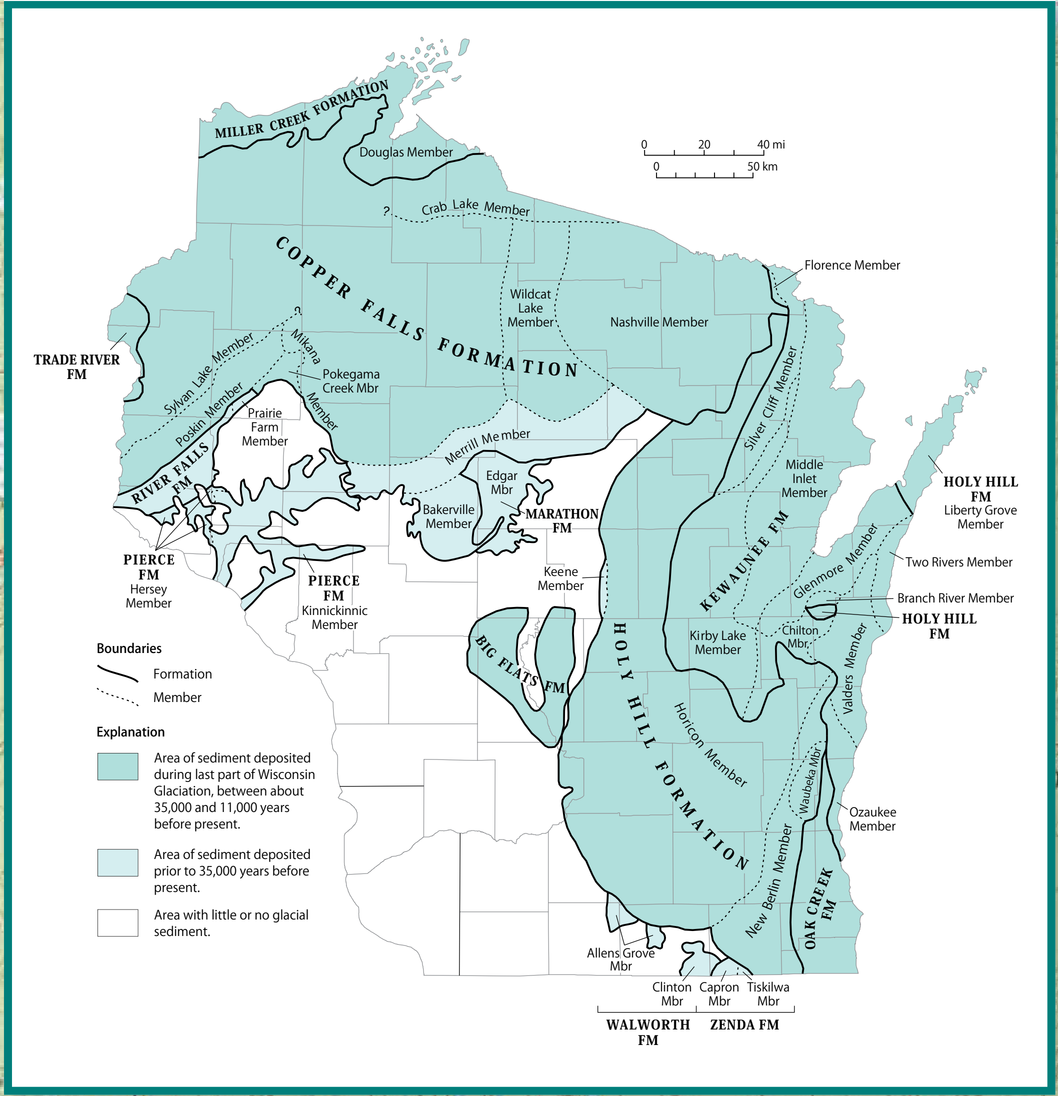
# Lexicon of Pleistocene Stratigraphic Units of Wisconsin



## EDITORS

Kent M. Syverson
Lee Clayton
John W. Attig
David M. Mickelson

Wisconsin Geological and Natural History Survey
Technical Report 1 | 2011

UW Extension
Cooperative Extension

## Introduction, appendix, references

## WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY

James M. Robertson, *Director and State Geologist*
Thomas J. Evans, *Assistant Director*

John W. Attig, *geologist*
William G. Batten, *geologist*
Kenneth R. Bradbury, *hydrogeologist*
Bill C. Bristoll, *information manager*
Bruce A. Brown, *geologist*
Eric C. Carson, *geologist*
Peter M. Chase, *geotechnician*
Lee Clayton, *geologist (emeritus)*
Linda G. Deith, *editor*
Donna M. Duffey, *Map Sales associate*
Madeline B. Gotkowitz, *hydrogeologist*
David J. Hart, *hydrogeologist*
Ronald G. Hennings, *hydrogeologist (emeritus)*
Rilla M. Hinkes, *office manager*
Barbara J. Irvin, *administrative manager*
Kathy A. Kane, *computer specialist*
Todd A. LaMaskin, *geologist*
Irene D. Lippelt, *water resources specialist*
Frederick W. Madison, *soil scientist*
Steven M. Mauel, *GIS specialist*
M. Carol McCartney, *outreach manager*
Patrick I. McLaughlin, *geologist*
Stanley A. Nichols, *biologist (emeritus)*
Michael J. Parsen, *hydrogeologist*
Deborah L. Patterson, *GIS specialist*
Roger M. Peters, *subsurface geologist*
Kathy Campbell Roushar, *GIS specialist*
Apichart Santipiromkul, *computer specialist*
Peter R. Schoephoester, *GIS specialist*
Alexander Zaporozec, *hydrogeologist (emeritus)*

*plus approximately 10 graduate and undergraduate student workers*

## RESEARCH ASSOCIATES

Gregory J. Allord, *U.S. Geological Survey*
Mary P. Anderson, *University of Wisconsin–Madison (emeritus)*
Jean M. Bahr, *University of Wisconsin–Madison*
Mark A. Borchardt, *USDA–Agricultural Research Station*
Philip E. Brown, *University of Wisconsin–Madison*
Charles W. Byers, *University of Wisconsin–Madison*
William F. Cannon, *U.S. Geological Survey*
Anders E. Carlson, *University of Wisconsin–Madison*
John A. Cherry, *University of Waterloo (emeritus)*
William S. Cordua, *University of Wisconsin–River Falls*
Robert H. Dott, Jr., *University of Wisconsin–Madison (emeritus)*
Charles P. Dunning, *U.S. Geological Survey*
Daniel T. Feinstein, *U.S. Geological Survey*
Timothy J. Grundl, *University of Wisconsin–Milwaukee*
Nelson R. Ham, *St. Norbert College*
Paul R. Hanson, *University of Nebraska–Lincoln*
Karen G. Havholm, *University of Wisconsin–Eau Claire*
Thomas S. Hooyer, *University of Wisconsin–Milwaukee*
Randy J. Hunt, *U.S. Geological Survey*
Mark D. Johnson, *University of Gothenburg*
Joanne L. Kluessendorf, *Weis Earth Science Museum*
James C. Knox, *University of Wisconsin–Madison*
George J. Kraft, *Central Wisconsin Groundwater Center*
Michael D. Lemcke, *Wisconsin Dept. of Natural Resources*
J. Brian Mahoney, *University of Wisconsin–Eau Claire*
Joseph A. Mason, *University of Wisconsin–Madison*
Daniel J. Masterpole, *Chippewa Co. Land Conservation Dept.*
Kevin McSweeney, *University of Wisconsin–Madison*
David M. Mickelson, *University of Wisconsin–Madison (emeritus)*
Donald G. Mikulic, *Illinois State Geological Survey*
William N. Mode, *University of Wisconsin–Oshkosh*
Maureen A. Muldoon, *University of Wisconsin–Oshkosh*
Beth L. Parker, *University of Guelph*
Robert E. Pearson, *Wisconsin Dept. of Transportation*
Kenneth W. Potter, *University of Wisconsin–Madison*
J. Elmo Rawling III, *University of Wisconsin–Platteville*
Todd W. Rayne, *Hamilton College*
Daniel D. Reid, *Wisconsin Dept. of Transportation*
Allan F. Schneider, *University of Wisconsin–Parkside (emeritus)*
Madeline E. Schreiber, *Virginia Tech*
Susan K. Swanson, *Beloit College*
Kent M. Syverson, *University of Wisconsin–Eau Claire*

