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Kent M. Syverson

Wisconsin Geological and Natural History Survey
Bulletin 103 | 2007

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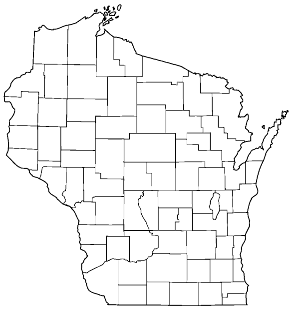

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The Survey conducts earth-science surveys, field studies, and research. We provide objective scientific information about the geology, mineral resources, water resources, soil, and biology of Wisconsin. We collect, interpret, disseminate, and archive 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.

FIGURES

TABLES

PLATES (in back pocket)

Pleistocene Geology of Chippewa County, Wisconsin

Kent M. Syverson

ABSTRACT

Chippewa County was glaciated many times during the Pleistocene Epoch. The earliest known glacial advance was the Reeve Phase, which occurred more than 780,000 years ago. No till of this advance has been found in Chippewa County, but ice flowing from the west dammed the Chippewa River and its tributaries, and rhythmically bedded silty and sandy sediment of the Kinnickinnic Member of the Pierce Formation was deposited in these lakes. After ice wastage and a long period of weathering and erosion, reddish-brown sandy loam till of the River Falls Formation was deposited by the Superior and Chippewa Lobes more than 130,000 years ago during the Foster, Baldwin, and Dallas Phases. Thick gravelly stream sediment was deposited in western Chippewa County as the ice wasted. During the period of weathering that followed, soil-derived clay accumulated in the uppermost 5 m of this stream sediment. Erosion has destroyed the original glacial topography associated with these early glacial phases, and dendritic stream valleys deeply dissect the glacial sediment and Paleozoic bedrock in areas glaciated before the Wisconsin Glaciation.

During the Hamburg Phase in the early part of the Wisconsin Glaciation, the Chippewa Lobe advanced and deposited reddish-brown, sandy loam to loam till of the Merrill Member of the Lincoln Formation in southeastern Chippewa County. Later, the Chippewa Lobe readvanced over the northeastern part of Chippewa County during the last part of the Wisconsin Glaciation from 26,000 to 9,500 years before present and deposited reddish-brown till of the Copper Falls Formation. Ice-wedge casts in Chippewa County indicate that permafrost conditions existed during the early part of this interval.

During the last part of the Wisconsin Glaciation, several phases of the Chippewa Lobe occurred. The earliest advances, the Early Chippewa and Stanley Phases, left few traces in the landscape. The ice margin then receded at least a few kilometers, and the low- to moderate-relief Perkinstown moraine was formed in eastern Chippewa County during the Perkinstown Phase. During the Late Chippewa Phase, the Chippewa Lobe flowed into western Chippewa County and formed the high-relief Chippewa moraine. Water from the melting ice deposited an extensive outwash plain along the Chippewa River system. The Perkinstown and Chippewa moraines contain hummocks, kettles, ice-walled-lake plains, and eskers as well as one tunnel channel. A decrease in the amount of sediment supplied to the Chippewa River system near the termination of the Wisconsin Glaciation caused major incision of the Chippewa River and its tributaries. A well defined series of terraces formed, the highest of which is the Wissota terrace.

INTRODUCTION

General setting

Chippewa County lies within the Chippewa River drainage basin of west-central Wisconsin (figs. 1 and 2). The county is just north of the unglaciated Driftless Area of southwestern Wisconsin, but all Chippewa County was glaciated many times during the Pleistocene Epoch (figs. 1 and 3). The western and southern parts of the county were glaciated prior to the last part of the Wisconsin Glaciation, and in these areas stream dissection of the glacial sediment and Paleozoic bedrock strongly influence the topography. The Chippewa Lobe covered the northeastern third of the county during the last part of the Wisconsin Glaciation, and the thickness of glacial sediment is the dominant control on the landscape there (fig. 4A). The geologic map (plate 1) shows sediment types, distributions, and ages of these earth materials. Elevations in the county range from 240 to 470 m (790 to 1,540 ft). Local relief in the county is generally between 10 and 70 m. The physiography of Chippewa County can be divided into ten landscape regions, as shown in figure 2.

Sources of information

U.S. Geological Survey 7.5-minute topographic maps were the primary base maps for field work. More than 3,500 domestic well construction reports were plotted on the topographic maps for reference. I also used aerial photographs (photograph scale, 1:20,400), and the Chippewa County soil survey (Jakel and Dahl, 1989) to construct a preliminary 1:24,000-scale surficial glacial geology map.

