clearly part of the Sunrise Member and may represent a Snake River terrace deposit.

Description of unit. The Sunrise Member contains rhythmically laminated sand, silt, and clay. The bulk of the sediment consists of couplets of slightly calcareous, dark reddish-brown (5YR 3/3) to dark reddish-gray (5YR 4/2) silt and slightly calcareous, dark reddish-brown (2.5YR to 5YR 3/4) clay. The couplets generally range in thickness from 0.5 to 3.0 cm, although couplets as thin as 0.2 cm or as thick as 25.0 cm are present in places. Where the Sunrise Member overlies till, the sediment at the base of the unit near the contact consists of silt, sand, gravel, and till-like material interbedded with thin, widely separated clay layers. Near its eastern and western limits, the character of the Sunrise Member changes; thick beds of silt and sand, some of which are highly convoluted, are in places interbedded with pure clay.

In places, the laminated silt and clay grade upward into progressively thicker and coarser silt layers with intervening thin red clay beds. This sequence in turn grades upwards into sand, some of which has bedding that is characteristic of beach and fluvial sand. The sand contains pebbles in places; some are red clay clasts derived from the laminated part of the Sunrise Member.

Nature of contacts. Where observed, the lower contact of the Sunrise Member is sharp and overlies Copper Falls Formation till. Beneath the sand barrens of Polk and Burnett Counties, Wisconsin, and parts of Chisago and Pine Counties, Minnesota, the upper contact is sharp and is overlain by a lag gravel and fluvial sand. In the same counties, the upper, sandy part of the Sunrise Member is overlain by Trade River Formation till; a few centimeters of laminated gray clay are at the sharp contact.

Differentiation from other units. The Sunrise Member is most similar to the Falun Member of the Trade River Formation, but they are easily differentiated on the basis of color (reddish rather than gray) and stratigraphic position (Sunrise Member is lower).

Regional extent and thickness. The Sunrise Member is exposed along the St. Croix River and its tributaries in northwestern Wisconsin and east-central Minnesota, and it is present only in the subsurface in all other areas. The southernmost outcrops are along the Sunrise River in central Chisago County, Minnesota; the northernmost, at St. Croix State Park, Pine County, Minnesota. The Sunrise Member is well exposed along the Wood, Clam, and Trade Rivers in Wisconsin and along Rock Creek, Goose Creek, and the Snake River in Minnesota. The thickness of the Sunrise Member varies from a few meters to as much as 30 m (found in material from a drill hole near Sunrise, Minnesota); most exposures contain 5 to 10 m. In places where the coarsening-upward sequence is preserved, the sand may be more than 20 m thick.

Origin. The Sunrise Member was deposited in glacial Lake Lind while the Superior Lobe was retreating from western Wisconsin and eastern Minnesota (Johnson and Hemstad, 1998; Johnson and others, 1999; Johnson, 2000). The laminated sediments are interpreted to represent varves deposited in deep water away from strandlines. The coarser sediment at the base of the unit is interpreted to represent near-glacier sedimentation in the bottom of the lake as the Superior Lobe retreated and the lake expanded. Individual varve thickness is greatest above the till and becomes thinner upwards after 25 to 40 varves. Coarser sediment exposed along the Sunrise and Snake Rivers near the margins of the unit's extent is interpreted to represent near-shore sedimentation where sediment supply may have been higher and water depth more shallow. The coarsening-upward sequence preserved in places above the varved sequence is interpreted to represent deposition of deltaic and fluvial sand and a gradual filling in of the lake.

Age and correlation. The age of the Sunrise Member is not well known, but it was probably deposited between about 17,300 to 19,200 cal. yr B.P. The Sunrise Member is probably correlative with a buried unit of red and brown lacustrine sediment in southern Chisago County and central Anoka County as mapped by Helgesen and Lindholm (1977). It is younger than fluvial and glacial deposits of the Copper Falls Formation elsewhere in Polk County and older than the sediment of the Trade River Formation.

Previous usage. Formalized in Johnson (2000).

Hayton Formation

Betty J. Socha

Source of name. An unincorporated village in east-central Calumet County, Wisconsin.

Location and description of type section. Exposures in the quarry owned by Valders Stone & Marble, at Valders, Wisconsin, south of County Road JJ, about 1.6 km (1 mile) northeast of the junction of State Highway 148 and US Highway 151. It is located in the NW¼NE¼, and the NE¼NW¼ sec. 32, T. 19 N., R. 22 E., Manitowoc County, an area shown on the Valders 7.5-minute quadrangle (fig. 68). Fresh exposures (in 2008) are located at the north end of the quarry. This quarry also serves as the type section for the Cato Falls Member.

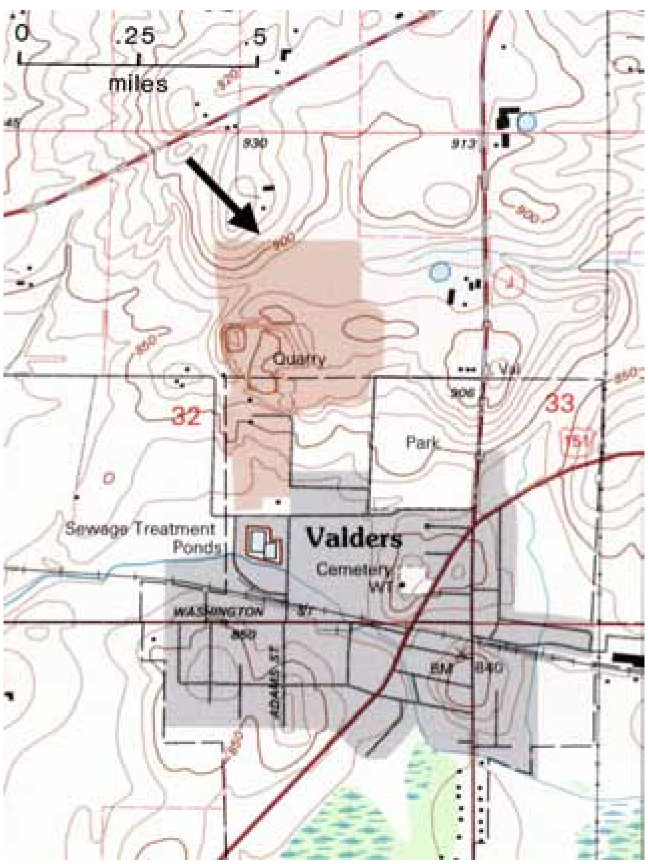

Figure 68. Part of the Valders 7.5-minute quadrangle showing the location of the type section of the Hayton Formation and the Cato Falls Member.

The part of the quarry being mined is located in a drumlin trending approximately north to south. The core of the drumlin predominantly contains Hayton Formation till with some Holy Hill Formation till in the upper part of the drumlin.

The northern wall of the quarry exposes 18 to 24 m of diamicton with a few thin beds of fluvial sand and gravel. Diamicton of the Valders Member of the Kewaunee Formation is exposed at the top of the outcrop. Valders Member till is 1 to 2 m thick, brown (7.5YR 5/2) to yellowish-red (5YR 5/6), and silt- and clay-rich. The Valders Member is underlain by 2 to 4 m of yellowish-brown (10YR 6/6), silty-sandy till of the Holy Hill Formation. The Holy Hill Formation till is underlain by up to 18 m of dense, gray (5YR 6/1) to grayish-brown (10YR 4/6), sandy-silty till of the Cato Falls Member of the Hayton Formation.

The eastern wall of the quarry exposes 3 to 12 m of diamicton over sorted sediment. The uppermost diamicton is brown (7.5YR 5/2) to yellowish-red (5YR 5/6), silty-clayey till of the Valders Member. Till of the Valders Member is up to 8 m thick. Valders Member till is underlain by about 8 m of yellowish-brown (10YR 6/6), silty-sandy till of the Holy Hill Formation. The Holy Hill Formation till thins in the central and southern parts of the quarry wall, and it overlies yellowish-brown and gray, laminated, lacustrine silt and fine sand and fluvial sand and gravel near the base of the section.

Pebbles in the Hayton and Holy Hill Formation till units are oriented north-northeast to south-southwest, parallel to the striations on the underlying polished Silurian dolomite and sub-parallel to the drumlin axis. Ice flowing from the east out of the Lake Michigan basin deposited till of the Valders Member which drapes the drumlin.

Location of reference section. The reference section is an exposure in the quarry located in the SW¼SE¼ sec. 30, T. 20 N., R. 19 E., Calumet County, an area shown on the Sherwood 7.5-minute quadrangle (see fig. 69 in the High Cliff Member description). Exposures in the quarry are described in detail by Socha (2007a,b). The reference section for the Hayton Formation also serves as the reference section for the Cato Falls Member and the type section for the High Cliff Member of the Hayton Formation (see High Cliff Member for a detailed description of this exposure).

Description of the unit. The Hayton Formation includes diamicton, silt and fine sand, and associated coarse-grained sorted sediment. The gray, sandy-silty diamicton of the Cato Falls Member is interpreted to be primarily basal till (Socha, 2007a). The till is massive, very dense, cohesive and contains abundant gravel-sized clasts. The till matrix averages 37 percent sand, 48 percent silt, and 15 percent clay (13 samples). Thin layers of sand and gravel are interbedded with the till. Pebbles in the gray, sandy-silty till are oriented north-northeast to south-southwest.

The overlying High Cliff Member contains gray or dark gray silt and fine sand that is typically uniform and massive, but in places the sediment is laminated and thinly bedded. The unit contains interbeds and laminae of reddish-brown clay where overlain by reddish-brown, silty-clayey diamicton. Regionally it is distributed as a thin blanket over the former landscape. The High Cliff Member commonly contains small, dispersed pieces of leaves, stems, mosses, and twigs that indicate a tundra environment (Socha, 2007a). The upper part of the unit also may display an organic-rich soil horizon. Details about pebble lithology, carbonate content, and grain-size distribution are presented in each member description.

Nature of contacts. The Hayton Formation is in the subsurface where it rests on bedrock, sand, or reddish-brown or pinkish till of unknown origin. The contact with the underlying diamicton and bedrock is generally sharp. The contact with the overlying brown, sandy diamicton of the Holy Hill Formation is generally sharp, but the contact is convoluted over 5 to 8 m in places at the type section. The contact between the Hayton Formation and overlying reddish-brown, clayey diamicton of the Kewaunee Formation is erosional and sharp; elsewhere the erosional contact is interbedded or interlaminated over a thickness of about a half meter. At several sites, an organic-rich soil horizon in the upper part of the Hayton Formation suggests little erosion by later ice advances.

Differentiation from other units. Till of the Hayton Formation is easily distinguished in the field by its grayish color, cohesive and very dense matrix, numerous carbonate pebbles, and numerous well-rounded, polished and striated gravel-sized clasts. The till is grayer and siltier than till of the Holy Hill Formation. More well-rounded, polished and striated igneous and metamorphic clasts are present in the till of the Hayton Formation than in the till of the Holy Hill Formation. Orientation of pebbles in the diamicton of the Hayton Formation indicates ice flow generally from the north-northeast to south-southwest, whereas in northeastern Wisconsin the orientation of pebbles in the Holy Hill Formation till indicates variable ice-flow directions within the Green Bay and Lake Michigan Lobes. Hayton Formation till is grayer and sandier than the reddish-brown, clayey till of the Kewaunee Formation.

Regional extent and thickness. The Hayton Formation is buried by younger deposits of both the Green Bay and Lake Michigan Lobes in much of northeastern and east-central Wisconsin, an area including Outagamie, Calumet, Manitowoc, Sheboygan, Fond du Lac, and Dodge Counties. The Cato Falls Member has been described in most of this region; the informally named Kekoshkee member is described from locations in Dodge and Fond du Lac Counties (Battista, 1990). The Hayton Formation is generally less than 1 m thick along the Silurian Escarpment, is at least 24 m thick at the type section in central Manitowoc County, and is greater than 43 m thick in southern Manitowoc County (Crystal, Inc., 1994, unpublished logs of exploration drill holes). The High Cliff Member is generally about 1 m thick but is as much as 3.5 m thick (BT Squared, Inc., 2009). The High Cliff Member has an irregular distribution over the till of the Hayton Formation and the bedrock surface.

Hayton Formation

Origin. The Hayton Formation was deposited by ice, meltwater, and eolian processes associated with the Green Bay and Lake Michigan Lobes, or possibly an undivided ice lobe flowing from the north-northeast. The ice flowed along the axis of the Green Bay-Fox River lowland, a direction parallel to the subcrop of the Maquoketa shale. The grayish color and silty texture of the till may be due to incorporation of shale of the Maquoketa Formation into the till matrix. Diamicton of the Cato Falls Member was deposited predominantly as basal till (Socha, 2007a). The laminated and thinly bedded gray silt and fine sand of the High Cliff Member was deposited by wind near the retreating ice margin; in places it may have been deposited in water or it may have slumped into shallow ponds (Socha, 2007a).

Age and correlation. The Hayton Formation was likely deposited during the last part of the Wisconsin Glaciation prior to about 25,000 cal. yr B.P. No radiocarbon dates mark the beginning of the glacial advance or advances that deposited the Hayton Formation till. The Hayton Formation is overlain by till of the Kewaunee Formation. At the High Cliff Member type section, tundra vegetation (mosses) found in normal growth positions on top of the Hayton Formation have an age of 13,370 ± 90 ^{14}C yr B.P. (16,302 ± 428 cal. yr B.P., Beta – 119360, Socha, 2007a); this date provides a minimum age for deposition of the Hayton Formation. The organic-rich soil horizon in the High Cliff and Cato Falls Members suggest that the Hayton Formation must have been deposited and weathered long before glacial ice readvanced over the area. The Hayton Formation likely correlates with the informally named Kekoshkee member as described in Dodge and Fond du Lac Counties (Battista, 1990).

Previous usage. This unit name was originally used informally by Socha (2007a,b). It is formalized in this publication.

Hayton Formation: Cato Falls Member

Betty J. Socha

Source of name. Falls on the Manitowoc River in Cato Township, central Manitowoc County, Wisconsin.

Location and description of type section. Exposures in the quarry owned by Valders Stone & Marble, at Valders, Wisconsin, south of County Road JJ, about 1.6 km (1 mile) northeast of the junction of State Highway 148 and US Highway 151. It is located in the NW¼NE¼, and the NE¼NW¼ sec. 32, T. 19 N., R. 22 E., Manitowoc County, an area shown on the Valders 7.5-minute quadrangle (fig. 68). Fresh exposures (in 2008) are located at the north end of the quarry. This quarry also serves as the type section for the Hayton Formation. See the Hayton Formation section for a detailed sediment description of this outcrop.

Location of reference section. The reference section is an exposure in the quarry located in sec. 30, T. 20 N., R. 19 E., Calumet County, an area shown on the Sherwood 7.5-minute quadrangle (see fig. 69 in the High Cliff Member description). Exposures in the quarry are described in detail by Socha (2007a,b). This reference section for the Cato Falls Member also serves as the type section for the High Cliff Member of the Hayton Formation (see High Cliff Member for detailed description of this exposure).

Description of the unit. The Cato Falls Member includes gray, sandy-silty diamicton that is interpreted to be primarily basal till. The till is massive, dense, cohesive, clast rich, and in places contains thin beds of sand and gravel. Pebbles in the till are oriented north-northeast to south-southwest, parallel to the striations on the underlying bedrock surface. The till matrix averages 37 percent sand, 48 percent silt, and 15 percent clay (13 samples). The silt-sized fraction contains about 64 percent carbonate (4 percent calcite and 60 percent dolomite; 13 samples). Magnetic susceptibility (MKS units) ranges from 1.2×10^{-3} to 3.3×10^{-3} and averages 2.5×10^{-3} (13 samples). Clasts in the gray, sandy-silty till are about 80 percent dolomite and chert, and about 20 percent metamorphic, plutonic, and volcanic rock types. These clasts are mostly rounded and smooth, and some are striated and polished. The upper part of the unit also may display an organic-rich soil horizon.

Nature of contacts. The Cato Falls Member is in the subsurface in much of northeastern and east-central Wisconsin, and it rests on bedrock, sand, or reddish-brown or pinkish till of unknown origin. The contact with the underlying diamicton and bedrock is generally sharp. The contact with the overlying brown, sandy diamicton of the Holy Hill Formation is generally sharp, but the contact is convoluted over 5 to 8 m in places at the type section. The contact between the Cato Falls Member and overlying reddish-brown, clayey diamicton of the Kewaunee Formation is erosional and sharp; elsewhere the erosional contact is interbedded or interlaminated over a thickness of about a half meter.

Differentiation from other units. Till of the Cato Falls Member is easily distinguished in the field by its grayish color, cohesive and very dense matrix, abundant carbonate, and numerous well-rounded, polished, and striated gravel-sized clasts. Compared to till of the Holy Hill Formation, till of the Cato Falls Member is grayer, has more silt in the matrix, and has a greater number of well-rounded, polished and striated igneous and metamorphic clasts. Cato Falls Member till is grayer and sandier than the reddish-brown, clayey till of the Kewaunee Formation.

Regional extent and thickness. The Cato Falls Member is buried beneath sediment of both the Green Bay and Michigan Lobes in much of northeastern and east-central Wisconsin, including Outagamie, Calumet, Manitowoc, Sheboygan, and Fond du Lac Counties. The Cato Falls Member is generally less than 1 m thick along the Silurian Escarpment, is at least 24 m thick at the type section in central Manitowoc County, and is greater than 43 m thick in southern Manitowoc County (Crystal, Inc., 1994, unpublished logs of exploration boreholes).

Origin. The Cato Falls Member was deposited by ice and meltwater of the Green Bay and Lake Michigan Lobes, or possibly an undivided ice lobe that advanced from the north-northeast. Ice flowed down the axis of the Green Bay-Fox River lowland parallel to the subcrop of the Maquoketa Formation shale. The gray color and silty texture of the till may be due to incorporation of Maquoketa Formation shale along this flowline. Diamicton of the Cato Falls Member is mainly basal till.

Age and correlation. Till of the Cato Falls Member was likely deposited during the last part of the Wisconsin Glaciation prior to about 25,000 cal. yr B.P. No radiocarbon dates mark the beginning of the glacial advance or advances that deposited the Cato Falls Member. At the High Cliff Member type section, tundra vegetation (mosses) found in growth positions above the High Cliff and Cato Falls Members have an age of 13,370 ± 90 ^{14}C yr B.P. (16,302 ± 428 cal. yr B.P., Beta – 119360, Socha, 2007a); this date provides a minimum age for deposition of the Cato Falls Member. The organic-rich soil horizon in Cato Falls Member suggests that the unit must have been deposited and weathered long before glacial ice readvanced over the area.

Previous usage. This unit name was originally used informally by Socha (2007a,b) and is formalized here.

Hayton Formation: High Cliff Member

Betty J. Socha

Source of name. High Cliff State Park, Calumet County, Wisconsin.

Location and description of type section. The type section is in the quarry at Sherwood, Wisconsin, south of Clifton Road, about 0.8 km (0.5 mile) west of the junction of State Highways 114 and 55. It is located in the SW¼SE¼ sec. 30, T. 20 N., R. 19 E., Calumet County, an area shown on the Sherwood 7.5-minute quadrangle (fig. 69). Fresh exposures (in 2007) are located at the south end of the quarry. Sections in the quarry are described in detail by Socha (2007a,b). This type section for the High Cliff Member also serves as the reference section for the Cato Falls Member of the Hayton Formation.

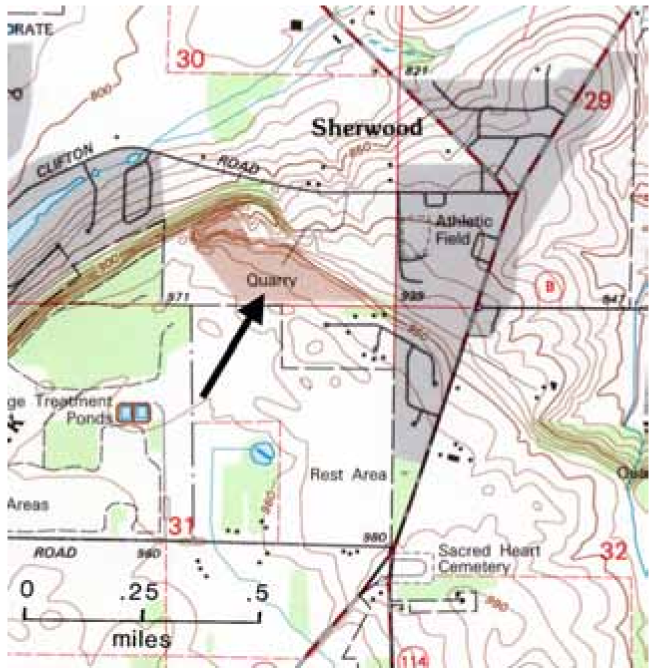

Figure 69. Part of the Sherwood 7.5-minute quadrangle showing the location of the type section of the High Cliff Member. This also serves as the reference section for the Hayton Formation.

Quarry operations on the Silurian Escarpment expose glacigenic sediment in an end moraine along the west and south walls. The west wall exposes about 5.5 m of sediment. The uppermost sediment unit is about 4 m of reddish-brown, clayey till of the Chilton Member of the Kewaunee Formation. Chilton Member till is underlain by up to 1 m of gray, fine sand and silt of the High Cliff Member. The High Cliff Member contains 47 percent sand, 42 percent silt, and 11 percent clay (1 sample). The High Cliff Member is interbedded with the Chilton Member till at the contact and grades to the south to diffusely laminated fine sand, silt, and clay. Tundra plant remains overlie the High Cliff Member on the stoss side of a bedrock bump; concentrations or mats of plant remains are mostly mosses in normal growth positions, but also include include leaves, stems, mosses and twigs (Socha, 2007a). Small pieces of plant remains also are dispersed in the overlying Chilton Member till.

Underlying the High Cliff Member is about 0.5 m of grayish-brown, silty-sandy till of the Cato Falls Member of the Hayton Formation. The matrix of the Cato Falls Member till is 38 percent sand, 39 percent silt, and 22 percent clay (1 sample). The pebble-sized fraction in the Cato Falls Member till contains 93 percent dolomite and 7 percent igneous and metamorphic rock types. The Cato Falls Member till overlies a striated to rough dolomite bedrock surface. Bedrock striation trends range from 125°/305° to 050°/230°. A pebble-fabric analysis of the Cato Falls till indicates a preferred orientation of clasts trending 180° to 195°.

The exposure in the southern quarry wall is about 300 m long. At the base of the exposure, Cato Falls Member till ranges in thickness from 0.1 to 1 m and generally fills low areas on the dolomite surface. Overlying the Cato Falls Member till is about 1 m of gray silt of the High Cliff Member. The sediment varies from massive silt displaying conchoidal fractures to diffusely laminated silt. Small pieces of leaves, stems, mosses, and twigs are dispersed in the silt.

The High Cliff Member is overlain by 1.8 to 3 m of reddish-brown, clayey till of the Chilton Member. The pebble-sized fraction in the Chilton Member till contains 81 percent dolomite and 16 percent igneous and metamorphic rock types. Chilton Member till is generally massive and uniform, but in places it has stringers of gray silt spaced several centimeters apart in the meter above the contact with the High Cliff Member. Small pieces of plant remains are dispersed in the Chilton Member till and the associated gray silt stringers. The upper part of the Chilton Member till is fractured and contains the modern soil profile.

Location of reference sections. Drill holes B23, B24, MW29D, and MW30C (described by RMT, Inc., 1996) are the reference sections for the High Cliff Member. The drill holes are located in the NE¼ sec. 23, T. 19 N., R. 19 E., Calumet County, an area shown on the Chilton 7.5-minute quadrangle (fig. 70). At the reference sections, 13 to 17 m of reddish-brown, clayey Chilton Member till is present at the surface. Chilton Member till overlies 0.3 to 1.4 m of silt and fine sand of the High Cliff Member, which in turn overlies 1 to 4 m of Cato Falls Member till. The Cato Falls Member rests on dolomite bedrock.

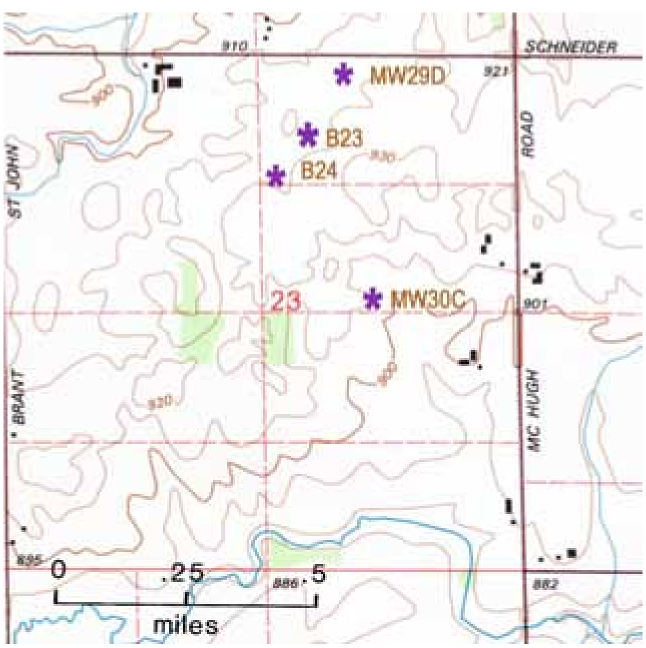

Figure 70. Part of the Chilton 7.5-minute quadrangle showing the location of the reference sections of the High Cliff Member. Individual borehole locations are plotted and labeled.

Description of the unit. The High Cliff Member typically contains uniform, well-sorted, gray or dark gray silt and fine sand. The silt and fine sand varies from massive to diffusely laminated or thinly bedded. Samples collected at the reference section are classified as silty clay (CL-ML) and lean clay (CL) using the Unified Soil Classification System (BT Squared, Inc., 2009). The unit contains interbeds and laminae of reddish-brown clay at some locations where it is overlain by reddish-brown diamicton of the Kewaunee Formation. The member typically is about 1 m thick but is as much as 3.5 m thick (BT Squared, Inc., 2009). It forms a discontinuous blanket over the former land surface. At some locations small pieces of tundra vegetation (leaves, stems, mosses, and twigs) are dispersed in the High Cliff Member, and at the type section tundra mosses in growth positions are found on top of High Cliff Member. An organic-rich soil horizon may be developed in the High Cliff Member.

Nature of contacts. The High Cliff Member is typically in the subsurface, and it rests on till of the Cato Falls Member, sand, or bedrock. The contact with Cato Falls Member till is sharp or gradational. In east-central Wisconsin, the High Cliff Member is overlain by brown, sandy diamicton of the Holy Hill Formation. In northeastern Wisconsin, it is overlain by diamicton of the Holy Hill Formation and reddish-brown, clayey till of the Kewaunee Formation. At the type section, the contact with the Kewaunee Formation till is erosional and interbedded or interlaminated over a thickness of about a half meter. Eroded plant materials from the High Cliff Member also are dispersed in the base of the till of the Kewaunee Formation. At other locations, the contact between the Kewaunee Formation till and the High Cliff Member is sharp. Little erosion by later ice advances is suggested at other sites where an organic-rich soil horizon is preserved in the uppermost part of the High Cliff Member.

Differentiation from other units. The High Cliff Member is easily distinguished in the field by its grayish color and its uniform, fine-grained texture. It is less cohesive than the gray Cato Falls Member till and generally lacks gravel. Its gray color and well-sorted, uniform, silt or fine-sand composition distinguish it from the overlying reddish-brown, clayey diamicton of the Kewaunee Formation.

Regional extent and thickness. The High Cliff Member underlies younger deposits of the Green Bay and Lake Michigan Lobes in much of northeastern and east-central Wisconsin, including Outagamie, Calumet, Manitowoc, Sheboygan, Fond du Lac and Dodge Counties (Crystal, Inc., 1994, unpublished logs of exploration drill holes). The High Cliff Member typically is about 1 m thick but is as much as 3.5 m thick; it forms a discontinuous layer over the till of the Hayton Formation and the bedrock.

Origin. The gray silt and fine sand of the High Cliff Member was deposited by wind near the retreating ice margin. Locally, the wind-blown sediment may have been deposited in water or it may have slumped into shallow ponds. The grayish color and silty texture of the High Cliff Member is likely derived from the Cato Falls Member till and shale of the Maquoketa Formation.

Age and correlation. Eolian sediment of the High Cliff Member was likely deposited during the last part of the Wisconsin Glaciation prior to about 25,000 cal. yr B.P. There are no radiocarbon dates to mark the beginning of the glacial advance or advances that deposited the till associated with the eolian sediment. Tundra plant material, mostly mosses in growth positions on top of the High Cliff Member, has an age of 13,400 ^{14}C yr B.P. (16,300 cal. yr B.P.) at the High Cliff Member type section. This age represents an approximate date for the ice advance that deposited till of the Kewaunee Formation on top of the older High Cliff Member. The plant remains are much older than the Two Creeks Forest Bed characterized by spruce wood with a typical range of ages from about 11,200 to 12,400 ^{14}C yr B.P. (approximately 13,100 to 14,600 cal. yr B.P.) (Mickelson and others, 2007).

Previous usage. This unit name was originally used informally by Socha (2007a,b) and is formalized in this publication.

Holy Hill Formation

Kent M. Syverson and David M. Mickelson

Source of name. Holy Hill, a large hill with a church at the crest of the Kettle Moraine in southern Washington County, Wisconsin, located in sec. 14, T. 9 N., R. 18 E.

Location and description of type section. Exposures in a pit at Slinger Speedway, Slinger, Wisconsin, north of County Highway AA, approximately 2 km (1.3 miles) north-northeast of the junction of State Highways 60 and 144. It is located in the SE¼SW¼SW¼ sec. 8, T. 10 N., R. 19 E., Washington County, an area shown on the Hartford East 7.5-minute quadrangle (fig. 71). Fresh exposures (in 1987) are located in a fenced area east of the raceway.

The gravel pit is located in a high-relief, hummocky area within the Kettle Moraine. The north-facing exposure contains brown sandy silt, sand, and sandy gravel. Bedding is overturned in places. The 15 m high south-facing exposure contains steeply dipping sediment, first described by Syverson (1988). Light yellowish-brown gravelly diamicton is interbedded with poorly to moderately well-sorted gravel, sandy gravel, and gravelly sand. Sandy and gravelly beds weather faster than the cohesive diamicton beds, causing a ribbed or pillared appearance in the outcrop. Most beds dip to the east at a 65° angle, but in the western part of the outcrop, beds of diamicton and sandy gravel are nearly vertical and overturned. This may have been caused by the pushing of ice or the intrusion of a diapir from below.

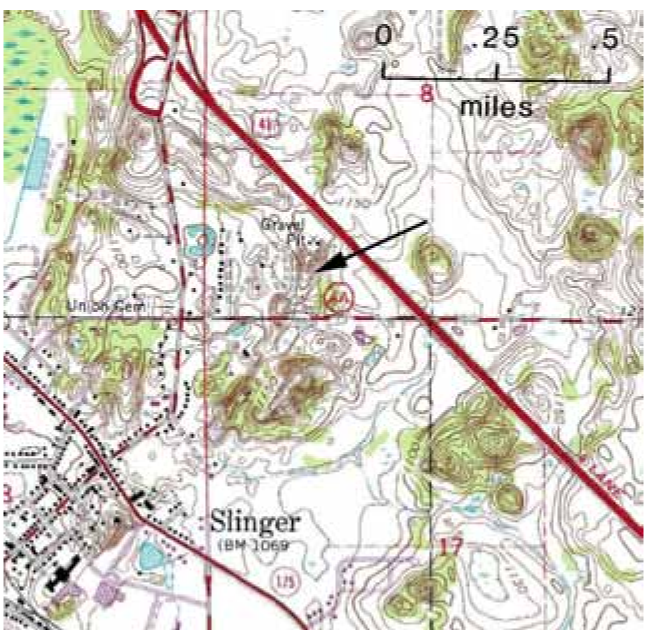

Figure 71. Part of the Hartford East 7.5-minute quadrangle showing the location of the type section of the Holy Hill Formation.

Most clasts in the sediment are dolomite, although numerous Precambrian granite, gabbro, and gneiss boulders are present. Precambrian boulders are abundant near the crest of the hill. Large Precambrian rocks of this type are far-traveled (greater than 300 km) and generally associated with supraglacial sediment in southeastern Wisconsin. Clasts range from well rounded to angular; striated clasts are especially abundant in diamicton beds.

Location and description of reference sections. The type sections for all members of this formation serve as reference sections for this unit. These members include the Keene, Horicon, New Berlin, Waubeka, and Liberty Grove Members. See each member for the locations and descriptions of these reference sections.

Description of unit. The Holy Hill Formation includes till and associated lake and stream sediment. The till is generally yellowish brown to brown (10YR–7.5YR) or, less commonly, reddish brown (5YR), sandy, and contains abundant carbonate where unleached. Sand content varies considerably, generally ranging from 50 to 80 percent. The till is coarser grained where it overlies sandstone and finer grained (21–42 percent sand) where it overlies shale of the Maquoketa Formation in the Green Bay lowland (Battista, 1990). Gravel as much as 12 m thick forms the basal unit of the Holy Hill Formation east of the Kettle Moraine from southern Sheboygan County to Walworth

County. Details about pebble lithology, clay mineralogy, and grain size are presented in the member descriptions.

Nature of contacts. The Holy Hill Formation is the surficial unit in much of south-central and southeastern Wisconsin, including the Kettle Moraine region. West of the Kettle Moraine, the formation lies directly on bedrock, on pink diamicton of unknown origin, or on sand and gravel with a sharp contact. In northeastern and eastern Wisconsin, Holy Hill Formation till is overlain by reddish-brown, finer-grained till of the Kewaunee Formation. East of the Kettle Moraine and south of Port Washington, the till is underlain by till of the Tiskilwa Member of the Zenda Formation and overlain by diamicton of the Oak Creek Formation. These contacts are generally sharp, although silt and sand beds between these units remain undifferentiated.

Differentiation from other units. Till of the Holy Hill Formation is distinguished easily in the field by its yellowish-brown to brown color, abundant pebbles, sandy texture, and abundant carbonate. The till is generally stonier, less silty, and lighter in color than the older Tiskilwa Member of the Zenda Formation. The till is much stonier and less clayey than the younger till of the Oak Creek Formation. The younger Kewaunee Formation to the north is much redder (2.5YR or 5YR) and finer grained than the Holy Hill Formation till.

Regional extent and thickness. The Holy Hill Formation is the surficial unit throughout much of south-central and southeastern Wisconsin. It can be traced in the subsurface to the Lake Michigan shoreline in Ozaukee and Milwaukee Counties. The Holy Hill Formation is at least 100 m thick in parts of the Kettle Moraine. West of the Kettle Moraine, the formation ranges in thickness from less than 1 m along the Niagaran Escarpment to greater than 100 m in buried valleys. The formation is generally up to 30 m thick east of the Kettle Moraine.

Origin. The Holy Hill Formation was deposited by ice and meltwater associated with the Green Bay and Lake Michigan Lobes. Till of the Horicon, Keene, and Liberty Grove Members was deposited by the Green Bay Lobe (fig. 3). Till of the New Berlin and Waubeka Members was deposited by the Lake Michigan Lobe. Stratified gravel and sand of the Holy Hill Formation in the Kettle Moraine region was deposited in an interlobate corridor between the Green Bay and Lake Michigan Lobes, predominantly by meltwater flowing in subaerial streams and subglacial tunnels.

Age and correlation. The oldest member of the Holy Hill Formation, the Keene Member, likely was deposited before the last part of the Wisconsin Glaciation (before 35,000 cal. yr B.P.) and probably also before the early part (before 70,000 cal. yr B.P.). Other members of the Holy Hill Formation were deposited during the last part of the Wisconsin Glaciation. No dependable radiocarbon ages are available to limit the time of deposition for this formation. Mickelson, Hooyer and Forman (unpublished data, 2009) used the OSL method to date three lake sediment samples from Madison, an area near the outermost extent of the Green Bay Lobe; the lake sediment, located between two till layers, had average ages of about 26,000 cal. yr B.P. Hooyer and others (2003) reported OSL dates for the retreat of ice in the Green Bay Lobe, and Hooyer and Mode (2009) suggested that ice retreated far enough for glacial Lake Oshkosh to form by about 20,000 cal. yr B.P. New OSL ages indicate that the Green Bay Lobe ice margin was at its maximum position about 20,000 cal. yr B.P. in the Baraboo area (Attig and others, 2009). The minimum age of the Holy Hill Formation is poorly defined. The unit is older than the Two Creeks Forest Bed (age between about 11,200 to 12,400 ^{14}C yr B.P., which is approximately 13,100 to 14,600 cal. yr B.P., Mickelson and others, 2007) and till of the Ozaukee and Valders Members of the Kewaunee Formation.