*The Wisconsin Geological and Natural History Survey also maintains collaborative relationships with a number of local, state, regional, and federal agencies and organizations regarding educational outreach and a broad range of natural resource issues.*

# Lexicon of Pleistocene Stratigraphic Units of Wisconsin

Wisconsin Geological and Natural History Survey
Technical Report 1 | 2011

## Editors

Kent M. Syverson
Lee Clayton
John W. Attig
David M. Mickelson

## Contributors

Larry Acomb
John W. Attig
Robert W. Baker
Jim Brownell
Lee Clayton
Carl Fricke
Tod A. Frolking
John C. Frye
Chris Hemstad
Peter M. Jacobs
Mark D. Johnson
James C. Knox
David S. Leigh
Joseph A. Mason
M. Carol McCartney
David M. Mickelson
William N. Mode
Maureen A. Muldoon
E.A. Need
Allan F. Schneider
William W. Simpkins
Betty J. Socha
Kent M. Syverson
H.B. Willman

**Suggested citation:**
Syverson, K.M., Clayton, Lee, Attig, J.W., and Mickelson, D.M., eds., 2011, Lexicon of Pleistocene Stratigraphic Units of Wisconsin: Wisconsin Geological and Natural History Survey Technical Report 1, 180 p.

UW Extension
Cooperative Extension

*Published by and available from*
**Wisconsin Geological and Natural History Survey**
3817 Mineral Point Road • Madison, Wisconsin 53705-5100
608/263.7389 FAX 608/262.8086 WisconsinGeologicalSurvey.org
James M. Robertson, Director and State Geologist

ISSN: 2159-9351
ISBN: 978-0-88169-001-9

# Contents

Introduction

Appendix

## 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

## 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-2007$^{online}$ 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.

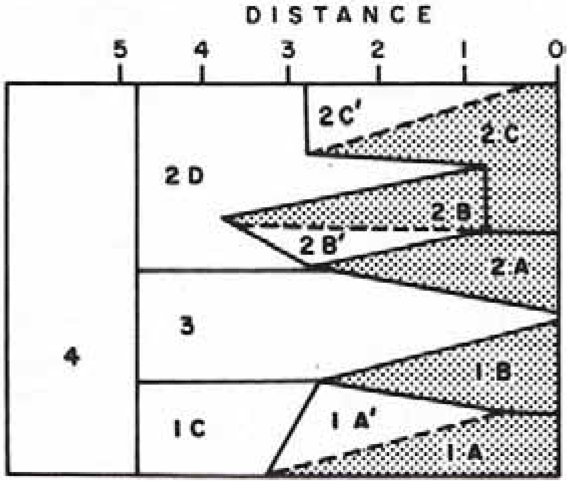


Figure 1. Hypothetical depth–distance stratigraphic diagram to illustrate the subdivision of units into formations and members (from Mickelson and others, 1984). Distances are arbitrary. Units with pattern are till. Others are fluvial, eolian, or lacustrine deposits. For purposes of discussion they are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

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

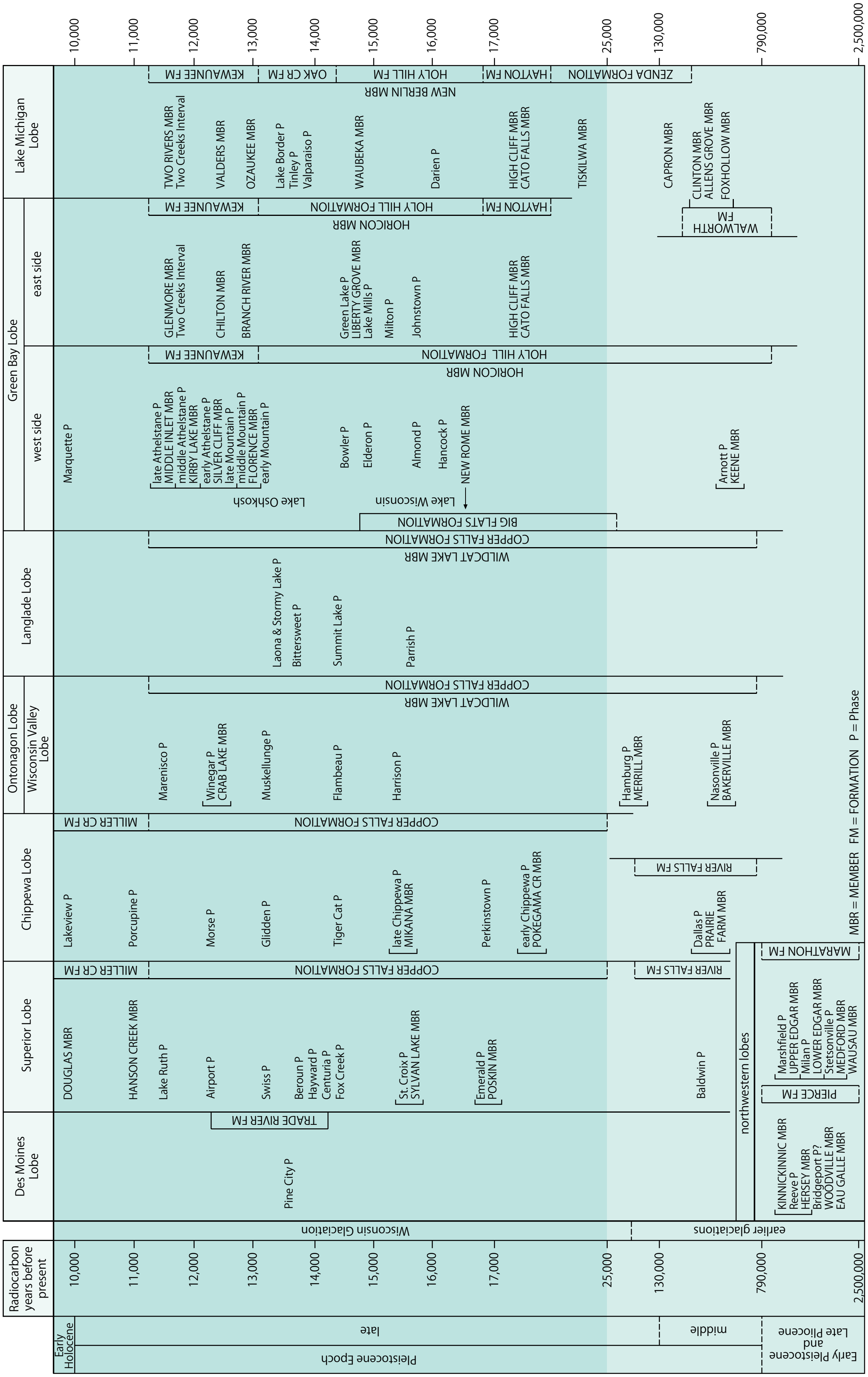


Figure 2. Organization of Pleistocene lithostratigraphic units of Wisconsin by glacial lobe (west to east) and approximate time of deposition. Modified from Clayton and others (2006).

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).