I spent eight months conducting field work in Chippewa County during the years 1998, 1999, and 2000. I drove all roads and examined building excavations, roadcuts, gravel pits, and rock quarries. Hand augering, generally to a depth of 1.2 m, was used to collect additional information. Soil profiles were described and measured in outcrops and boreholes using standard soil-description parameters. Staff of the Wisconsin Geological and Natural History Survey used a drill rig to bore 63 holes in critical areas during the summers of 1996 to 2000 (depths ranging from 1.5 to 24 m; locations are plotted on plate 1). I modified contacts on maps in the field as appropriate and compiled them at the publication scale (plate 1).

Sediment samples were analyzed in the University of Wisconsin–Madison Department of Geology and Geophysics Quaternary Laboratory. Grain size was determined by the sieve and hydrometer method using 2 mm, 0.0625 mm, and 0.002 mm boundaries for sand, silt, and clay (Grender and Sutherland, 1989). Sediment grain sizes for the less-than 2 mm fraction are reported using U.S. Department of Agriculture terminology. Field colors were measured using a Munsell soil color chart. Carbonate content was determined using the Chittick method. Magnetic susceptibility (in dimensionless SI units) was measured with a Bison 3101A magnetic susceptibility meter; magnetic susceptibility was also measured for some archived till samples at the University of Wisconsin–Madison Department of Geology and Geophysics. I also collected University of Wisconsin–Madison Quaternary Laboratory till data from published and unpublished glacial geology studies elsewhere in northern Wisconsin. Grain-size, carbonate, magnetic susceptibility, and lithostratigraphy data for regional till units were organized in a database for comparison to Chippewa County sediment (Mace and others, 2000; Treague and Syverson, 2002).

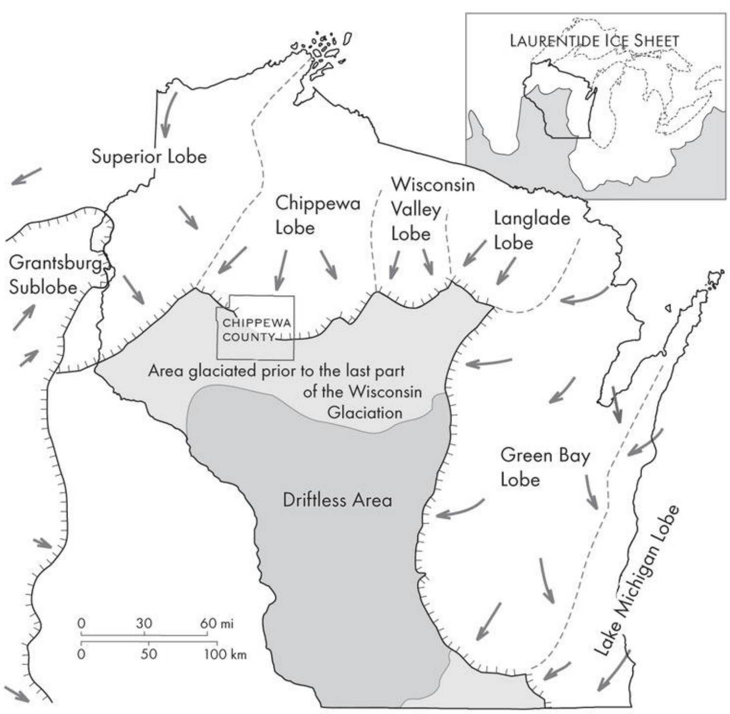
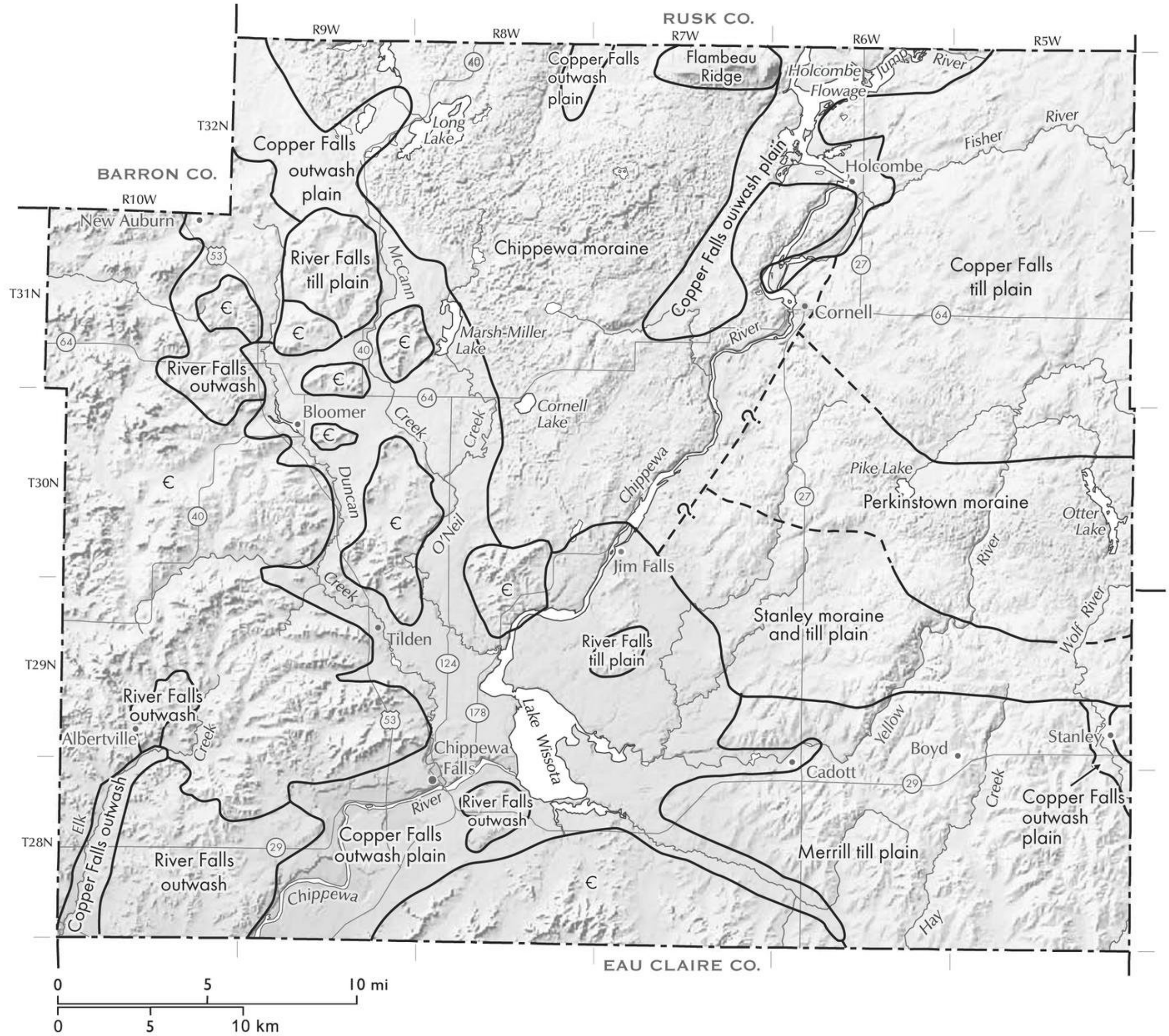