Previous usage. This name was formalized in Mickelson and Syverson (1997). Previously named units have been incorporated into the Holy Hill Formation. The Horicon and New Berlin Members (previously defined as the Horicon and New Berlin Formations of Mickelson and others, 1984), the Liberty Grove Member (defined in Mickelson and others, 1984), the Keene Member (defined in Attig and others, 1988), and the Waubeka Member (defined in Mickelson and Syverson, 1997) are all now considered members of the Holy Hill Formation (fig. 3).

Holy Hill Formation: Keene Member

Lee Clayton

Source of name. Community of Keene, Portage County, Wisconsin.

Location and description of type section. An auger hole west of County Highway N along Bluff Road, on the south side of the SE¼ lot 23, sec. 30, T. 22 N., R. 9 E. (equivalent to the SE¼SW¼SW¼E½ sec. 30, T. 22 N., R. 9 E.), Portage County, an area shown on the Almond 7.5-minute quadrangle (fig. 72).

The sediment encountered in the auger hole (expressed in depths below the surface) includes: 0 to 5 m, reddish-yellow, slightly gravelly sandy loam till; 5 to 11 m, reddish-brown, slightly gravelly to gravelly loamy sand or sandy loam till; 11 to about 27 m, brown gravelly loamy sand till; and from about 27 to 31 m, slightly gravelly to gravelly sand.

Description of unit. The Keene Member is brown or reddish brown (7.5YR 4/4 or 5YR 4/4) and unbedded. It consists of 2 to 20 percent gravel; the less-than-2 mm fraction is 60 to 85 percent sand, 5 to 25 percent silt, and 8 to 17 percent clay. Carbonates are absent to a depth of several meters; below that depth the sand and gravel fractions contain as much as several percent dolomite. In outcrop, the Keene Member has differential concentrations of iron oxides in joints and across other permeability discontinuities; bright oxide stains can be seen in auger holes to a depth of 10 m. Weathered-looking feldspar grains are abundant in the upper 10 m.

Nature of contacts. The Keene Member is the surface unit in the type area; it overlies sand of the Holy Hill Formation, although it might rest on older formations elsewhere. In eastern Portage County, it is presumably overlain by the Horicon Member of the Holy Hill Formation.

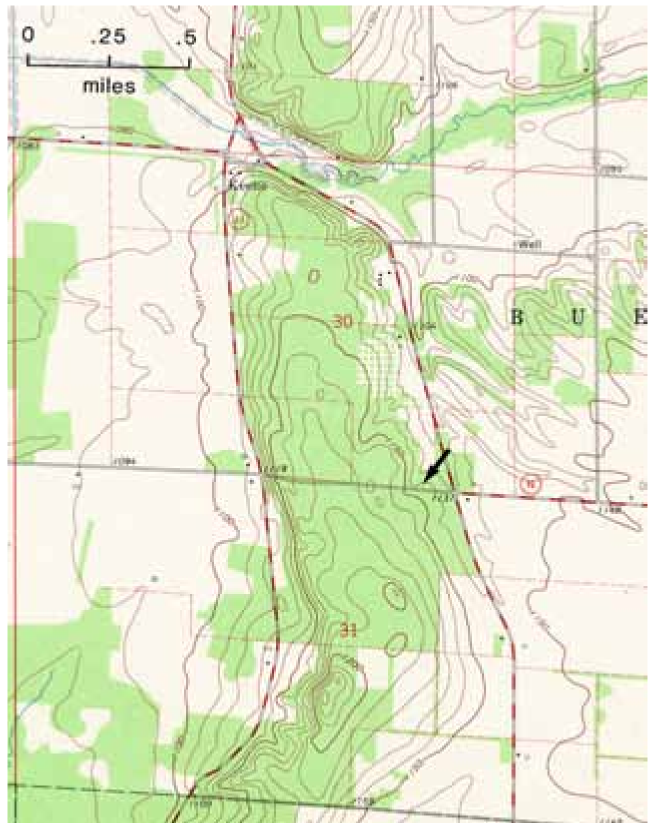

Figure 72. Part of the Almond 7.5-minute quadrangle showing the location of the type section of the Keene Member.

Differentiation from other units. The Keene Member differs from the overlying Horicon Member primarily in the absence of near-surface carbonates. In addition, the Keene Member has a lower carbonate percentage at depth, is finer grained, is more weathered looking, and has greater magnetic susceptibility below a depth of 5 m than the Horicon Member. Like the Horicon Member, the Keene Member contains lithologies derived from the northeast, unlike the Marathon Formation in Marathon County which contains clasts derived from the north or northwest.

Regional extent and thickness. Typically, 10 to 30 m of the unit underlies a north-south-trending ridge about 25 km (15.5 miles) long and 1 km (0.6 mile) wide in central Portage County. It has not been found outside of this ridge.

Origin. The Keene Member is composed primarily of till in an end moraine deposited by the Green Bay Lobe. Some associated meltwater deposits also may be included in the unit, although Clayton (1986b) has shown that most proglacial stream sediment just to the west of the Keene Member is part of younger members of the Holy Hill Formation. The surface of the unit probably includes as much as a few meters of deposits from solifluction (slow downslope flow of waterlogged soil, commonly over frozen ground).

Age and correlation. The till and end moraine were deposited during the Arnott Phase of the Green Bay Lobe (fig. 6), which has not been dated. The degree of weathering and erosion indicates that the Keene Member was deposited before the last part of the Wisconsin Glaciation (before 35,000 cal. yr B.P.) and probably also before the early part (before 70,000 cal. yr B.P.). No correlative units are known at the present time.

Previous usage. The unit was named and described by Clayton (1986b). Formalized in Attig and others (1988).

Holy Hill Formation: Horicon Member

David M. Mickelson

Source of name. City of Horicon, Dodge County, Wisconsin.

Location and description of type section. Road cut on the south side of Mapleview Road, 100 m west of the intersection of Mapleview Road and Maple Road, and about 3 km (1.9 miles) east of State Highways 45, 47 and 52, just south of Antigo. It is located in the NE¼NW¼ sec. 1, T. 30 N., R. 10 E., Langlade County, an area shown on the Mattoon 7.5-minute quadrangle (fig. 73).

The road cut on the south side of Mapleview Road is 8 m high, and consists entirely of Horicon Member subglacial till, with the exception of possible supraglacial debris at the top of the section. A sample taken 4.5 m below the surface contained 8 percent igneous, 39 percent metamorphic, and 53 percent sedimentary clasts in the pebble fraction. This proportion of sedimentary rock is large compared to most of the other samples in Langlade County. The less-than-2 mm fraction for a sample collected 2.5 m below the surface contained 80 percent sand, 16 percent silt, and 5 percent clay (less than 0.002 mm). When the exposure was described, vegetation covered much of the cut and any stratification or variability that might be present was not observed.

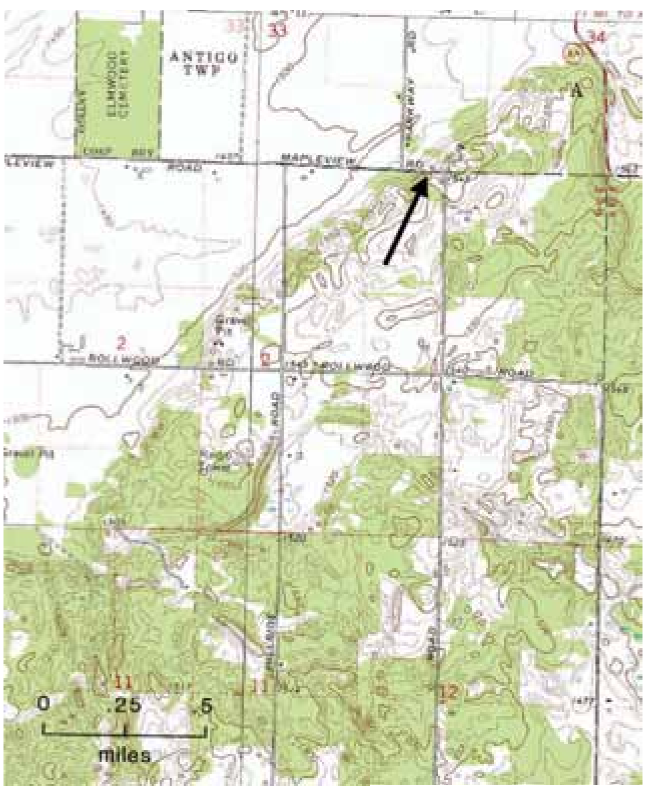

Figure 73. Parts of the Aniwa and Mattoon 7.5-minute quadrangles showing the location of the type section of the Horicon Member.

Location and description of reference section. Lower till in Ski Hill Section, road cut at entrance to County Ski Area off State Highway 52. It is located in the NW¼NW¼NW¼ sec. 8, T. 32 N., R. 13 E., Langlade County, an area shown on the Pickerel 7.5-minute quadrangle (fig. 74). A sketch of the exposure is shown in figure 75.

Figure 74. Part of the Pickerel 7.5-minute quadrangle showing the location of the Ski Area reference section of the Horicon Member.

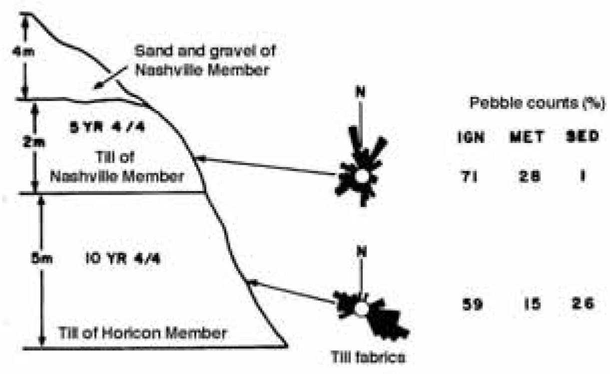

Figure 75. Sketch of exposure at Ski Area reference section for the Horicon Member.

Description of unit. The Horicon Member includes till, associated sand and gravel, and other stratified deposits. The till is generally brown (7.5YR hue) or, less commonly, reddish brown (5YR hue) and sandy. Sand content varies considerably but is generally between 60 to 80 percent. Clast composition also varies considerably depending on location and the till facies (supraglacial or subglacial).

Nature of contacts. The Horicon Member is the surficial unit in much of south-central Wisconsin (fig. 3) where it generally lies directly on bedrock or sand and gravel with a sharp contact. In areas close to Green Bay it is overlain by reddish, finer-grained till of the Kewaunee Formation. This contact is usually clear and abrupt.

Differentiation from other units. Horicon Member till can be distinguished readily from the overlying Kewaunee Formation. The Kewaunee Formation is redder (2.5 or 5YR hues) and finer grained. Till of the Horicon and New Berlin Members is very similar. Mickelson and Syverson (1997) were not able to differentiate the Horicon and New Berlin Members in the field based on the percentage of Niagaran dolomite pebbles. The Kettle Moraine marks a somewhat arbitrary boundary between the Horicon Member (deposited by the Green Bay Lobe) and the New Berlin Member (deposited by the Lake Michigan Lobe).

Regional extent and thickness. With the exception of the Copper Falls Formation, the Horicon Member covers a larger area of the state than any other (fig. 3). It is at the surface in much of eastern Wisconsin and is present in numerous sections below deposits of the Kewaunee Formation. No detailed studies of thickness have been done, but in buried valleys, it is more than 100 m thick. In places near its southwestern edge and along the Niagaran escarpment, it is less than 1 m thick.

Origin. Till of the Horicon Member was deposited by ice of the Green Bay Lobe to the west of the Kettle Moraine. In at least some locations, subglacial and supraglacial facies can be identified. Large amounts of sand and gravel are associated with the till in counties along the Horicon Member's western extent, but these have not been mapped in sufficient detail to formalize as lithostratigraphic units.

Age and correlation. The Horicon Member was deposited during the last part of the Wisconsin Glaciation. No dependable radiocarbon ages are available to limit the time of deposition. The OSL method was used to date three lake sediment samples from Madison, an area near the outermost extent of the Green Bay Lobe; the lake sediment, located between two till layers, had average ages of about 26,000 cal. yr B.P. (Mickelson, Hooyer and Forman, unpublished data, 2009). Hooyer and others (2003) reported OSL dates for the retreat of ice in the Green Bay Lobe, and Hooyer and Mode (2009) suggested that ice retreated far enough for glacial Lake Oshkosh to form by about 20,000 cal. yr B.P. New OSL ages indicate that the Green Bay Lobe ice margin was at its maximum position about 20,000 cal. yr B.P. in the Baraboo area (Attig and others, 2009). The minimum age of the Horicon Member is poorly defined. The unit is older than the Two Creeks Forest Bed (about 11,200 to 12,400 ^{14}C yr B.P. or 13,100 to 14,600 cal. yr B.P., Mickelson and others, 2007) and till of the Silver Cliff, Kirby Lake, and Chilton Members of the Kewaunee Formation.

The Horicon Member (Green Bay Lobe) correlates time stratigraphically with the New Berlin Member (Lake Michigan Lobe), and the two units are in contact along the Kettle Moraine in eastern Wisconsin.

Previous usage. First formalized as the Horicon Formation in Mickelson and others (1984). Formally reclassified as a member of the Holy Hill Formation in Mickelson and Syverson (1997).

Holy Hill Formation: New Berlin Member

Allan F. Schneider

Source of name. City of New Berlin, Waukesha County, Wisconsin.

Location and description of type section. Gravel pit complex operated by Kohler Pit, Inc. and New Berlin RediMix, Inc., on the north side of County Highway I (Lawnsdale Road), 0.8 to 1.6 km (0.5 to 1.0 mile) west of County Highway Y (Racine Avenue). It is located in the SE¼ sec. 19 and SW¼ sec. 20, T. 6 N., R. 20 E., Waukesha County, an area shown on the Muskego 7.5-minute quadrangle (fig. 76).

The type section of the New Berlin Member is in the heart of the Waukesha drumlin field. The type section is a compound gravel pit, which originally consisted of several separate pits that have been merged into a single large operation. Except for some variation in thicknesses of the two major facies of the member, a similar section is present throughout most of the site. The lower facies consists of well-sorted and stratified sand and gravel; between 10 and 13 m of this unit is well exposed in the pit walls. The upper facies, although somewhat finer grained than average, is typical of this part of the formation; it is a highly calcareous pebbly loam till containing 43 percent sand, 37 percent silt, and 20 percent clay. The upper two thirds of the till is oxidized to a brown or yellowish-brown color; the lower part of the unit is unoxidized and gray and rests sharply on the sand and gravel unit. The till ranges in thickness from 2 to 10 m. About 7 to 9 m is exposed in the upper part of most of the pit walls. The clay mineralogy of the less-than-0.002 mm clay fraction of the till shows 13 percent expandable clay minerals, 70 percent illite, and 17 percent kaolinite plus chlorite (H.D. Glass, Illinois State Geological Survey, written communication, 1982).

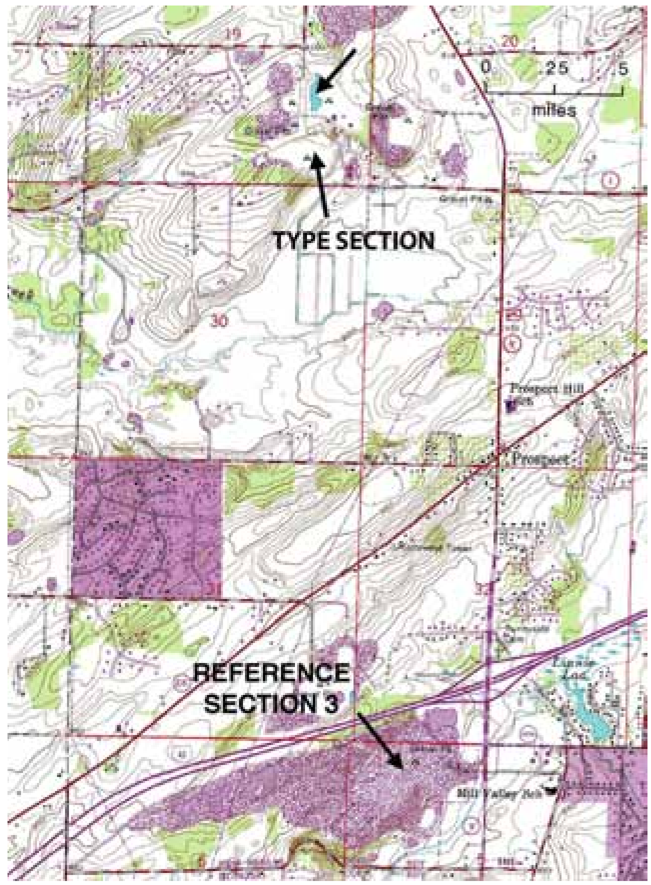

Figure 76. Part of the Muskego 7.5-minute quadrangle showing the locations of the type section and reference section 3 of the New Berlin Member.

Location and description of reference sections. (1) Gravel pit in the village of Fontana. It is located in the SE¼NW¼NE¼ sec. 15, T. 1 N., R. 16 E., Walworth County, an area shown on the Walworth 7.5-minute quadrangle (fig. 77). (2) Gravel pit 1.6 km (1 mile) northeast of the city of Lake Geneva on the northwest side of State Highway 36. It is located in the W½SW¼ sec. 19, T. 2 N., R. 18 E., Walworth County, an area shown on the Lake Geneva 7.5-minute quadrangle (fig. 78). (3) Gravel pit operated by Valley Sand and Gravel Company south of State Highway 15 on the west side of County Highway Y (Racine Avenue). It is located in the NW¼ sec. 5, T. 5 N., R. 20 E., Waukesha County, an area shown on the Muskego 7.5-minute quadrangle (fig. 76).

At all three of these reference sections, both the lower (sand and gravel) facies and the upper (till) facies of the New Berlin Member are well exposed. The sand and gravel facies is the thicker of the two units, generally 12 to 15 m thick. The upper till facies commonly ranges in thickness from 2 to 8 m at these sites. The contact between the two units is sharp at all three localities. The contact between the lower sand and gravel unit and the underlying Tiskilwa Member of the Zenda Formation is well displayed at reference section 2. Both typical yellowish-brown New Berlin Member till and pinkish New Berlin Member till "contaminated" by incorporation of Tiskilwa Member till can also be observed at reference section 2. Other significant aspects of the New Berlin Member visible at these reference sections are described below.

Description of unit. The New Berlin Member consists of two principal facies, a lower sand and gravel unit and an upper till unit. Both facies can be recognized throughout most of the area where the member is at or near the surface. Neither unit is formally defined at this time, however. The upper unit typically is gravelly sandy loam till, averaging 58 percent sand, 29 percent silt, and 13 percent clay in the less-than-2 mm fraction. In some places it is considerably sandier than this, containing as much as 72 percent sand. In other places, however, it is somewhat less sandy and would fall into the gravelly loam category. Oxidized till is yellowish brown (10YR 5/4 to 7.5YR 5/4) or, less commonly, brown (7.5YR 4/4 to 10YR 5/3); unoxidized till is grayish brown (10YR 5/2 or 2.5Y 5/2). The till everywhere is strongly calcareous and has a pH value of about 8. These characteristics are from large amounts of crushed carbonate (dolomite) rock in all size fractions. Dolomite pebbles and cobbles also dominate the stone assemblage, which includes a wide variety of igneous and

Figure 77. Part of the Walworth 7.5-minute quadrangle showing the location of reference section 1 of the New Berlin Member.

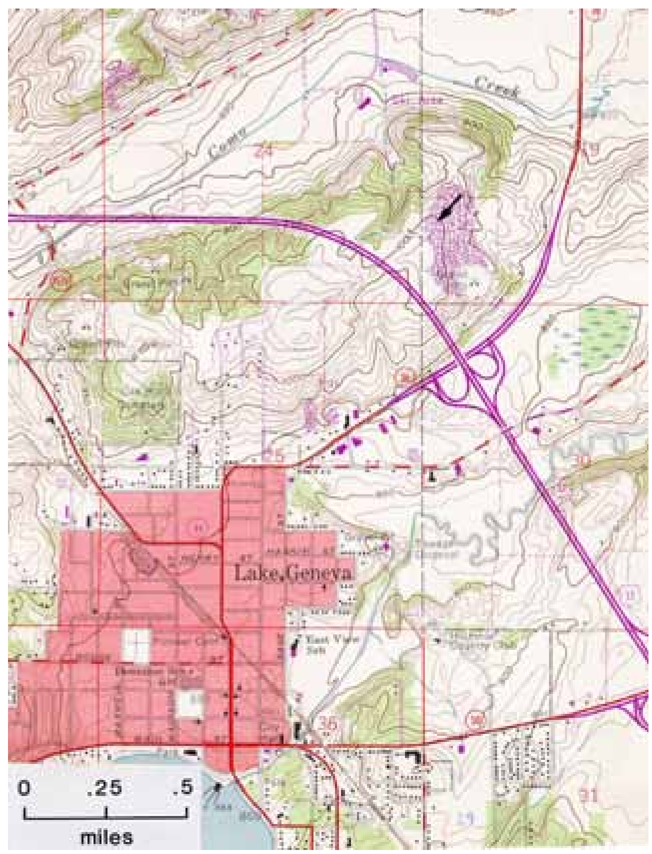

Figure 78. Part of the Lake Geneva 7.5-minute quadrangle showing the location of reference section 2 of the New Berlin Member.

metamorphic rock types. Semiquantitative clay mineral analyses reveal 66 percent illite, 17 percent expandable clay, and 17 percent kaolinite plus chlorite (H.D. Glass, written communication, 1982). In parts of Walworth County, particularly in the area mapped by Alden (1918) as the Elkhorn moraine, New Berlin Member till has a distinct pinkish cast, which is attributed to the incorporation and assimilation of pink till from the underlying Tiskilwa Member of the Zenda Formation, the surface till in much of the moraine. At several sites, as at reference section 1, the till splits into two units, separated from each other by beds of outwash sand and gravel similar to those found in the lower facies. This till unit has been recognized at several places along the Lake Michigan shoreline and was informally designated till 1A by Mickelson and others (1977). At other localities such as the Valley Sand and Gravel Company pit (reference section 3), some of the till is conformable with the underlying sand and gravel member and some crosscuts the structure of the gravel (Whittecar and Mickelson, 1979).

Nature of contacts. Both the upper and lower boundaries of the New Berlin Member are generally sharp. The lower contact with the underlying Tiskilwa Member of the Zenda Formation is commonly the sharper; it has been observed in several gravel pits in southeastern Wisconsin where the top of the Tiskilwa Member generally marks the floors of the pits. The upper contact with the overlying Oak Creek Formation is disturbed or irregular in some places. The contact with the overlying Waubeka Member is sharp where it has been observed (Mickelson and others, 1977).

Differentiation from other units. Till of the New Berlin Member is readily identified by its numerous pebbles, sandy texture, brown to yellowish-brown color, and high carbonate content. It is far stonier, much sandier, and much more loosely packed than till of the Oak Creek Formation. It is generally stonier, less silty, and more yellowish in color than the older Tiskilwa Member of the Zenda Formation. However, in places where New Berlin Member till has incorporated much Tiskilwa Member till, its color becomes somewhat pink and the till is difficult to distinguish from the Tiskilwa Member. This is particularly true in a belt extending from Lake Geneva to the area north and west of Elkhorn. Both till units are definitely present here, and in some places they are distinct, especially where they have been found in contact, but in other places they are difficult to distinguish. Till of the New Berlin Member is also similar to till of the Clinton Member of the Walworth Formation. According to Alden (1918), till of the New Berlin Member could be distinguished from till of the Horicon Member (deposited by the Green Bay Lobe) by its higher content of Niagaran dolomite pebbles. However, Mickelson and Syverson (1997) were not able to distinguish the New Berlin and Horicon Members in the field based on dolomite lithology.

Regional extent and thickness. The New Berlin Member is widely distributed in southeastern Wisconsin (fig. 3). It is the surface unit throughout much of Waukesha and Walworth Counties, and it is also present in parts of Kenosha, Racine, Milwaukee, Washington, and Ozaukee Counties. Geomorphologically, it covers the area behind (northeast of) the Darien moraine and between the Kettle Moraine to the west and the Valparaiso moraine (or its equivalent) to the east. It extends eastward in the subsurface to Lake Michigan, at least in places, because it is exposed near the base of the shore bluff as far south as Sheridan Park in southern Milwaukee County. Whether it is present beneath thick deposits of the Oak Creek Formation in eastern Racine and eastern Kenosha Counties is not known, however. The New Berlin Member is up to 22 m thick. The lower sand and gravel unit is generally the thicker of the two units and is as much as about 12 m thick. Several gravel pits in Walworth and Waukesha Counties expose the full thickness of the sand and gravel unit where both the lower and upper contacts are visible. The upper till unit of the New Berlin Member is generally thinner and as much as 10 m thick.

Origin. The lower sand and gravel unit of the New Berlin Member is interpreted as a proglacial outwash unit deposited as an outwash plain in front of and around the margins of the advancing Delavan Sublobe of the Lake Michigan Lobe (Alden, 1904, 1918; Schneider, 1983). The upper till unit is interpreted as basal till deposited by the Delavan Sublobe, which terminated at the Darien moraine on the southwest and along the Kettle Moraine on the west and northwest. 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 member also includes thick, coarse ice-contact deposits, which reach their greatest extent adjacent to the Fox River in western Kenosha, western Racine, and eastern Walworth Counties.

Age and correlation. The New Berlin Member was deposited during the last part of the Wisconsin Glaciation, probably between 17,000 and 19,000 cal. yr B.P. No radiocarbon dates are available for confirmation of its precise age, however. The New Berlin Member is correlated with the Horicon Member of the Holy Hill Formation of the Green Bay Lobe. It is equivalent to at least part of the Haeger Till Member of the Wedron Formation of northeastern Illinois (Willman and Frye, 1970); the lower sand and gravel unit in the New Berlin Member possibly correlates with the older Malden and Yorkville Till Members of the Wedron Formation.

Previous usage. First formalized as the New Berlin Formation in Mickelson and others (1984). Formally reclassified as a member of the Holy Hill Formation in Mickelson and Syverson (1997).

Holy Hill Formation: Waubeka Member

David M. Mickelson and Kent M. Syverson

Source of name. Community of Waubeka, Ozaukee County, Wisconsin.

Location and description of type section. Exposure in gravel pit at southeast edge of Newburg, 300 m east of the intersection of State Highway 33 and County Highway I. It is located in the NW¼SW¼SE¼ sec. 12, T. 11 N., R. 20 E., Washington County, an area shown on the Newburg 7.5-minute quadrangle (fig. 79).

The gravel pit is located in a drumlin that trends east–west. This drumlin is smaller than an adjacent drumlin to the south, but shows roughly the same orientation. The 5 m high exposure on the south side of the pit contains 1 to 2 m of till of the Waubeka Member overlying stratified sand and gravel. The sand and gravel is cemented at the western end of the pit, but it is typically not cemented at the eastern end. The drumlin orientation at this site does not agree with the ice-flow direction suggested by the outermost edge of the Waubeka Member. We suggest that the till at the type section lies on an unconformity developed on gravel of the New Berlin Member.

Location and description of reference sections. (1) Bluff located along the Lake Michigan shoreline in the city of St. Francis in the NE¼NE¼NE¼ sec. 23, T. 6 N., R. 22 E., Milwaukee County, an area shown on the South Milwaukee 7.5-minute quadrangle (fig. 80A). The Waubeka Member lies above till of the New Berlin Member and below sand and gravel that is undifferentiated. (2) Road cut at the intersection of St. Finbars Road and Shady Lane Road, about 4 km (2.5 miles) east of the type section. It is located in the NW¼SW¼SW¼ sec. 9, T. 11 N., R. 21 E., Ozaukee County, an area shown on the Port Washington West and Newburg 7.5-minute quadrangles (fig. 80B). Diamicton is about 5 m thick and overlies compact silt.

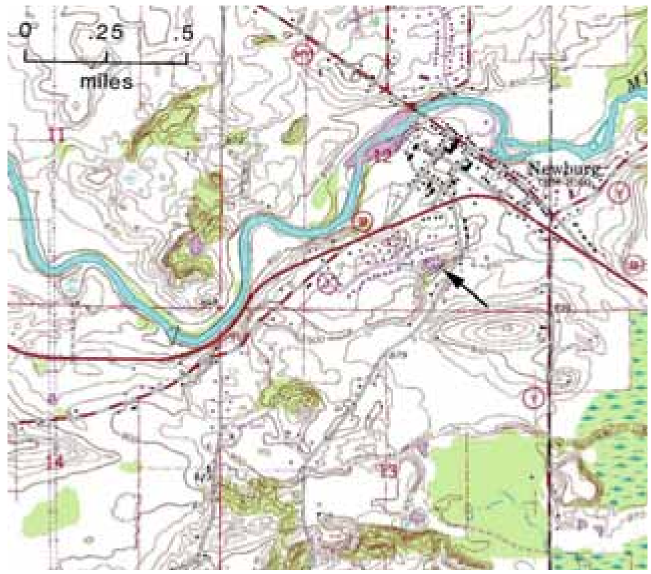

Figure 79. Part of the Newburg 7.5-minute quadrangle showing the location of the type section of the Waubeka Member.

Figure 80A. Part of the South Milwaukee 7.5-minute quadrangle showing the location of reference section 1 of the Waubeka Member and the Oak Creek Formation.

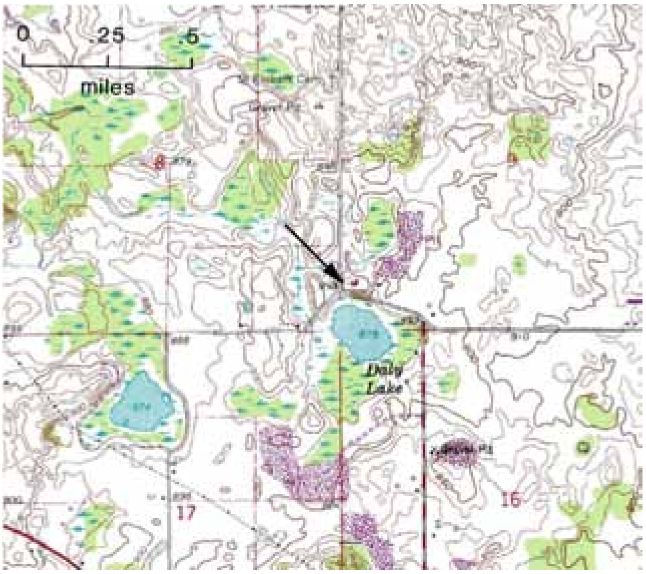

Figure 80B. Parts of the Port Washington West and Newburg 7.5-minute quadrangles showing the location of reference section 2 of the Waubeka Member.

Description of unit. The Waubeka Member includes till and associated lake and stream sediment (Mickelson and Syverson, 1997). The till is generally yellowish brown to brown (10YR to 7.5 YR) and is grayer where unoxidized. The texture of the till of this member is intermediate in composition between that of the underlying New Berlin Member and the overlying till of the Oak Creek Formation. The till averages 35 percent sand, 51 percent silt, and 14 percent clay where it was sampled in Ozaukee and Washington Counties. The unit is calcareous and rich in dolomite clasts.

Nature of contacts. In eastern Washington County, till of the Waubeka Member overlies sand and gravel in places. The contact often shows till mixing with the underlying sand and gravel, which has not been assigned to a lithostratigraphic unit. One drill hole in southern Ozaukee County (OZ-539) penetrated thick Oak Creek Formation till over till of the Waubeka Member with an abrupt contact.

Differentiation from other units. Till of the Waubeka Member is distinguished in the field from till of the overlying Oak Creek Formation by its greater sand content and correspondingly lower silt and clay content. It is clearly distinguished from till of the Kewaunee Formation by its gray to brown color. Waubeka Member till has less sand and more silt and clay than till of the New Berlin Member.

Regional extent and thickness. The Waubeka Member is the surficial unit in western Ozaukee and eastern Washington Counties (Mickelson and Syverson, 1997). It can be traced in the subsurface as far south as St. Francis (Milwaukee County) along the Lake Michigan shoreline. It is exposed at several locations along the northern Milwaukee County shoreline and was identified as unit 1B by Mickelson and others (1977).

Origin. The Waubeka Member was deposited by the Lake Michigan Lobe and meltwater flowing away from the glacier into streams and lakes. The former ice-flow direction appears to have been from the northeast. This is more northerly than the flow direction of ice that deposited the underlying New Berlin Member. The small end moraine built by ice that deposited the Waubeka Member is truncated north of Germantown by the outermost moraine containing till of the Oak Creek Formation. This implies that ice flowed from a more easterly direction during deposition of the overlying till of the Oak Creek Formation.

Age and correlation. The Waubeka Member was deposited during the last part of the Wisconsin Glaciation, approximately 16,400 to 18,000 cal. yr B.P. No radiocarbon ages are available to limit the time of deposition of this member. Although texturally similar to some formations above the Haeger Formation of northeast Illinois, the Waubeka Member must be younger than those formations. It represents a relatively minor readvance of the Lake Michigan Lobe during general retreat of the glacier that deposited till of the New Berlin Member.

Previous usage. Till of the Waubeka Member was previously referred to as till 1B by Mickelson and others (1977) and in subsequent papers. Formalized in Mickelson and Syverson (1997).

Holy Hill Formation: Liberty Grove Member

Allan F. Schneider

Source of name. Liberty Grove Township, northern Door County, Wisconsin.

Location and description of type section. Road cut on the north side of Waters End Road, west of the intersection with County Highway ZZ, 4.8 km (3 miles) northeast of Sister Bay. It is located in the SE¼SE¼SW¼ sec. 35, T. 32 N., R. 28 E., Door County, an area shown on the Sister Bay 7.5-minute quadrangle (fig. 81).

The type section of the Liberty Grove Member is a road cut through a 6 m high drumlin in the Liberty Grove drumlin field (Kowalke, 1952; Thwaites and Bertrand, 1957, p. 847; Schneider, 1981). About 3 m of till is well exposed. Although the cut on the north side of Waters End Road serves as the type section, the unit is also well exposed on the south side of the road. Both cuts have remained free of vegetation for many years, and the exposed sediment is very typical of the Liberty Grove Member. The clay-mineral composition of the till here is 16 percent expandable clays, 67 percent illite, and 17 percent kaolinite plus chlorite (H.D. Glass, Illinois State Geological Survey, written communication, 1982).

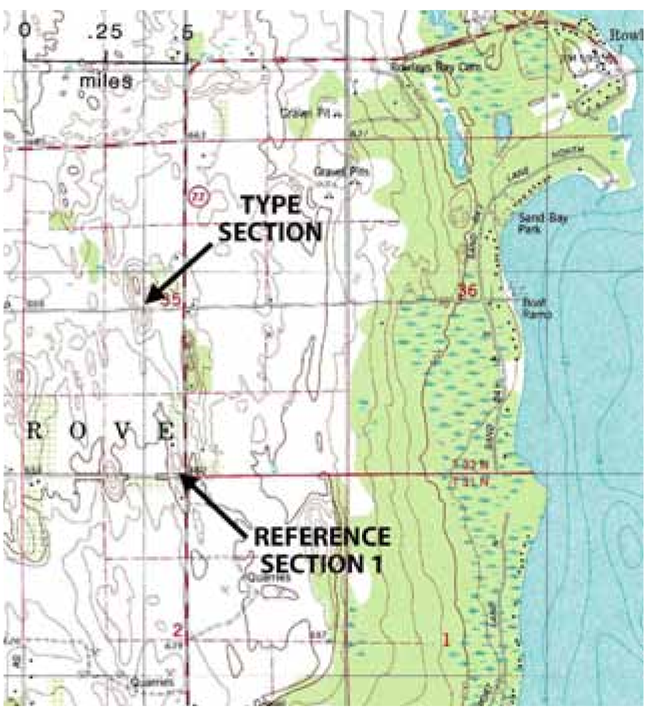

Figure 81. Part of the Sister Bay 7.5-minute quadrangle showing the locations of the type section and reference section 1 of the Liberty Grove Member.

Location and description of reference sections. (1) Road cut on north side of Hill Road, just west of the intersection with County Highway ZZ. It is located in the SE¼SE¼SW¼ sec. 35, T. 32 N., R. 28 E., Door County, an area shown on the Sister Bay 7.5-minute quadrangle (fig. 81). This cut is similar to the type section, exposing 3 to 4 m of calcareous brown (7.5YR 5/4 to 10YR 5/3), coarse-grained till in a drumlin of the Liberty Grove drumlin field, well known to local residents as the Hill Road drumlin. (2) Road cut on north side of County Highway H, about 0.8 km (0.5 mile) east of intersection of County Highways H and XC. It is located in the SE¼SE¼SW¼ sec. 2, T. 26 N., R. 24 E., Door County, an area shown on the Brussels 7.5-minute quadrangle (fig. 82). About 3 to 4 m of light yellowish-brown (10YR 6/4) sandy till is exposed for a distance of more than 200 m in this relatively fresh cut.