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

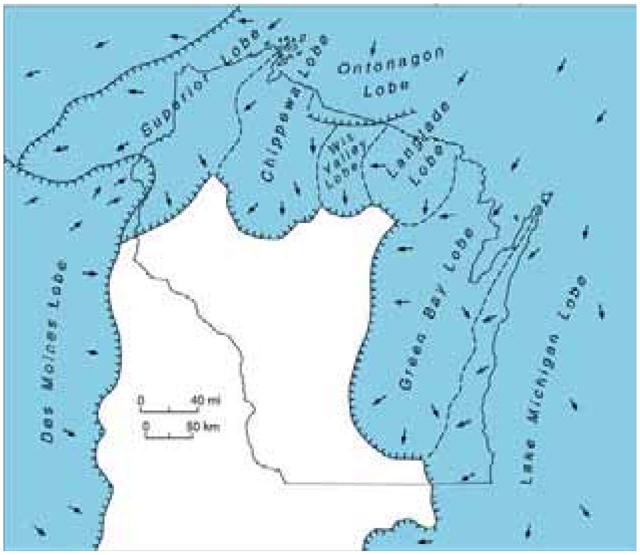


Figure 5. Glacial lobes in Wisconsin during the Wisconsin Glaciation. Arrows indicate the direction of ice movement. From Clayton and others (2006).

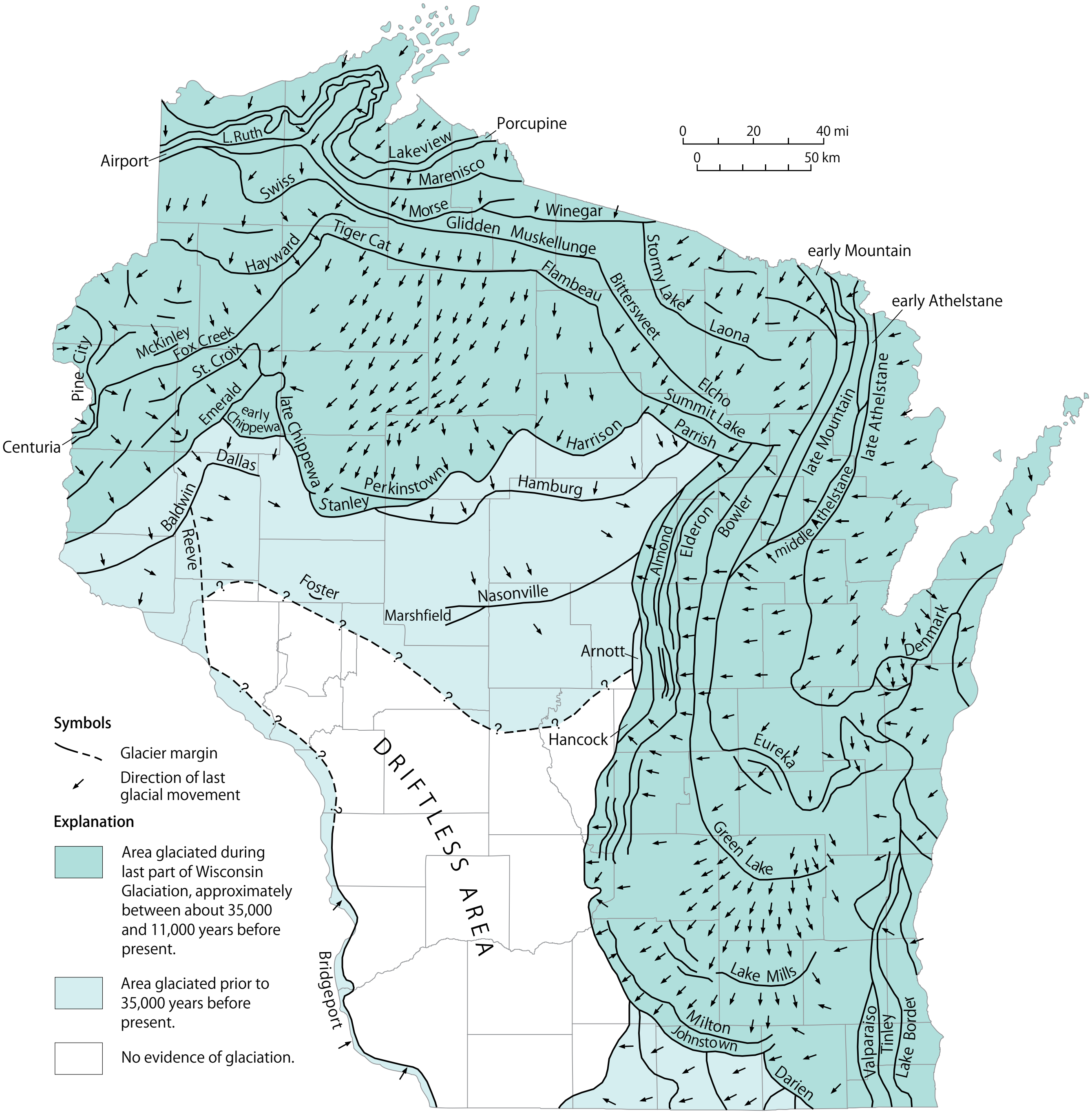


Figure 6. Glacial ice phases in Wisconsin. A phase is a geologic event rather than a period of time. Most phases represent at least a minor advance of the edge of the ice sheet. Each line marks the outermost edge of the ice sheet during a phase of glaciation. Modified from Clayton and others (2006) and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

# **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.

# References

Acomb, L.J., 1978, Stratigraphic relations and extent of Wisconsin's Lake Michigan Lobe red tills: Madison, University of Wisconsin, M.S. thesis, 63 p.

Acomb, L.J., Mickelson, D.M., and Evenson, E.B., 1982, Till stratigraphy and late glacial events in the Lake Michigan Lobe of eastern Wisconsin: *Geological Society of America Bulletin*, vol. 93, p. 289–296.

Alden, W.C., 1904, The Delavan Lobe of the Lake Michigan glacier of the Wisconsin stage of glaciation: U.S. Geological Survey Professional Paper 34, 106 p.

——— 1918, The Quaternary geology of southeastern Wisconsin: U.S. Geological Survey Professional Paper 106, 356 p.

American Commission on Stratigraphic Nomenclature, 1970, Code of stratigraphic nomenclature: American Association of Petroleum Geologists, 22 p.

Andrews, C.W., 1958, Windrow formation of upper Mississippi valley region: A sedimentary and stratigraphic study: *Journal of Geology*, vol. 66, p. 597–624.

Attig, J.W., 1984, Pleistocene geology of Vilas County, Wisconsin: Madison, University of Wisconsin, Ph.D. dissertation, 265 p.

——— 1985, Pleistocene geology of Vilas County, Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 50, 32 p.

——— 1993, Pleistocene geology of Taylor County, Wisconsin: Wisconsin Geological and Natural History Survey Bulletin 90, 25 p.

Attig, J.W., Clayton, Lee, and Mickelson, D.M., 1985, Correlation of late Wisconsin glacial phases in the western Great Lakes area: *Geological Society of America Bulletin*, vol. 96, p. 1585–1593.

Attig, J.W., Clayton, Lee, and Mickelson, D.M., eds., 1988, Pleistocene stratigraphic units of Wisconsin 1984–87: Wisconsin Geological and Natural History Survey Information Circular 62, 61 p.

Attig, J.W., and Ham, N.R., 1999, Quaternary geology of northern Oconto County, Wisconsin: Wisconsin Geological and Natural History Survey Bulletin 97, 13 p.

Attig, J.W., Hanson, P.R., Rawling, J.E., Young, A.R., and Carson, E.C., 2009, Optical ages from ice-marginal lake deposits in the Baraboo Hills indicate the Green Bay Lobe was at its maximum extent about 20,000 years ago: Geological Society of America, Abstracts with Programs, vol. 41, no. 7, p. 334.

Attig, J.W., and Muldoon, M.A., 1989, Pleistocene geology of Marathon County, Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 65, 27 p.

Baker, R.W., 1984, Pleistocene history of west-central Wisconsin: Wisconsin Geological and Natural History Survey Field Trip Guide Book 11, p. 1–16.

Baker, R.W., Diehl, J.F., Beske-Diehl, S., Simpson, T.W., and Zelazny, L.W., 1982, Paleomagnetic and pedogenic reexamination of the "Rockian Substage" in western Wisconsin: Geological Society of America, Abstracts with Programs, vol. 14, no. 5, p. 254.

Baker, R.W., Diehl, J.F., Simpson, T.W., Zelazny, L.W., and Beske-Diehl, S., 1983, Pre-Wisconsinan glacial stratigraphy, chronology, and paleomagnetics of west-central Wisconsin: *Geological Society of America Bulletin*, vol. 94, no. 12, p. 1442–1449.

Baker, R.W., Knox, J.C., Lively, R.S., and Olsen, B.M., 1998, Evidence for early entrenchment of the upper Mississippi valley, *in* Patterson, C.J, and Wright, H.E., Jr., eds., Contributions to Quaternary Studies in Minnesota, 1998: Minnesota Geological Survey Report of Investigations 49, p. 113–120.

Baker, R.W., and Simpson, T.W., 1981, Pre-Woodfordian glaciation in west-central Wisconsin: Geological Society of America, Abstracts with Programs, vol. 13, no. 6, p. 270.

Battista, J.R., 1990, Quaternary geology of the Horicon Marsh area: Madison, University of Wisconsin, M.S. thesis, 132 p.

Bell, E.A., and Sherrill, M.G., 1974, Water availability in central Wisconsin—an area of near-surface crystalline rock: U.S. Geological Survey Water Supply Paper 2022, 32 p.

Berg, T.E., 1960, Differentiation of the St. Croix and Emerald moraines, in west-central Wisconsin [abs.]: Institute on Lake Superior Geology, Sixth Annual Meeting, Madison, Wisconsin, p. 14.

Bettis, E.A., III (editor), 1990, Holocene alluvial stratigraphy and selected aspects of the Quaternary history of western Iowa, Midwest Friends of the Pleistocene 37th Field Conference, Iowa Geological Survey Bureau Guidebook Series No. 9, 197 p.

Bettis, E.A., III, Muhs, D.R., Roberts, H.M., and Wintle, A.G., 2003, Last glacial loess in the conterminous USA: *Quaternary Science Reviews*, vol. 22, p. 1907–1946.

Black, R.F., 1959, Friends of the Pleistocene: *Science*, vol. 130, p. 172–173.

——— 1974, Geology of Ice Age National Scientific Reserve of Wisconsin: National Park Service Scientific Monograph Series, no. 2, 234 p.

——— 1980, Valders–Two Creeks, Wisconsin, revisited: The Valders Till is most likely post-Twocreekan: *Geological Society of America Bulletin*, part 1, vol. 91, p. 713–723.

Black, R.F., and Reed, E.C., 1965, Guidebook for field conference C, upper Mississippi valley: International Association for Quaternary Research, 7th Congress, 126 p.

# References

Bleuer, N.K., 1970, Glacial stratigraphy of south-central Wisconsin, *in* Black, R.F., and others, Pleistocene geology of southern Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 15, Part J, 35 p.

——— 1971, Glacial stratigraphy of south-central Wisconsin: Madison, University of Wisconsin, Ph.D. dissertation, 173 p.

Brownell, J.R., 1986, Stratigraphy of unlithified sediment in the Central Sand Plain, Wisconsin: Madison, University of Wisconsin, M.S. thesis, 140 p.

BT Squared, Inc., 2009, Initial site report, Veolia ES Hickory Meadows Landfill expansion, Chilton, Wisconsin: Madison, Wisconsin, BT Squared, Inc.

Busacca, A.J., Beget, J.E., Markewich, H.W., Muhs, D.R., Lancaster, N., and Sweeney, M.R., 2004, Eolian sediments, *in* Gillespie, A.R., Porter, S.C., and Atwater, B.F., eds., The Quaternary Period in the United States: Developments in Quaternary science 1: Amsterdam, Elsevier, p. 275–309.

Cahow, A.C., 1976, Glacial geomorphology of the southwest segment of the Chippewa Lobe moraine complex, Wisconsin: Ann Arbor, Michigan State University, Ph.D. dissertation, 217 p.

Canfield, H.E. and Mickelson, D.M., 1985, An outline of the Quaternary history of south-central Wisconsin, *in* Berg, R.C., Kempton, J.P., Follmer, L.R., and McKenna, D.P., eds., Illinoian and Wisconsinan stratigraphy and environments in northern Illinois, the Altonian revisited: Illinois State Geological Survey Guidebook 19, p. 35–44.

Carlson, A.E., 2002, Quaternary geology of southern Sheboygan County, Wisconsin: Madison, University of Wisconsin, M.S. thesis, 197 p.

Carlson, A.E., Principato, S.M., Chapel, D.M., and Mickelson, D.M., in press, Quaternary geology of Sheboygan County, Wisconsin: Wisconsin Geological and Natural History Survey Bulletin 106.

Chamberlin, R.T., 1910, Older drifts of the St. Croix Dalles region: *Journal of Geology*, vol. 18, p. 542–548.

Chamberlin, T.C., 1897, Supplementary hypothesis respecting the origin of the loess of the Mississippi valley: *Journal of Geology*, vol. 5, p. 795–802.

Clark, P.U., Nelson, A.R., McCoy, W.D., Miller, B.B., and Barnes, D.B., 1989, Quaternary aminostratigraphy of Mississippi valley loess: *Geological Society of America Bulletin*, vol. 101, p. 918–926.

Clayton, Lee, 1984, Pleistocene geology of the Superior Region, Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 46, 40 p.

——— 1986a, Pleistocene geology of Florence County, Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 51, 13 p.

——— 1986b, Pleistocene geology of Portage County, Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 56, 19 p.

——— 1991, Pleistocene geology of Wood County, Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 68, 18 p.

Clayton, Lee, and Attig, J.W., 1990, Geology of Sauk County, Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 67, 68 p.

Clayton, Lee, Attig, J.W., Mickelson, D.M., Johnson, M.D., and Syverson, K.M., 2006, Glaciation of Wisconsin [3rd edition]: Wisconsin Geological and Natural History Survey Educational Series 36, 4 p.

Clayton, Lee, and Moran, S.R., 1982, Chronology of Late Wisconsin glaciation in middle North America: *Quaternary Science Reviews*, vol. 1, p. 55–82.

Curry, B.B., Berg, R.C., and Vaiden, R.C., 1997, Geologic mapping for environmental planning, McHenry County, Illinois: Illinois State Geological Survey Circular 559, 79 p.

Dagle, M., Mickelson, D.M., Acomb, L.J., Edil, T., and Pulley, S., 1980, Shoreline erosion and bluff stability along Lake Michigan and Lake Superior shorelines of Wisconsin, appendix 7, Northern Manitowoc, Kewaunee, and Door County shorelines of Lake Michigan: Wisconsin Coastal Management program, Shore Erosion Study Technical Report, 116 p.

Daniels, R.B., and Handy, R.L., 1959, Suggested new type section for the Loveland Loess in western Iowa: *Journal of Geology*, vol. 67, p. 114–119.

Danzeglocke, U., Jöris, O., Weninger, B., 2010, CalPal-2007online: http://www.calpal-online.de/, accessed 1/12/2010.

Dreeszen, V.H., 1970, The stratigraphic framework of Pleistocene glacial and periglacial deposits in the central Plains, *in* Dort, W., and Jones, J.K., eds., Pleistocene and Recent Environments of the Central Great Plains: Lawrence, Kansas, University of Kansas, p. 9–22.

Edil, T.B., and Mickelson, D.M., 1995, Overconsolidated glacial tills in eastern Wisconsin: National Research Council, Transportation Research Board Record No. 1479, p. 99–106.

Evenson, E.B., 1973, Late Pleistocene shorelines and stratigraphic relations in the Lake Michigan basin: *Geological Society of America Bulletin*, vol. 84, p. 2281–2298.

Follmer, L.R., 1983, Sangamonian and Wisconsinan pedogenesis in the Midwestern United States, *in* Wright Jr, H.E., and Porter, S.C., eds., Late Quaternary environments of the United States, volume 1, the late Pleistocene: Minneapolis, University of Minnesota Press, p. 138–144.