Description of unit. The Liberty Grove Member contains coarse-grained till, best described texturally as pebbly sandy loam. Because of its abundant stones, road cuts and other exposures generally give the impression that the material is gravel rather than till. In many places, particularly where the till is thin and rests directly on bedrock, it is a very rubbly deposit containing many subangular pebbles, cobbles, and boulders. Most clasts are dolomite derived from the underlying Silurian units. A count of 117 clasts larger than 15 cm in diameter from till in southern Kewaunee County averaged 73 percent

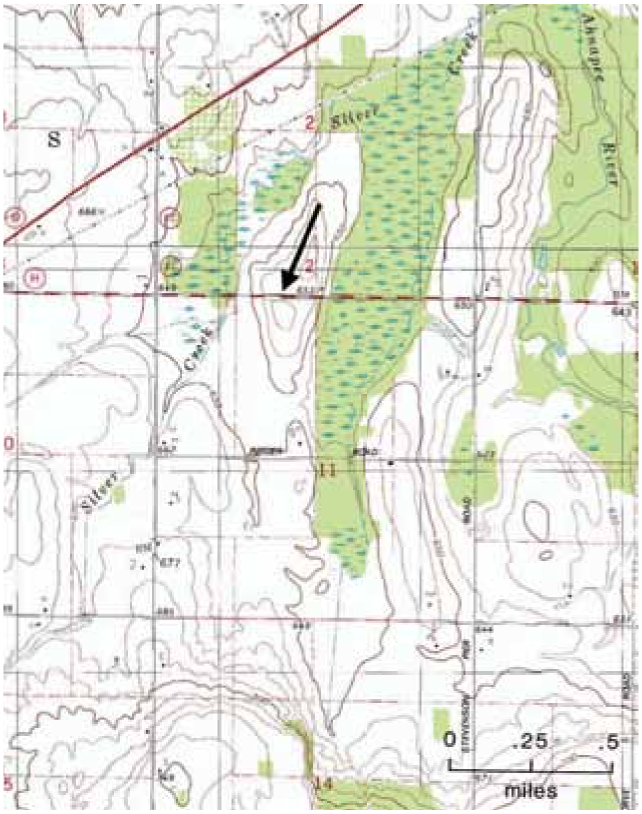

Figure 82. Parts of the Brussels and Little Sturgeon 7.5-minute quadrangles showing the location of reference section 2 of the Liberty Grove Member.

Niagaran dolomite, 8 percent light-colored igneous rocks, 16 percent dark-colored igneous rocks, and 3 percent miscellaneous rock types (Thwaites and Bertrand, 1957, p. 843). Based on a limited number of analyses, the less-than-2 mm fraction of the till contains between 50 and 60 percent sand, 30 to 40 percent silt, and 5 to 15 percent clay. In many places the sand content is higher. Semiquantitative clay mineral analyses indicate that the till averages 16 percent expandable clay minerals, 65 percent illite, and 19 percent kaolinite plus chlorite (H.D. Glass, written communication, 1982). The color of the till ranges from light brown (7.5YR 6/4) or brown (7.5YR 4/4 to 5/4 or 10YR 5/3) to light yellowish brown (10YR 6/4) or yellowish brown (10YR 5/4). Commonly it is almost midway between 7.5YR 5/4 and 10YR 5/3 on the Munsell charts. In many places it has a pale pinkish or salmon cast, which is attributed to the incorporation of ground-up Niagaran dolomite.

Nature of contacts. The Liberty Grove Member rests on bedrock at all localities where the base of the unit has been seen. In most places it overlies Silurian dolomite of the Alexandrian or Niagaran Series, but it has also been found in contact with the Maquoketa Formation of Late Ordovician age. Where it is not the surface deposit, the Liberty Grove Member generally underlies calcareous, red clayey till of the Kewaunee Formation, especially the Glenmore Member. In some places it probably underlies the Two Rivers Member. At a few sites in Door County, the Liberty Grove Member underlies an unnamed pink sandy till of unknown origin and distribution. The contact with the overlying Glenmore Member is generally sharp; the contact with the pink till is sharp to diffuse.

Differentiation from other units. The Liberty Grove Member is fairly similar to the Horicon Member of the Holy Hill Formation. Till of the Liberty Grove Member, however, is finer grained and distinctly lighter in color, ranging from brown (7.5YR hue) to yellowish brown (10YR hue), whereas Horicon Member till ranges from brown (7.5YR hue) to reddish brown (5YR hue). Liberty Grove Member till differs greatly from the fine-grained reddish-brown till of the Glenmore Member and other members of the Kewaunee Formation; the Liberty Grove is much coarser grained and more yellowish in color than the Kewaunee Formation till units.

Regional extent and thickness. The Liberty Grove Member is the surficial deposit throughout much of Door County to the north of Sturgeon Bay (Schneider, 1981, fig. 3). It extends southward, mainly as a subsurface unit beneath the Glenmore Member of the Kewaunee Formation, through southern Door County and at least as far south as central and southern Kewaunee County. The Liberty Grove Member is thin and is generally less than 3 m thick in much of Door County. Although its maximum thickness is unknown, in some places, as in the Liberty Grove drumlin field, it is as much as 10 m thick.

Origin. The Liberty Grove Member of the Holy Hill Formation is glacial till deposited by ice of the Green Bay Lobe, which crossed northern Door County flowing in a direction of S. 5° E. to S. 20° E. (Schneider, 1981).

Age and correlation. The Liberty Grove Member was deposited during the last part of the Wisconsin Glaciation. Although unconfirmed by radiocarbon dates, the Liberty Grove Member was likely deposited about 17,000 to 18,000 cal. yr B.P. The Liberty Grove Member is correlated with the Horicon Member of the Holy Hill Formation, which has been mapped on the west side of the Green Bay lowland. Very likely, it is equivalent to the informally named Wayside till recognized by McCartney and Mickelson (1982) in southern Brown County. The Liberty Grove Member is part of the widespread till of the Door Peninsula that was placed in the Cary Substage by Thwaites and Bertrand (1957).

Previous usage. The name was used by Schneider (1981). First formalized as a member of the Horicon Formation in Mickelson and others (1984). Formally reclassified as a member of the Holy Hill Formation in Mickelson and Syverson (1997).

Big Flats Formation

Jim Brownell

Source of name. Big Flats Township, northwestern Adams County, Wisconsin.

Location and description of type section. Drill hole located at the unincorporated community of Big Flats, 100 m east of State Highway 13 on County Highway C. It is located in the NW¼NW¼NE¼ sec. 20, T. 19 N., R. 6 E., northwestern Adams County, in an area shown on the Roche A Cri 7.5-minute quadrangle (fig. 83).

The drill hole penetrated about 8 m of well-sorted fine sand of the Big Flats Formation above New Rome Member silt and clay. The sand contains about 1 to 3 percent non-quartz grains and is noncalcareous. The New Rome Member is about 4.5 m thick at the type section. The New Rome Member overlies at least 3.5 m of sand; the distance to the base of the Big Flats Formation is unknown.

Description of unit. Most of the Big Flats Formation is composed of beds of moderately well-sorted to well-sorted sand. The mean grain size is 0.26 mm, and grains range in size from 0.19 to 0.32 mm (21 samples). Sixty-two percent of the samples have a mean size in the medium-sand range (0.25 to 0.50 mm), and 38 percent have a mean size in the fine-sand range (0.125 to 0.25 mm). Most of the sand is quartz derived from Cambrian formations. Non-quartz grains commonly make up less than 1 percent of the sand beds, but may be as much as 5 to 10 percent. Field colors are generally dark grayish brown to dark yellowish brown (10YR 4/2 to 4/6) or brown (7.5YR 4/4). The New Rome Member (described in a separate section), and other poorly known silt and clay beds that occur below it, compose the remainder of the Big Flats Formation.

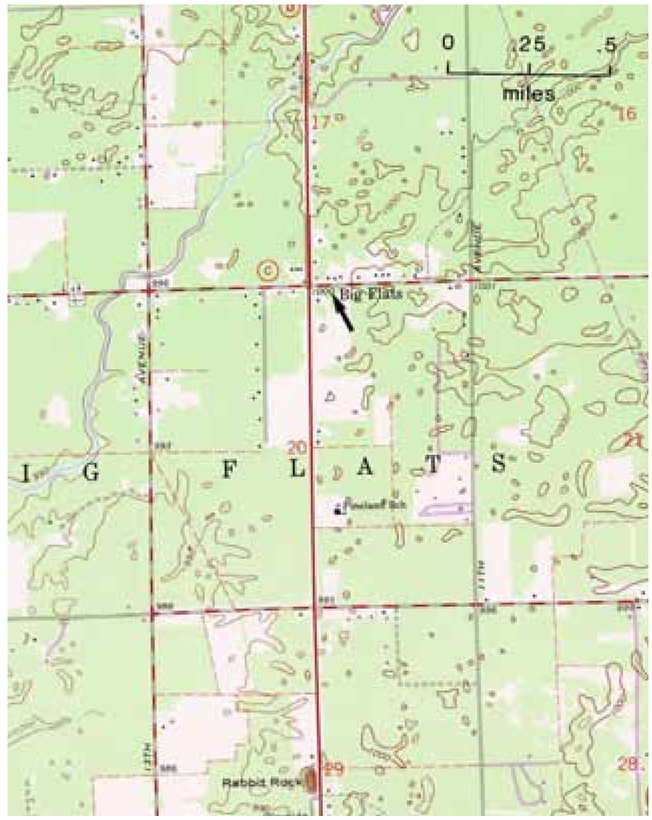

Figure 83. Part of the Roche a Cri 7.5-minute quadrangle showing the location of the type section of the Big Flats Formation and the reference section of the New Rome Member.

Nature of contacts. Typically, the Big Flats Formation is found at the surface (fig. 3). The unit overlies rock of Cambrian or Precambrian formations, sand of the Copper Falls Formation, or the Horicon Member of the Holy Hill Formation. Where the Big Flats Formation overlies Precambrian igneous and metamorphic rock, the contact is sharp; it is sharp to diffuse where the Big Flats Formation overlies Cambrian sand or sandstone or other Pleistocene sand.

Big Flats Formation

Differentiation from other units. The Big Flats Formation is distinguished from overlying and underlying sand units by stratigraphic position, grain-size distribution, and the percentage and lithology of non-quartz grains; from underlying Cambrian sand, by its grain size, color, and lithification. Big Flats Formation sand commonly includes rather angular dark-colored grains; the Cambrian sand is almost entirely well-rounded quartz and is commonly whiter and more lithified. A widespread paleosol separates the Big Flats Formation from overlying sand found in Holocene eolian dunes (Lee Clayton, Wisconsin Geological and Natural History Survey, oral communication, 1986). Big Flats Formation sand is differentiated from sand of the Copper Falls and Holy Hill Formations by the degree of sorting and the percentage and lithology of non-quartz grains in samples. Big Flats Formation sand is better sorted (contains little or no very coarse sand and gravel), commonly has less than 1 percent non-quartz grains, and is generally noncalcareous.

Regional extent and thickness. The Big Flats Formation is the surface unit throughout much of Wisconsin's Central Sand Plain. The eastern limit of the Big Flats Formation is marked by a break in slope located several kilometers west of the Hancock moraine in Waushara and Adams Counties; the western limit is marked by the sandstone escarpment on the east side of the Driftless Area in Juneau and Monroe Counties. At the northwest end of the Central Sand Plain in Jackson County, it includes sand on, and east of, the drainage divide between the Yellow and Black Rivers. The southern limit is marked by the Baraboo Hills. The northern limit is near the boundaries between Wood/Juneau Counties and Portage/Adams Counties. The Big Flats Formation is absent under the Wisconsin River and its terraces, and it is typically absent between the Wisconsin and Yellow Rivers. The Big Flats Formation ranges in thickness from about 1 m to more than 40 m. It is generally between 1 and 10 m thick west of the Wisconsin River in Juneau County, and generally from 10 m to more than 40 m thick east of the Wisconsin River in Adams County.

Origin. The Big Flats Formation mainly is composed of lake and stream sediment. The silt and clay beds are offshore sediment of glacial Lake Wisconsin. The sand units probably include meltwater-stream sediment deposited west of the Green Bay Lobe; offshore, nearshore, and beach sediment of Lake Wisconsin; nonglacial-stream sediment derived from Cambrian uplands; and eolian sediment.

Age and correlation. The upper part of the Big Flats Formation was deposited about 16,000 to 24,000 cal. yr B.P., during the last part of the Wisconsin Glaciation. The lower part of the formation may have been deposited before or during the early part of the Wisconsin Glaciation.

Previous usage. Name first used by Brownell (1986). Formalized in Attig and others (1988).

Big Flats Formation: New Rome Member

Jim Brownell

Source of name. Community of New Rome, northwestern Adams County, Wisconsin.

Location and description of type section. Clay pit in a terrace scarp of the Wisconsin River about 0.3 km (0.2 mile) north of Apache Avenue. It is located in the NE¼SE¼SE¼ sec. 15, T. 20 N., R. 5 E., Adams County, an area shown on the Arkdale NW 7.5-minute quadrangle (fig. 84).

Approximately 2.4 m of fine-grained New Rome Member sediment is exposed in the clay pit. It is overlain and underlain by eolian or lacustrine sand of the Big Flats Formation. New Rome Member sediment is rhythmically bedded. In the upper 0.3 m the rhythmites have been destroyed, and the material has been leached of its carbonates, possibly by soil formation.

Location of reference section. The type section for the Big Flats Formation (fig. 83) serves as the reference section for this unit.

Description of unit. The New Rome Member is composed of thinly laminated, commonly rhythmically bedded, glacial-lake sediment. The average grain size of the less-than-2 mm fraction at 48 sites is 27 percent sand (2.0 to 0.63 mm), 48 percent silt (0.063 to 0.004 mm), and 25 percent clay (less than 0.004 mm) (103 samples). The average gravel content of these samples is 1 percent. A rhythmite is typically composed of a pink (7.5YR 7/4) to very pale brown (10YR 7/4) clay bed and a pinkish gray (7.5YR 6/2) silt bed. Where the rhythmites are not apparent, the color is typically brown (7.5YR 5/4). Carbonate in the 0.0625-to-0.037 mm fraction, as measured with a Chittick apparatus, averages 20 percent dolomite and 3 percent calcite (71 samples, Brownell, 1986). In some places the New Rome Member is interbedded with sand.

Nature of contacts. In most drill holes the upper contact of the New Rome Member is sharp; its lower contact is sharp to gradational.

Differentiation from other units. The New Rome Member is easily differentiated from most other units of the Central Sand Plain by the abundance of rhythmically bedded silt and clay. It is differentiated from older, bedded silt and clay lacustrine units by stratigraphic position.

Figure 84. Part of the Arkdale NW 7.5-minute quadrangle showing the location of the type section of the New Rome Member.

Regional extent and thickness. The New Rome Member is found throughout the Central Sand Plain. This member's eastern limit appears to be marked by the Hancock moraine in southern Adams County, but the eastern limit is about 24 km (15 miles) west of the moraine in southwestern Portage County. Throughout the Central Sand Plain, the New Rome Member is absent under the terraces adjacent to the Wisconsin River. In the southwest, the New Rome Member extends to the sandstone escarpment marking the boundary between the Driftless Area and the Central Sand Plain. At the northwest end of the plain, it is not found between Babcock and City Point. The New Rome Member is at least 9 m thick in places. It is near or at the surface along the lower Yellow River in Juneau County.

Origin. The New Rome Member was deposited in glacial Lake Wisconsin when the Green Bay Lobe blocked the Wisconsin River at the east end of the Baraboo Hills and at the Devils Nose southeast of Devils Lake.

Age and correlation. The New Rome Member was deposited during the last part of the Wisconsin Glaciation (sometime between about 17,000 and 24,000 cal. yr B.P.) and is contemporaneous with the Horicon Member of the Holy Hill Formation. However, the upper part of the Horicon Member is probably younger and the lower part is probably older than the New Rome Member.

Previous usage. Name first used by Brownell (1986). Formalized in Attig and others (1988).

Oak Creek Formation

Allan F. Schneider

Source of name. City of Oak Creek, southeastern Milwaukee County, Wisconsin.

Location and description of type section. The type section, called the Oakwood Road South Section, is a bluff exposure along the Lake Michigan shoreline between the end of Oakwood Road and the end of Elm Road, and immediately north of the Oak Creek Power Plant. It is located in the NE¼NE¼NE¼ sec. 36, T. 5 N., R. 22 E. and the NW¼ sec. 31, T. 5 N., R. 23 E., Milwaukee County, an area shown on the Racine North 7.5-minute quadrangle (fig. 85).

Figure 85. Part of the Racine North 7.5-minute quadrangle showing the location of the type section of the Oak Creek Formation.

Numerous mudflows and slump blocks commonly conceal parts of the bluff exposure, but because the beach is narrower in the northern part of this shore segment, the Oak Creek Formation is generally much better exposed from the ravine at Oakwood Road southward for about 600 m than farther to the south. Two to three till units are present in the upper half of the exposure. These range in thickness from 1.2 to 5.2 m and are separated by layers of sand and gravel or lacustrine sand and silt.

All units in the type section belong to the Oak Creek Formation. A sample from one of these till units contains 7 percent sand, 48 percent silt, and 45 percent clay; its clay mineral composition is 13 percent expandables, 69 percent illite, and 18 percent kaolinite plus chlorite (H.D. Glass, Illinois State Geological Survey, written communication, 1982). The lower half of the exposure consists mostly of lacustrine silt and fine sand, but the lacustrine sediment contains till interbeds. Silty clay loam or silty clay till, ranging in thickness from less than 1.5 m at the north end of the exposure to 4.6 m near the south end, caps the bluff in most places. The bluff is about 30 m high.

Location and description of reference section. Sheridan Park Section, a Lake Michigan bluff exposure at the north end of Sheridan Park, just south of the St. Francis Power Plant. It is located in the SW¼NW¼ and the NW¼SW¼ sec. 24, T. 6 N., R. 22 E., Milwaukee County, an area shown on the South Milwaukee 7.5-minute quadrangle (fig. 86). This is the best exposure of multiple tills along the Lake Michigan shoreline in southeastern Wisconsin and it also serves as the reference section for the Waubeka Member of the Holy Hill Formation (Mickelson and Syverson, 1997). The oldest till units at the section (tills 1A and 1B of Mickelson and others, 1977) are present at the base of the bluff. These sandy and stony till units are as much as 4 m thick and are placed in the New

Berlin and Waubeka Members of the Holy Hill Formation (Mickelson and Syverson, 1997). A boulder lag separates the till of the Holy Hill Formation from till of the overlying Oak Creek Formation (till 2B of Mickelson and others, 1977).

The two overlying till units belong to the Oak Creek Formation (tills 2B and 2C of Mickelson and others, 1977). Till unit 2B is 6 m thick in the lower half of the exposure, and till unit 2C is 2 m thick at or near the top of the bluff. Both units contain interbeds of silt and clay. These till units are separated by a thick sand and gravel unit, which apparently grades upward into lacustrine silt and silty clay, all of which are included in the Oak Creek Formation. Oak Creek Formation till is much less sandy and stony than till of both the New Berlin and Waubeka Members of the Holy Hill Formation.

Description of unit. The Oak Creek Formation includes fine-grained glacial till; lacustrine clay, silt, and sand; and some glaciofluvial sand and gravel. Three till units were identified by Mickelson and others (1977), but these are not formally named in this paper. The lacustrine and glaciofluvial sediments seem to be much more characteristic of the eastern part of the Oak Creek Formation's areal extent (near Lake Michigan) than farther west, where the Oak Creek Formation consists predominantly of till. This till is everywhere highly calcareous and fine grained, commonly containing between 80 to 90 percent silt and clay in the less-than-2 mm fraction. Because the relative amounts of silt and clay vary, the texture of the till ranges from silty clay through clay loam and silty clay loam to silt loam. Generally the till texture is silty clay or silty clay loam. The average composition is about 12 percent sand, 43 percent silt, and 45 percent clay. Stones are generally small and not abundant. Oak Creek Formation till typically has a 10YR hue; the color of the oxidized till in most places is brown (10YR 4/3 to 5/3), yellowish brown (10YR 5/4 to 5/6), or dark yellowish brown (10YR 4/4). In a few places it has a 7.5YR hue (brown, 7.5YR 4/4). The till is gray (10YR 5/1) where unoxidized. Clay minerals in the till average 72 percent illite, 15 percent expandable clay minerals, and 13 percent kaolinite plus chlorite (H.D. Glass, Illinois State Geological Survey, written communication, 1982).

Figure 86. Part of the South Milwaukee 7.5-minute quadrangle showing the location of the reference section of the Oak Creek Formation and the Waubeka Member of the Holy Hill Formation.

Dolomite dominates the pebble assemblage, but the sediment contains many different igneous and metamorphic rock types from the Canadian Shield; basalt is particularly common. Dark gray shale fragments are perhaps the most diagnostic lithology; these are presumably derived from the Lake Michigan basin.

Nature of contacts. Till of the Oak Creek Formation overlies till of the New Berlin and Waubeka Members of the Holy Hill Formation. This lower contact with the New Berlin Member is sharp in most places, but in some places it is marked by interbedding, probably produced by the incorporation of thrust slices of the older till. One drill hole in southern Ozaukee County (OZ-539) penetrated thick Oak Creek Formation till over till of the Waubeka Member with a sharp contact. In eastern Kenosha and southeastern Racine Counties, Oak Creek Formation till is sharply overlain by lacustrine deposits, including both sandy shallow-water sediment and massive to laminated and varved sediment deposited in the quieter waters of glacial Lake Chicago. From St. Francis northward, the Oak Creek Formation is overlain by till and associated sediment of the Kewaunee Formation. According to soil scientists who have mapped in the area, till of the Oak Creek Formation is overlain by a thin loess cap in many places. Nowhere is the loess sufficiently thick to extend through the solum.

Differentiation from other units. Till of the Oak Creek Formation is readily distinguished from all other till units in southeastern Wisconsin by its color (both oxidized and unoxidized), by its high silt and clay content (generally 80 to 90 percent), by its abundant dolomite clasts, and by its dark gray to black shale fragments. The underlying New Berlin Member till is much sandier, stonier, and somewhat lighter in color than till of the Oak Creek Formation. The texture of the underlying Waubeka Member till is intermediate between the New Berlin Member till and the Oak Creek Formation till. The Waubeka Member till is sandier and less clayey than till of the Oak Creek Formation. The younger Kewaunee Formation tills are distinctly redder and generally lack the shale fragments found in the Oak Creek Formation.

Regional extent and thickness. The Oak Creek Formation is the surface till in southeastern Wisconsin, where it extends in a north-south belt from the Illinois border northward through Kenosha, Racine, Milwaukee, and eastern Waukesha Counties at least as far north as Sheboygan County (fig. 3). Its western limit for much of this distance is the Valparaiso moraine, whose distal (western) margin is generally followed by the Fox River. The eastern boundary of the formation from the Illinois border northward to Racine is the plain of glacial Lake Chicago. Between Racine and Milwaukee the formation extends to Lake Michigan, and from Milwaukee northward the formation is overlain by the Ozaukee Member of the Kewaunee Formation, which borders the lake in this area. In addition to being the surface unit in the Valparaiso moraine, Oak Creek Formation till is the dominant constituent of the Tinley moraine and the several Lake Border moraines, as well as in areas between these ridges. East of the front of the Tinley moraine (Alden's outermost Lake Border moraine), the till is much thicker than farther west. Although its maximum thickness is unknown, bluff exposures along the Lake Michigan shoreline in southern Milwaukee County show that the Oak Creek Formation is at least 35 m in places.

Origin. Till of the Oak Creek Formation was deposited by ice of the Lake Michigan Lobe as it flowed west-southwestward out of the Lake Michigan basin across a large area of southeastern Wisconsin. Lacustrine sediment in the formation was deposited mainly in glacial lake environments during brief intervals of ice-front recession.

Age and correlation. The Oak Creek Formation was deposited during the last part of the Wisconsin Glaciation, between about 15,000 to 17,000 cal. yr B.P. Till of the Oak Creek Formation correlates with the Wadsworth Formation in Illinois (Hansel and Johnson, 1996), with which it is contiguous for many miles along the Wisconsin-Illinois state boundary. Most likely it is equivalent in age to the upper part of the Horicon Member of the Holy Hill Formation (Green Bay Lobe).

Previous usage. Formalized in Mickelson and others (1984).

Trade River Formation

Mark D. Johnson

Source of name. The Trade River in Polk and Burnett Counties, Wisconsin.

Location and description of type section. A gravel pit located in the SE¼SW¼SE¼ sec. 10, T. 35 N., R. 19 W., northwestern Polk County, an area shown on the Cushing 7.5-minute quadrangle (fig. 87).

The type section exposes 4 m of Trade River Formation till overlying 4 to 8 m of Copper Falls Formation pebbly sand and sand. A drill hole at the type section revealed 23 m of Copper Falls Formation pebbly sand and sand. The lower 0.5 m of the Trade River Formation till is redder and contains three or four faint laminations that show intermixing of the red with the overlying gray. Pebble fabrics are fairly strong and indicate ice movement to the east (in the lower red-laminated part) to N. 60° E. (in the gray part above). The till is massive and contains a few pods of sorted sand and a pod of red clay. The region around the type section is slightly hummocky and contains a number of kettle lakes.

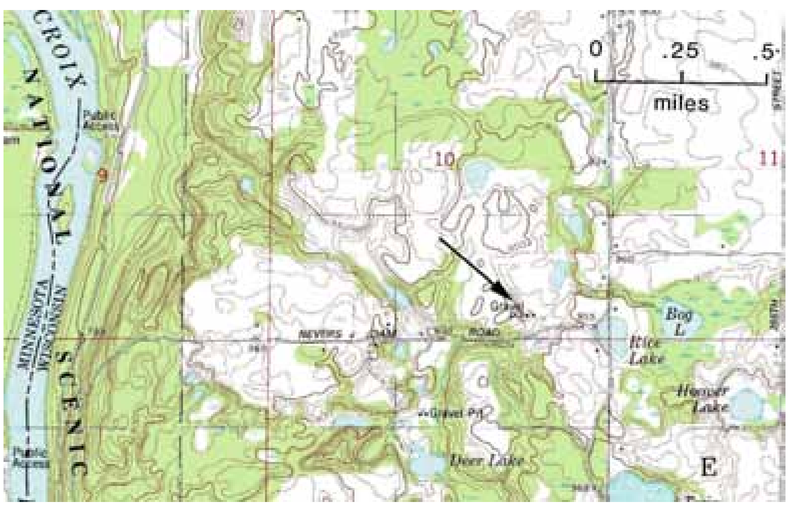

Figure 87. Part of the Cushing (Minnesota/Wisconsin) 7.5-minute quadrangle showing the location of the type section of the Trade River Formation.

Location and description of reference sections. The two reference sections are in southwestern Burnett County. (A) Along the western bank of the Trade River near the S½SE¼ sec. 19, T. 37 N., R. 18 W., approximately 150 m north of a barn shown on the Trade River 7.5-minute quadrangle (fig. 88). (B) Road cut on the east side of Melo Drive in the same section. It is located in the SW¼SE¼NW¼ sec. 19, T. 37 N., R. 18 W., an area shown on the Trade River 7.5-minute quadrangle (fig. 88).

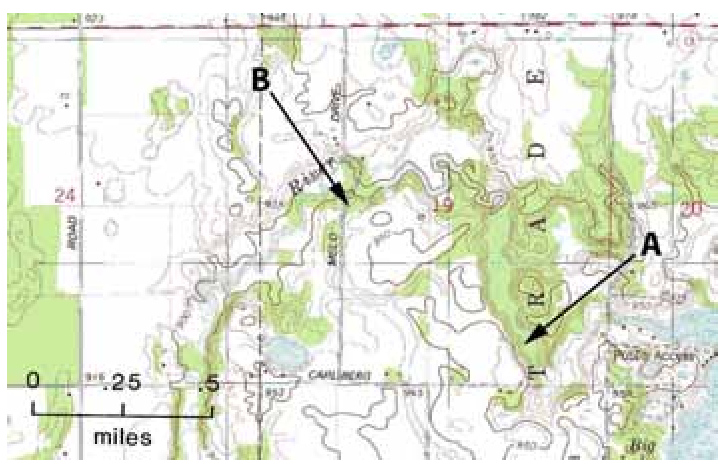

Figure 88. Part of the Trade River 7.5-minute quadrangle showing the locations of the reference sections of the Trade River Formation.

At reference section A, 15 m of oxidized and unoxidized Trade River Formation till sharply overlies 2 m of Copper Falls Formation stream sediment. At reference section B, 5 m of Trade River Formation till overlies about 1 m of red and gray laminated (varved) lake sediment, which in turn overlies Copper Falls Formation sand.

Description of unit. The Trade River Formation contains till, lake sediment, and stream sediment derived from debris transported by the Grantsburg Sublobe. Trade River Formation till is calcareous loam to clay loam (a few samples were sandy loam and sandy clay loam). The till averages 50 percent sand, 30 percent silt, and 20 percent clay (38 samples); gravel content is less than 5 percent. The average magnetic susceptibility is 2.1 x 10^{-3} (SI units, 38 samples). Samples of Trade River Formation till at and near the surface are oxidized and brown, dark brown, yellowish brown, to dark yellowish brown (7.5YR 4/4, 10YR 4/4 to 5/4). Generally, the redder samples (with hues of 7.5YR) are closer to the eastern edge of the Trade River Formation till plain. In places, the lower part of the till unit is redder (7.5YR 4/4) and is interlaminated with the overlying grayer layers. Unoxidized Trade River Formation till is present in the subsurface in poorly drained settings and is dark gray (10YR 4/1). The pebbles in the till display a variety of rock types, but the abundant clasts of soft, Cretaceous shale from the Red River Valley area and limestone and dolomite from Manitoba are noteworthy. Lignite clasts are not uncommon.

Distinctly varved to massive silt and clay deposited in glacial Lake Grantsburg are included in the Falun Member of the Trade River Formation (see next section). Silty and sandy lake sediment also was deposited in smaller ice-dammed lakes in northwestern Polk County. Trade River Formation stream sediment is not extensive and in places its lithologic composition is different because of mixing with older sediment, mostly sediment of the Copper Falls Formation.

Nature of contacts. The base of the Trade River Formation till overlies stream and lake sediment of the Copper Falls Formation in western Wisconsin. The contact is sharp everywhere. In places, several centimeters of Trade River Formation lake sediment separate till of the Trade River Formation and underlying sediment.

Differentiation from other units. Till of the Trade River Formation is most similar to till of the Pierce Formation in western Wisconsin. It can be easily distinguished from the Pierce Formation primarily by the abundance of Cretaceous shale, but also by its stratigraphic position.

Regional extent and thickness. Till of the Trade River Formation is at the surface in an arc-shaped band approximately 5 to 8 km (3 to 5 miles) wide and extending from Grantsburg, Wisconsin, south to a point a few kilometers north of St. Croix Falls. A few small patches of Trade River Formation till are located in St. Croix Falls and on the Osceola bench near Osceola, Wisconsin. Outcrops, drill holes, and well constructor's reports suggest the till is 4 to 15 m thick. Trade River Formation stream sediment and lake sediment is thin and patchy.

Origin. Till of the Trade River Formation was deposited underneath the Grantsburg Sublobe glacier as the ice advanced from the Minneapolis and St. Paul lowland to the northeast during the Pine City Phase (fig. 6, Johnson, 2000).

Age and correlation. The Trade River Formation may have been deposited as early as 16,000 ^{14}C yr B.P. (19,000 cal. yr B.P.) (Wright, 1972; Wright and others, 1973) and as late as 12,300 ^{14}C yr B.P. (14,500 cal. yr B.P.) (Clayton and Moran, 1982). Johnson (2000) suggests it was deposited about 14,000 ^{14}C yr B.P. (approximately 17,000 cal. yr B.P.). The till of the Trade River Formation is equivalent to the Twin Cities Formation as defined by Stone (1966) and is roughly the same age as the New Ulm till in southwest Minnesota (Matsch, 1972).

Previous usage. Formalized in Johnson (2000).

Trade River Formation: Falun Member

Mark D. Johnson and Chris Hemstad

Source of name. Community of Falun in Burnett County, Wisconsin.

Location and description of type section. Back-hoe excavation (June 1992) on the south side of Wisconsin State Highway 70, approximately 3 km (1.9 miles) east of Grantsburg, Wisconsin. It is located in the NE¼NW¼NE¼ sec. 19, T. 38 N., R. 18 W., Burnett County, an area shown on the Grantsburg 7.5-minute quadrangle (fig. 89).

At the type section, sediment of the Falun Member is overlain by 75 cm of tan to gray loose sand with a mixed zone of sandy gray loam at the contact; the Falun Member sediment is 115 cm thick and consists of 40 cm of massive clay and silty clay overlying 75 cm of rhythmically bedded clay and silty clay. The massive clay and silty clay are likely a result of soil-forming processes mixing the bedded clay. Thirty-eight varves are in the bedded part; the lowest 17 are quite thin (0.5 to 3.0 cm) and red. The 21 upper varves are thicker (2.5 to 4.0 cm) and grayer; the clayey winter layer is darker than the silty summer layer. Some of the winter layers in this section are slightly redder at their bases. The Falun Member is between 280 and 283 m in elevation.

The Falun Member overlies red, ripple-bedded to laminated, fine- to medium-grained sand of the Copper Falls Formation. Ripple-crest and cross-bed orientations show current flow to the west and northwest.

Location and description of reference sections. (A) Gravel pit on the north side of M-Y Road. It is located in the NW¼SW¼SW¼ sec. 3, T. 37 N., R. 18 W., Burnett County, an area shown on the Trade Lake 7.5-minute quadrangle (fig. 90). (B) Back-hoe excavation (June 1992) on farm property is located in the NE¼SE¼NW¼ sec. 10,

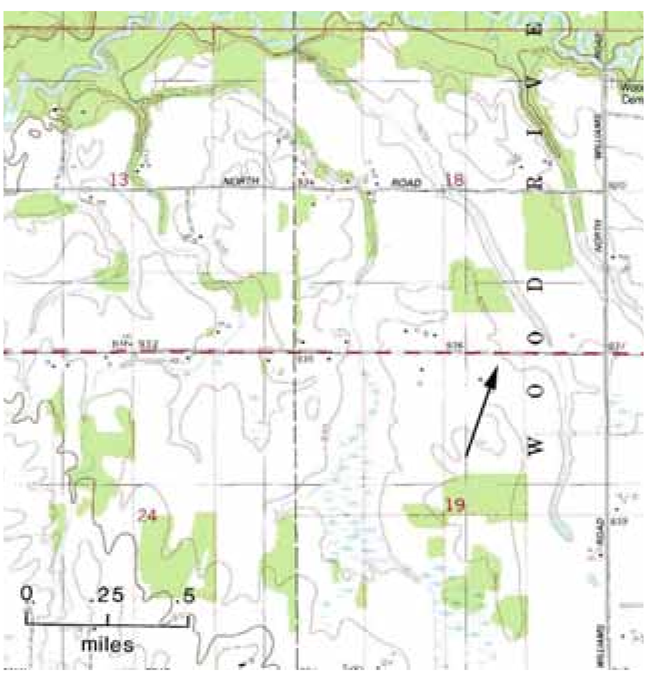

Figure 89. Part of the Grantsburg (Minnesota/Wisconsin) 7.5-minute quadrangle showing the location of the type section of the Falun Member.

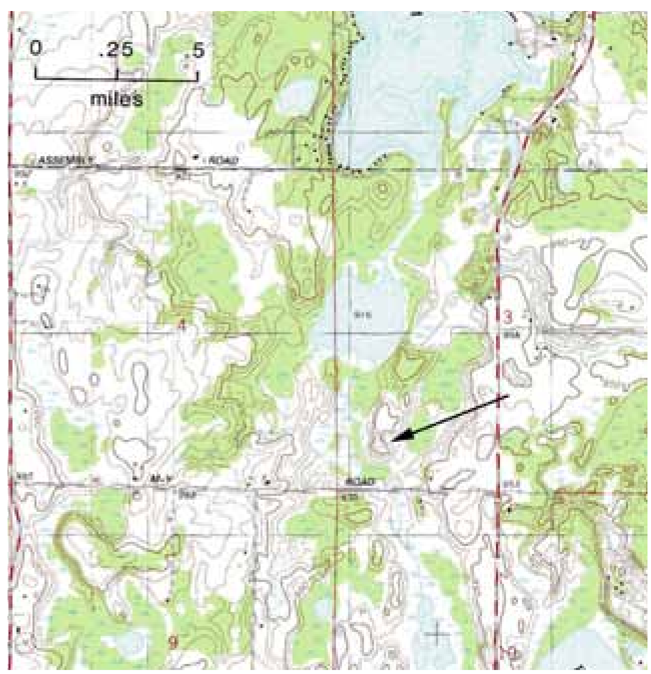

Figure 90. Part of the Trade Lake 7.5-minute quadrangle showing the location of reference section A of the Falun Member.