Forman, S.L., Bettis, E.A., III, Kemmis, T.J., and Miller, B.B., 1992, Chronologic evidence for multiple periods of loess deposition during the late Pleistocene in the Missouri and Mississippi River valley, United States: Implications for the activity of the Laurentide Ice Sheet: *Palaeogeography, Palaeoclimatology, Palaeoecology*, vol. 93, p. 71–83.

Forman, S.L., and Pierson, J., 2002, Late Pleistocene luminescence chronology of loess deposition in the Missouri and Mississippi River valleys: *Palaeogeography, Palaeoclimatology, Palaeoecology*, vol. 186, p. 25.

Fricke, C.A.P., 1976, The Pleistocene geology and geomorphology of a portion of central-southern Wisconsin: Madison, University of Wisconsin, M.S. thesis, 120 p.

## References

Fricke, C.A.P., and Johnson, T.M., 1983, The Pleistocene stratigraphy and geomorphology of central-southern Wisconsin and part of northern Illinois: *Geoscience Wisconsin*, vol. 8, p. 22–44.

Frolking, T.A., 1978, The upland red clays of the Driftless Area of southwestern Wisconsin: Their genesis, distribution, and geomorphic significance: Madison, University of Wisconsin, M.S. thesis, 175 p.

Frye, J.C., Glass, H.D., Kempton, J.P., and Willman, H.B., 1969, Glacial tills of northwestern Illinois: Illinois Geological Survey Circular 437, 45 p.

Frye, J.C., and Willman, H.B., 1965, Field guide for Illinois, *in* Schultz, C.B., and Smith, H.T.U., eds., Guidebook for field conference C—upper Mississippi valley: International Association for Quaternary Research, 7th Congress, Nebraska Academy of Science, p. 81–110.

Goodwin, R.G., 1976, Vegetation response to the Two Rivers till advance based on a pollen diagram from Kellners Lake, Manitowoc County, Wisconsin: Madison, University of Wisconsin, M.S. thesis, 78 p.

Hallberg, G.R., 1980, Pleistocene stratigraphy in east-central Iowa: Iowa Geological Survey Technical Information Series, no. 10, 168 p.

Ham, N.R., and Attig, J.W., 1997, Pleistocene geology of Lincoln County, Wisconsin: Wisconsin Geological and Natural History Survey Bulletin 93, 31 p.

——— 2004, Preliminary Pleistocene geologic map of Walworth County, Wisconsin: Wisconsin Geological and Natural History Survey Open-File Report 2004-08, 1 color plate, scale 1:100,000.

Hansel, A.K. and Johnson, W.H., 1996, Wedron and Mason Groups: Lithostratigraphic reclassification of deposits of the Wisconsin Episode, Lake Michigan Lobe area: Illinois State Geological Survey Bulletin 104, 116 p.

Helgesen, J.O., and Lindholm, G.F., 1977, Geology and water-supply potential of the Anoka sand-plain aquifer, Minnesota: Minnesota Department of Natural Resources, Division of Waters, Technical Paper Number 6, 17 p.

Hobbs, H.C., 1983, Structure and geomorphology of the St. Croix moraine, Swanville area, Minnesota: Geological Society of America, Abstracts with Programs, vol. 15, no. 4, p. 251.

Hogan, J.D., and Beatty, M.T., 1963, Age and properties of Peorian loess and buried paleosols in southwestern Wisconsin: *Soil Science Society of America Proceedings*, vol. 27, p. 345–350.

Hole, F.D., 1943, Correlation of the glacial border drifts of north-central Wisconsin: *American Journal of Science*, vol. 241, p. 498–516.

——— 1950, Aeolian silt and sand deposits of Wisconsin: Wisconsin Geological and Natural History Survey, page-size map.

Hooyer, T.S., and Mode, W.N., 2009, Quaternary geology of Winnebago County, Wisconsin: Wisconsin Geological and Natural History Survey Bulletin 105, 41 p.

Hooyer, T.S., Mode, W.N., Forman, S., Attig, J.W., and Clayton, Lee, 2003, Assessing the deglacial chronology of the Green Bay Lobe: Evidence from glacial Lake Oshkosh: Geological Society of America, Abstracts with Programs, vol. 35, no. 6, p. 109.

Jacobs, P.M., 1990, Parent materials, paleosols, and the evolution of the Oil City interfluve, Wisconsin: Madison, University of Wisconsin, M.S. thesis, 196 p.

Jacobs, P.M., and Knox, J.C., 1994, Provenance and pedology of a long-term Pleistocene depositional sequence in Wisconsin's Driftless Area: *Catena*, vol. 22, p. 49–68.

Jacobs, P.M., Knox, J.C., and Mason, J.A., 1997, Preservation and recognition of middle and early Pleistocene loess in the Driftless Area, Wisconsin: *Quaternary Research*, vol. 47, p. 147–154.

Jacobs, P.M., and Mason, J.A., 2007, Landscape activity and loess deposition during deglaciation of the Green Bay Lobe land surface: Geological Society of America, Abstracts with Programs, vol. 39, no. 3, p. 16.

Jacobs, P.M., Polk, C.E., and Mason, J.A., 2008, A model for the source and distribution of loess on the Green Bay Lobe land surface, Wisconsin: Geological Society of America, Abstracts with Programs, vol. 40, no. 6, p. 533.

Johnson, M.D., 1980, Origin of the Lake Superior red clay and glacial history of Wisconsin's Lake Superior shoreline west of the Bayfield Peninsula: Madison, University of Wisconsin, M.S. thesis, 108 p.

——— 1984, Glacial geology of Barron County, Wisconsin: Madison, University of Wisconsin, Ph.D. dissertation, 371 p.

——— 1986, Pleistocene geology of Barron County, Wisconsin: Wisconsin Geological and Natural History Survey Circular 55, 42 p.

——— 2000, Pleistocene geology of Polk County, Wisconsin: Wisconsin Geological and Natural History Survey Bulletin 92, 70 p.

Johnson, M.D., Addis, K.L., Ferber, L.R., Hemstad, C.B., Meyer, G.N., and Komai, L.T., 1999, Glacial Lake Lind, Wisconsin and Minnesota, USA: *Geological Society of America Bulletin*, vol. 111, p. 1371–1386.

Johnson, M.D., and Hemstad, C.B., 1998, Glacial Lake Grantsburg: A short-lived lake recording the advance and retreat of the Grantsburg sublobe, *in* Patterson, C.J. & Wright, H.E., Jr. eds., Contributions to Quaternary studies in Minnesota: Minnesota Geological Survey Report of Investigations 49, p. 49–60.

Johnson, T.M., 1976, Surficial geology of a portion of south-central Walworth, County, Wisconsin with planning applications: Madison, University of Wisconsin, M.S. thesis, 104 p.

Johnson, W.H., 1986, Stratigraphy and correlation of the glacial deposits of the Lake Michigan Lobe prior to 14 ka BP: *Quaternary Science Reviews*, vol. 5, p. 17–22.

Johnson, W.H., and Follmer, L.R., 1989, Source and origin of Roxana Silt and middle Wisconsinan midcontinent glacial activity: *Quaternary Research*, vol. 31, p. 319–331.

Kay, G.F., and Graham, J.B., 1943, The Illinoian and post-Illinoian Pleistocene geology of Iowa: Iowa Geological Survey Annual Report 38, p. 1–262.

# References

Kempton, J.P., Berg, R.C., and Follmer, L.R., 1985, Revision of the stratigraphy and nomenclature of glacial deposits in central northern Illinois, *in* Berg, R.C., Kempton, J.P., Follmer, L.R., and McKenna, D.P., eds., Illinoian and Wisconsinan stratigraphy and environments in northern Illinois, the Altonian revisited: Illinois State Geological Survey Guidebook 19, p. 1–19.

Knox, J.C., 1982, Quaternary history of the Kickapoo and lower Wisconsin River valleys, Wisconsin, *in* Knox, J.C., Clayton, Lee, and Mickelson, D.M., eds., Quaternary history of the Driftless Area: Wisconsin Geological and Natural History Survey Field Trip Guide Book 5, p. 1–65.