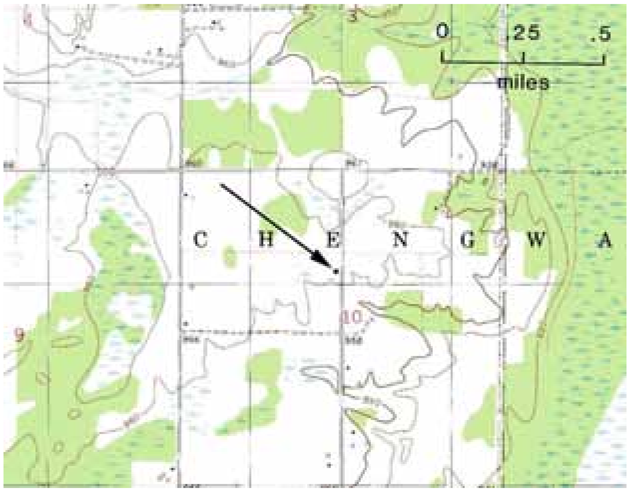

Figure 91. Part of the Cedar Lake (Minnesota) 7.5-minute quadrangle showing the location of reference section B of the Falun Member (a back-hoe excavation).

T. 39 N., R. 20 W., Pine County, Minnesota, an area shown on the Cedar Lake 7.5-minute quadrangle (fig. 91).

At reference section A, a clayey, slightly pebbly till-like sediment about 1.0 m thick overlies 1.5 m of Falun Member sediment, approximately 1.0 m of which is massive and 0.5 m is laminated. The laminations, 34 of which are present, are interpreted to be varves. The lowest 12 to 14 varves are red. The Falun Member sharply overlies several meters of pebbly sand of the Copper Falls Formation.

At reference section B, approximately 1.0 m of silt (possibly loess) overlies 3.0 m of rhythmically bedded silty clay and clay interpreted to be varves. Eighty-two couplets are present at this site and range in thickness from 1.0 to 15.0 cm; most are between 2.5 and 4.5 cm. The varves are predominantly gray, but a few thin red winter layers are among the first six varves. Above varve number 40, the winter layers begin to show redder colors, and varves 64 to 82 have reddish-brown (5YR 4/4) winter layers with relatively thin summer layers (0.5 cm). Within some of the summer layers in the central part of the sequence, fine laminations of coarse silt and very fine-grained sand are present. The varved part of the Falun Member at this site overlies 2.0 m of a dark grayish-brown (10YR 4/2) to strong brown (7.5YR 5/6) and yellowish brown (10YR 5/6), calcareous, coarse silt and fine-grained sand facies of the Falun Member. In places this silty and sandy facies has slightly convoluted bedding. The lower part of this silt and sand facies has been oxidized and is brown to dark brown (7.5YR 4/4). The Falun Member sharply overlies red coarse sand of the Copper Falls Formation.

Description of unit. The Falun Member consists predominantly of calcareous, rhythmically laminated, rhythmically bedded, massive clay and silty clay. At reference section B, the Falun Member includes silt and fine-grained sand at the base of the unit. In places, sand is found within the member. Silty clay layers are dark yellowish brown to yellowish brown (10YR 4/4 to 5/4), clay layers are predominantly dark grayish brown to brown (10YR 4/2 to 7.5YR 4/4), but in places are reddish brown (5YR 4/4).

Nature of contacts. The basal contact of the Falun Member is sharp and overlies red sand, slightly pebbly sand, and pebbly sand of the Copper Falls Formation. The Falun Member is at or near the surface and is overlain in places by sand up to a few meters thick or silt up to 0.5 m thick. The upper contact is in many places not as sharp, presumably because soil-forming processes mixed overlying sediment with the Falun Member.

Differentiation from other units. The Falun Member is most similar to sediment of the Sunrise Member of the Copper Falls Formation, but can be differentiated easily from it because the Falun Member is gray and more calcareous than the Sunrise Member, has thicker beds and laminations, and occupies a higher stratigraphic position.

Regional extent and thickness. The Falun Member is near the surface throughout central and southwestern Burnett County, Wisconsin, in an east–west band in Minnesota between Pine City and Hinckley in Pine County, and continuing westward into southern Kanabec County. It probably extends farther west, but has not been mapped there. The Falun Member ranges in thickness from approximately 1.0 to 5.0 m. The Falun Member is 1.2 m thick at the type section, 1.5 m thick at reference section A, and 5.2 m thick at reference section B. The unit is thickest near the Pine City Phase ice margin (fig. 6) and in low swales between upland areas. It is usually absent on hilltops and slopes.

Origin. The Falun Member was deposited in glacial Lake Grantsburg while the Grantsburg Sublobe stood at the Pine City Phase ice-margin limit (fig. 6). The rhythmically laminated layers are interpreted to be varves. Many rhythmites were probably deposited as the ice advanced to the Pine City Phase margin and as the ice retreated from this margin.

Age and correlation. The age of the Falun Member is not well known, but it is approximately the same age as the till of the Trade River Formation. Till of the Trade River Formation may have been deposited as early as 16,000 ^{14}C yr B.P. (19,000 cal. yr B.P.) (Wright, 1972; Wright and others, 1973) and as late as 12,300 ^{14}C yr B.P. (14,500 cal. yr B.P.) (Clayton and Moran, 1982). Johnson (2000) suggests it was deposited about 14,000 ^{14}C yr B.P. (approximately 17,000 cal. yr B.P.).

Previous usage. Formalized in Johnson (2000).

Kewaunee Formation

David M. Mickelson

Source of name. Kewaunee County, Wisconsin.

Location and description of type section. A site in the lake bluff at the south edge of the City of Kewaunee; it is reached by walking from State Highway 42 toward the lake bluff along a line of Lombardy poplar trees, then walking south along the bluff top about 100 m. It is located in the NE¼SE¼SE¼ sec. 19. T. 23 N., R. 25 E., Kewaunee County, an area shown on the Kewaunee 7.5-minute quadrangle (fig. 92).

At the top of the lake bluff is 2 to 2.5 m of till of the Two Rivers Member. This overlies a small exposure of organic material about 0.2 m thick. In places this organic material overlies about 1 m of oxidized gravel. Below this is 3.5 m of unoxidized (gray) till of what may be the Valders Member. Acomb and others (1982) interpreted this as Haven Member till, a unit no longer defined formally. This overlies 1.5 m of gravel and then 3 m of what is presumed to be unoxidized till of the Ozaukee Member. This till overlies 5 m of poorly laminated silt and clay with some fine sand beds. The laminated sediment and an underlying till are not clearly associated with the Kewaunee Formation, so the base of the formation is now defined as the top of the laminated sediment.

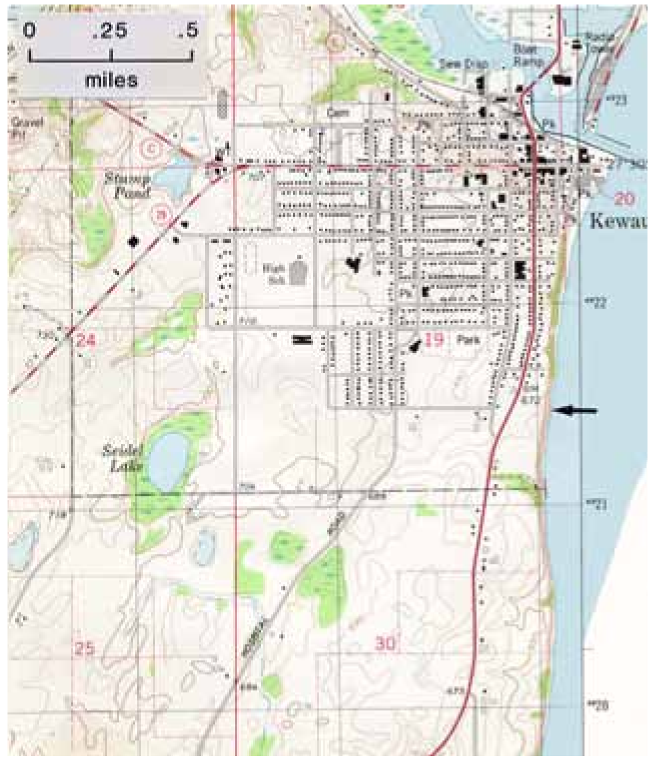

Figure 92. Part of the Kewaunee 7.5-minute quadrangle showing the location of the type section of the Kewaunee Formation.

Location and description of reference sections. All type sections of the included members are reference sections for the Kewaunee Formation. These include the Two Rivers, Valders, Ozaukee, Glenmore, Chilton, Branch River, Middle Inlet, Kirby Lake, Silver Cliff, and Florence Members. See each member for locations and descriptions.

Description of unit. The Kewaunee Formation consists of the Two Rivers, Valders, Ozaukee, Glenmore, Chilton, Branch River, Middle Inlet, Kirby Lake, Silver Cliff, and Florence Members, and several unnamed members. All till in the formation is brown (7.5YR 5/4) or reddish brown (5YR 4/4). All till and associated sediment are calcareous but have different amounts of sand, silt, and clay (see member descriptions).

Nature of contacts. The Kewaunee Formation is at the surface over much of northeastern Wisconsin. In places it is overlain by younger organic and alluvial deposits of an unnamed formation. The basal contact of the formation is generally distinct.

Differentiation from other units. Although the Kewaunee Formation is variable in color, it is nearly everywhere redder than the underlying Holy Hill and Oak Creek Formations. It has significantly less sand than sediment of the Holy Hill Formation and about the same or slightly more sand than the Oak Creek Formation. See member descriptions for the properties of individual members.

Regional extent and thickness. The Kewaunee Formation ranges in thickness from less than 1 m to at least 18 m. It covers much of northeastern Wisconsin as far south as the south shore of Lake Winnebago, and it is present along the shore of Lake Michigan south to Milwaukee (fig. 3).

Origin. The Kewaunee Formation contains till deposited by ice of the Lake Michigan and Green Bay Lobes. In many places subglacial till is common, but supraglacial till is common locally. The formation also contains fluvial sand and gravel and lacustrine sand, silt, and clay.

Age and correlation. The Kewaunee Formation is time equivalent to the Kewaunee and Equality Formations of Illinois (Hansel and Johnson, 1996) and the younger parts of the Copper Falls Formation in northern Wisconsin. It includes the Two Creeks Forest Bed which is dated at between about 11,200 to 12,400 ^{14}C yr B.P. (approximately 13,100 to 14,600 cal. yr B.P.) (Mickelson and others, 2007), and so the Kewaunee Formation is both older and younger than this. The maximum age of the unit is not fixed with precision. However, Socha (2007a) has described Chilton Member till overlying plant material (in normal growth position) with an age of 13,370 ± 90 ^{14}C yr B.P. (16,302 ± 428 cal. yr B.P., Beta – 119360). Because the Chilton Member is not the oldest till member of the Kewaunee Formation, at least part of the Kewaunee Formation was deposited before 13,370 ^{14}C yr B.P. (16,300 cal. yr B.P.). This formation is equivalent to what was called the "Valders till" by many writers after Thwaites (1943).

Previous usage. Formalized in Mickelson and others (1984).

Kewaunee Formation: Ozaukee Member

Larry Acomb and David M. Mickelson

Source of name. Ozaukee County, Wisconsin, on the shoreline of Lake Michigan.

Location and description of type section. The Lake Park Section is a bluff bordering Lake Michigan, immediately north of the harbor in Port Washington, Wisconsin. It is located in the NW¼SE¼NE¼ sec. 28, T. 11 N., R. 22 E., Ozaukee County, an area shown on the Port Washington East 7.5-minute quadrangle (fig. 93).

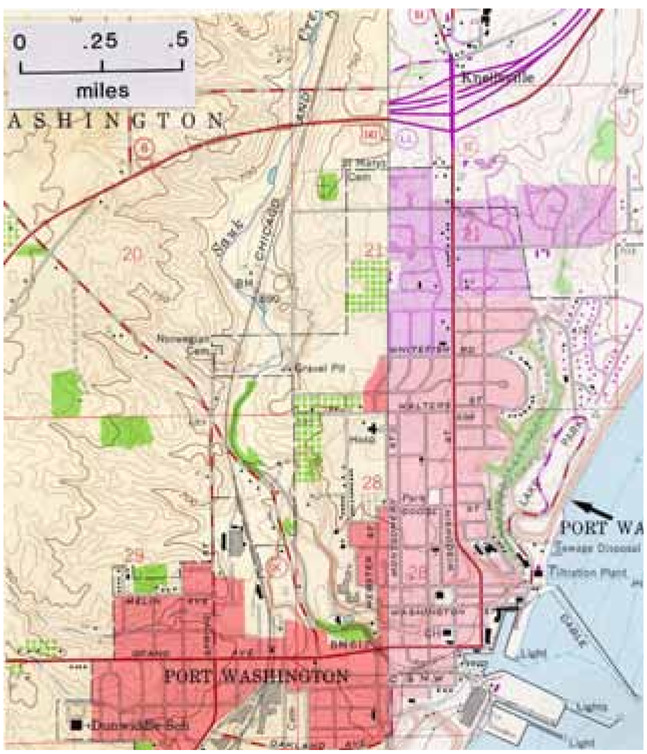

Figure 93. Parts of the Port Washington East and West 7.5-minute quadrangles showing the location of the type section of the Ozaukee Member.

The total bluff height above Lake Michigan is approximately 37 m. The Ozaukee Member is exposed in the upper half of the bluff, and the lower half of the bluff is slumped material.

Location and description of reference section. The Virmond Park Section is located in the NE¼NE¼SW¼ sec. 28, T. 9 N., R. 22 E., Ozaukee County, an area shown on the Thiensville 7.5-minute quadrangle (fig. 94). Ozaukee Member till at the top of the bluff is about 23 m thick and overlies lake sediment and older till.

Description of unit. The Ozaukee Member contains pebbly, clayey, and silty till and associated lake sediment. The color of its clay fraction varies from light reddish brown

Figure 94. Part of the Theinsville 7.5-minute quadrangle showing the location of the Virmond Park reference section of the Ozaukee Member.

(5YR 6/3) or pinkish gray (5YR 6/2) to gray (10YR 6/1). The till is hard and blocky to crumbly when dry, but it is very plastic when wet. Most exposures are the faces of slump scarps. Till of the Ozaukee Member contains numerous dolomite pebbles and cobbles, and a smaller quantity of igneous rock types. The unit averages 13 percent sand, 47 percent silt, and 40 percent clay. Semiquantitative clay mineral analyses reveal 20 to 30 percent expandables, 50 to 63 percent illite, and about 20 percent kaolinite plus chlorite (Acomb and others, 1982).

Nature of contacts. The lower contact of the Ozaukee Member is somewhat gradational where the underlying material is of similar grain size (clay and silt) and sharp when the underlying material is coarser-grained sediment (sand or gravel). The Ozaukee Member is the surface unit in Milwaukee, Ozaukee, and southern Sheboygan Counties. The Ozaukee Member exposed in the lake bluff south of Kewaunee has distinct upper and lower contacts, but north of Kewaunee the contacts are less distinct.

Differentiation from other units. The Ozaukee Member is most easily differentiated from the older gray Oak Creek Formation by its red color. The Ozaukee Member can be distinguished from the younger red till units of the Kewaunee Formation by its fine grain size and high illite percentage (Acomb and others, 1982).

Regional extent and thickness. The Ozaukee Member is present at the top of the Lake Michigan coastal bluff from Milwaukee northward to about the Ozaukee-Sheboygan County border. In this area the member extends inland to Alden's (1918) red till boundary which roughly parallels the ice-marginal Milwaukee River. This boundary defines a wedge of red till increasing in width from about 1.6 km in the Milwaukee area to almost 14.5 km north of Port Washington (fig. 3). North of the Ozaukee-Sheboygan County boundary, there is no lake bluff, but the Ozaukee Member is at the surface inland from the shore (Carlson, 2002; Carlson and others, in press). It is exposed near the base of the bluff beneath Valders Member till and lake sediment in places north of Sheboygan. The member ranges in thickness from about 20 m (at Shorewood and Virmond Park) to less than 3 m in other locations. In shoreline exposures the member averages about 9 m thick.

Origin. The Ozaukee Member contains basal till deposited by ice flowing southward in the Lake Michigan basin, as well as associated fluvial and lacustrine deposits.

Age and correlation. Radiocarbon dates from the Ozaukee Member do not exist. The Ozaukee Member is likely correlative with the Shorewood Member of the Kewaunee Formation (Hansel and Johnson, 1996) in the Lake Michigan basin and with units of similar texture and mineralogy in Michigan (Taylor, 1978). The unit is the time equivalent of the Branch River Member of the Green Bay Lobe.

Previous usage. This unit name was first used informally by Acomb (1978) and subsequently by Acomb and others (1982). Formalized in Mickelson and others (1984).

Kewaunee Formation: Valders Member

Larry Acomb and David M. Mickelson

Source of name. Village of Valders, Manitowoc County, Wisconsin.

Location and description of type section. Valders Lime Quarry located in the SW¼NE¼ sec. 32, T. 19 N., R. 22 E., Manitowoc County, an area shown on the Valders 7.5-minute quadrangle (fig. 95).

At the type section, about 2 m of till of the Valders Member overlies a striated dolomite surface in the north-eastern corner of the quarry. Along the northern part of the quarry exposure, 2 m of brown, sandy till of the Horicon Member of the Holy Hill Formation lies between the overlying Valders Member till and the underlying dolomite surface. On the northeastern side of the quarry

Figure 95. Part of the Valders 7.5-minute quadrangle showing the location of the type section of the Valders Member.

in the 1990s, pond sediment was located below Valders Member till and above Holy Hill Formation till (Maher and others, 1998).

Location and description of reference sections. (1) Stoney Point Section, in the lake bluff. It is located in sec. 34, T. 16 N., R. 23 E., Sheboygan County, an area shown on the Sheboygan North 7.5-minute quadrangle (fig. 96). Here approximately 2 m of Valders Member till overlies sandy, stoney till. (2) Pods Section, in the lake

Figure 96. Parts of the Howards Grove and Sheboygan North 7.5-minute quadrangles showing the location of reference section 1 of the Valders Member.

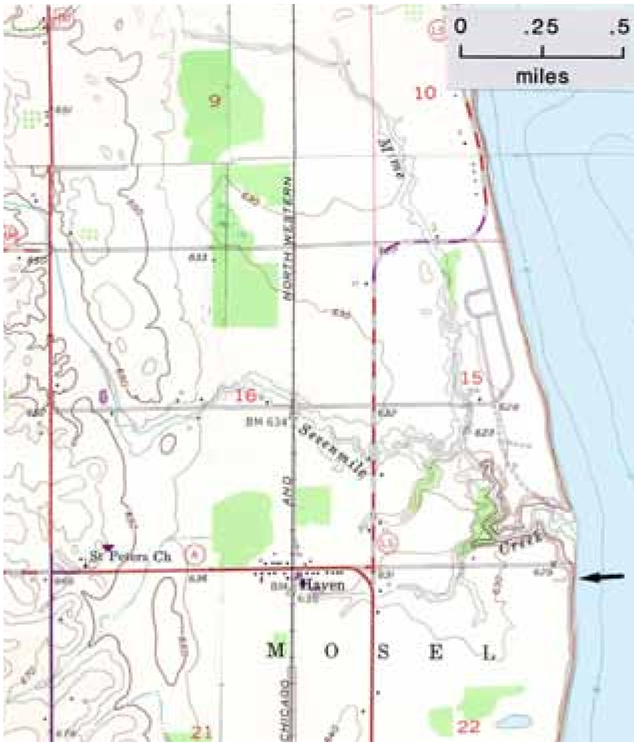

Figure 97. Parts of the Howards Grove and Sheboygan North 7.5-minute quadrangles showing the location of reference section 2 of the Valders Member.

bluff. It is located in sec. 22, T. 16 N., R. 23 E., Sheboygan County, an area shown on the Sheboygan North 7.5-minute quadrangle (fig. 97). Here discontinuous lenses and pods of Valders Member till are present in lake sediment in the upper part of the bluff.

Description of unit. The Valders Member contains pebbly and cobbly, sandy, silty till. In most exposures it is somewhat crumbly when dry and plastic when wet. Its color ranges from pink (5YR 7/3) and reddish yellow (5YR 6/6, 7/6) to reddish brown (2.5YR 5/4). Till of the Valders Member is quite pebbly, containing numerous cobbles and sand lenses. The till averages 30 percent sand, 52 percent silt, and 17 percent clay. Semiquantitative clay mineral analyses average 46 percent expandables, 42 percent illite, and 12 percent kaolinite plus chlorite. Geotechnical data shows the unit to be distinctly overconsolidated (Edil and Mickelson, 1995).

Nature of contacts. The lower contact of the Valders Member in exposures inland from the lake bluff is usually sharp; however, along the shoreline the lower contact can be gradational, or interbedded with a lower sand unit. The Valders Member is the surface unit over much of Sheboygan and Manitowoc Counties (fig. 3). In these areas, a well-developed soil has formed on the Valders Member, and it has been leached to depths greater than 75 cm (Mickelson and Evenson, 1975). North and east of the East Twin River, the Valders Member is presumably covered by the Two Rivers Member, but the contact has not been seen.

Differentiation from other units. The Valders Member is most easily distinguished from other till in the region by its clay mineralogy. It has the most expandable clay (46 percent) and least illite (mean about 40 percent) of any unit in the area. Additionally, the Valders Member can be differentiated from the Ozaukee Member by its coarser-grained texture (more sand, pebbles, and cobbles).

Regional extent and thickness. The Valders Member presumably extends along the Lake Michigan shoreline from near Sheboygan to north of Algoma. However, the unit is not exposed in the lake bluff north of Two Rivers. To the west the unit reaches the Kettle Moraine in Sheboygan County and drapes over the Kettle Moraine in the Valders area. It is at the surface immediately west of the East Twin River, but not to the east. The Valders Member is on average about 2.4 m thick, and ranges in thickness from 1.8 to 3 m. The Valders Member contains basal glacial till deposited by ice of the Lake Michigan Lobe, as well as associated fluvial and lacustrine deposits.

Age and correlation. The Valders Member is stratigraphically below the Two Creeks Forest Bed, suggesting an age of more than 11,200 to 12,400 ^{14}C yr B.P. (approximately 13,100 to 14,600 cal. yr B.P., Mickelson and others, 2007). Radiocarbon dates on material from Kellners Lake (Goodwin, 1976) indicate earlier deposition; however, the dated sediment was probably contaminated with dead carbon. Radiocarbon dates on organic matter collected from the glaciolacustrine unit below the Valders Member range from (14,210 ± 90 to 12,965 ± 200 ^{14}C yr B.P. (17,434 ± 256 to 15,779 ± 540 cal. yr B.P.) (Maher and others, 1998). The organic assemblage indicates a cold, tundra-like, open-ground environment (Maher and Mickelson, 1996; Maher and others, 1998).

A lateral equivalent in Lake Michigan has not been recognized to date; however, it is presumed that the unit is correlative with the Manitowoc Member of the Kewaunee Formation (Hansel and Johnson, 1996). The Chilton Member on the east side of the Fox River and the Kirby Lake Member on the west side of the Fox River are Green Bay Lobe equivalents of the Valders Member (deposited by the Lake Michigan Lobe).

Previous usage. First use of the unit name was by Thwaites (1943). It was redescribed by Acomb (1978) and subsequently used by Acomb and others (1982). Formalized in Mickelson and others (1984).

Kewaunee Formation: Two Rivers Member

Larry Acomb and David M. Mickelson

Source of name. City of Two Rivers, Manitowoc County, Wisconsin.

Location and description of type section. Car Dealer Section located in the NW¼SW¼NW¼ sec. 31, T. 20 N., R. 25 E., Manitowoc County, an area shown on the Two Rivers 7.5-minute quadrangle (fig. 98). The type section is behind the car dealership on east side of State Highway 42 on the north side of Two Rivers.

In a west-facing pit face at the type section, approximately 3 m of red clayey till overlies sandy sediment presumed to be of lacustrine origin. A drill hole indicates that the lacustrine sediment is about 15 m thick. The till is complex and probably includes thrusted masses of Valders Member till and soil material.

Location and description of reference sections. (1) Two Creeks Section located in the NE¼NE¼ sec. 2, T. 21 N., R. 24 E., Manitowoc County, an area shown on the Two Creeks 7.5-minute quadrangle (fig. 99). About 2 m of Two Rivers Member till overlies sand and silt containing the Two Creeks Forest Bed. Beneath the lake sediment is Ozaukee Member till at beach level. (2) In the lake bluff located in the NE¼ sec. 31, T. 23 N., R. 25 E., Kewaunee County, an area shown on the Kewaunee 7.5-minute quadrangle (fig. 100). Approximately 3 m of Two Rivers Member till is present at the top of the bluff. This unit may include subglacial and supraglacial facies. This is underlain by lake sediment, Valders Member till, more lake sediment and probably Ozaukee Member till (Acomb

Figure 98. Part of the Two Rivers 7.5-minute quadrangle showing the location of the type section of the Two Rivers Member.

Figure 99. Part of the Two Creeks 7.5-minute quadrangle showing the location of reference section 1 of the Two Rivers Member.

Figure 100. Part of the Kewaunee 7.5-minute quadrangle showing the location of reference section 2 of the Two Rivers Member.

and others, 1982; note changes in status of Haven and Ozaukee Members in this volume).

Description of unit. Till of the Two Rivers Member is pebbly and cobbly, sandy silt. Its color is either light reddish brown to pink (5YR 6/4, 7.5YR 7/4) or reddish yellow (5YR 6/6, 7/6). The unit is rather crumbly when dry and plastic when wet. The pebbles and cobbles are predominantly locally derived dolomite; however, igneous rock types are common. Till of the Two Rivers Member averages 31 percent sand, 50 percent silt, and 19 percent clay in the less-than-2 mm fraction. Its clay-mineral assemblage averages 35 percent expandable clay, 52 percent illite, and 13 percent kaolinite plus chlorite (Acomb and others, 1982).

Nature of contacts. The lower contact of the Two Rivers Member with the lacustrine sediment is often diffuse and veined. At the Two Rivers moraine, a zone of alternating till and lacustrine sediment is interpreted to be subaqueous flow till. In other shoreline exposures, the lower contact is highly distorted by load-cast involutions (Mickelson and Evenson, 1974). In the Point Beach area of Wisconsin, the Two Rivers Member is overlain by sandy nearshore deposits. This contact is sharp. To the west, the Two Rivers Member is at the surface with a well-developed soil on it, but the soil is leached only to depths of less than 60 cm (Mickelson and Evenson, 1975).

Differentiation from other units. The Two Rivers Member is distinguished from the very similar Valders and Ozaukee Members by its clay mineralogy, color, and grain-size distribution. It is more orange, coarser grained, and has more expandable clay and less kaolinite plus chlorite than the Ozaukee Member, whereas it has less expandable clay and more illite than the Valders Member. The grain-size distribution and color of the Valders and Two Rivers Members are very similar (Acomb and others, 1982).

Regional extent and thickness. The Two Rivers Member extends from Two Rivers northward to at least Algoma along the Lake Michigan bluff top (fig. 3). Inland, the margin of the unit roughly parallels the East Twin River north of the Kewaunee River where it probably merges with the Glenmore Member (Green Bay Lobe). The width of the onshore portion of the member is approximately 10 km (6 miles). This till overlies the Two Creeks Forest Bed. The relatively thin Two Rivers Member is on average about 2 m thick at the Two Creeks Forest Bed type section to more than 10 m thick in the Two Rivers moraine.

Origin. The Two Rivers Member contains basal till deposited by glaciers flowing southward in the Lake Michigan basin, as well as associated fluvial and lacustrine deposits.

Age and correlation. The Two Rivers Member directly overlies the well-dated Two Creeks Forest Bed, so it was deposited shortly after 11,200 to 12,400 ^{14}C yr B.P. (approximately 13,100 to 14,600 cal. yr B.P.) (Mickelson and others, 2007). The Two Rivers Member is correlated laterally with the Two Rivers Till Member mapped in Lake Michigan (Lineback and others, 1974) and with sediment in Michigan reported by Taylor (1978). The unit is the time equivalent of the Glenmore Member (Green Bay Lobe).

Previous usage. Name first used by Evenson (1973). Formalized in Mickelson and others (1984).

Kewaunee Formation: Branch River Member

David M. Mickelson

Source of name. The Branch River in Morrison Township, Brown County, Wisconsin.

Location and description of type section. Greenleaf Quarry located in the SE¼SW¼ sec. 4, T. 21 N., R. 20 E., Brown County. The quarry is on the north side of State Highway 96, 0.7 km (0.4 mile) east of Greenleaf, an area shown on the Greenleaf 7.5-minute quadrangle (fig. 101).

In 1979 the best exposure was along the east quarry face. Under spoil material is 0.5 to 1.5 m of Chilton Member till, leached to its base. Much of this is in the B horizon of the soil. Beneath the Chilton Member till is 0.1 to 0.5 m of sand of unknown association. Lying below the sand and above dolomite is about 1 m of unleached Branch River Member till. No Glenmore Member till has been seen in the quarry face.

Figure 101. Part of the Greenleaf 7.5-minute quadrangle showing the location of the type section of the Branch River Member and reference section 1 of the Chilton Member.

Location and description of reference sections. (1) Road cut on east side of Campbell Road, 0.4 km (0.25 mile) south of Collins Road. It is located in the NW¼NW¼ sec. 24, T. 21, N., R. 20 E., Brown County, an area shown on the Greenleaf 7.5-minute quadrangle (fig. 102). Till of the Branch River Member is about 2 m thick over dolomite. (2) Small borrow pit on the southwest corner of the intersection of County Highways Z and PP. It is located in the NE corner sec. 28, T. 21 N., R. 20 E., Brown County, an area shown on the Greenleaf 7.5-minute quadrangle (fig. 103). Till of the Branch River Member is about 1 m thick and overlies gravel of unknown thickness. The till is overlain locally by about 1 m of Chilton Member till.

Description of unit. Till of the Branch River Member is brown (7.5YR 5/4) and averages 29 percent sand, 48 percent silt, and 23 percent clay. The 0.0625-to-0.037 mm fraction contains less than 1 percent calcite and about 27 percent dolomite. The mean magnetic susceptibility value is 6.8 (arbitrary units, McCartney and Mickelson, 1982).

Nature of contacts. The Branch River Member is the surface unit in a small part of Manitowoc and Brown Counties, and it is overlain in places by organic deposits and alluvium. Where overlain by the Chilton Member, the contact is distinct. Where the Branch River Member overlies dolomite or sediment of the Horicon Member of the Holy Hill Formation, the contact is also distinct. Its contact with the correlative Silver Cliff Member is an arbitrary vertical contact at the Fox River.

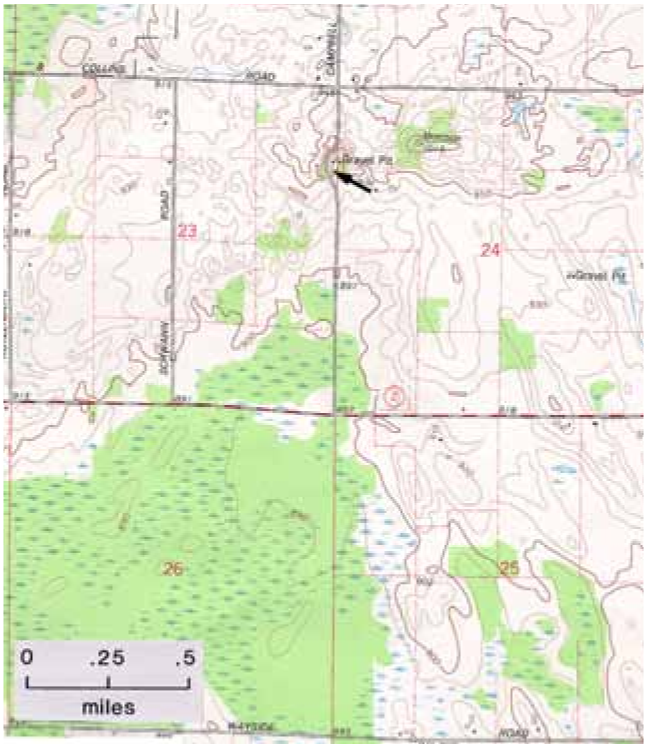

Figure 102. Part of the Greenleaf 7.5-minute quadrangle showing the location of reference section 1 of the Branch River Member.

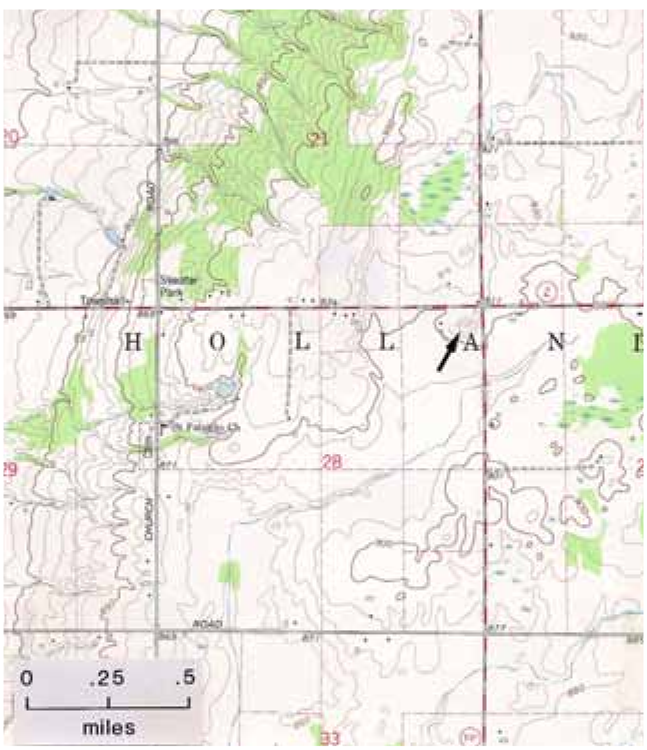

Figure 103. Part of the Greenleaf 7.5-minute quadrangle showing the location of reference section 2 of the Branch River Member.

Differentiation from other units. Till of the Branch River Member is distinguished from that of the underlying Horicon Member of the Holy Hill Formation by its somewhat more reddish color and lower sand percentage. It is distinguished from the overlying Chilton and Glenmore Members by its more abundant sand (29 percent in the Branch River Member, 17 percent in the Chilton Member, and 15 percent in the Glenmore Member).

Regional extent and thickness. The extent of the Branch River Member is not well known in the subsurface. It appears at the surface in southeastern Brown and northwestern Manitowoc Counties (fig. 3). Average thickness is probably about 2 m, although very few sections have been described.

Origin. Till of the Branch River Member was deposited by ice of the Green Bay Lobe.

Age and correlation. The Branch River Member is correlative with the Silver Cliff Member west of the Fox River. It is probably correlative with the Ozaukee Member in the area covered by the Lake Michigan Lobe. At no location are materials of this member in contact with sediment of the Ozaukee Member, and no radiocarbon dates are available to correlate with confidence. The Branch River Member is below the Chilton Member, meaning it was deposited before the Two Creeks Forest Bed (11,200 to 12,400 ^{14}C yr B.P., which is approximately 13,100 to 14,600 cal. yr B.P., Mickelson and others, 2007).

Previous usage. This unit name was used informally by McCartney and Mickelson (1982). Formalized in Mickelson and others (1984).

Kewaunee Formation: Chilton Member

David M. Mickelson

Source of name. City of Chilton, Calumet County, Wisconsin.

Location and description of type section. The DePere site, a gravel pit just north of County Highway X near the top of the Silurian escarpment. The north-facing exposure is about 100 m northwest of a large radio tower. It is located in the SE part of sec. 38, T. 23 N., R. 20 E., Brown County, an area shown on the DePere 7.5-minute quadrangle (fig. 104). This type section is also the type section for the Glenmore Member.

The uppermost unit is Glenmore Member till, and it is approximately 6 m thick. It has low magnetic susceptibility (3.3, arbitrary units, 2 samples). This directly overlies organic material (wood fragments, spruce needles) and what is interpreted to be a soil, formed in a sand unit about 2 m thick. This sand of the Chilton Member overlies 2.5 m of till of the Chilton Member. The till overlies gravel at least 8 m thick, but its lithostratigraphic association is not known.

Location and description of reference sections. (1) Greenleaf Quarry located in the SE¼SW¼ sec. 4, T. 21 N., R. 20 E., Brown County, an area shown on the Greenleaf 7.5-minute quadrangle. This quarry also serves as the type section for the Branch River Member (see Branch River Member and figure 101 for description). (2) Brillion Quarry located in the SW¼SW¼SW¼ sec. 24, T. 20 N., R. 20 E., Calumet County, an area shown on the Brillion 7.5-minute quadrangle (fig. 105). On the north

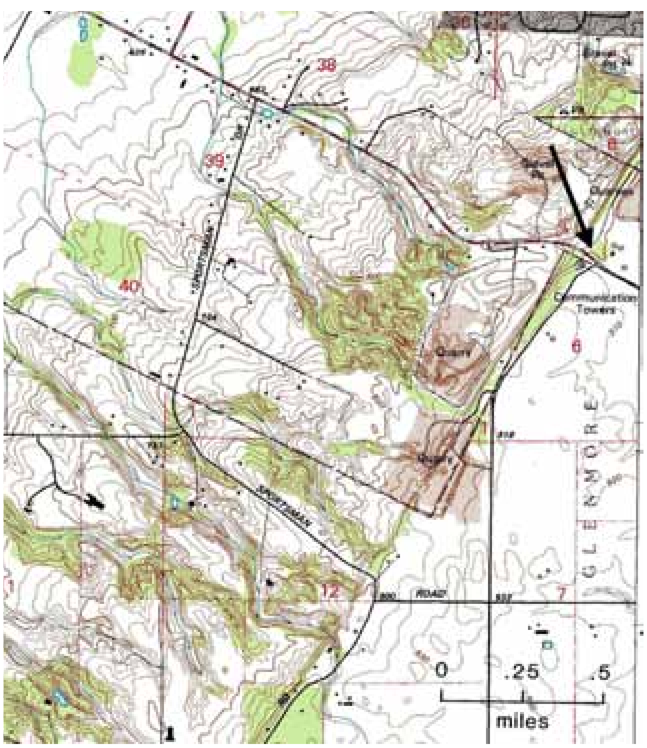

Figure 104. Part of the DePere 7.5-minute quadrangle showing the location of the type sections of the Chilton and Glenmore Members.

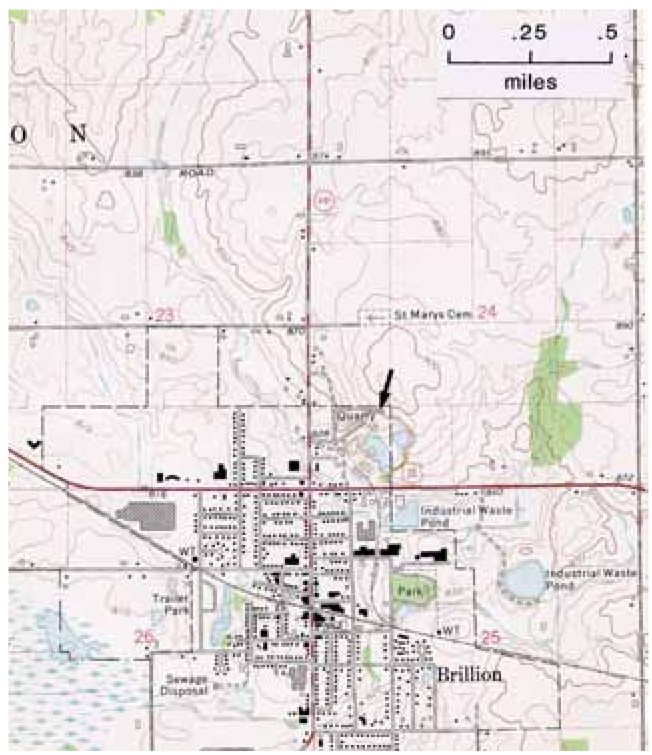

Figure 105. Part of the Brillion 7.5-minute quadrangle showing the location of reference section 2 of the Chilton Member.

face of the quarry, 2 to 3 m of Chilton Member till overlies till of the Horicon Member of the Holy Hill Formation. A sand lens separates two slightly different layers of Chilton Member till.

Description of unit. Till of the Chilton Member is reddish brown (5YR 4/4) and averages 17 percent sand, 49 percent silt, and 33 percent clay in the less-than-2 mm fraction. The 0.0625-to-0.037 mm fraction contains less than 1 percent calcite and about 32 percent dolomite. The mean value of magnetic susceptibility is 6.4 (arbitrary units, McCartney and Mickelson, 1982). In many places the till appears to have two facies but these have not been defined, and consistent differences have not been found at many locations.

Nature of contacts. The Chilton Member is the surface unit in eastern Calumet County (fig. 3). Here it is overlain in places by organic and alluvial deposits of an unnamed unit of Holocene age. The lower contact with the underlying Horicon Member of the Holy Hill Formation or the Branch River Member is generally distinct. Its contact with the correlative Kirby Lake Member is an arbitrary vertical contact at the Fox River.

Differentiation from other units. Till of the Chilton Member contains less sand than the underlying Branch River Member (17 percent in the Chilton Member, 29 percent in the Branch River Member). It is distinguished from till of the Valders Member to the east by its lower percentage of sand (17 percent in the Chilton Member, 30 percent in the Valders Member); from the overlying till of the Glenmore Member by its higher magnetic susceptibility (6.4 in the Chilton, 3.9 in the Glenmore Member, arbitrary units); and from the Kirby Lake Member by its geographic position east of the Fox River (McCartney and Mickelson, 1982).

Regional extent and thickness. Till of the Chilton Member is generally 1 to 3 m thick. Associated deposits of sand and gravel may be considerably thicker. The Chilton Member is a surficial unit to the east of Lake Winnebago in Calumet, Fond du Lac, and northwestern Manitowoc Counties (fig. 3).

Origin. Till of the Chilton Member was deposited by glacial ice of the Green Bay Lobe. Facies of this till (McCartney and Mickelson, 1982) may represent a subglacial origin during two separate ice phases, or they may be subglacial and supraglacial facies of a single ice phase.

Age and correlation. The Chilton Member is correlative with the Valders Member deposited by the Lake Michigan Lobe (Black, 1980; Acomb and others, 1982; McCartney and Mickelson, 1982), and the Kirby Lake Member to the west. At its type section the Chilton Member underlies organic material dated at 11,980 ± 100 ^{14}C yr B.P. (13,961 ± 232 cal. yr B.P., ISGS-480), and the member was deposited before the Two Creeks Forest Bed (11,200 to 12,400 ^{14}C yr B.P., which is approximately 13,100 to 14,600 cal. yr B.P., Mickelson and others, 2007). At the type section for the High Cliff Member of the Hayton Formation, Chilton Member till overlies plant material (in growth position on the Hayton Formation) with an age of 13,370 ± 90 ^{14}C yr B.P. (16,302 ± 428 cal. yr B.P., Beta – 119360), providing a maximum age for the Chilton Member till (Socha, 2007a).

Previous usage. This unit name was first used by McCartney and Mickelson (1982). Formalized in Mickelson and others (1984).

Kewaunee Formation: Glenmore Member

David M. Mickelson

Source of name. Township of Glenmore, Brown County, Wisconsin.

Location and description of type section. The DePere Site, a gravel pit just north of County Highway X near the top of the Silurian escarpment. The north-facing exposure is about 100 m northwest of a large radio tower. It is located in the SE part of sec. 38, T. 23 N., R. 20 E., Brown County, an area shown on the Depere 7.5-minute quadrangle (fig. 104). This type section is also the type section of the Chilton Member.

The uppermost unit is Glenmore Member till, and it is approximately 6 m thick. It has low magnetic susceptibility (3.3, arbitrary units, 2 samples). This directly overlies organic material (wood fragments, spruce needles) and what is interpreted to be a soil, formed in a sand unit about 2 m thick. This sand of the Chilton Member overlies 2.5 m of till of the Chilton Member with high magnetic susceptibility (6.4, arbitrary units, 2 samples). Chilton Member till overlies gravel at least 8 m thick, but its lithostratigraphic association is not known.

Location and description of reference sections. (1) The Highway W site on the south side of an unnamed creek, 60 m east of County Highway W. It is located in the NW¼NE¼ sec. 3, T. 20 N., R. 20 E., Calumet County, an area shown on the Brillion 7.5-minute quadrangle (fig. 106). Exposed in this section is about 12 m of Glenmore Member till containing many wood fragments. Two drill holes about 5 m south of the top of the exposure penetrated sand at nearly the stream level and what is presumed to be dolomite bedrock 1 m below stream level. (2) A low road cut (2.5 m high) on the south side of School Road. It is located in the NE¼NE¼NE¼ sec. 32, T. 22 N., R. 21 E., Brown County, an area shown on the Morrison 7.5-minute quadrangle (fig. 107). All till exposed is Glenmore Member till.

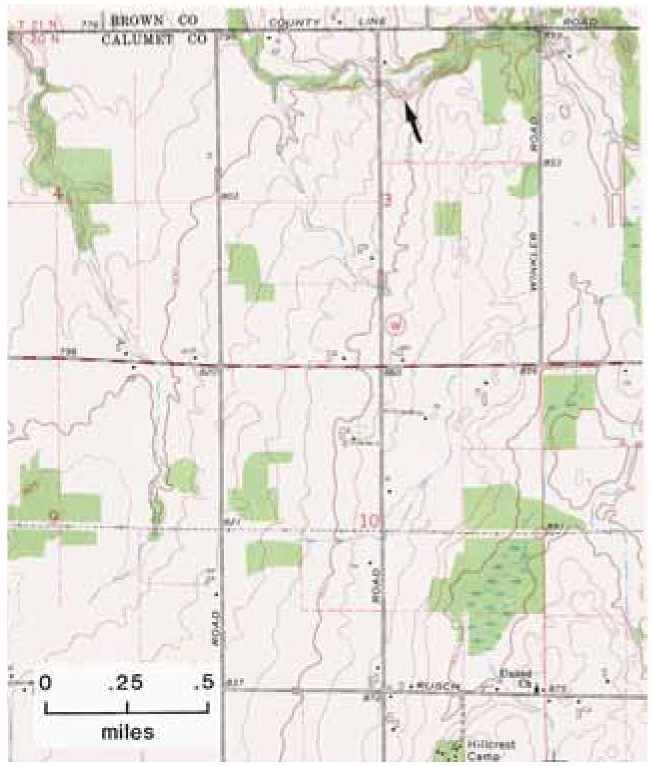

Figure 106. Part of the Brillion 7.5-minute quadrangle showing the location of reference section 1 of the Glenmore Member.

Description of unit. Till of the Glenmore Member is reddish brown (5YR 4/4) and averages 15 percent sand, 48 percent silt and 37 percent clay in the less-than-2 mm fraction. The 0.0625-to-0.037 mm fraction contains about 6 percent calcite and 26 percent dolomite. The mean value of magnetic susceptibility is 3.9 (arbitrary units) (McCartney and Mickelson, 1982).

Nature of contacts. The Glenmore Member is the surface unit in many places where it is present (fig. 3). In places it is overlain by organic sediment or lacustrine silt and clay of younger, unnamed units. The lower contact is usually abrupt, although when it overlies till of the Chilton Member, magnetic susceptibility often must be

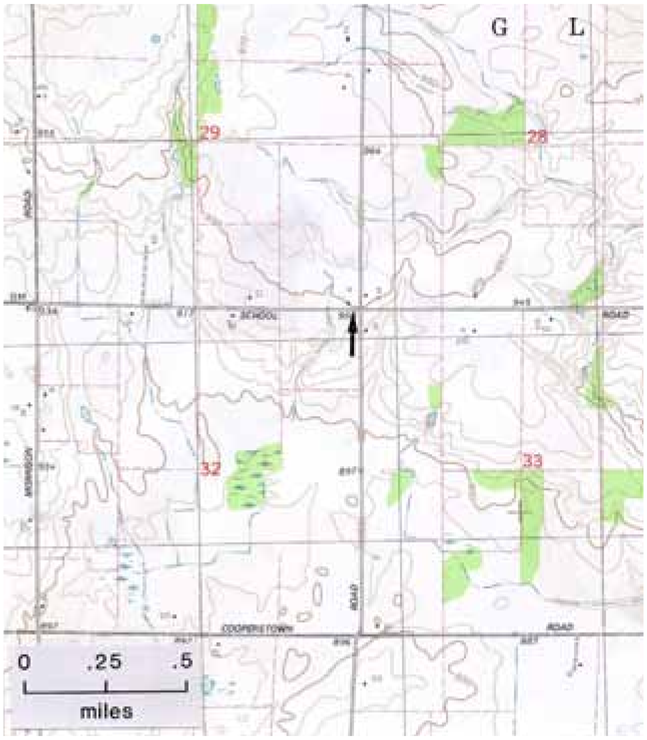

Figure 107. Part of the Morrison 7.5-minute quadrangle showing the location of reference section 2 of the Glenmore Member.

measured to identify the contact. The contact between the Glenmore Member and the Middle Inlet Member is an arbitrary vertical contact at the Fox River.

Differentiation from other units. Till of the Glenmore Member is distinguishable from till of the underlying Chilton Member by its lower magnetic susceptibility (mean 3.9 in the Glenmore Member and 6.4 in the Chilton Member, arbitrary units). It is distinguished from the older Branch River Member by the greater amount of silt and clay (85 percent in the Glenmore Member, 71 percent in the Branch River Member). Till of the Glenmore Member has less sand (15 percent) than the correlative till of the Two Rivers Member (31 percent). Till of the Glenmore Member can also be distinguished from older units by its shallower depth of leaching (Mickelson and Evenson, 1975).

Regional extent and thickness. Till of the Glenmore Member is as much as 8 m thick. It appears that the thickest sections are in the Denmark moraine located within 2 km (1.25 miles) of the outer extent of the unit. Gravel of the member may be thicker than 8 m in places. The Glenmore Member is the surficial unit east of the Fox River and Green Bay in Door, Kewaunee, Brown, Outagamie, and Calumet Counties (fig. 3).

Origin. Till of the Glenmore Member was deposited by glacial ice of the Green Bay Lobe. Sand and gravel associated with the till was deposited by rivers.

Age and correlation. The Glenmore Member is correlative with the Two Rivers Member deposited by the Lake Michigan Lobe and the Middle Inlet Member deposited by the western part of the Green Bay Lobe. At its type section, the Glenmore Member overlies organic material dated at 11,980 ± 100 ^{14}C yr B.P. (13,961 ± 232 cal. yr B.P., ISGS-480), so the member was therefore deposited after the Two Creeks Forest Bed (11,200 to 12,400 ^{14}C yr B.P., approximately 13,100 to 14,600 cal. yr B.P., McCartney and Mickelson, 1982; Mickelson and others, 2007).

Previous usage. This unit name was first used by McCartney and Mickelson (1982). Formalized in Mickelson and others (1984).

Kewaunee Formation: Florence Member

Lee Clayton

Source of name. Florence County, Wisconsin.

Location and description of type section. An auger hole located in the southwesternmost part of sec. 2, T. 38 N., R. 18 E., Florence County, an area shown on the Iron Mountain SW 7.5-minute quadrangle (fig. 108). The type section contains as much as 10 m of slightly gravelly, reddish-brown silty clay loam, silty clay, and clay till, in addition to 10 to 15 m of sand.

Description of unit. The Florence Member is reddish brown (2.5YR 4/4) and is unbedded. It contains about 1 percent gravel, and samples from the less-than-2 mm fraction average 16 percent sand, 45 percent silt, and 39 percent clay. The till is leached of carbonate to a depth of about 1 m; where unleached, the till contains about 10 percent dolomite.

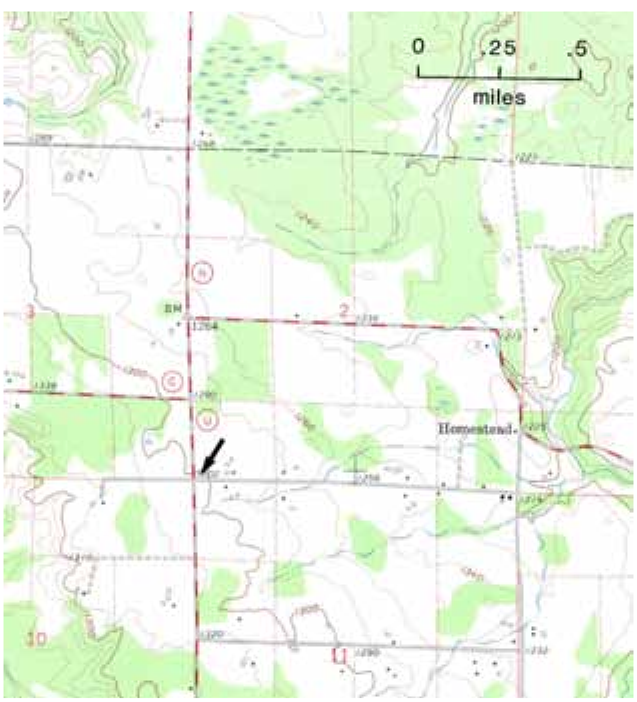

Figure 108. Part of the Iron Mountain SW (Wisconsin/Michigan) 7.5-minute quadrangle showing the location of the type section of the Florence Member.

Nature of contacts. The Florence Member is the surface unit in the type area, and it overlies sand of the Horicon Member of the Holy Hill Formation. To the east of the type area, it is described in several water-well logs beneath till or fluvial sediment of the Silver Cliff Member.

Differentiation from other units. The Florence Member with 39 percent clay is more clayey than the underlying Horicon Member of the Holy Hill Formation (less than 20 percent) and the overlying Silver Cliff Member (7 percent). The Florence Member is similar to the Kirby Lake Member, which overlies the Silver Cliff Member.

Regional extent and thickness. The unit occurs at the surface in about 25 km^2 of east-central Florence County, in one area south of the community of Florence, and in one area west of the community of Homestead, where it is 8 to 12 m thick. It probably occurs in the subsurface to the north, east, and south, but its extent is unknown.

Origin. The Florence Member is interpreted to be till deposited during the middle Mountain Phase of the Green Bay Lobe (Clayton, 1986a).

Age and correlation. The Florence Member was deposited about 16,000 cal. yr B.P. Correlation outside Florence County is uncertain. No member of the Kewaunee Formation has previously been defined below the Silver Cliff Member. A clayey unit, which might be the Florence Member, occurs below the Silver Cliff Member in the Kirby Lake Member type section in Marinette County (Mickelson and others, 1984, see fig. 112 in the Kirby Lake Member description).

Previous usage. The unit was first named and described by Clayton (1986a) and formalized in Attig and others (1988).

Kewaunee Formation: Silver Cliff Member

M. Carol McCartney, modified by Lee Clayton

Source of name. Township of Silver Cliff in western Marinette County, Wisconsin.

Location and description of type section. Road cut at the crest of the Inner Mountain moraine on the north side of Eagle River Road. It is located in the SW¼SW¼SW¼ sec. 9, T. 34 N., R. 18 E., Marinette County, an area shown on the Roaring Rapids 7.5-minute quadrangle (fig. 109).

The road cut is about 2 m high and seems to consist entirely of Silver Cliff Member till, a sample of which contained 62 percent sand, 31 percent silt, and 7 percent clay. Holy Hill Formation till may be present at the road level.

Location and description of reference sections. (1) Road cut on the north side of Eagle River Road about 1.5 km (0.9 mile) east of the type section. It is located in the SW¼SW¼SW¼ sec. 10, T. 34 N., R. 18 E., Marinette County, an area shown on the Leahman Lake 7.5-minute quadrangle (fig. 110). Silver Cliff Member till is overlain by silty sand and yellowish medium sand in this cut.
(2) The Crivitz Section, a road cut on south side of County Highway W, 0.16 km (0.1 mile) west of Kirby Lake Road. It is located in the NE¼NW¼SE¼ sec. 27, T. 32 N., R. 19 E., Marinette County, an area shown on the Crivitz 7.5-minute quadrangle (see figure 111 in the Kirby Lake Member description). This also serves as the reference section 2 for the Middle Inlet Member and the type section of the Kirby Lake Member. See the Kirby Lake Member and figure 112 for a detailed description of the Crivitz section.

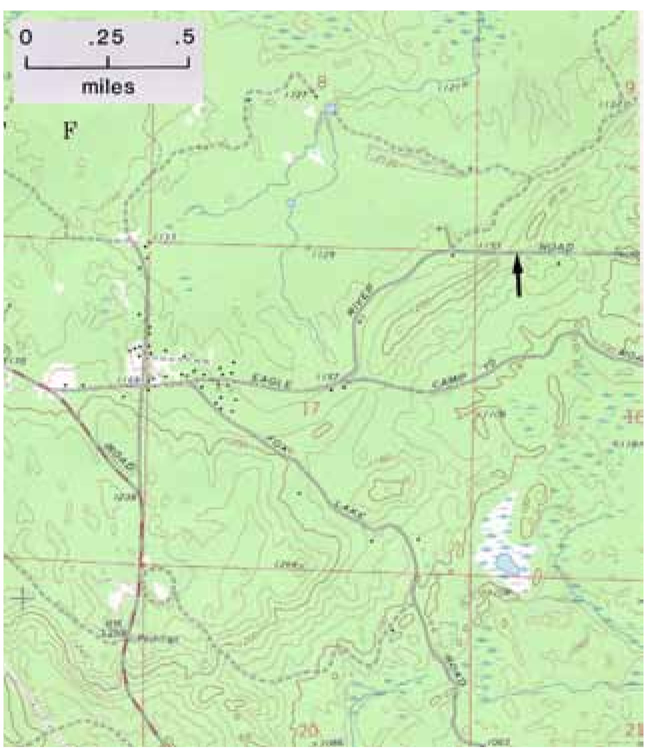

Figure 109. Part of the Roaring Rapids 7.5-minute quadrangle showing the location of the type section of the Silver Cliff Member.

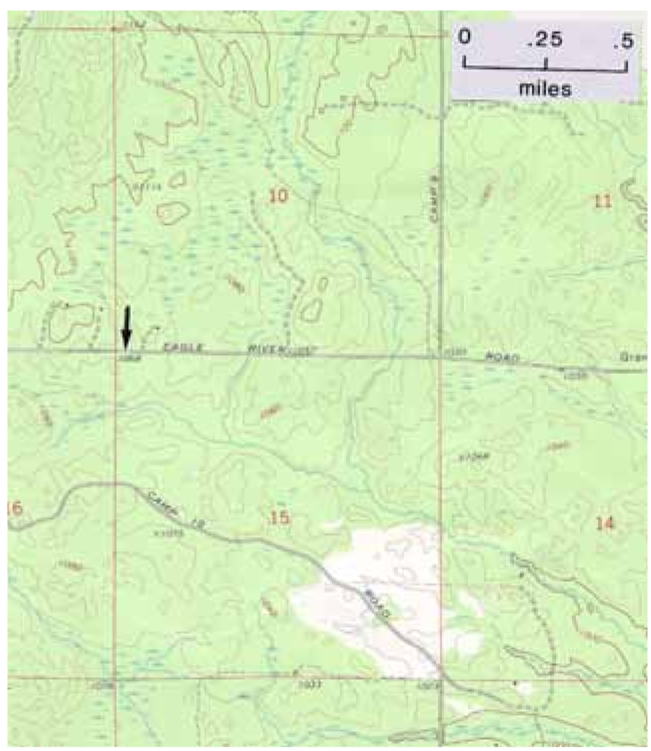

Figure 110. Part of the Leahman Lake 7.5-minute quadrangle showing the location of reference section 1 of the Silver Cliff Member.

Kewaunee Formation: Silver Cliff Member

Description of unit. Silver Cliff Member till is generally reddish brown (5YR 4/4 to 5/4). The till averages 61 percent sand, 32 percent silt, and 7 percent clay in Marinette and Oconto Counties. Carbonates average 27 percent (standard deviation 7 percent) in the less-than-0.063 mm fraction, 9 percent (standard deviation 4 percent) in the 0.13-to-0.25 mm fraction, and 39 percent (standard deviation 13 percent) in the 1-to-2 mm fraction (11 samples, McCartney and Mickelson, 1982). Carbonates are typically leached to a depth of 1 to 2 m.

Nature of contacts. The Silver Cliff Member is generally poorly exposed. It unconformably overlies sorted sand and silt in places, but in some places it rests on older till or pre-Pleistocene rock. It is the surface unit in some areas, but is unconformably overlain by silty sand, sand, or gravelly sand in many areas, and to the east it is overlain by the younger Kirby Lake and Middle Inlet Member till units. Its contact with the correlative Branch River Member is an arbitrary vertical contact at the Fox River.

Differentiation from other units. Till of the Silver Cliff Member is distinguished from the till of the older Horicon Member of the Holy Hill Formation by its redder color and slightly finer grain size. Silver Cliff Member till (61 percent sand) is considerably coarser than the younger Kirby Lake Member till (36 percent sand). Where the Kirby Lake Member till is absent, the Silver Cliff Member till may be difficult to distinguish from the younger Middle Inlet Member till, but in similar settings the Silver Cliff Member till is leached of carbonates to a greater depth than the Middle Inlet Member till.

Regional extent and thickness. The Silver Cliff Member is thin and discontinuous. Its western boundary is the westernmost moraine of the Mountain system (Thwaites, 1943; McCartney, 1979; Attig and Ham, 1999). Its southern and northern limits are unknown.

Origin. Most of the material in the Silver Cliff Member is till deposited by ice of the Green Bay Lobe, but some lenses of fluvial sand and gravel are interbedded with the till. The Silver Cliff Member was deposited during what is now called the early Mountain Phase (fig. 6) in Marinette and Oconto Counties, as well as the late Mountain and early Athelstane Phases in Florence County (Clayton, 1986a).

Age and correlation. The Silver Cliff Member till was deposited during the last part of the Wisconsin Glaciation, presumably before 14,000 cal. yr B.P. The Silver Cliff Member is probably the time equivalent of the Branch River Member deposited on the eastern side of the Green Bay Lobe.

Previous usage. This unit name originally was used informally by McCartney (1979) and subsequently by McCartney and Mickelson (1982). Formalized in Mickelson and others (1984).

Kewaunee Formation: Kirby Lake Member

M. Carol McCartney, modified by Lee Clayton

Source of name. Kirby Lake, a lake 15 km (9.4 miles) west of Crivitz, Marinette County, Wisconsin.

Location and description of type section. The Crivitz Section is a road cut on south side of County Highway W, 0.16 km (0.1 mile) west of Kirby Lake Road. It is located in the NE¼NW¼SE¼ sec. 27, T. 32 N., R. 19 E., Marinette County, an area shown on the Crivitz 7.5-minute quadrangle (fig. 111). This also serves as reference section 2 for both the Middle Inlet and Silver Cliff Members of the Kewaunee Formation.

Figure 111. Part of the Crivitz 7.5-minute quadrangle showing the location of the type section of the Kirby Lake Member. This section is also the reference section 2 of the Silver Cliff Member and reference section 2 of the Middle Inlet Member. A sketch of the Crivitz Section is shown in figure 112.

A sketch of the type section is shown in figure 112. Till of the Middle Inlet Member is approximately 2 m thick at the top of the section. A sample from this unit contains 67 percent sand, 24 percent silt, and 9 percent clay. Below this is approximately 1 m of Kirby Lake Member till that contains 38 percent sand, 41 percent silt, and 21 percent clay. The clay mineralogy of this unit averages 46 percent illite, 38 percent expandables, and 17 percent kaolinite plus chlorite (H.D. Glass, Illinois State Geological Survey, written communication, 1982).

Kirby Lake Member till overlies about 4 m of Silver Cliff Member till containing 50 percent sand, 37 percent silt, and 13 percent clay. Beneath till of the Silver Cliff Member is about 1 m of till that contains 48 percent sand, 35 percent silt and 17 percent clay, and this unit is tentatively thought to be the Florence Member till. Below the Florence Member till, sand of unknown association extends to the base of the section.

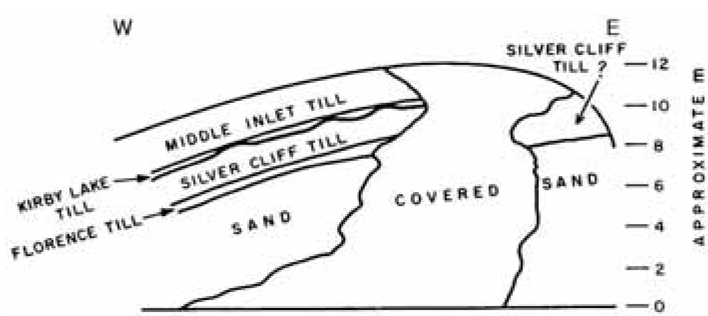

Figure 112. Diagrammatic sketch of the Crivitz Section, the type section of Kirby Lake Member and reference section for the Silver Cliff and Middle Inlet Members, showing the relationship of units.

Location of reference section. Till at the base of the gravel pit located in the SW¼SW¼NW¼ sec. 27, T. 35 N., R. 21 E., Amberg Township, Marinette County, an area shown on the Resort Lake 7.5-minute quadrangle (fig. 113).

Description of unit. Till of the Kirby Lake Member averages 36 percent sand, 47 percent silt, and 17 percent clay in the less-than-2 mm fraction in Marinette and Oconto Counties. The till grain size varies markedly (standard deviations of 14, 10, and 10 percent in the sand, silt, and clay fractions, respectively). At the type section the unit is more clayey. The till is commonly reddish brown (2.5YR 4/4 and 5YR 5/3 to 5/4), but infrequently is yellowish red (5YR 3/6) or light brown 7.5YR 6/4). Carbonate content averages 31 percent (8 percent standard deviation) in the less-than-0.63 mm fraction, 14 percent (5 percent standard deviation) in the 0.13-to-0.25 mm fraction,

Figure 113. Parts of the Wausaukee North and Resort Lake 7.5-minute quadrangles showing the location of the reference section of the Kirby Lake Member.

and 44 percent (14 percent standard deviation) in the 1-to-2 mm fraction (21 samples, McCartney, 1979).

Nature of contacts. The Kirby Lake Member is generally poorly exposed. It overlies sandy till, bedded sand, bedded silt and clay, or pre-Pleistocene rock. It is overlain by bedded sand, silty sand, or till. The contact between the Kirby Lake Member and the correlative Chilton Member is an arbitrary vertical contact at the Fox River.

Differentiation from other units. Till of the Kirby Lake Member is distinguished from both the underlying and overlying till units by its finer grain size.

Regional extent and thickness. Till of the Kirby Lake Member is patchy at the surface in the southern half of Marinette County and is absent at the surface in the northern half of the county. The western limit of the till is the eastern edge of glacial Lake Oconto and the Athelstane moraine system south of Athelstane (Thwaites, 1943). Kirby Lake Member till is covered by Middle Inlet Member till north of Athelstane as well as to the west of an irregular ice margin that is partly contiguous with the western moraine of the Athelstane moraine system of Thwaites (1943). The Kirby Lake Member till is typically very thin at the surface (less than 1 m thick), but it is as much as 10 m thick in the subsurface.

Origin. Much of the Kirby Lake Member is subglacial till deposited by ice of the Green Bay Lobe.

Age and correlation. Till of the Kirby Lake Member was deposited during the last part of the Wisconsin Glaciation, before deposition of the Two Creeks Forest Bed (11,200 to 12,400 ^{14}C yr B.P., which is approximately 13,100 to 14,600 cal. yr B.P., Mickelson and others, 2007). The Kirby Lake Member is probably the age equivalent of the Chilton Member deposited by the eastern side of the Green Bay Lobe.

Previous usage. This unit name was used informally by McCartney (1979) and subsequently by McCartney and Mickelson (1982). The unit was formalized in Mickelson and others (1984).

Kewaunee Formation: Middle Inlet Member

M. Carol McCartney, modified by Lee Clayton

Source of name. Middle Inlet Township in central Marinette County, Wisconsin.

Location and description of type section. Road cut located in the NE¼NW¼SE¼ sec. 8, T. 33 N., R. 23 E., Marinette County, an area shown on the McAllister 7.5-minute quadrangle (fig. 114). This cut is on Caylor Road, about 1.5 km (0.9 mile) north of County Highway JJ, on the north side of the road. The type section is about 4.5 m high and is composed entirely of Middle Inlet Member till.

Location and description of reference sections. (1) Road cut located in the NE¼NE¼SW¼ sec. 8, T. 33 N., R. 23 E., Marinette County, on the west side of Caylor Road, about 1.1 km (0.7 mile) north of County Highway JJ, an area shown on the McAllister 7.5-minute quadrangle (fig. 114). The whole exposure is Middle Inlet Member till. (2) The Crivitz Section, which is described as the type section of the Kirby Lake Member and shown in figures 111 and 112. See the Kirby Lake Member for a detailed description of the Crivitz Section.

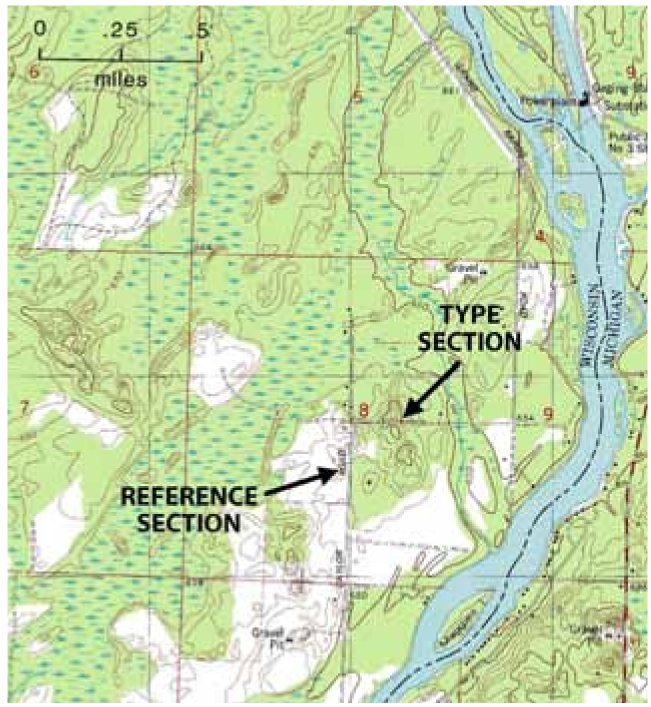

Figure 114. Part of the McAllister (Wisconsin/Michigan) 7.5-minute quadrangle showing the locations of the type section and reference section 1 of the Middle Inlet Member.

Description of unit. Till of the Middle Inlet Member averages 64 percent sand, 28 percent silt, and 8 percent clay in the less-than-2 mm fraction in Marinette and Oconto Counties. Most colors are brown (7.5YR 5/3 to 5/4) or, more commonly, reddish brown (5YR 5/3 to 5/4). Carbonate content averages 32 percent (7 percent standard deviation) in the less-than-0.063 mm fraction, 13 percent (5 percent standard deviation) in the 0.13-to-0.25 mm fraction, and 32 percent (12 percent standard deviation) in the 1-to-2 mm fraction (28 samples, McCartney, 1979).

Nature of contacts. Till of the Middle Inlet Member commonly overlies bedded sand or silty sand. In some areas, it directly overlies till of the Kirby Lake Member, and the contact is sharp. The contact between the Middle Inlet Member and the correlative Glenmore Member is an arbitrary vertical contact at the Fox River.

Differentiation from other units. Till of the Middle Inlet Member is sandier and slightly lighter colored than the Kirby Lake Member till. Where the Kirby Lake Member is missing and the Middle Inlet Member rests directly on the Silver Cliff Member, they may be hard to distinguish. In similar landscape settings, the Middle Inlet Member can be distinguished from the Silver Cliff Member by depth of leaching; the Middle Inlet Member is typically leached to a depth of less than 0.3 m, whereas the Silver Cliff Member is leached to a depth greater than 1 m.

Regional extent and thickness. Till of the Middle Inlet Member is at the surface in much of Marinette County. Its western border is, at least in part, the eastern moraine of the Athelstane moraine system (Thwaites, 1943). The till is also a surficial unit in Oconto, Shawano, Brown, Outagamie, and northern Winnebago Counties (fig. 3). The Middle Inlet Member is probably thin in most areas, but its base has been seen in too few places to determine the average thickness.

Origin. The Middle Inlet Member is composed largely of subglacial till deposited by ice of the Green Bay Lobe.

Age and correlation. The Middle Inlet Member was deposited during the last part of the Wisconsin Glaciation after the Two Creeks Forest Bed (11,200 to 12,400 ^{14}C yr B.P., which is approximately 13,100 to 14,600 cal. yr B.P., Mickelson and others, 2007). The Middle Inlet Member correlates with the Glenmore Member which was deposited on the east side of the Green Bay Lobe.

Previous usage. This unit name was first used informally by McCartney (1979) and subsequently by McCartney and Mickelson (1982). The unit was formalized in Mickelson and others (1984).

Miller Creek Formation

Lee Clayton

Source of name. A tributary of the Amnicon River, Douglas County, Wisconsin.