——— 1989, Long- and short-term storage and removal of sediment in watersheds of southwestern Wisconsin and northwestern Illinois, *in* Hadley, R.F., and Ongley, E.D., eds., Sediment and the environment: International Association of Scientific Hydrology, Publication 184, p. 157–164.

Knox, J.C., and Attig, J.W., 1988, Geology of the Pre-Illinoian sediment in the Bridgeport Terrace, lower Wisconsin River valley: *Journal of Geology*, vol. 96, p. 505–514.

Knox, J.C., Attig, J.W., and Johnson, M.D., 1982, Pre-Wisconsinan deposits in the Bridgeport terrace of the lower Wisconsin River valley, *in* Knox, J.C., Clayton, Lee, and Mickelson, D.M., eds., Quaternary history of the Driftless Area: Wisconsin Geological and Natural History Survey Field Trip Guide Book 5, p. 103–115.

Knox, J.C., Leigh, D.S., and Frolking, T.A., 1990, Rountree Formation (new), *in* Clayton, Lee, and Attig, J.W., eds., Geology of Sauk County, Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 67, p. 64–67.

Knox, J.C., and Maher, L.J., 1974, Late Quaternary environments of the Driftless Area, southwestern Wisconsin: Madison, Wisconsin, American Quaternary Association Guidebook, Field Trip 2, p. 24–43.

Kostka, S.J., Hinke, H.J., Mickelson, D.M., and Baker, R.W., 2004, Preliminary Quaternary geologic map of St. Croix County, Wisconsin: Wisconsin Geological and Natural History Survey Open-File Report 2004-22, 1 color plate, scale 1:100,000.

Kowalke, O.L., 1952, Location of drumlins in the Town of Liberty Grove, Door County, Wisconsin: *Wisconsin Academy of Sciences, Arts and Letters Transactions*, vol. 41, p. 15–16.

Krumm, R.J., and Berg, R.C., 1985, Stratigraphic relationships of the Capron Till Member of the Winnebago Formation, *in* Berg, R.C., Kempton, J.P., Follmer, L.R., and McKenna, D.P., eds., Illinoian and Wisconsinan stratigraphy and environments in northern Illinois, the Altonian revisited: Illinois State Geological Survey Guidebook 19, p. 45–59.

LaBerge, G.L., and Myers, P.E., 1971, Progress report on mapping of Precambrian geology of Marathon County: Wisconsin Geological and Natural History Survey, 27 p.

——— 1983, Precambrian geology of Marathon County, Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 45, 88 p.

Leigh, D.S., 1991, Origin and paleoenvironment of the upper Mississippi valley Roxana Silt: Madison, University of Wisconsin, Ph.D. dissertation, 186 p.

——— 1994, Roxana silt of the upper Mississippi valley: Lithology, source, and paleoenvironment: *Geological Society of America Bulletin*, vol. 106, p. 430–442.

Leigh, D.S., and Knox, J.C., 1993, AMS radiocarbon age of the upper Mississippi valley Roxana Silt: *Quaternary Research*, vol. 39, p. 282–289.

——— 1994, Loess of the upper Mississippi valley Driftless Area: *Quaternary Research*, vol. 42, p. 30–40.

Leigh, D.S., McSweeney, K., and Knox, J.C., 1989, Micromorphology of a "welded" Sangamonian to Wisconsinan age paleosol in southwestern Wisconsin: *Catena*, vol. 16, p. 575–587.

Leverett, F., 1928, Moraines and shorelines of the Lake Superior Basin: U.S. Geological Survey Professional Paper 154-A, 72 p.

——— 1932, Quaternary geology of Minnesota and parts of adjacent states: U.S. Geological Survey Professional Paper 161, 149 p.

Lineback, J.A., 1979, Quaternary deposits of Illinois: Illinois State Geological Survey, map with descriptive legend, scale 1:500,000.

Lineback, J.A., Gross, D.L., and Meyer, R.P., 1974, Glacial tills under Lake Michigan: Illinois State Geological Survey Environmental Geology Note 69, 48 p.

Maher, L.J., Jr., and Mickelson, D.M., 1996, Palynological and radiocarbon evidence for deglaciation events in the Green Bay Lobe, Wisconsin, *Quaternary Research*, vol. 46, p. 251–259.

Maher, L.J., Jr., Miller, N.G., Baker, R.G., Curry, B.B., and Mickelson, D.M., 1998, Paleobiology of the sand beneath the Valders diamicton at Valders, Wisconsin: *Quaternary Research*, vol. 49, p. 208–221.

Markewich, H.W., Wysocki, D.A., Pavich, M.J., Rutledge, E.M., Millard, H.T., Jr., Rich, F.J., Maat, P.B., Rubin, M., and McGeehin, J.P., 1998, Paleopedology plus TL, $^{10}$Be, and $^{14}$C dating as tools in stratigraphic and paleoclimatic investigations, Mississippi River valley, USA: *Quaternary International*, vol. 51/52, p. 143–167.

Mason, J.A., Joeckel, R.M., and Bettis, E.A., III, 2007, Middle to late Pleistocene loess record in eastern Nebraska, USA, and implications for the unique nature of Oxygen Isotope Stage 2: *Quaternary Science Reviews*, vol. 26, p. 773–792.

Mason, J.A., and Knox, J.C., 1997, Age of colluvium indicates accelerated Late Wisconsin hillslope erosion in the upper Mississippi valley: *Geology*, vol. 25, p. 267–270.

Mason, J.A., Nater, E.A., and Hobbs, H.C., 1994, Transport direction of Wisconsinan loess in southeastern Minnesota: *Quaternary Research*, vol. 41, p. 44–51.

Matsch, C.L., 1972, Quaternary geology of southwestern Minnesota, *in* Sims, P.K., and Morey, G.B., eds., Geology of Minnesota: A centennial volume: Minnesota Geological Survey, p. 548–560.

McCartney, M.C., 1979, Stratigraphy and compositional variability of till sheets in part of northeastern Wisconsin: Madison, University of Wisconsin, Ph.D. dissertation, 147 p.

## References

McCartney, M.C., and Mickelson, D.M., 1982, Late Woodfordian and Greatlakean history of the Green Bay Lobe, Wisconsin: *Geological Society of America Bulletin*, vol. 93, p. 297–302.

McKay, E.D., 1979, Wisconsinan loess stratigraphy in Illinois, *in* Follmer, L.R., McKay, E.D., Lineback, J.A., and Gross, D.A., eds., Wisconsinan, Sangamonian, and Illinoian Stratigraphy in Central Illinois: Illinois State Geological Survey Guidebook Series 14, p. 37–67.

Mickelson, D.M., Acomb, L.J., Brouwer, N., Edil, T.B., Fricke, C., Haas, B.J., Hadley, D., Hess, C., Klauk, R., Lasca, N., and Schneider, A.F., 1977, Shoreline erosion and bluff stability along Lake Michigan and Lake Superior shorelines of Wisconsin: Wisconsin Coastal Management, Office of State Planning and Energy, Shore Erosion Study Technical Report, 199 p.

Mickelson, D.M., Clayton, Lee, Baker, R.W., Mode, W.N., and Schneider, A.F., eds., 1984, Pleistocene stratigraphic units of Wisconsin: Wisconsin Geological and Natural History Survey Miscellaneous Paper 84-1, 15 p. plus appendices.

Mickelson, D.M., Clayton, Lee, Fullerton, D.S., and Borns, H.W., Jr., 1983, The Late Wisconsin glacial record of the Laurentide Ice Sheet in the United States, *in* Wright, H.E., Jr., and Porter, S.C., eds., Late Quaternary Environments of the United States, vol. 1, The Late Pleistocene: Minneapolis, University of Minnesota Press, p. 3–37.