Location and description of type section. The type section is a bluff along Lake Superior, 0.4 km (0.25 mile) west of the mouth of the Amnicon River, and can be reached from a campground just to the south. It is located in the SE¼SW¼SW¼ sec. 27, T. 49 N., R. 12 W., Douglas County, an area shown on the Poplar NE 7.5-minute quadrangle (fig. 115). This exposure also serves as the type section for the Hanson Creek and Douglas Members of the Miller Creek Formation.

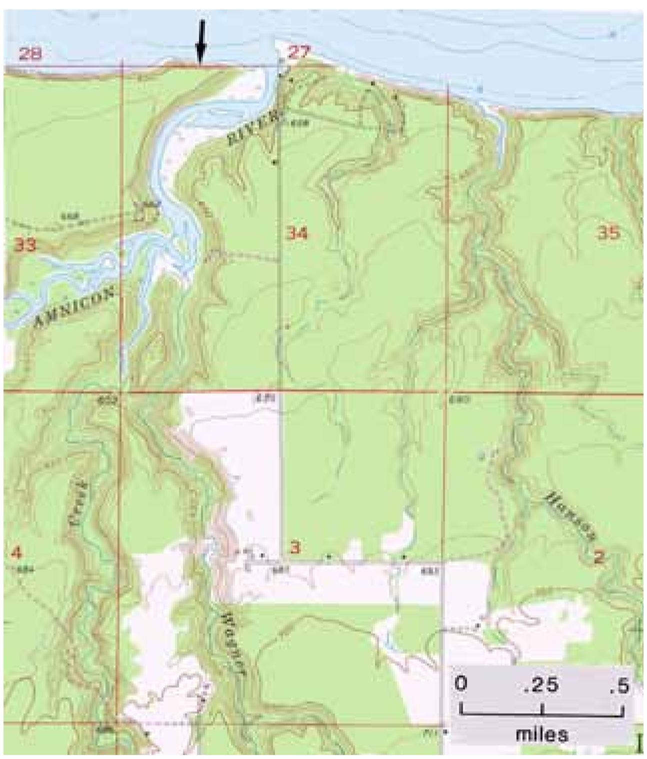

Figure 115. Part of the Poplar NE 7.5-minute quadrangle showing the locations of the type sections of the Miller Creek Formation and the Hanson Creek and Douglas Members.

The lake bluff is 16 m high. The upper 8.5 m consists of Douglas Member till, and the lower 7.5 m consists of the Hanson Creek Member till. Hanson Creek Member till averages 5 percent sand, 34 percent silt, and 61 percent clay (7 samples collected from an area 200 m west of the type section).

Location and description of reference sections. (1) A shore bluff of Oronto Bay by Lake Superior, about 2.8 km (1.7 miles) northwest of Saxon Harbor. It is located in the NE¼NW¼NE¼ sec. 10, T. 47 N., R. 1 W., Iron County, Wisconsin, an area shown on the Oronto Bay 7.5-minute quadrangle (fig. 116). The bluff displays a representative exposure of the Miller Creek Formation east of the

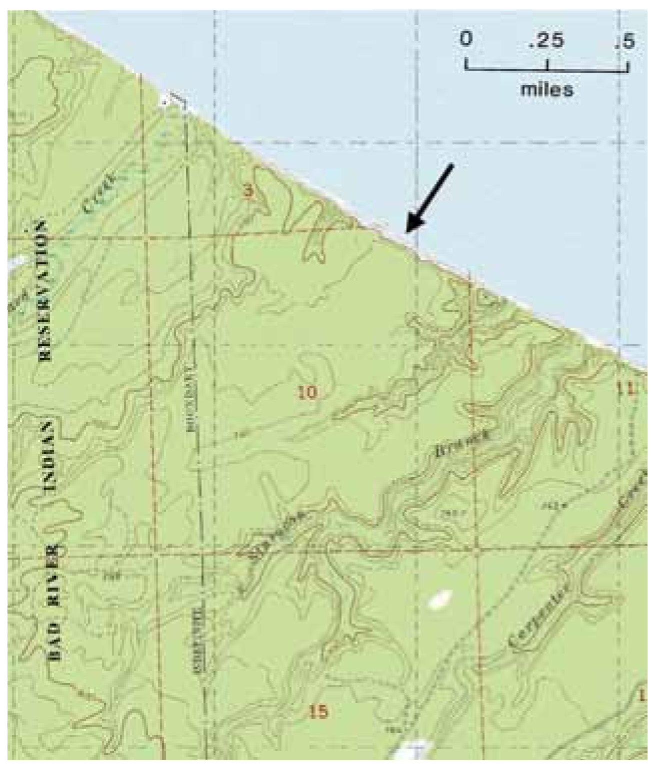

Figure 116. Part of the Oronto Bay 7.5-minute quadrangle showing the location of reference section 1 of the Miller Creek Formation.

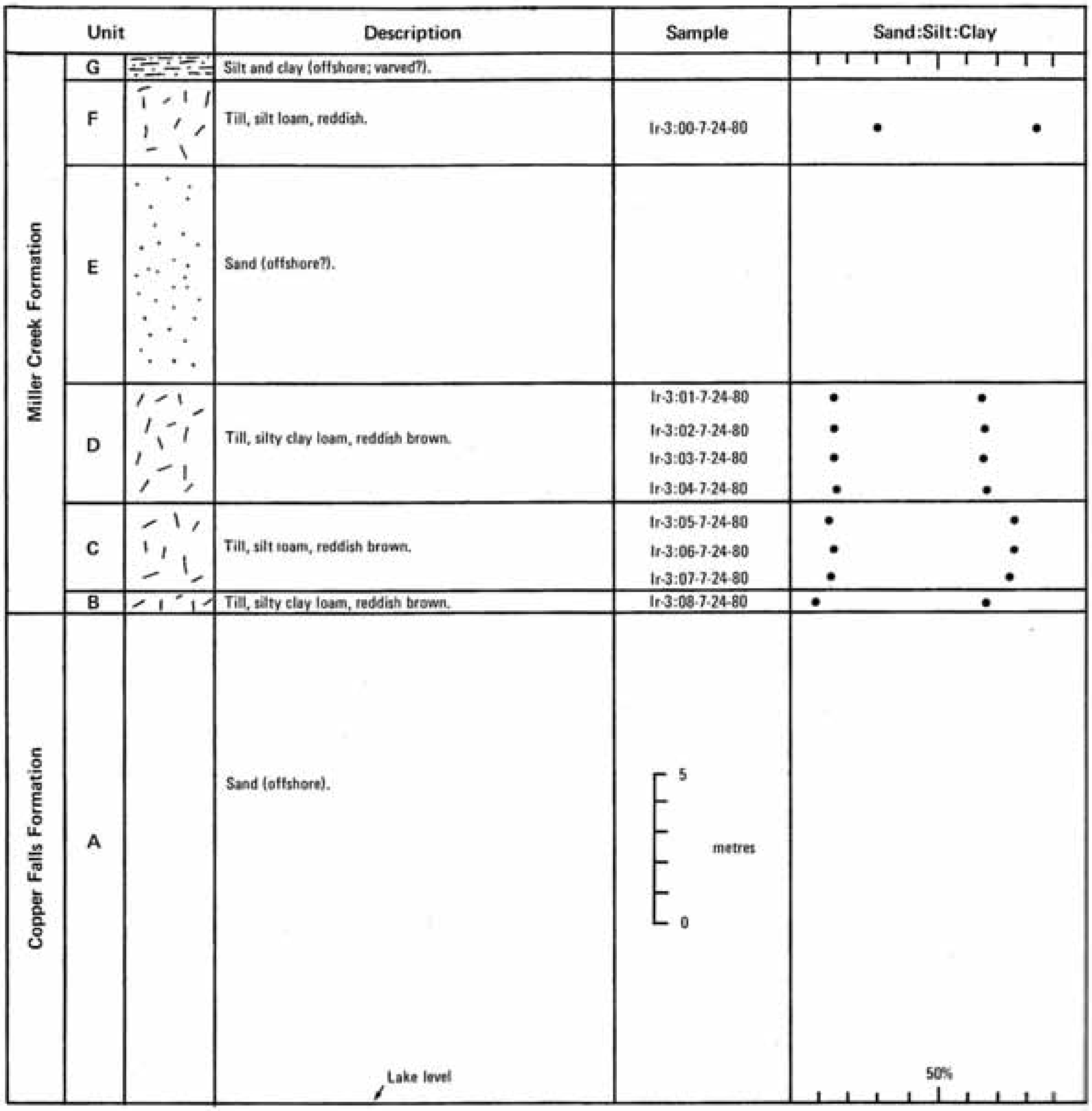

Figure 117. Sketch of reference section 1 of the Miller Creek Formation. Location shown in figure 116.

Bayfield Peninsula and is shown in figure 117. The uppermost till unit (F, fig. 117) is the surface unit over most of the region. The lower till units (B, C, D) plunge below beach level a short distance southeast of the reference section. (2) The reference sections for the Hanson Creek and Douglas Members also serve as reference sections for the Miller Creek Formation (see the individual member sections for descriptions and location figures 118, 119, and 120).

Description of unit. The Miller Creek Formation contains reddish clay sediment of the Superior lowland. In the past the unit has been called Red Clay. It includes the Hanson Creek and Douglas Members west of the Bayfield Peninsula. East of the Bayfield Peninsula it includes units that may correlate with the Hanson Creek and Douglas Members; they tend to be siltier and less clayey than the units west of the Bayfield Peninsula. In addition to these units, which are largely till, the formation also contains offshore sediment, which is generally reddish bedded silt and clay. Offshore sediment is observed above, below, or between the till units. A small amount of interbedded sand and gravel is also included in the formation.

Nature of contacts. Except for Holocene fluvial, lacustrine, and organic deposits, the Miller Creek Formation is the surface unit in the Superior lowland. Where observed, the contact with the underlying Copper Falls Formation or pre-Pleistocene units is sharp.

Differentiation from other units. The Miller Creek Formation is somewhat redder and is more clayey and silty than the underlying Copper Falls Formation. Till of the Miller Creek Formation typically contains less than 20 percent sand, although it may have as much as 60 percent sand where it overlies fluvial sand. In contrast, till of the Copper Falls Formation generally contains more than 35 percent sand (Mickelson and others, 1984).

Regional extent and thickness. The Miller Creek Formation occurs in most places below the 330 m contour in northwestern Wisconsin, that is, almost everywhere below the Duluth level of Lake Superior (fig. 3). East of Gurney, however, it occurs above the Duluth beach, to an elevation of 370 m, where it makes up the end moraines near Saxon. The Miller Creek Formation is typically about 10 to 20 m thick, but it is more than 90 m thick near the cities of Superior and Ashland.

Origin. Probably at least three-fourths of the Miller Creek Formation is till deposited by ice of the Superior and Chippewa Lobes, and most of the rest is lake sediment that was deposited offshore.

Age and correlation. The Miller Creek Formation was deposited during the latest part of the Wisconsin Glaciation and in earliest Holocene time, perhaps about 13,000 cal. yr B.P. to soon after 11,500 cal. yr B.P.; greater detail is given in the discussion of the Hanson Creek and Douglas Members. The Wrenshall Formation in Minnesota (Wright and others, 1970) consists of offshore sediment deposits in the southwestern end of the Superior basin. The Wrenshall Formation can be traced to the Wisconsin border, but its relationship to the members of the Miller Creek Formation is unclear; it may overlie the Hanson Creek Member and underlie, or be laterally equivalent to, the Douglas Member.

Previous usage. The unit name was formalized in Mickelson and others (1984).

Miller Creek Formation: Hanson Creek Member

E.A. Need, modified by Lee Clayton

Source of name. Hanson Creek, flowing into Lake Superior 1 km (0.6 mile) east of the mouth of the Amnicon River, Douglas County, Wisconsin.

Location and description of type section. The type section is a bluff along Lake Superior, 1.5 km (0.9 mile) west of the mouth of Hanson Creek, and can be reached from a campground just to the south. It is located in the SE¼SW¼SW¼ sec. 27, T. 49 N., R. 12 W., Douglas County, an area shown on the Poplar NE 7.5-minute quadrangle (fig. 115). This type section also serves as the type section for the Miller Creek Formation and the Douglas Member.

The lake bluff is 16 m high. The upper 8.5 m consists of Douglas Member till, and the lower 7.5 m consists of the Hanson Creek Member till. Hanson Creek Member till averages 5 percent sand, 34 percent silt, and 61 percent clay (7 samples collected from an area 200 m west of the type section).

Location of reference section. Bluff 0.3 km (0.2 mile) southwest of the mouth of Pearson Creek. It is located in the SE¼SE¼NW¼ sec. 22, T. 49 N., R. 11 W., Douglas County, an area shown on the Cloverland 7.5-minute quadrangle (fig. 118).

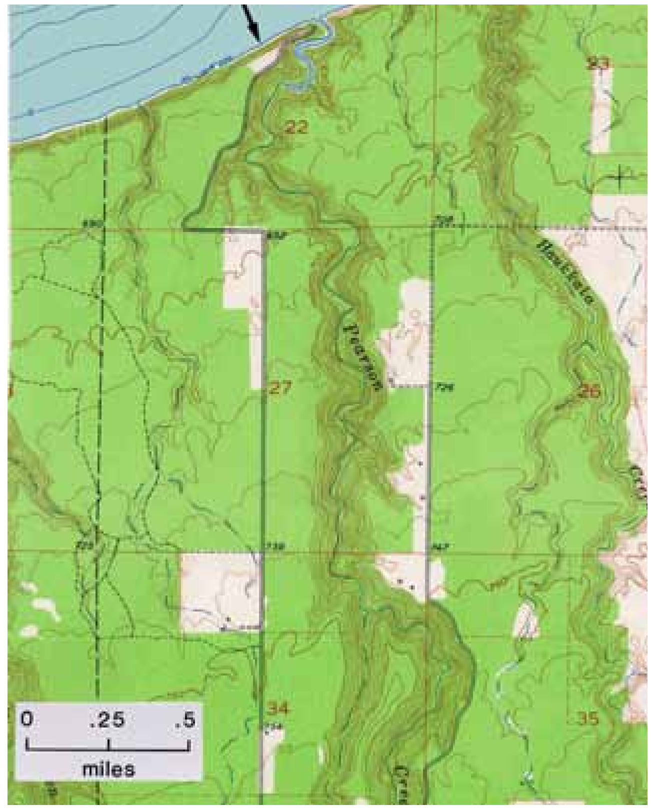

Figure 118. Part of the Cloverland 7.5-minute quadrangle showing the location of the reference section of the Hanson Creek Member.

Description of unit. West of the Bayfield Peninsula in Bayfield and Douglas Counties, till of the Hanson Creek Member averages 10 percent sand, 32 percent silt, and 58 percent clay in the less-than-2 mm fraction. The till is typically dark reddish brown (5YR 3/4) and commonly contains dark gray (5YR 4/1) and reddish-brown (2.5YR 4/4) stringers. It contains 54 percent illite, 34 percent smectite, 6 percent vermiculite, and 6 percent kaolinite plus chlorite in the less-than-0.002 mm fraction. The till averages 11 percent carbonate in the less-than-0.063 mm fraction and 3 percent in the 0.063-to-0.037 mm fraction.

Nature of contacts. The Hanson Creek Member overlies sandy Copper Falls Formation till, silty offshore deposits, or pre-Pleistocene rock. It is overlain in most places by Douglas Member till, but is overlain by sand in some places.

Differentiation from other units. Till of the Hanson Creek Member is siltier and browner than Douglas Member till and is finer grained than the Copper Falls Formation till. Lake sediment associated with the Hanson Creek and Douglas Members has not been differentiated.

Regional extent and thickness. The Hanson Creek Member occurs along the Lake Superior shoreline throughout Douglas County. Its eastern limit in Bayfield County is the mouth of the Iron River. Water well logs indicate that the unit may pinch out under the Douglas Member about 8 to 13 km (5 to 8 miles) south of the shoreline in northeastern Douglas County, or it may extend as far south as the Duluth beach of Lake Superior (at an elevation of about 330 m). In the Superior bluffs, it ranges in thickness from 0.5 to 11 m, and is typically about 7.5 m thick.

Origin. The Hanson Creek Member consists largely of till deposited by the Superior Lobe.

Age and correlation. The Hanson Creek Member has never been dated, but it was probably deposited in the latest part of the Wisconsin Glaciation, perhaps about 13,000 cal. yr B.P. The Hanson Creek Member has not been correlated westward beyond Douglas County or eastward around the Bayfield Peninsula. However, at least two till members of the Miller Creek Formation exist in the Superior lowlands east of the Bayfield Peninsula, and presumably the Hanson Creek Member correlates with the lowest one.

Previous usage. This unit name was first used informally by Need (1980) and Johnson (1980). The unit was formalized in Mickelson and others (1984).

Miller Creek Formation: Douglas Member

E.A. Need, modified by Lee Clayton

Source of name. Douglas County, Wisconsin.

Location and description of type section. The type section is a bluff along Lake Superior, 0.4 km (0.25 mile) west of the mouth of the Amnicon River, and can be reached from a campground just to the south. It is located in the SE¼SW¼SW¼ sec. 27, T. 49 N., R. 12 W., Douglas County, an area shown on the Poplar NE 7.5-minute quadrangle (fig. 115). This type section also serves as the type section for the Miller Creek Formation and the Hanson Creek Member.

The lake bluff is 16 m high. The upper 8.5 m consists of Douglas Member till, and the lower 7.5 m consists of the Hanson Creek Member till.

Location and description of reference sections. (1) Typical clay facies: Bluff exposure 1.2 km (0.7 mile) west of the mouth of the Iron River and immediately west of the mouth of Reefer Creek. It is located in the SW¼NE¼NW¼ sec. 4, T. 49 N., R. 9 W., Bayfield County, an area shown on the Oulu 7.5-minute quadrangle (fig. 119). (2) Sandier facies: Bluff on the northwestern side of Bark Point. It is located in the SW¼NE¼NE¼ sec. 26, T. 51 N., R. 7 W., Bayfield County, an area shown on the Cornucopia 15-minute quadrangle (fig. 120).

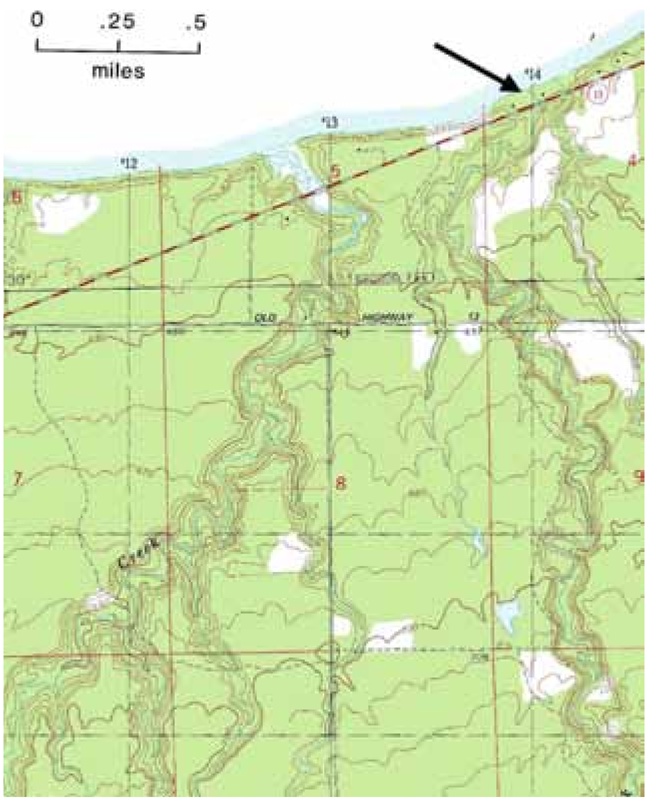

Figure 119. Part of the Oulu 7.5-minute quadrangle showing the location of reference section 1 of the Douglas Member. This reference section displays a typical clay facies of the Douglas Member.

Figure 120. Part of the Cornucopia 15-minute quadrangle showing the location of reference section 2 of the Douglas Member. This reference section displays a sandier facies of the Douglas Member.

Description of unit. In most places the Douglas Member till averages 10 percent sand, 26 percent silt, and 64 percent clay in the less-than-2 mm fraction. It is typically reddish brown (2.5YR 4/4). The till averages 54 percent illite, 32 percent smectite, 9 percent vermiculite, and 5 percent kaolinite plus chlorite in the less-than-0.002 mm fraction. Carbonates average 13 percent in the less-than-0.063 mm fraction and 4 percent in the 0.063-to-0.037 mm fraction.

Where the Douglas Member till overlies sand, the till averages 40 percent sand, 27 percent silt, and 33 percent clay in the less-than-2 mm fraction. Carbonates average 9 percent in the less-than-0.063 mm fraction and 3 percent in the 0.063-to-0.037 mm fraction.

Nature of contacts. The Douglas Member overlies till of the Hanson Creek Member, till of the Copper Falls Formation, sand and gravel of either the Miller Creek or Copper Falls Formations, laminated clay and silt of the Miller Creek Formation, and pre-Pleistocene rock. The Douglas Member is generally the surface unit, but in a few places it is overlain by fluvial or lacustrine sand and gravel, offshore silt and clay of the Miller Creek Formation, or younger fluvial, lacustrine, and organic sediment.

Differentiation from other units. Typical Douglas Member till is redder and more clayey than Hanson Creek Member till. The sandy facies is much sandier than the Hanson Creek Member till, but not as sandy as most Copper Falls Formation till.

Regional extent and thickness. The Douglas Member crops out in Lake Superior bluffs from Wisconsin Point eastward to the mouth of the Bark River (fig. 3); the more clayey facies is located west of Port Wing, and the sandier facies is located east of Port Wing. Douglas Member till is probably the surficial unit on most Lake Superior bluffs along the south shore. The more clayey till facies ranges in thickness from 1 to 15 m, and averages 7.5 m thick; the sandier till facies ranges in thickness from 0.5 to 6 m, and averages 1 m thick.

Origin. Most of the Douglas Member is till deposited by ice of the Superior Lobe.

Age and correlation. Till of the Douglas Member was probably deposited in earliest Holocene time, most likely soon after 11,500 cal. yr B.P. Douglas Member till has not been correlated eastward around the Bayfield Peninsula, but presumably it correlates with the upper till member of the Miller Creek Formation in the Ashland region, and it may make up the younger end moraines in the Saxon area, which contain wood dated 9,730 ± 140 ^{14}C yr B.P. (11,062 ± 211 cal. yr B.P., I-5082) and 10,100 ± 100 ^{14}C yr B.P. (11,692 ± 243 cal. yr B.P., WIS-409). Clayton and Moran (1982) have correlated the Douglas Member with a unit in northern Michigan dated 9,900 ^{14}C yr B.P. (approximately 11,400 cal. yr B.P.).

Previous usage. This unit name was first used informally by Need (1980) and Johnson (1980). The unit was formalized in Mickelson and others (1984).

Rountree Formation

James C. Knox, David S. Leigh, and Tod A. Frolking

Source of name. The Rountree Formation is named after Rountree Branch, a tributary of the Little Platte River in Grant County, Wisconsin. This tributary flows adjacent to the upland dolomite quarry containing the type section of the Rountree Formation. Rountree Branch was named for John H. Rountree, pioneer lead miner and co-founder of the city of Platteville in 1827.

Location and description of type section. The type section is in a dolomite quarry on a narrow interfluve in the SE¼NW¼SW¼NE¼ sec. 14, T. 3 N., R. 1 W., Grant County, an area shown on the Platteville 7.5-minute quadrangle (fig. 121). The type section is a west-facing exposure at the east edge of the quarry and located at the crest of the interfluve. This site has been previously identified as the Rosemeyer Farm Quarry (Knox and Maher, 1974). At this site, loess of the Peoria and Roxana Members of the Kieler Formation overlies the red clay of the Rountree Formation, which in turn overlies cherty dolomite of the lower member of the Galena Formation (Middle Ordovician) at an elevation of about 295 m (970 ft) (figs. 122 and 123).

The overlying Peoria Member consists of about 2.2 m of dark yellowish-brown (10YR 4/4 to 10YR 5/4) to yellowish-brown (10YR 5/5) loess that averages less than 1 percent sand, 76 percent silt, and 23 percent clay below the depth of leaching (fig. 123). The Peoria Member was deposited during the last part of the Wisconsin Glaciation. The Roxana Member of the Kieler Formation underlies the Peoria Member at a depth of 2.23 to 2.35 m. The Roxana Member, correlated with the Roxana Formation in northwestern Illinois, is a dark brown (10YR 4/3) silt. The Roxana Member here tends to be slightly less silty and more clayey than the overlying unleached lower Peoria Member (fig. 123). The Roxana Member is leached and

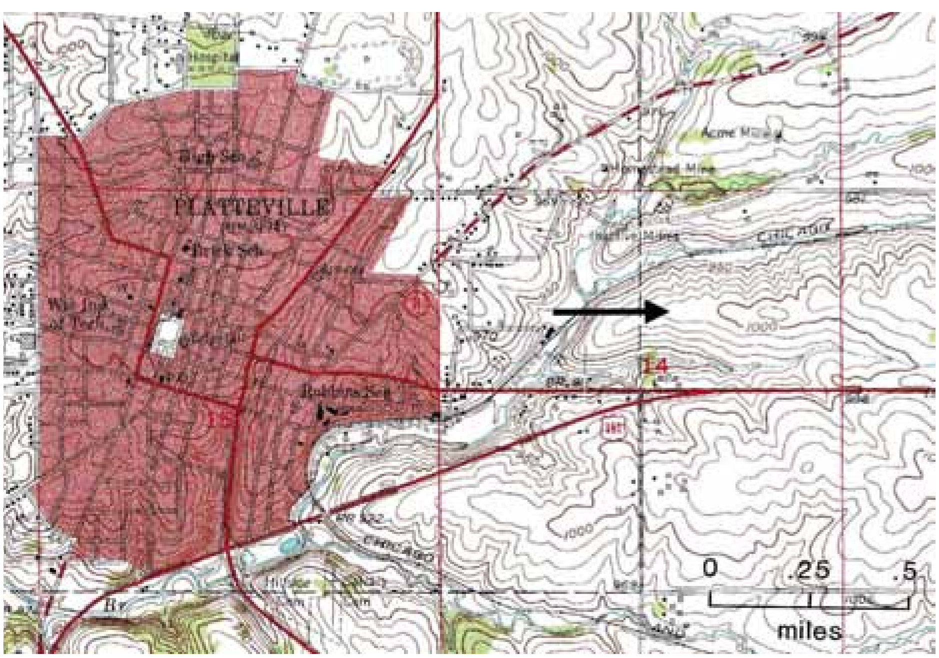

Figure 121. Part of the Platteville 7.5-minute quadrangle showing the location of the type section of the Rountree Formation.

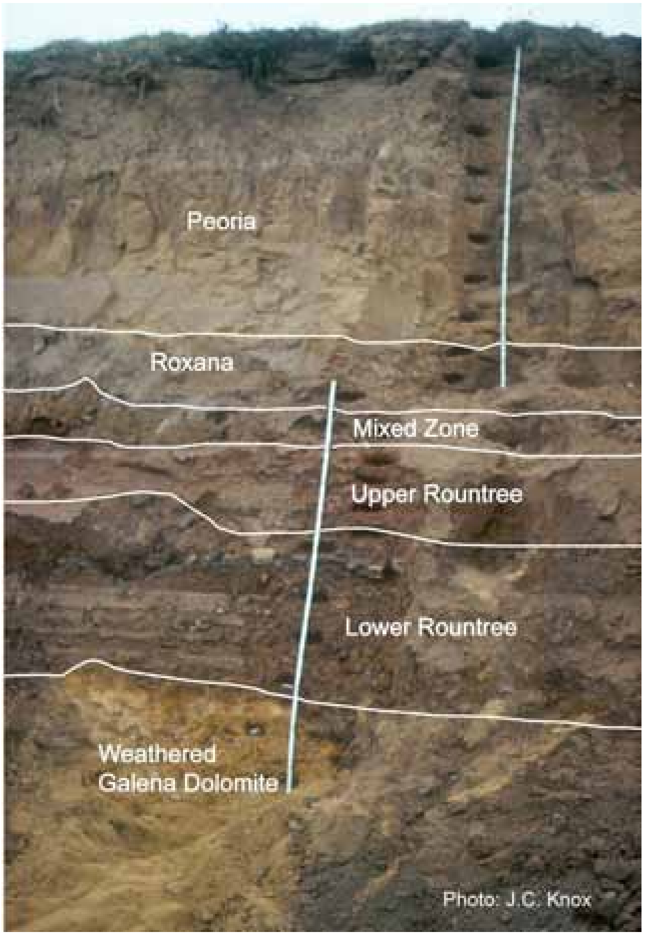

Figure 122. Photograph of the type section of the Rountree Formation at the Rosemeyer Quarry (date of photo, 1975). The vertical rods are each 2 m long. The Rountree Formation is overlain by the Roxana and Peoria Members of the Kieler Formation.

characterized by a moderately coarse, platey structure. Small charcoal bits are common. The basal yellowish-brown silt of the Peoria Member between depths of about 1.90 and 2.23 m is interstratified with dark brown silt eroded from the Roxana Formation. In turn, the main unit of the Roxana Member is separated from the Rountree Formation by a leached, dark brown (7.5YR 4/4) mixed zone occurring between depths of 2.35 and 2.59 m (fig. 123). Unlike the basal Peoria Member, where thin bedding identifies the interstratification within the Roxana Member, no bedding is apparent in the mixed zone at the interface between the Roxana Member and the Rountree Formation. The mixed zone is distinguished from the Roxana Member by its redder hue and the inclusion of occasional chert fragments.

The dark brown (7.5YR 4/3) to reddish-brown (5YR 4/3) Rountree Formation directly underlies the mixed zone at a depth of 2.59 m on the crest of the divide at the type section (fig. 123). The Rountree Formation consists of two prominent subdivisions: an upper reddish-brown (5YR 4/3) clay unit and a lower dark brown to strong brown (7.5YR 4/4 to 4/6) clay unit. The clay content in the less-than-2 mm fraction ranges from 50 to 60 percent in the upper unit, and in the lower unit, from 60 to 80 percent. A lens of yellow (2.5Y 8/8) carbonate-leached silt occurs within the lower Rountree Formation between 4.16 and 4.27 m and contains chert fragments; it is unclear

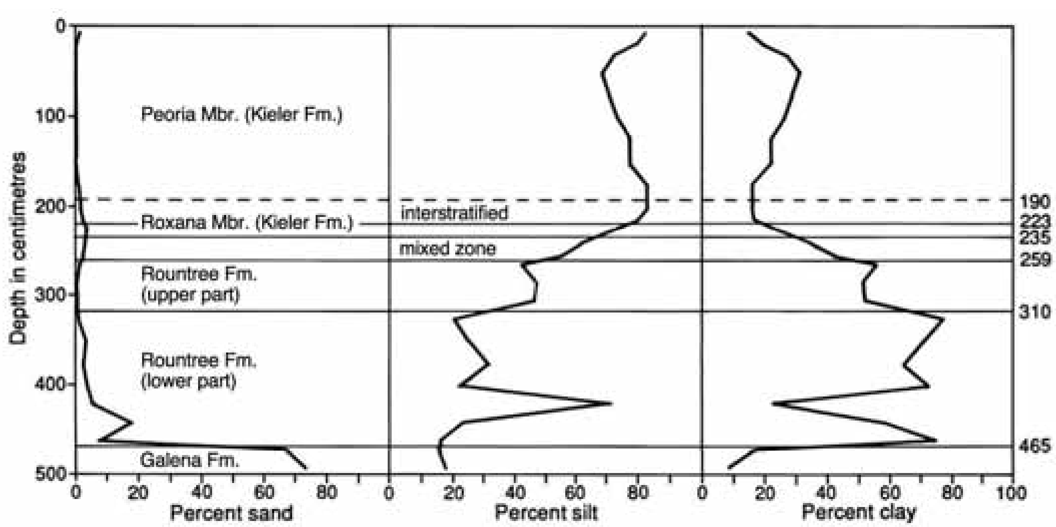

Figure 123. Grain-size analysis of the Rountree Formation at its type section. From Knox and others (1990).

whether this silt is residuum or material illuviated from above. Although angular chert fragments are common in both units, the quantity of chert is considerably greater in the lower unit than in the upper unit. The redder hues of the Rountree Formation in comparison to the overlying loess deposits are due to more abundant extractable iron, which commonly ranges from 3 to 6 percent (citrate-bicarbonate-dithionite extraction). The reddish-brown to strong brown cherty clay of the Rountree Formation abuts brownish-yellow (10YR 6/6) dolomitic sand on the weathered surface of the lower Galena Formation at a depth of 4.65 m.

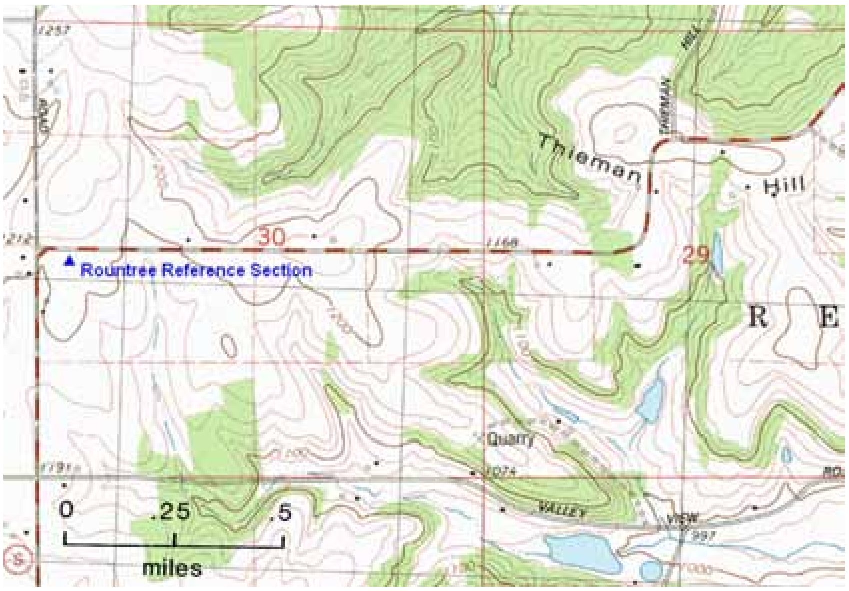

Figure 124. Part of the Loganville 7.5-minute quadrangle showing the location of the reference section of the Rountree Formation (a drill hole).

Location and description of reference section. A drill hole (WGNHS Geologic Log SK-286-F) 8 km (5 miles) east of Lime Ridge, located in the NW corner of SW1/4 sec. 30, T. 12 N., R. 4 E, Sauk County, as shown on the Loganville 7.5-minute quadrangle (fig. 124). Lithologic properties for the Rountree Formation at the reference section are plotted in figure 125.

Description of unit. At the type section on the crest of the divide, the Rountree Formation is 2.06 m thick. The upper reddish-brown (5YR 4/3) clay has a strong, fine, angular, blocky structure and is 0.51 m thick. The

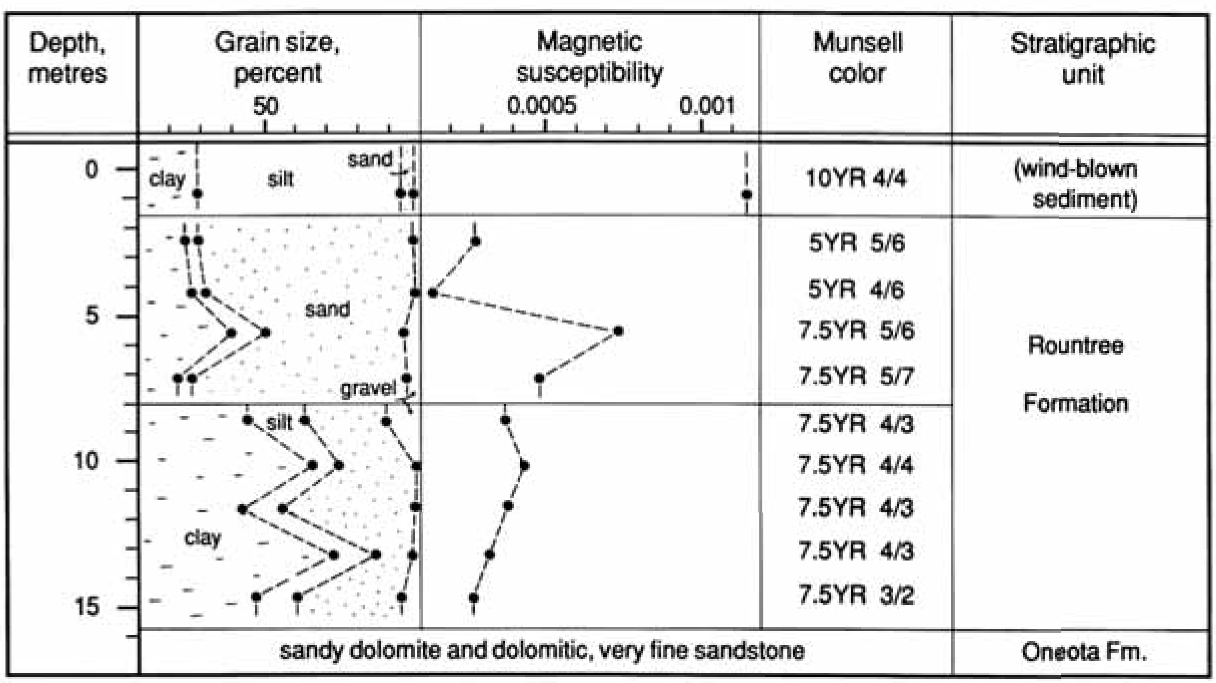

Figure 125. Lithologic properties for the Rountree Formation at its reference section (WGNHS Geologic Log SK-286-F). From Clayton and Attig (1990, p. 34).

lower dark brown to strong brown (7.5YR 4/4 to 4/6) clay is 1.55 m thick and contains many metallic black manganese coatings on ped faces; its strong, coarse, platey structure becomes more pronounced with depth (fig. 123). Both units are leached of carbonates throughout. The less abundant clay in the upper Rountree Formation is mainly associated with more abundant silt. Grain-size differences between the two units reflect an influx of silt from overlying loess units as well as the downward illuviation of clay within the Rountree Formation. The clay mineralogy and a modest increase of organic carbon in relation to depth support the notion that illuviation is an active process.

At the type section, Frolking (1978) found that montmorillonite (>50 percent) and mixed-layer intergrades dominate the clay fractions, kaolinite (5 to 15 percent) and quartz (<5 percent) tend to occur in moderate amounts, and mica (5 to 15 percent in upper red clays; <5 percent in lower red clays) and vermiculite (5 to 15 percent) are present in small amounts. Except for greater amounts of vermiculite in the overlying loess (16 to 30 percent), clay mineralogy of the overlying loess is broadly similar to that of the Rountree Formation. On the other hand, the underlying dolomite insoluble residue is dominantly mica and quartz. However, the mineralogy of the clay within dolomitic sand weathered from the Galena dolomite is similar to that of the overlying Rountree Formation clay, indicating that mica is slowly being altered to montmorillonite and kaolinite. These observations support the idea that clay in the Rountree Formation includes contributions both from overlying loess and underlying bedrock. Further evidence of downward migration of clay from overlying units into the Rountree Formation is indicated by horizontal chert beds that can be traced laterally from unweathered dolomite into clayey Rountree Formation. This shows that the red clay is moving downward and replacing the dolomite on a volume-per-volume basis because the amount of clay produced by the volume of weathered dolomite is incapable of providing the quantity of clay underlying these chert beds.

Regional extent and thickness. The thickness and distribution of the Rountree Formation varies with the type of underlying bedrock, slope steepness, and interfluve width. Rountree Formation at the Rosemeyer Quarry can be absent or greater than 2 m thick across the interfluve. Some of the variation in thickness found here is due to the highly irregular surface of the weathering front on the Galena Formation dolomite, but much is due to slope steepness. At the type section, much mass wasting and fluvial erosion occurred on side slopes prior to deposition of the loess of the Peoria Member. As a result, the Rountree Formation clay thins near the valley sides, and chert is concentrated in lag deposits up to 50 cm thick (Knox and Maher, 1974).The Rountree Formation is mainly concentrated in areas underlain by carbonate formations; the greatest thicknesses are associated with Paleozoic units that are rich in chert, such as the lower parts of the Prairie du Chien and Galena Formations. The chert lag deposits have provided a protective armor and reduced the erosional susceptibility of the Rountree Formation. The Rountree Formation usually is absent or in thin layers on slopes steeper than 3 to 5 percent.

The thickness of the Rountree Formation tends to be greater on wide flat upland interfluves than on narrow interfluves, but the relationship is not strong due to the previously mentioned factors. Because of the wide range of thicknesses of the Rountree Formation, it is meaningless to assign an average thickness for the entire region. The greatest thickness occurs north of the lower Wisconsin River; this appears to be related to karst depressions on upland interfluves underlain by the chert-rich Prairie du Chien Formation where depths exceeding 15 m are not uncommon.

South of the Wisconsin River the Galena Formation dolomite is the main source of chert on uplands, but chert is considerably less abundant than in the lower part of the Prairie du Chien Formation. Consequently, south of the Wisconsin River, the maximum thickness of the Rountree Formation generally does not exceed 3 m on uplands underlain by the Galena dolomite, and the average thickness may be closer to 1.5 m. The Rountree Formation thickness commonly may be only a few centimeters on other upland landscapes not underlain by cherty dolomite bedrock south of the Wisconsin River.

Origin. The Rountree Formation had a complex origin that involved illuviation from overlying loess deposits and slow accretion of residual sediment from underlying dolomite. Frolking (1978) concluded that the large amount of fine and medium clay, the textural and mineralogical homogeneity throughout the profile, the concentrations of organic matter and amorphous iron, and oriented clays at the base of the Rountree Formation are strong evidence for clay illuviation. Frolking also suggested that the montmorillonite dominance in the fine and medium red clay is similar to that of the overlying loess and distinctly different from the dolomite insoluble residues dominated by mica and quartz. Frolking (1978) used neutron activation analysis on the 0.001-to-0.01 mm medium clay through fine silt fractions. Frolking found that an undisturbed Rountree Formation sediment sample directly overlying dolomite was similar to that of the underlying dolomite, but that a Rountree Formation sediment sample higher in the profile had trace-element concentrations intermediate between those of the dolomite and loess, suggesting mixing. In contrast, the mineralogy of the silt and sand fractions within the Rountree Formation are generally quite similar to the dolomite insoluble residues, indicating that most of this sediment is residual and does not involve significant downward mixing from higher in the profile (Frolking, 1978).

Age and correlation. The Rountree Formation is older than the Peoria and Roxana Members of the Kieler Formation that bury it on upland sites, but its complex origin makes it impossible to assign a specific age. On some upland sites in western Wisconsin, it is associated with the Windrow Formation, which might indicate that it has been forming since the Cretaceous Period (Andrews, 1958). It is unlikely to be of great antiquity at most places in the Driftless Area because severe mass wasting during Pleistocene periglacial climates in the region resulted in much erosional stripping of the upland landscapes (Knox, 1982). For example, a study of a small southwestern Wisconsin watershed showed that the loss of sediment from upland hillslopes between 12,000 and 20,000 ^{14}C yr B.P. (approximately 14,000 to 24,000 cal. yr B.P.) was about 200 Mg km^{-2}yr^{-1} (Knox, 1989). This rate is approximately double the modern agriculturally accelerated rate of 112 Mg km^{-2}yr^{-1}. The number of such erosional episodes during the Pleistocene is unknown, but such events probably have occurred several times and they explain why the Rountree Formation is either relatively thin or absent at many locations throughout the southwestern Wisconsin region.

Previous usage. Formalized in Clayton and Attig (1990).

Kieler Formation

James C. Knox, David S. Leigh, Peter M. Jacobs, Joseph A. Mason, and John W. Attig

Source of the name. The village of Kieler, Grant County, Wisconsin.

Location and description of type section. An interstream divide approximately 1.3 km (0.8 mile) south of Kieler. It is located in the SW¼ SE¼ sec. 9, T. 1 N., R. 2 W., Grant County, an area shown on the Kieler 7.5-minute quadrangle (fig. 126).

Three of the four members of the Kieler Formation—the Peoria, the Roxana, and the Loveland—are exposed at the type section (fig. 127). The Peoria Member extends from the surface to a depth of 4.1 m. It consists of yellowish-brown (10YR 5/4) silt loam in the upper oxidized zone to light brownish-gray (10YR 6/2) to pale brown (10YR 6/3) silt loam in the lower zone where chemical reduction has occurred. The less-than-2 mm fraction averages less than 1 percent sand, 78 percent silt, and 22 percent clay.

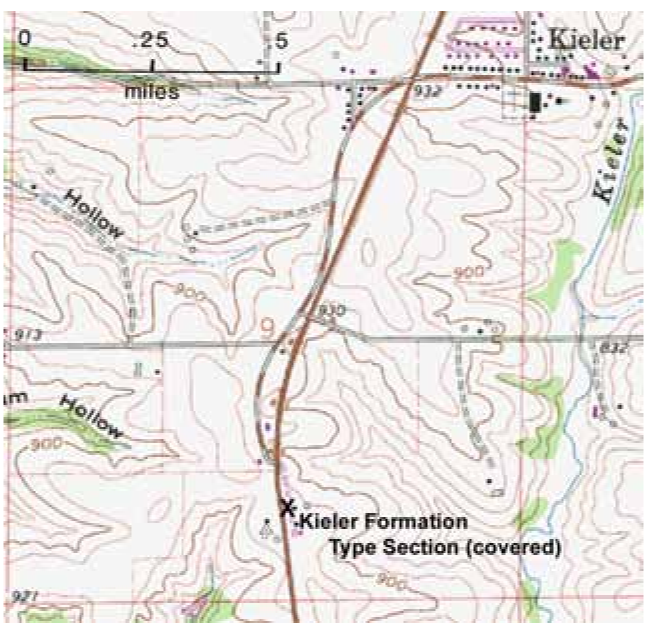

Figure 126. Part of the Kieler 7.5-minute quadrangle showing the location of the type section of the Kieler Formation. This locality also serves as a reference section for the Loveland, Roxana, and Peoria Members.

Calcite is leached to a depth of 2.0 m at the type section. Thin beds of brown silt loam (probably eroded from the underlying Roxana Member) are commonly interstratified in the basal section of the Peoria Member as shown in figure 127. The Peoria Member sharply overlies the Roxana Member.

The Roxana Member extends from a depth of 4.1 to 4.7 m and averages less than 1 percent sand, 76 percent silt, and 24 percent clay. The unit commonly contains charred plant fragments. The Roxana Member is a brown to dark brown (10YR 4/3) non-calcareous silt loam in which the Farmdale Geosol is formed (Follmer, 1983). The Roxana Member has been truncated by post-depositional erosion at the site, and the remaining unit is characterized by a massive to weak blocky structure representative of pedogenic B-horizon development. The basal Roxana Member grades into the underlying Sangamon Geosol developed in the Loveland Member of the Kieler Formation.

The Loveland Member extends from a depth of 4.7 to 6.1 m. The silty clay loam of the Loveland Member is non-calcareous throughout. The solum of the Sangamon Geosol extends across the entire thickness of the Loveland Member. The Sangamon Geosol A horizon is exceptionally well preserved except for minor color loss and overprinting with weak subangular blocky structure. This overprinting was caused by burial and pedogenesis during formation of the Farmdale Geosol in the overlying Roxana Member. Nonetheless, the paleo-A horizon in the Sangamon Geosol is dominated by granular structure and is relatively dark brown (10YR 4/3) in comparison with the underlying lighter brown (7.5YR 4/4 to 5/4) B horizon of the Sangamon Geosol. The Sangamon B horizon displays strong, medium, subangular blocky pedogenic structure. The Loveland Member averages less than 1 percent sand, 63 to 69 percent silt, and 31 to 37 percent clay. The

Loveland Member overlies the lighter colored and more strongly weathered Rountree Formation with a sharp contact.

Highly weathered silty clay at a depth of 6.1 to 6.6 m underlies the Kieler Formation at the type section. This unnamed silty clay traditionally has been recognized as an upper member of the Rountree Formation (Knox and Maher, 1974; Knox and others, 1990; Jacobs and others, 1997). Its placement within the Rountree Formation is controversial because it is typically composed of 40 to 50 percent silt, suggesting a strong contribution from loess sources. At the Kieler Formation type section, the unit averages 1 percent sand, 51 percent silt, and 48 percent clay. The high clay content of the unit probably is a result of several processes, including eolian accretion, particle-size reduction associated with intense weathering, and long-term mixing with underlying clayey residuum. Occasional inclusions of clastic fragments from underlying bedrock provide evidence that the unit is derived in part from, or mixed with, weathered sediment from the underlying bedrock. Although the unnamed silty clay is pedologically continuous with the residuum of the basal Rountree Formation, the typical browner color (7.5YR 4/3 versus 7.5YR 4/4 to 4/6) and characteristic pervasive clay coatings on the fine subangular blocky structure of the upper Rountree Formation unit differentiate it from the basal Rountree Formation unit. While evidence of a strong loess contribution to this unit supports the idea that it may better fit as a lower member of the Kieler Formation, the high percentage of clay is the principal basis for placement of this sediment within the upper

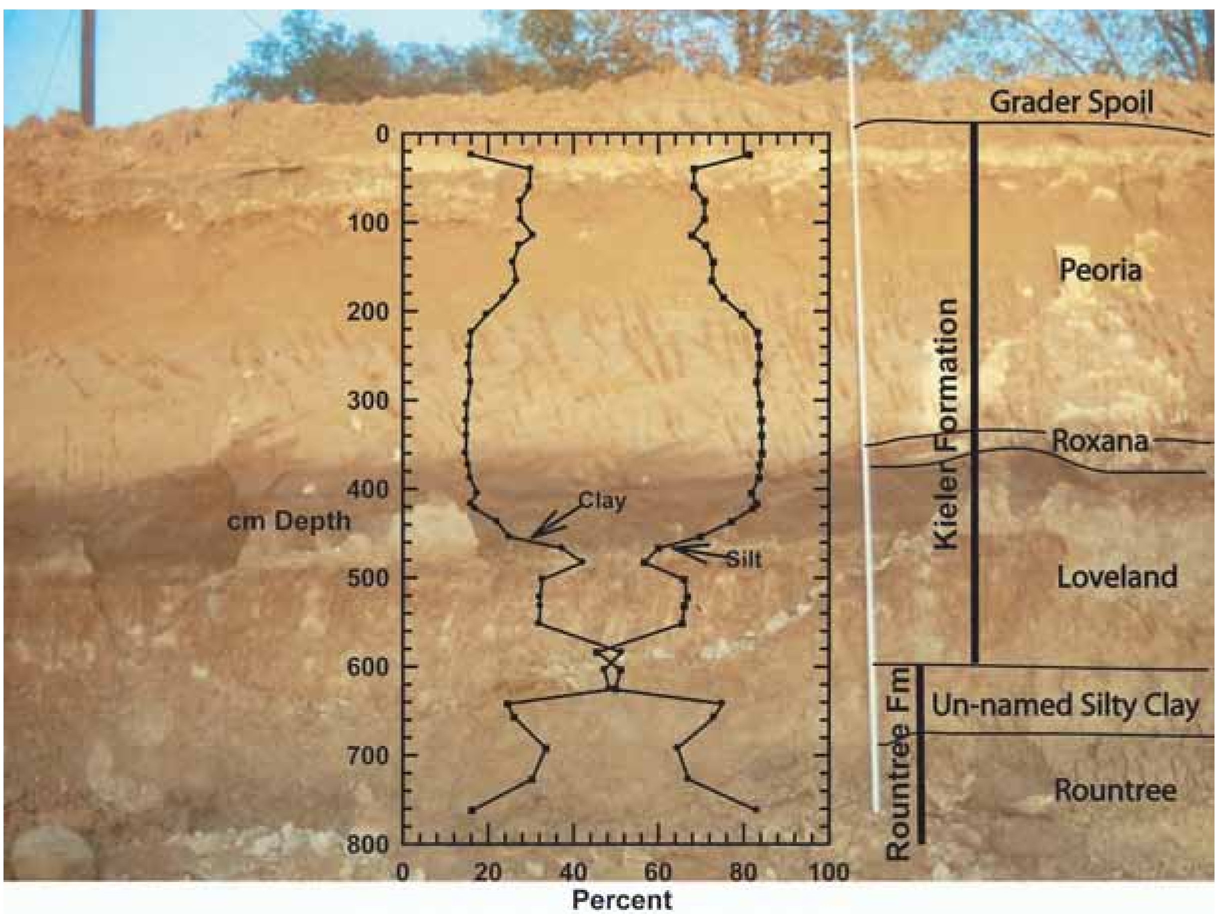

Figure 127. Kieler Formation type section near Kieler, Wisconsin. The Kieler Formation consists largely of loess and reworked loess at upland sites, but on steep hillslopes and basal hillslopes where colluvial activity has been very important, its composition can include a wide range of clast sizes and its thickness can vary from a few tens of centimeters to several meters (fig. 128). Photo: J.C. Knox.

Rountree Formation. Evidence of loess deposition before the Illinoian Glaciation has been documented elsewhere in the region, but post-deposition erosion and weathering have destroyed evidence of early Quaternary loess deposition at most sites (Jacobs and Knox, 1994).

Description of unit (summarized from Leigh, 1991). The Kieler Formation consists largely of loess, reworked loess, and colluvium found on uplands, terraces, and valley margins. Its presence is most extensive in the Driftless Area of southwestern Wisconsin where four named members are recognized, in addition to a few locally restricted and unnamed units deposited before the Illinoian Glaciation (see Knox and others in the introduction to this publication, for historical background and geologic framework). The named members from oldest to youngest are: Wyalusing, Loveland, Roxana, and Peoria Members. The Wyalusing and Loveland Members are thought to have been deposited during the Illinoian Glaciation, while radiocarbon ages quantitatively show that the Roxana and Peoria Members were deposited during the middle to the last part of the Wisconsin Glaciation (Leigh and Knox, 1994). Sediment of the Peoria Member makes up the majority of the Kieler Formation.

The Kieler Formation consists primarily of massive silt and silt loam. Color differs as influenced by drainage conditions and pedogenic alteration at any given site. In most places (well-drained settings), it is typically yellowish brown to light yellowish brown (10YR 5/4 to 10YR 6/4). In poorly drained settings it is typically grayer in color. The unweathered part of the Kieler Formation is commonly calcareous and contains up to 15 percent carbonate minerals; dolomite is generally more abundant than calcite. Unweathered parts of the Kieler Formation are generally massive, but may include beds of silty sediment that are thinly laminated and stratified. The Kieler Formation typically does not include distinct beds of sand or clay like those that are characteristic of fluvial and lacustrine sediment. In addition, it does not include fining-upward sequences of gravel, sand, and silt, or any sedimentary structures that are characteristic of fluvial deposits. Stone lines and thin beds of sand are present in the Kieler Formation, but they are not ubiquitous features.

The Kieler Formation ranges in thickness from several centimeters to 20 meters. The coarsest textures and thickest deposits are generally found near large river valleys, and it becomes finer and thinner with distance from the valleys. In landscape settings immediately adjacent to large river valleys, the sand content may be as much as 50 percent; at sites more than 20 km (12.5 miles) from large river valleys, the unweathered Kieler Formation is more clayey (up to 25 percent clay). On hillslopes it typically includes clasts of the local bedrock set in a massive silty matrix (fig. 128). Paleosols typically bound separate members of the Kieler Formation, which are

Figure 128. Example of basal hillslope colluvial phase of the Kieler Formation located in the SW¼NW¼ sec. 18, T. 2 N., R. 1 W., an area on the Dickeyville 7.5-minute quadrangle. Here, angular carbonate cobbles and boulders are embedded in silt, all mass wasted from upper hillslope positions. The colluvial phase commonly is dominated by silt of the Peoria Member, but its thickness varies from very shallow on steep slopes to very thick on gentle slopes or at basal hillslope positions. Photo: J.C. Knox.

distinguished on the basis of stratigraphic position, color, texture, structure, and chemical characteristics (see specific member descriptions for details). Isolated remnants of loess-derived sediment pre-date the Illinoian Glaciation. Such remnants suggest that the earliest Kieler Formation sediment was initially more extensive on the landscape, but weathering and erosion removed most of this sediment. Further description of Kieler Formation units is presented in Jacobs and others (1997).

Nature of contacts. The Kieler Formation is generally at the surface. It sharply overlies the Rountree Formation, bedrock, and other Pleistocene sediment.

Differentiation from other units. The Kieler Formation is differentiated from other units by its massive structure and abundant silt. It does not typically contain isolated beds of gravel, sand, or clay, and the macro-stratification of the Kieler Formation does not include fining-upward sequences or beds of gravel, sand, and silt, or any sedimentary structures that are typical of fluvial deposits. Massive sandy deposits containing more than 50 percent sand are not included in the Kieler Formation.

Regional extent and thickness. The Kieler Formation is the surface deposit over most uplands in the Driftless Area of southwestern Wisconsin, and it is fairly extensive elsewhere on till surfaces that predate the last part of the Wisconsin Glaciation (MIS 2) (Hole, 1950). It is thickest (up to 20 m) and most noticeable within 25 km (15.5 miles) of large rivers of southwestern Wisconsin. However, it occurs as a thin deposit throughout much of the state. The Peoria Member makes up the vast majority of the Kieler Formation. The occurrence of the Kieler Formation in the landscape is most prevalent on upland interstream divides and hillslopes. The Kieler Formation also occurs in some valley bottoms, on Pleistocene terraces, and within late Pleistocene hillslope and alluvial fan deposits along valley margins. The Kieler Formation also is present in cut-off bedrock valley meanders in southwestern Wisconsin.

Origin. The massive silt that dominates the Kieler Formation originated as loess blown from river floodplains and lake plains. The massive silt also was derived from sparsely vegetated periglacial landscapes and the floodplains of the sediment-laden streams that drained those landscapes.

Age and correlation. It is likely that most of the Kieler Formation is younger than the Brunhes-Matuyama magnetostratigraphic boundary formed about 790,000 cal. yr B.P. because older loess units deposited before the Illinoian Glaciation have normal remanent magnetism, as observed on upland interfluves in the central Driftless Area (Jacobs, 1990). An AMS radiocarbon age of 24,250 ± 970 ^{14}C yr B.P. (29,076 ± 1041 cal. yr B.P.) on snail shells was obtained for a stratigraphic horizon 25 cm above the base of the Peoria Member at a site 30 km (18.6 miles) north of the Kieler Formation type section (Leigh and Knox, 1993). The Peoria Member is the thickest member of the Kieler Formation, so most of the Kieler Formation was deposited between 25,000 to 12,000 ^{14}C yr B.P. (approximately 30,000 to 14,000 cal. yr B.P.) (Knox, 1989; Forman and others, 1992).

The Kieler Formation correlates lithostratigraphically and chronostratigraphically with all Pleistocene loess-derived formations of the Illinois State Geological Survey (the Loveland Silt, Roxana Silt, and Peoria Loess Formations of Willman and Frye, 1970) and with other Pleistocene loess deposits in the Midwest (Ruhe, 1976; Forman and Pierson, 2002; Bettis and others, 2003; Busacca and others, 2004). In states other than Illinois, loess lithostratigraphic units also are classified as individual formations. In Wisconsin, the Kieler Formation was created and the Peoria, Roxana, and Loveland units were reduced in rank to members because pre-Peoria members are insufficiently extensive to be mappable units in Wisconsin.

Previous usage: First used informally by Leigh (1991). Formalized in this publication.

Kieler Formation: Wyalusing Member

David S. Leigh and James C. Knox

Source of the name. Wyalusing State Park, Grant County, Wisconsin. The type section is visible northward across the mouth of the Wisconsin River from the scenic overlook on the north edge of Wyalusing State Park.

Location and description of type section. A core site (CR-3 of Leigh and Knox, 1994) on the crest of the drainage divide on a terrace of the lower Wisconsin River, approximately 1 km (0.6 mile) northwest of Bridgeport, Wisconsin. The core site is 4 m south of the south edge of Ward Road and in line with a windbreak of tall larch trees on the north side of the road. It is located on the center of the north line of the NE¼NW¼ sec. 10, T. 6 N., R. 6 W., Crawford County, an area shown on the Bridgeport 7.5-minute quadrangle (fig. 129). This type section also serves as the reference section for the Loveland, Roxana, and Peoria Members of the Kieler Formation. Sediment properties at the site are summarized in figure 130.

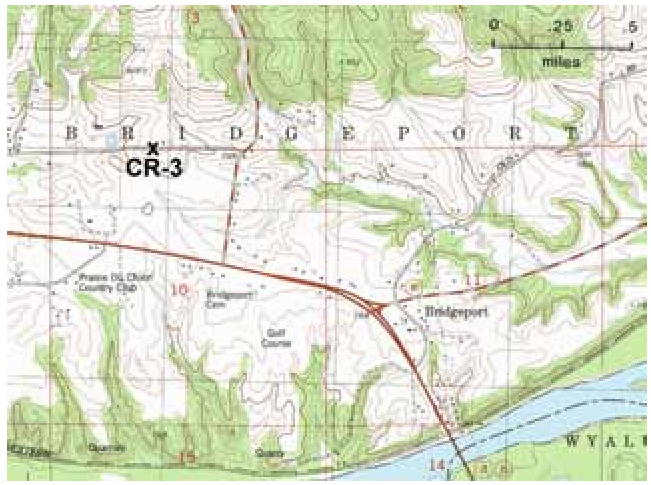

Figure 129. Part of the Bridgeport 7.5-minute quadrangle showing the location of the type section (core site CR-3) for the Wyalusing Member. This locality also serves as a reference section for the Loveland, Roxana, and Peoria Members.

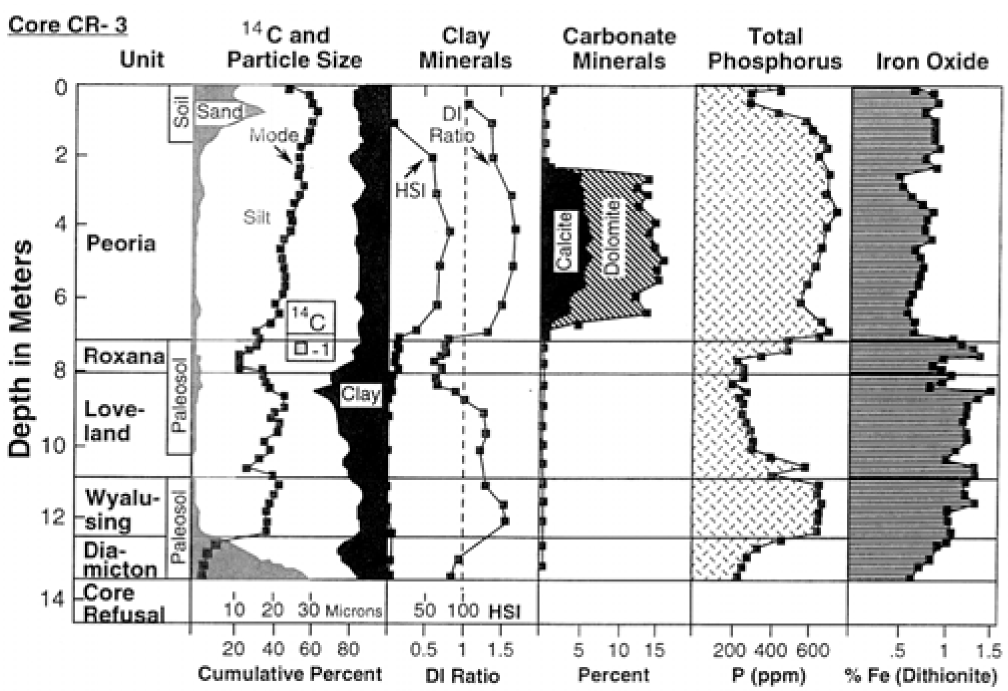

Figure 130. Sediment properties at the reference section for the Wyalusing, Loveland, Roxana, and Peoria Members of the Kieler Formation (core site CR-3). From Leigh (1994).

Kieler Formation: Wyalusing Member

Description of unit. The Wyalusing Member underlies the Loveland Member and is typically composed of unbedded yellowish-brown (10YR 5/4) to brown (10YR 4/3) silt to silt loam that has been slightly to moderately altered by pedogenesis. Weak to moderate platy to blocky pedogenic structure is typical. Known sections of the Wyalusing Member are not calcareous. Pedogenic features typically include nodules of iron and manganese compounds and weak to moderate platy or blocky structure. Evidence of clay illuviation in the form of argillans is not typical. Like other loess-derived units, the Wyalusing Member typically contains less than 5 percent sand, 75 to 90 percent silt, and less than 25 percent clay. The mineralogy is mostly quartz and feldspar in the silt fraction, and clay mineral x-ray diffraction patterns suggest that there are abundant mixed-layered clay minerals present. The Wyalusing Member is lithologically similar to the Roxana Member, except that the Wyalusing Member lacks charred plant material and is in a lower stratigraphic position.

Nature of contacts. The lower contact is generally gradational with the underlying material and may include a mixed zone between the two units. The base of the mixed zone should be considered the base of the Wyalusing Member. The upper boundary with the Loveland Member is typically sharp because of texture and color differences.

Differentiation from other units. The Wyalusing Member is differentiated from other silty units by its stratigraphic position and color. It directly underlies the Loveland Member and has weak expression of pedogenesis. The Wyalusing Member is darker colored and may include more iron and manganese nodules than the overlying Loveland Member.

Regional extent and thickness. The Wyalusing Member is a subsurface unit with a very limited regional extent. It has been found in very stable landscape positions such as flat interfluves and cutoff valley meanders that escaped erosion during the late Quaternary. Fewer than 10 percent of 60 upland coring sites of Leigh and Knox (1994) encountered the Wyalusing Member.

Origin. The Wyalusing Member probably was deposited as loess blown from floodplains of major rivers, including the Mississippi and Wisconsin Rivers. Like all members of the Kieler Formation, the original loess probably has been reworked by hillslope and pedologic processes.

Age. There are no finite ages for the Wyalusing Member, but the stratigraphic position (beneath the Loveland Member) suggests that it was deposited before or during the Illinoian Glaciation. The Wyalusing Member has normal remanent magnetism, which suggests that it postdates the Brunhes-Matuyama magnetic polarity reversal at about 790,000 cal. yr B.P. (Jacobs, 1990).

Correlation. The Wyalusing Member may correlate with other pre-Loveland deposits of the midcontinent, but insufficient chronologies are available to allow accurate correlations.

Previous usage: The name was first used by Leigh (1991) and Leigh and Knox (1994). Formalized in this publication.

Kieler Formation: Loveland Member

David S. Leigh and James C. Knox

Source of the name. Loveland, Iowa.

Location and description of type section. The type locality listed by Kay and Graham (1943, p. 64) was in sec. 3, T. 77 N., R. 44 W., Rockford Township, Pottawattamie County, Iowa. This type section was destroyed in 1957, and a replacement section was established in a borrow pit a short distance northeast of Loveland, Iowa (Daniels and Handy, 1959). It is in the center of sec. 3, T. 77 N., R. 44 W., Pottawatamie County, an area shown on the Missouri Valley (Iowa/Nebraska) and Loveland (Iowa/Nebraska) 7.5-minute quadrangles (fig. 131). The type section is mainly on the Missouri Valley 7.5-minute quadrangle. See Daniels and Handy (1959) for detailed description of the type section.

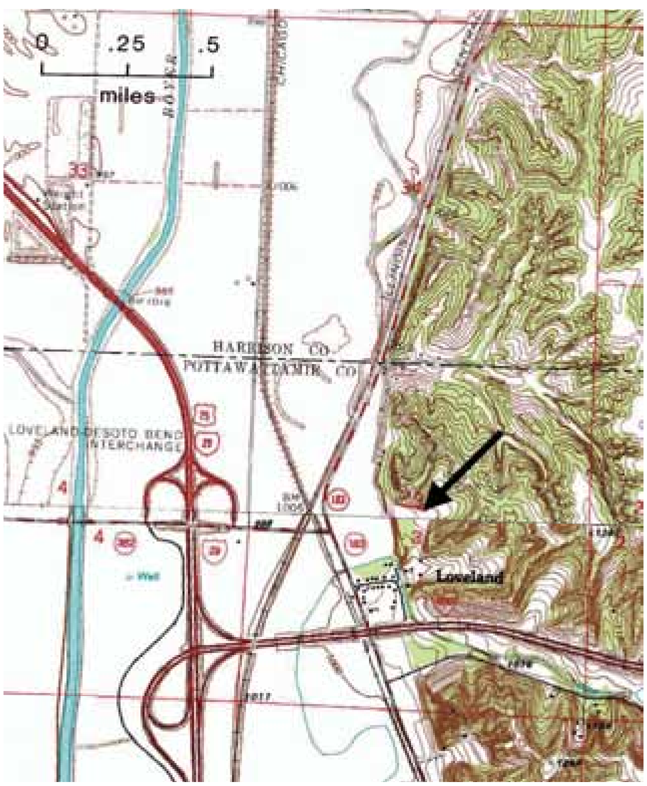

Figure 131. Parts of the Missouri Valley and Loveland 7.5-minute quadrangles (Iowa/Nebraska) showing the location of the type section of the Loveland Member.

Location and description of reference sections. Three reference sections for the Loveland Member are located in Wisconsin. (1) The type section of the Kieler Formation also serves as a reference section for the Loveland Member. It is located in the SW¼ SE¼ sec. 9, T. 1 N., R. 2 W., Grant County, an area shown on the Kieler 7.5-minute quadrangle (figs. 126, 127). See full outcrop description in the Kieler Formation description. (2) The type section of the Wyalusing Member also serves as a reference section for the Loveland Member. Core site CR-3 is located on the center of the north line of the NE¼NW¼ sec. 10, T. 6 N., R. 6 W., Crawford County, an area shown on the Bridgeport 7.5-minute quadrangle (figs. 129, 130). (3) Core site GT-7 is located in a shallow roadside ditch along the south line of the SE¼SE¼ sec. 25, T. 8 N., R. 1 W., Grant County, an area shown on the Muscoda 7.5-minute quadrangle (fig. 132).

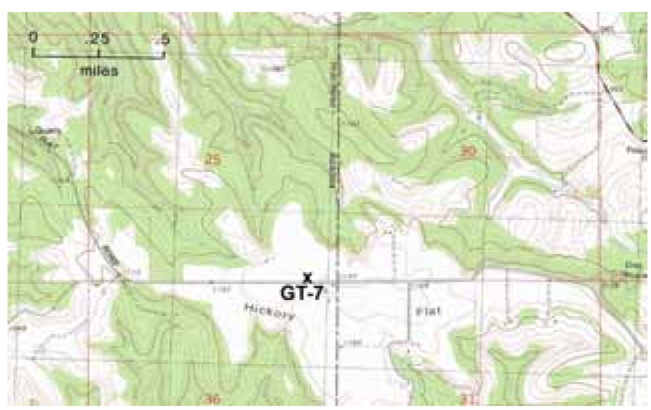

Figure 132. Part of the Muscoda 7.5-minute quadrangle showing the location of reference section 3 (core site GT-7) of the Loveland Member. This locality also serves as a reference section for the Roxana and Peoria Members.

Sediments in reference sections 2 and 3 are summarized in figures 130 and 133, respectively, and core samples of these reference sections are available at the University of Wisconsin–Madison Department of Geography. The reference sections illustrate variability within the Loveland Member and illustrate how it differs from similarly named lithostratigraphic units in Illinois and elsewhere.

Description of unit. The Loveland Member is similar to the Peoria Member in terms of its color and texture. In the unweathered state it is a yellowish-brown (10YR 5/4) to light brownish-gray (2.5Y 6/2) unbedded silt to silt loam. The unit averages 2 percent sand, 62 percent silt, and 36 percent clay at the Kieler type section. The Loveland Member typically has a well-developed paleosol at its top and the associated pedological characteristics are generally noticeable throughout its thickness. The paleosol typically exhibits a brown (7.5YR 4/4) to yellowish-brown (10YR 4/4) Bt-horizon matrix with brown (7.5YR 4/4) clay coatings on ped faces. Strong angular blocky ped structures typify the top of the Btb horizon. No calcareous sections of the Loveland Member have been recognized in Wisconsin.

Nature of contacts. The lower contact of the Loveland Member is generally sharp with the underlying material in terms of its color and texture. Like other loess units, the basal part of the Loveland Member may be somewhat mixed with the underlying material. The upper boundary of the Loveland Member may be gradational with the basal part of overlying units due to pedogenic effects, or it may be sharp because of erosional truncation. The upper boundary is typically associated with the solum of the Sangamon Geosol.