Mickelson, D.M., and Evenson, E.B., 1974, Large-scale involutions in red till in the Manitowoc–Two Rivers–Two Creeks area of Wisconsin—Periglacial features or load structures?, *in* Knox, J.C., and Mickelson, D.M., eds., Late Quaternary environments of Wisconsin: American Quaternary Association, Third Biennial Meeting, Madison, p. 182–186.

——— 1975, Pre-Twocreekan age of the type Valders till, Wisconsin: *Geology*, vol. 3, p. 587–590.

Mickelson, D.M., Hooyer, T.S., Socha, B.J., and Winguth, C., 2007, Late-glacial ice advances and vegetation changes in east-central Wisconsin, *in* Hooyer, T.S., ed., Late-glacial history of east-central Wisconsin: Wisconsin Geological and Natural History Survey Open-File Report 2007-01, p. 72–87.

Mickelson, D.M., Nelson, A.R., and Stewart, M.T., 1974, Glacial events in north-central Wisconsin, *in* Knox, J.C., and Mickelson, D.M., eds., Late Quaternary environments of Wisconsin: American Quaternary Association, Third Biennial Meeting, Madison, p. 134–162.

Mickelson, D.M., and Socha, B.J., in press, Quaternary geology of Calumet and Manitowoc Counties, Wisconsin: Wisconsin Geological and Natural History Survey Bulletin.

Mickelson, D.M., and Syverson, K.M., 1997, Quaternary geology of Ozaukee and Washington Counties, Wisconsin: Wisconsin Geological and Natural History Survey Bulletin 91, 56 p.

Mickelson, J.C., 1949, Reclassification of the Pleistocene Loveland Formation of Iowa: Iowa City, University of Iowa, Ph.D. dissertation.

——— 1950, A post-Loveland pre-Iowan loess in western Iowa: *Iowa Academy of Science Proceedings*, vol. 57, p. 267–269.

Miller, J.W., 2000, Glacial stratigraphy and chronology of central southern Wisconsin, west of the Rock River, Wisconsin: Madison, University of Wisconsin, M.S. thesis, 147 p.

Mode, W.N., 1976, The glacial geology of a portion of north-central Wisconsin: Madison, University of Wisconsin, M.S. thesis, 85 p.

Muldoon, M.A, 1987, Hydrogeologic and geotechnical properties of pre-late Wisconsin till units in western Marathon County, Wisconsin: Madison, University of Wisconsin, M.S. thesis, 251 p.

Need, E.A., 1980, Till stratigraphy and glacial history of Wisconsin's Lake Superior shoreline: Wisconsin Point to Bark River: Madison, University of Wisconsin, M.S. thesis, 140 p.

Need, E.A., Johnson, M.D., and Mickelson, D.M., 1981, Till stratigraphy and glacial history along the western shoreline of Wisconsin's Bayfield Peninsula: Geological Society of America, Abstracts with Programs, vol. 13, no. 6, p. 311.

Nelson, A.R., 1973, Age relationships of the Wisconsin valley and Langlade glacial lobes of north-central Wisconsin: Madison, University of Wisconsin, M.S. thesis, 130 p.

North American Commission on Stratigraphic Nomenclature, 2005, North American Stratigraphic Code: *AAPG Bulletin*, vol. 89, p. 1547–1591.

Patterson, C.J., and Johnson, M.D., 2004, The status of glacial mapping in Minnesota, *in* Ehlers, J., and Gibbard, P.L., eds., Quaternary glaciations—extent and chronology, part II: North America: Amsterdam, Elsevier Publishing, p. 119–123.

Peterson, W.L., 1982, Preliminary surficial map of the Iron River 1 x 2° Quadrangle, Michigan and Wisconsin: U.S. Geological Survey Open-File Report 82-301, 18 p.

Pye, K., and Johnson, R., 1988, Stratigraphy, geochemistry, and thermoluminescence ages of lower Mississippi valley loess: *Earth Surface Processes and Landforms*, vol. 13, p. 103–124.

Rawling, J.E., III, Hanson, P.R., Young, A.R., and Attig, J.W., 2008, Late Pleistocene dune construction in the Central Sand Plain of Wisconsin, USA: *Geomorphology*, vol. 100, p. 494–505.

RMT, Inc., 1996, Feasibility report, proposed BFI–M&N landfill, town of Chilton, Calumet County, Wisconsin: Madison, Wisconsin, RMT, Inc.

Ruhe, R.V., 1976, Stratigraphy of mid-continent loess, U.S.A., *in* Mahaney, W.C., ed., The Quaternary stratigraphy of North America: Stroudsburg, Pennsylvania, Dowden, Hutchinson, and Ross, Inc., p. 197–211.

Ruhe, R.V., and Gould, L.M., 1954, Glacial geology of the Dakota County area, Minnesota: *Geological Society of America Bulletin*, vol. 65, p. 769–792.

Schaetzl, R.J., Stanley, K., Scull, P., Attig, J.W., Bigsby, M., and Hobbs, T., 2009, An overview of loess distribution in Wisconsin: Possible source areas and paleoenvironments: Geological Society of America, Abstracts with Programs, vol. 41, no. 4, p. 22.

Schneider, A.F., 1961, Pleistocene geology of the Randall region, central Minnesota: Minnesota Geological Survey Bulletin 40, 151 p.

## References

——— 1981, Late Wisconsinan glaciation of Door County, Wisconsin: Geological Society of America, Abstracts with Programs, vol. 13, no. 6, p. 316.

——— 1983, Wisconsinan stratigraphy and glacial sequence in southeastern Wisconsin. *Geoscience Wisconsin*, vol. 7, p. 59–85.

Shimek, B., 1909, Aftonian interglacial stage, *in* Geology of Harrison and Monona Counties: Iowa Geological Survey Annual Report 20, p. 273–485.

Simpkins, W.W., 1979, Surficial geology and geomorphology of Forest County, Wisconsin: Madison, University of Wisconsin, M.S. thesis, 105 p.

Simpkins, W.W., McCartney, M.C., and Mickelson, D.M., 1987, Pleistocene geology of Forest County, Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 61, 21 p.

Socha, B.J., 2007a, Basal till and tillite: Sedimentary characteristics and inferred sediment sources, mode of transport, depositional environment, and general conditions of the glacier bed: Madison, University of Wisconsin, Ph.D. dissertation, 247 p.

——— 2007b, Evidence of tundra plants overridden by ice approximately 16,000 cal yr BP, Sherwood, Wisconsin, Calumet County, Stop 8, *in* Hooyer, T.S., ed., Late-glacial history of east-central Wisconsin: Wisconsin Geological and Natural History Survey Open-File Report 2007-01, p. 49–52.

Stewart, M.T., 1973, Pre-Woodfordian drifts of north-central Wisconsin: Madison, University of Wisconsin, M.S. thesis, 92 p.

Stewart, M.T., and Mickelson, D.M., 1976, Clay mineralogy and relative age of tills in north-central Wisconsin: *Journal of Sedimentary Petrology*, vol. 46, no. 1, p. 200–205.

Stone, J.E., 1966, Surficial geology of the New Brighton Quadrangle, Minnesota: Minnesota Geological Survey Geologic Map Series 2, 39 p.

Stuiver, M., and Reimer, P.J., 1993, Extended $^{14}$C database and revised CALIB radiocarbon calibration program (version 5.0): *Radiocarbon*, vol. 35, p. 215–230.

Syverson, K.M., 1988, The glacial geology of the Kettle Interlobate Moraine region, Washington County, Wisconsin: Madison, University of Wisconsin, M.S. thesis, 123 p.

——— 2007, Pleistocene geology of Chippewa County, Wisconsin: Wisconsin Geological and Natural History Survey Bulletin 103, 53 p.

Syverson, K.M., Baker, R.W., Kostka, S., and Johnson, M.D., 2005, Pre-Wisconsinan and Wisconsinan glacial stratigraphy, history, and landscape evolution, western Wisconsin, *in* Robinson, L., ed., Field trip guidebook for selected geology in Minnesota and Wisconsin: Minnesota Geological Survey Guidebook 21, p. 238–278.