Differentiation from other units. The Loveland Member is differentiated from other loess units by its stratigraphic position, texture, and color. It directly underlies the Peoria

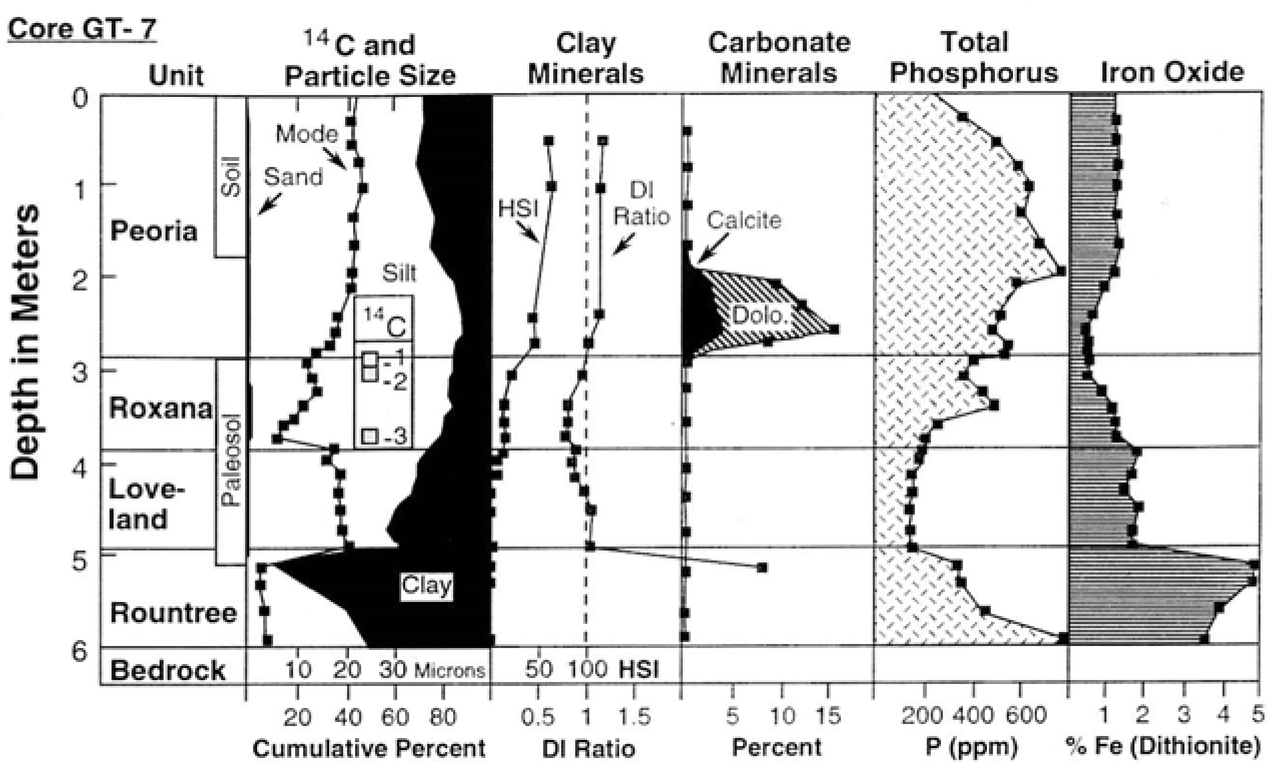

Figure 133. Sediment properties at the reference section for the Loveland, Roxana, and Peoria Members (core site GT-7). From Leigh (1994).

Member or the Roxana Member, and typically the upper part of the Loveland Member has a well-developed paleosol with an argillic horizon. The Loveland Member is generally lighter colored than the underlying Wyalusing Member and overlying Roxana Member. The Loveland Member contains coarser silt than the Roxana Member, but the Loveland Member typically has more clay than the bounding units because of illuvial clay development.

Regional extent and thickness. The Loveland Member is a subsurface deposit in the modern landscape. Fewer than 10 percent of the core sites (more than 60 sites) located on upland interstream divides in southwestern Wisconsin have encountered the Loveland Member. The Loveland Member probably was much more extensive in the past, but it has been eroded from most parts of the modern landscape. The Loveland Member ranges in thickness from several centimeters to 3 m. The thickest known sections of Loveland Member are located on the uplands close to major rivers including the Mississippi and Wisconsin Rivers.

Origin. The Loveland Member probably originated as loess that was deflated from river floodplains and sparsely vegetated uplands that were exposed during the Illinoian Glaciation (MIS 6–8) (Mason and others, 2007).

Age and correlation. There are no finite dates from the Loveland Member in Wisconsin. Amino acid racemization age studies of Loveland loess in Arkansas and correlative units in Illinois indicate deposition during the Illinoian Glaciation (Clark and others, 1989), as do well-established stratigraphic relationships (Johnson, W.H., 1986). Thermoluminescence ages for the Loveland Member and its correlatives along the Missouri and Mississippi Rivers are contradictory. In the Mississippi Valley, thermoluminescence ages for the Loveland Member and its correlatives generally fall between 70,000 and 100,000 cal. yr B.P. (Forman and others, 1992; Forman and Pierson, 2002; Markewich and others, 1998; Pye and Johnson, 1988), whereas at the type section in western Iowa, thermoluminescence ages for the Loveland Member average 135,000 ± 20,000 cal. yr B.P., but age estimates range from 130,000 to 180,000 cal. yr B.P. (Forman and others, 1992; Forman and Pierson, 2002).

The Loveland Member correlates with the Loveland Loess Formation of Iowa (Kay and Graham, 1943; Daniels and Handy, 1959) and the Loveland Silt Formation and Teneriffe Silt Formation of Illinois (Willman and Frye, 1970).

Previous usage: An excellent description of the history of the Loveland Formation is provided by Bettis (1990, p. 53–54). The Loveland Member was initially named as the Loveland joint clay (Shimek, 1909). The type locality was later listed by Kay and Graham (1943, p. 64) and the unit included additional lithofacies other than loess. Mickelson (1949, 1950) proposed that the name "Loveland" be restricted to the loess. The name was subsequently used by Leigh (1991) and Leigh and Knox (1994) in Wisconsin. It is formalized as the Loveland Member of the Kieler Formation in this publication.

Kieler Formation: Roxana Member

David S. Leigh and James C. Knox

Source of the name. Roxana, Illinois.

Location and description of type section. A borrow pit in the bluff of the Mississippi River 6.4 km (4 miles) southeast of Roxana, Illinois. The exact location of the original type section has been destroyed by excavation activities, but the Roxana Member may still be exposed in other parts of the borrow pit. It is located in the SW¼NE¼SE¼ sec. 20, T. 3 N., R. 8 W., Madison County, Illinois, an area shown on the Wood River 7.5-minute quadrangle (fig. 134). The type section of the Roxana Member is described by Willman and Frye (1970, p. 187) as the Roxana Silt of the Pleasant Grove School section.

Location and description of reference sections. Four reference sections for the Roxana Member are located in Wisconsin. (1) The type section of the Kieler Formation also serves as a reference section for the Roxana Member. It is located in the SW¼ SE¼ sec. 9, T. 1 N., R. 2 W., Grant County, an area shown on the Kieler 7.5-minute quadrangle (figs. 126, 127). See full outcrop description in the Kieler Formation description. (2) The type section of the Wyalusing Member also serves as a reference section for the Roxana Member. Core site CR-3 is located on the center of the north line of the NE¼NW¼ sec. 10, T. 6 N., R. 6 W., Crawford County, an area shown on the Bridgeport 7.5-minute quadrangle (figs. 129, 130). (3) Reference section 3 of the Loveland Member also serves as a reference section for the Roxana Member. Core site GT-7 is located in a shallow roadside ditch along the south line of the SE¼SE¼ sec. 25, T. 8 N., R. 1 W., Grant County, an area shown on the Muscoda 7.5-minute quadrangle (figs. 132, 133). (4) Core site GT-6, 30 m south of Adams Lane and 4 m east of the eastern edge of a house driveway, along the north line of the NW¼NW¼ sec. 3, T. 2 N., R. 4 W., Grant County, an area shown on the Balltown (Iowa/Wisconsin) 7.5-minute quadrangle (figs. 135, 136).

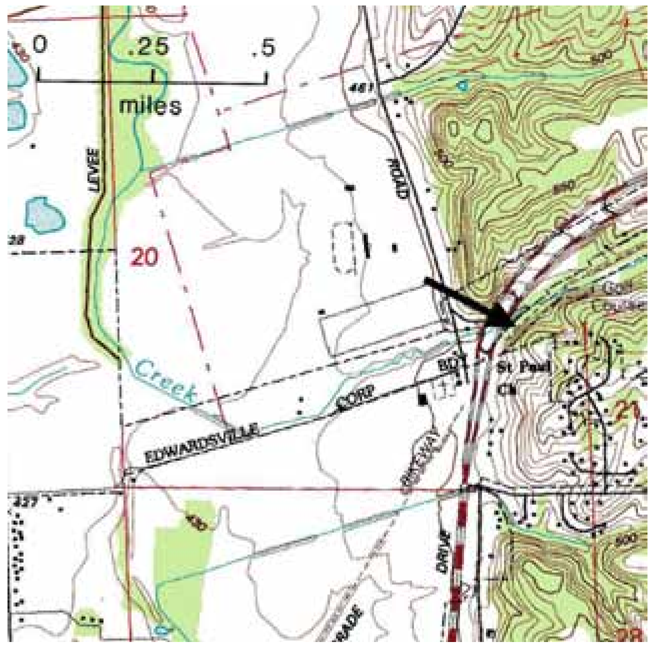

Figure 134. Part of the Wood River (Illinois) 7.5-minute quadrangle showing the location of the type section of the Roxana Member.

Figure 135. Part of the Balltown (Iowa/Wisconsin) 7.5-minute quadrangle showing the location of reference section 4 (core site GT-6) of the Roxana Member. This locality also serves as a reference section for the Peoria Member.

Sediments in reference sections 2, 3, and 4 are summarized in figures 130, 133, and 136, respectively, and core samples of these reference sections are available at the University of Wisconsin–Madison Department of Geography. The reference sections illustrate variability within the Roxana Member and illustrate how it differs from similarly named lithostratigraphic units in Illinois and elsewhere.

Description of unit. The Roxana Member is typically composed of brown (10YR 4/3) to dark yellowish-brown (10YR 4/4) silt to silty clay loam that is noncalcareous and has weak to moderate pedogenic expression. A pink to red hue is noticeable in sections of the Roxana Member that have not been, or have only slightly been, altered by pedogenesis. The Roxana Member is invariably buried by the Peoria Member, and it typically overlies a very well-developed paleosol (Sangamon Geosol), till, rock, or the Rountree Formation. Pedogenesis associated with the underlying stratigraphic unit generally extends upward across the lower boundary of the Roxana Member. Pedogenic features typically include platy structure, silt coats on ped faces, rootlets and pores, and nodules of iron and manganese. The Roxana Member rarely shows evidence of clay illuviation, such as the presence of argillans. Charred flecks of plant material (including *Picea* and *Larix* wood), typically smaller than 5 mm, are conspicuous fossils in the Roxana Member.

Like the Peoria Member, the Roxana Member typically contains less than 5 percent sand, 75 to 90 percent silt, and less than 25 percent clay. However, at the Roxana Member type section, the sediment averages 2 percent sand, 69 percent silt, and 29 percent clay. The Roxana

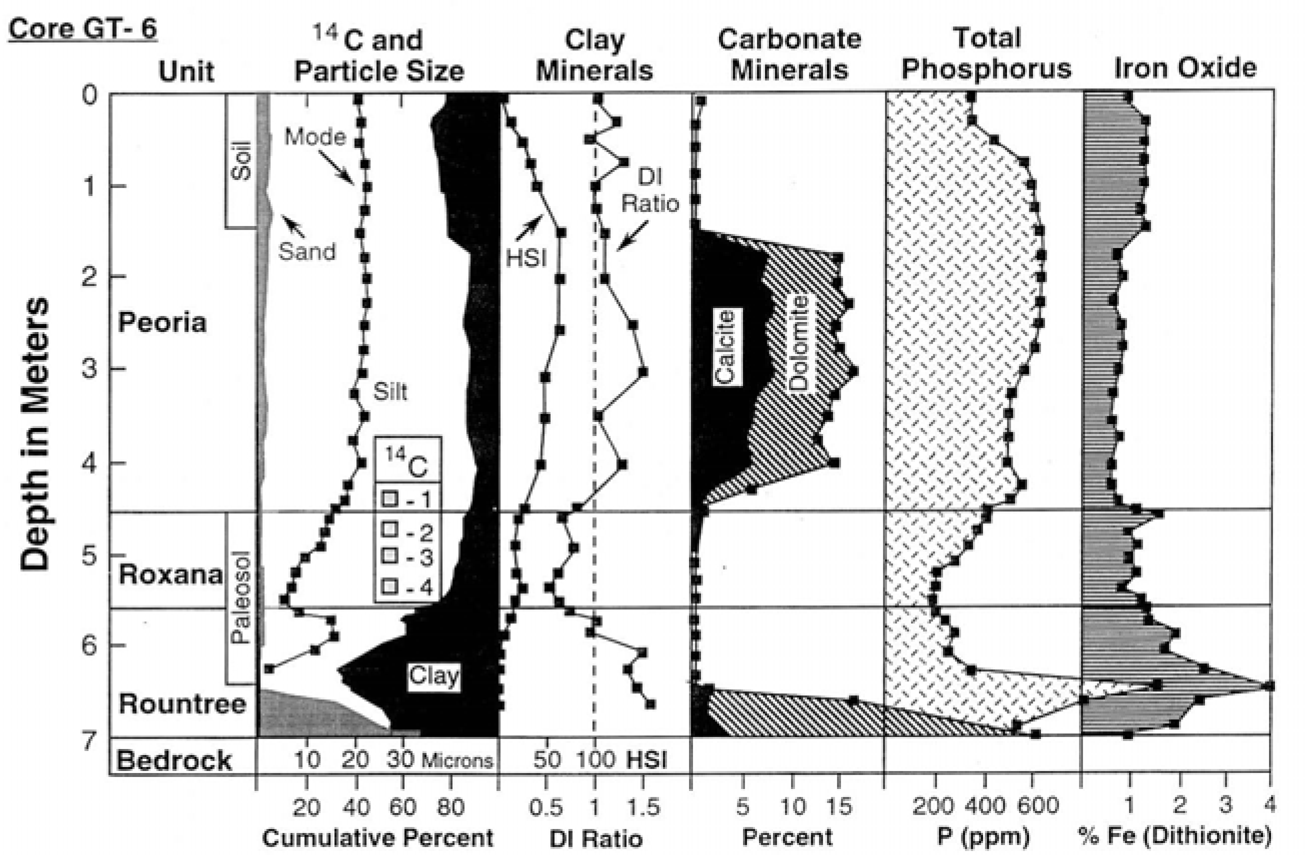

Figure 136. Sediment properties at reference section 4 for the Roxana and Peoria Members (core site GT-6). From Leigh (1994).

Member is typically finer than the overlying Peoria Member because the frequency distribution of the silt (0.002 to 0.063 mm) is finer grained than in the overlying Peoria Member at any individual site. In addition, the Roxana gradually becomes coarser towards the top of the member. The Roxana Member becomes finer with increasing distance from major river valleys such as the Mississippi and Wisconsin River valleys. The mineralogy is made up primarily of quartz and feldspars, and heavy minerals account for less than 5 percent by weight. Clay minerals predominate in the less-than-0.002 mm fraction and primarily include mixed-layer clay minerals and lesser amounts of kaolinite.

The clay mineralogy diffraction intensity ratio (DI ratio = 1.0 nm intensity divided by 0.7 nm intensity) provides a measurement of weathering, where lower numbers suggest more weathering. The DI ratio for the Roxana Member at the Kieler Formation type section near Kieler, Wisconsin is typically 0.7 to 0.8. By comparison, the DI ratio for the overlying Peoria Member averages between 0.9 and 1.0 and the DI ratio for the underlying Loveland Member typically ranges between 0.8 and 1.0 (Jacobs and others, 1997). Although the Roxana Member typically does not contain carbonate minerals, it does contain minor amounts of calcite and dolomite at the Hegery-1 core site, located in the lower Wisconsin River valley near Port Andrews, where it is preserved in relatively greater thickness than elsewhere. This preservation indicates a calcareous component probably also existed elsewhere, but has since been removed by weathering (Leigh and others, 1989).

Nature of contacts. The lower contact generally grades into the underlying material and typically includes a mixed zone between the two units where sedimentary structures have been obscured by pedogenesis (Leigh and others, 1989). The mixed zone commonly contains sediment clasts that resemble sediment in the underlying stratigraphic unit. The mixed zone near the base of the Roxana Member generally does not show any distinct bedding like that of the basal mixed zone in the Peoria Member. Pedogenesis may have obscured any bedding initially present in the unit. The base of the mixed zone is defined as the base of the Roxana Member because the basal sediment includes the initial accumulation of the lithic material that comprises the Roxana Member. The upper boundary between the Roxana Member and the overlying Peoria Member is typically sharp. However, in places the basal Peoria Member is inter-stratified with thin beds of eroded brown Roxana Member. In rare instances the upper part of the Roxana Member contains an organically enriched A-horizon that is correlative with the Farmdale Geosol described by Follmer (1983).

Differentiation from other units. The Roxana Member is darker colored than the overlying Peoria Member and is typically not calcareous, unlike the Peoria Member. It commonly has a characteristic chocolate brown color. The Roxana Member either overlies a well-developed paleosol that has an argillic horizon or a material completely dissimilar to the Roxana Member. The modal diameter of silt particles, detected from electronic particle counting (Coulter Counter) analyses, indicates that the Roxana Member is characteristically finer grained than the overlying Peoria Member and the underlying Loveland Member. Charred fragments of spruce and larch, generally smaller than 5 mm, are common in the Roxana Member. The DI ratio of clay minerals in the Roxana Member (0.7 to 0.8) is characteristically lower than the underlying Loveland Member (>0.8) and the overlying Peoria Member (>0.8). The Roxana Member does not occur as a surface deposit and is commonly found beneath the Peoria Member. Although the Roxana Member often contains a basal mixed zone, thin bedding and stratification are not characteristic of the Roxana Member.

Regional extent and thickness. The Roxana Member is a subsurface formation in Wisconsin. The Roxana Member probably covered most of the landscape throughout the Driftless Area and adjacent areas on top of glacial deposits deposited more than 50,000 ^{14}C yr B.P. (56,000 cal. yr B.P.). However, its modern occurrence is quite restricted to stable landscape positions that have not favored erosion, such as wide, flat upland interstream divides, terrace remnants, and cutoff valley meanders. The Roxana Member ranges in thickness from several centimeters to 2 m in the upper Mississippi Valley. The thickest known sections of the Roxana Member in Wisconsin are less than 1.5 m thick and are typically found within 2 km of the valley bluff margins of the Mississippi and Wisconsin River valleys. Somewhat thicker sections (1.5 to 1.7 m) are located in northwestern Illinois (Leigh, 1991). Like the Peoria Member, the Roxana Member generally thins with increasing distance from major rivers.

Origin. The Roxana Member was deposited as loess blown mainly from exposed river floodplains during the middle part of the Wisconsin Glaciation, 27,000 to 50,000 ^{14}C yr B.P. (32,000 to 56,000 cal. yr B.P.)(Leigh, 1991). An eolian origin is supported by particle size fining away from the major rivers. In addition, the differences in grain size and mineralogy compared to the underlying units indicate that the Roxana Member was not deposited by hillslope processes. Following deposition, hillslope and pedologic processes reworked the Roxana Member.

Age and correlation. A radiocarbon age of 29,400 ± 700 ^{14}C yr B.P. (33,634 ± 618 cal. yr B.P.) was determined for spruce charcoal collected from the Roxana Member in a road cut near the Kieler Formation type section (Hogan and Beatty, 1963). Numerous accelerator-mass-spectrometer (AMS) radiocarbon ages indicate the bulk of the Roxana Member was deposited between 27,000 and 55,000 ^{14}C yr B.P. (32,000 to 60,000 cal. yr B.P.) at sites near the Mississippi River valley bluffs (Leigh, 1991; Leigh and Knox, 1993).

The Roxana Member of Wisconsin correlates with the Roxana Silt Formation of Illinois (Willman and Frye, 1970), the Pisgah Formation of Iowa (Bettis, 1990, p. 55), and the Gilman Canyon Formation of Nebraska (Dreeszen, 1970). The Roxana Member correlates with the "lower Wisconsin loess" of Ruhe (1976).

Previous usage: The name was first used by Leigh (1991) and Leigh and Knox (1994) in Wisconsin. Formalized here as the Roxana Member of the Kieler Formation.

Kieler Formation: Peoria Member

David S. Leigh and James C. Knox

Source of the name. Peoria, Illinois.

Location and description of type section. The type section is the Tindall School Section in the west bluff of the Illinois River to the south of Peoria, Illinois. It is located in the SW¼SW¼NE¼ sec. 31, T. 7 N., R. 6 E., Peoria County, Illinois, an area shown on the Glasford 7.5-minute quadrangle (fig. 137). The type section is described by Willman and Frye (1970, p. 65–66, 188–189) as the Peoria Loess Formation.

Location and description of reference sections. Four reference sections for the Peoria Member are located in Wisconsin. (1) The type section of the Kieler Formation also serves as a reference section for the Peoria Member. It is located in the SW¼ SE¼ sec. 9, T. 1 N., R. 2 W., Grant County, an area shown on the Kieler 7.5-minute quadrangle (figs. 126, 127). See full outcrop description in the Kieler Formation description. (2) The type section of the Wyalusing Member also serves as a reference section for the Peoria Member. Core site CR-3 is located on the center of the north line of the NE¼NW¼ sec. 10, T. 6 N., R. 6 W., Crawford County, an area shown on the Bridgeport 7.5-minute quadrangle (figs. 129, 130). (3) Reference section 3 of the Loveland Member also serves as a reference section for the Peoria Member. Core site GT-7 is located in a shallow roadside ditch along the south line of the SE¼SE¼ sec. 25, T. 8 N., R. 1 W., Grant County, an area shown on the Muscoda 7.5-minute quadrangle (figs. 132, 133). (4) Reference section 4 of the Roxana Member also serves as a reference section for the Peoria Member. Core site GT-6, 30 m south of Adams Lane and 4 m east of the eastern edge of a house driveway, along the north line of the NW¼NW¼ sec. 3, T. 2 N., R. 4 W., Grant County, an area shown on the Balltown (Iowa/Wisconsin) 7.5-minute quadrangle (figs. 135, 136).

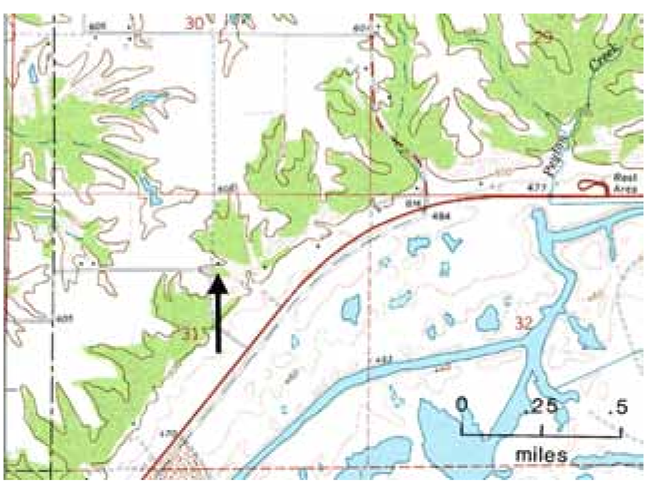

Figure 137. Part of the Glasford (Illinois) 7.5-minute quadrangle showing the location of the type section of the Peoria Member.

Sediments in reference sections 2, 3, and 4 are summarized in figures 130, 133, and 136, respectively, and core samples of these reference sections are available at the University of Wisconsin–Madison Department of Geography. The reference sections illustrate variability within the Peoria Member and how it differs from similarly named lithostratigraphic units in Illinois and elsewhere.

Description of unit. In its unweathered state, the Peoria Member typically is composed of calcareous, unbedded, light brownish-gray (2.5Y 6/2) to yellowish-brown (10YR 5/4) silt to silt loam. Drainage conditions and pedogenic history of a site influence the color of the unit. The upper 2 to 3 m of the Peoria Member typically is oxidized and noncalcareous due to pedogenesis associated with the modern soil. Unweathered Peoria Member typically contains less than 5 percent sand, 75 to 90 percent silt, and less than 25 percent clay. The unweathered Peoria Member at the Kieler type section averages 1 percent sand, 83 percent silt, and 16 percent clay. Sand is unusually abundant (up to 30 percent by weight) at sites close to former floodplain source areas for the Peoria Member. Distinct facies assemblages are apparent. Massive silty facies are the most common, but on hillslopes and related colluvial settings, the silty sediment may be thinly bedded and include clasts from juxtaposed and subjacent stratigraphic units. The Peoria Member generally fines and thins with increasing distance from former loess source areas such as the Mississippi and Wisconsin River valleys (Leigh and Knox, 1994), although sparsely vegetated uplands during periglacial conditions also were sediment sources for the Peoria Member (Mason and others, 1994; Schaetzl and others, 2009). The Peoria Member contains predominantly quartz and feldspar, and heavy minerals generally account for less than 5 percent by weight. Clay minerals predominate in the less-than-0.002 mm fraction and are mainly composed of smectite with lesser amounts of illite, chlorite, and kaolinite. The diffraction intensity ratio (DI ratio = 1.0 nm intensity divided by the 0.7 nm intensity) of clay minerals in the Peoria Member is generally greater than 1. Carbonate minerals (dolomite and calcite) typically make up 10 to 15 percent by mass of calcareous parts of the Peoria Member, and dolomite is generally more abundant. In places snail shells are present in the basal 50 cm of the Peoria Member. Thinly bedded silty sediment is usually most apparent near the lower contact, where the interbedded sediment may contrast sharply with sediment of the underlying stratigraphic unit.

Nature of contacts. The Peoria Member is present at the surface. The lower contact of the Peoria Member is usually quite sharp with the underlying materials (Paleozoic rock, Rountree Formation, Roxana Member, fluvial sediment, till, or a well-developed paleosol). The basal meter of the Peoria Member (or thin units of Peoria Member) is generally mixed with the underlying material; evidence of mixing becomes less apparent with increasing distance from the lower contact. Evidence of mixing typically consists either of interstratifications with underlying older Kieler Formation units or a poorly sorted matrix that includes clasts of the underlying stratigraphic units. The base of this mixed zone marks the base of the Peoria Member.

Differentiation from other units. The Peoria Member is generally lighter colored than underlying stratigraphic units. The basal part of thick sections (more than 3 m) of the Peoria Member is typically calcareous, whereas underlying lithostratigraphic units are typically not calcareous. Clay minerals distinguish the Peoria Member from other loess-derived deposits because the diffraction intensity ratio is generally greater than 1 (indicating less weathering), and smectite is more abundant in the Peoria Member than in most underlying stratigraphic units.

Regional extent and thickness. The Peoria Member is the surface deposit over most of the uplands in the Driftless Area of southwestern Wisconsin and on many other landscape surfaces throughout much of the state (Hole, 1950). The Peoria Member ranges in thickness from several centimeters to 10 m. Thin sediment of the Peoria Member (less than 50 cm thick) is usually mixed with the underlying material. The thickest Peoria Member sediment accumulated along the bluffs of the Mississippi River where it is commonly is 6 to 8 m thick. The Peoria Member generally thins with increasing distance from the Mississippi Valley and other river valleys and lake plains that were deflationary source areas for the loess of the Peoria Member (see map by Hole, 1950). In any given upland setting, the Peoria Member is typically thickest on the widest and flattest interfluve divides and becomes thinner as interfluve divides become narrower and hillslopes become steeper.

Origin. The Peoria Member originated as loess that mainly was blown from exposed river floodplains, exposed lake plains, and sparsely vegetated periglacial land surfaces during the last part of the Wisconsin Glaciation (MIS 2). Strong evidence for an eolian origin includes thinning patterns and textural fining trends away from major river valleys, a typically massive structure, and the location on upland divides. Peoria Member sediment was extensively reworked by mass wasting processes during (or shortly after) deposition (Knox, 1989; Mason and Knox, 1997).

Age and correlation. Snail shells located 25 cm above the base of the Peoria Member in the GT-6 reference section yielded an accelerator mass spectrometer age of 24,250 ± 970 ^{14}C yr B.P. (29,076 ± 1041 cal. yr B.P., GX-15888-AMS), and charred plant fragments located 10 to 15 cm below the boundary between the Peoria Member and the underlying Roxana Member yielded an accelerator mass spectrometry age of 29,290 ±380 ^{14}C yr B.P. (33,661 ± 409 cal. yr B.P., AA5801). In addition, other radiocarbon ages from near the top of the Roxana Member (Leigh, 1994; Leigh and Knox, 1993) indicate a minimum age of about 27,000 ^{14}C yr B.P. (32,000 cal. yr B.P.) for the Roxana Member. These ages suggest that the base of the Peoria Member at bluff-side locations was deposited about 25,000 ^{14}C yr B.P. (30,000 cal. yr B.P.) in Wisconsin. This date correlates well with the basal age of 25,000 ^{14}C yr B.P. (30,000 cal. yr B.P.) for the Peoria Loess in Illinois reported by McKay (1979) and by Hogan and Beatty (1963). Deposition of Peoria Member probably ceased at approximately 12,000 ^{14}C yr B.P. (14,000 cal. yr B.P.) as suggested by local and regional stratigraphic relationships and radiocarbon ages (McKay, 1979; Bettis and others, 2003).

The Peoria Member correlates with the Peoria Loess Formation of Illinois (Willman and Frye, 1970) and the Peoria Loess Formation of Iowa (Bettis, 1990). In addition, it correlates with the informal Peoria loess stratigraphic unit that is widely referenced in the midcontinent of the United States (Bettis and others, 2003; Forman and Pierson, 2002; Busacca and others, 2004).

Previous usage: The name was first used formally by Willman and Frye (1970) for the Peoria Loess Formation in Illinois. The name was subsequently used by Leigh (1991) and Leigh and Knox (1994) in Wisconsin. Formalized as the Peoria Member of the Kieler Formation in this publication.

Appendix: Redefined and abandoned Pleistocene lithostratigraphic units for Wisconsin

The Pleistocene lexicon of Wisconsin is always being modified as new studies refine our understanding of the units in Wisconsin. Since the original Pleistocene lithostratigraphic unit publications by Mickelson and others (1984) and Attig and others (1988), some units have been reclassified from formations to members of formations. In addition, some unit names have been abandoned. Because some lithostratigraphic names have been used in the literature for nearly 25 years, this section lists redefined and abandoned lithostratigraphic units and directs users to other references for more information.

Redefined units

Horicon Formation. First defined formally in Mickelson and others (1984). Mickelson and Syverson (1997) redefined this unit as the Horicon Member of the Holy Hill Formation. This was done because they could not differentiate Horicon and New Berlin Formation till units in the field based on the percentage of Niagaran dolomite pebbles, as proposed by Alden (1918).

Lincoln Formation: Bakerville Member. First defined formally in Mickelson and others (1984). Redefined here as the Bakerville Member of the Copper Falls Formation because researchers such as Attig (1993) and Syverson (2007) could not differentiate till of the Lincoln and Copper Falls Formations in the field.

Lincoln Formation: Merrill Member. First defined formally in Mickelson and others (1984). Redefined here as the Merrill Member of the Copper Falls Formation because researchers such as Attig (1993) and Syverson (2007) could not differentiate till of the Lincoln and Copper Falls Formations in the field.

New Berlin Formation. First defined formally in Mickelson and others (1984). Mickelson and Syverson (1997) redefined this unit as the New Berlin Member of the Holy Hill Formation. This was done because Mickelson and Syverson (1997) could not differentiate Horicon and New Berlin Formation till units in the field based on the percentage of Niagaran dolomite pebbles, as proposed by Alden (1918).

Abandoned units

Copper Falls Formation: Chetek Member. First defined formally in Attig and others (1988). This unit was defined in western Wisconsin as sand and gravel derived from the Chippewa and Superior Lobes that could not be associated with any other member in the Copper Falls Formation. Term abandoned here due to lack of usage. Sediment formerly mapped as Chetek Member is now classified as undifferentiated stream sediment of the Copper Falls Formation.

Horicon Formation: Mapleview Member. First defined formally in Mickelson and others (1984). Mickelson and Syverson (1997) redefined this unit as the Mapleview Member of the Holy Hill Formation. The Mapleview Member was differentiated from the Horicon Member based on high sand percentages (greater than 75 percent sand). Later studies have shown considerable changes in grain size between the Mapleview Member in Langlade County to the north (very sandy) and the Horicon Member in Dane and Rock Counties to the south (less sandy, more silty). The change is gradational, however, and therefore sediment of the Mapleview Member, as defined in Mickelson and others (1984), is clearly the same unit as the Horicon Member. Thus, the use of Mapleview Member has been discontinued in this publication.

Kewaunee Formation: Haven Member. First defined formally in Mickelson and others (1984). Four members were recognized initially in the area covered by the Lake Michigan Lobe (Acomb, 1978; Acomb and others, 1982; Mickelson and others, 1984). The lowest member, the

Ozaukee Member, is the surface till along the shoreline of Lake Michigan from northern Milwaukee County to the city of Port Washington. It is also present farther north in Manitowoc and Kewaunee Counties (Acomb, 1978; Dagle and others, 1980). Till of the Haven Member described between those two sites (Acomb and others, 1982) is now thought to be Ozaukee Member (Carlson, 2002; Carlson and others, in press), so the name Haven Member has been discontinued in this publication.

Lincoln Formation. First defined formally in Mickelson and others (1984). Term abandoned here because researchers such as Attig (1993) and Syverson (2007) could not differentiate till of the Lincoln Formation from till of the Copper Falls Formation in the field. Original members of this unit (the Merrill and Bakerville Members) have been redefined as members of the Copper Falls Formation in this publication.

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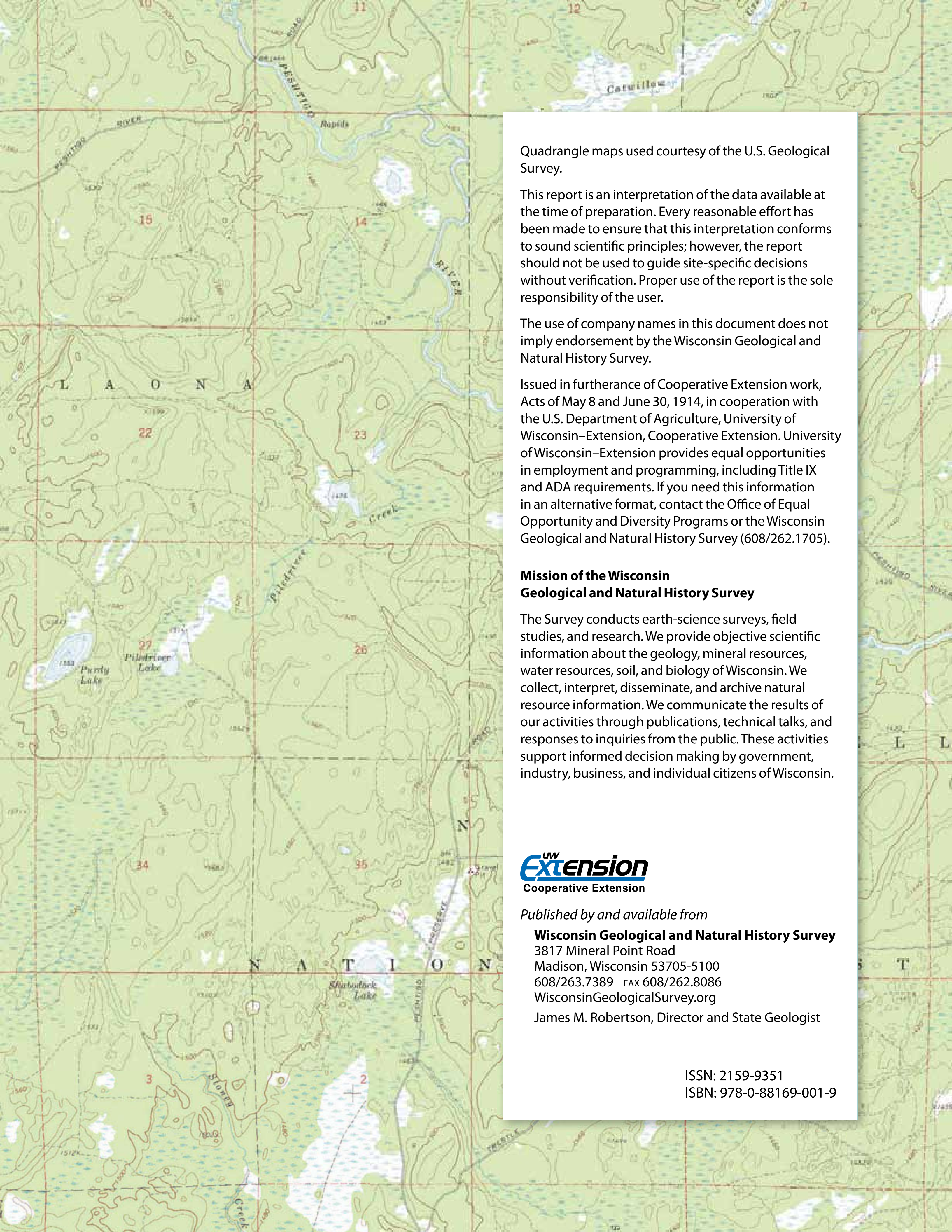

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