Syverson, K.M., and Colgan, P.M., 2004, The Quaternary of Wisconsin: A review of stratigraphy and glaciation history, *in* Ehlers, J., and Gibbard, P.L., eds., Quaternary glaciations—extent and chronology, Part II: North America: Amsterdam, Elsevier Publishing, p. 295–311.

——— in press, The Quaternary of Wisconsin: An updated review of stratigraphy, glacial history, and landforms, *in* Ehlers, J., Gibbard, P.L., and Hughes, P.D., eds., Quaternary glaciations—extent and chronology, Part IV—A closer look: Amsterdam, Elsevier Publishing.

Taylor, L.D., 1978, Glacial stratigraphy and clay mineralogy of till and lacustrine units along the east shore of Lake Michigan: Geological Society of America, Abstracts with Programs, vol. 10, no. 6, p. 286.

Thwaites, F.T., 1943, Pleistocene of part of northeastern Wisconsin: *Geological Society of America Bulletin*, vol. 54, p. 87–144.

Thwaites, F.T., and Bertrand, K., 1957, Pleistocene geology of the Door Peninsula, Wisconsin: *Geological Society of America Bulletin*, vol. 68, p. 831–879.

Weidman, S., 1907, The geology of north-central Wisconsin: Wisconsin Geological and Natural History Survey Bulletin 16, 697 p.

Wisconsin Geological and Natural History Survey, 2004, TILLPRO: A digital grain-size database of samples collected in Wisconsin: Wisconsin Geological and Natural History Survey Open-File Report 2004-07, CD-ROM.

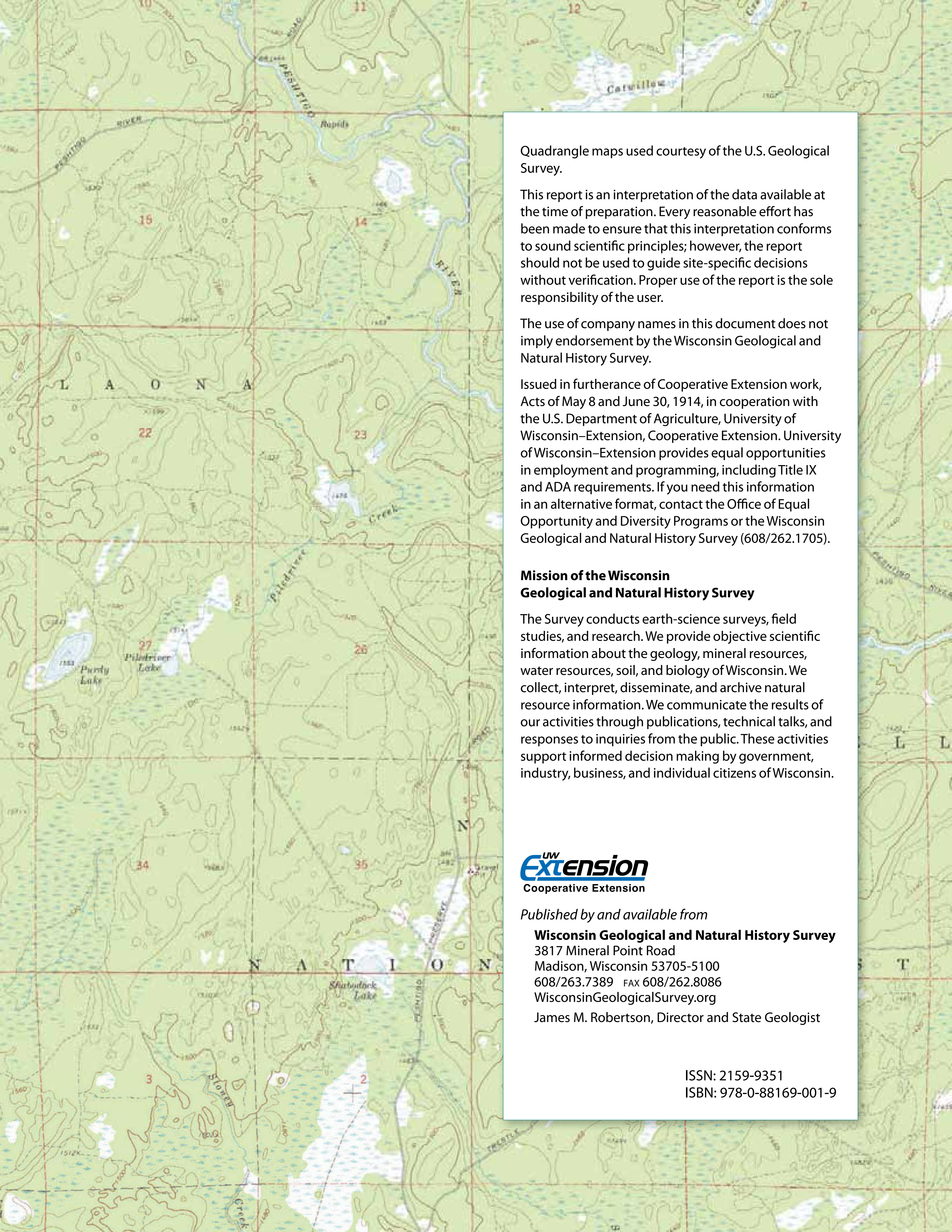
Whittecar, G.R., and Mickelson, D.M., 1979, Composition, internal structures, and an hypothesis of formation for drumlins, Waukesha County, Wisconsin, U.S.A.: *Journal of Glaciology*, vol. 22, p. 357–371.

Willman, H.B., and Frye, J.C., 1970, Pleistocene stratigraphy of Illinois: Illinois State Geological Survey Bulletin 94, 204 p.

Wright, H.E., Jr., 1972, Quaternary history of Minnesota, *in* Sims, P.K., and Morey, G.B., eds., Geology of Minnesota: A centennial volume: Minnesota Geological Survey, p. 515–547.

Wright, H.E., Jr., Matsch, C.L., and Cushing, E.J., 1973, The Superior and Des Moines Lobes, *in* Black, R.F., Goldthwait, R.P., and Willman, G.P., eds., The Wisconsinan Stage: Geological Society of America Memoir 136, p. 153–188.

Wright, H.E., Jr., Mattson, L.A., and Thomas, J.A., 1970, Geology of the Cloquet Quadrangle, Carlton County, Minnesota: Minnesota Geological Survey Geologic Map Series GM-3, 30 p.



Quadrangle maps used courtesy of the U.S. Geological Survey.

This report is an interpretation of the data available at the time of preparation. Every reasonable effort has been made to ensure that this interpretation conforms to sound scientific principles; however, the report should not be used to guide site-specific decisions without verification. Proper use of the report is the sole responsibility of the user.

The use of company names in this document does not imply endorsement by the Wisconsin Geological and Natural History Survey.

Issued in furtherance of Cooperative Extension work, Acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture, University of Wisconsin–Extension, Cooperative Extension. University of Wisconsin–Extension provides equal opportunities in employment and programming, including Title IX and ADA requirements. If you need this information in an alternative format, contact the Office of Equal Opportunity and Diversity Programs or the Wisconsin Geological and Natural History Survey (608/262.1705).

## Mission of the Wisconsin Geological and Natural History Survey

The Survey conducts earth-science surveys, field studies, and research. We provide objective scientific information about the geology, mineral resources, water resources, soil, and biology of Wisconsin. We collect, interpret, disseminate, and archive natural resource information. We communicate the results of our activities through publications, technical talks, and responses to inquiries from the public. These activities support informed decision making by government, industry, business, and individual citizens of Wisconsin.

UW Extension
Cooperative Extension

*Published by and available from*
**Wisconsin Geological and Natural History Survey**
3817 Mineral Point Road
Madison, Wisconsin 53705-5100
608/263.7389 FAX 608/262.8086
WisconsinGeologicalSurvey.org
James M. Robertson, Director and State Geologist

ISSN: 2159-9351
ISBN: 978-0-88169-001-9