Figure 1. Location of Chippewa County, Wisconsin, in relation to the maximum extent of the Laurentide Ice Sheet during the last part of the Wisconsin Glaciation. Arrows indicate direction of ice flow.

▶ **Figure 2.** Landscape regions, villages, and major drainages in Chippewa County. The western extents of the Stanley moraine and till plain and the Perkinstown moraine are uncertain.

Flambeau Ridge. Ridge is 2 km wide, 7 km long, and trends east to west near Holcombe. Flambeau Ridge is the highest place in the county (470 m [1,540 ft]), and it also has the highest local relief (150 m) of the county. Composed of resistant Precambrian quartzite and metaconglomerate, it was a major obstacle to the glacial flow that strongly influenced landform development.

Cambrian sandstone uplands (Є). Uplands underlain by fine- to coarse-grained, shaly Cambrian sandstone with little or no overlying glacial sediment. These high-relief areas have deep stream valleys and steep slopes.



River Falls till plain. Extensively eroded till surfaces underlain by till of the River Falls Formation and Cambrian sandstone.

River Falls dissected outwash. Extensively weathered and eroded meltwater stream sediment of the River Falls Formation. Sediment is cobble rich and up to 35 m thick, although the thickness is extremely variable and bedrock outcrops are common in this landscape region.

Merrill till plain. Rolling till surface in southeastern Chippewa County that exhibits streamlined glacial hills trending north to south. This area has thin till of the Merrill Member of the Lincoln Formation overlying bedrock.

Stanley moraine and till plain. East–west trending zone of relatively fresh, low-relief hummocky to rolling topography. This area is underlain by till and gravity-flow sediment of the Copper Falls Formation.

Perkinstown moraine. A 5 to 9 km wide, low- to moderate-relief hummocky moraine extending from Otter Lake to Cornell. The Perkinstown moraine is underlain by till, gravity-flow sediment, and lake sediment of the Copper Falls Formation.

Chippewa moraine. A high-relief, hummocky moraine up to 16 km wide. The Chippewa moraine is underlain by till, gravity-flow sediment, and lake sediment of the Copper Falls Formation.

Copper Falls till plain. Rolling, streamlined till surface with relief up to 10 m. This area is underlain by till of the Copper Falls Formation.

Copper Falls outwash plain. The valleys of the Chippewa River, Duncan Creek, McCann Creek, and O'Neil Creek contain major outwash plains underlain by meltwater stream sediment of the Copper Falls Formation. These outwash plains preserve the original stream surface and are incised by modern streams. The Wissota terrace, the highest outwash plain level, grades to the Chippewa and Perkinstown moraines.

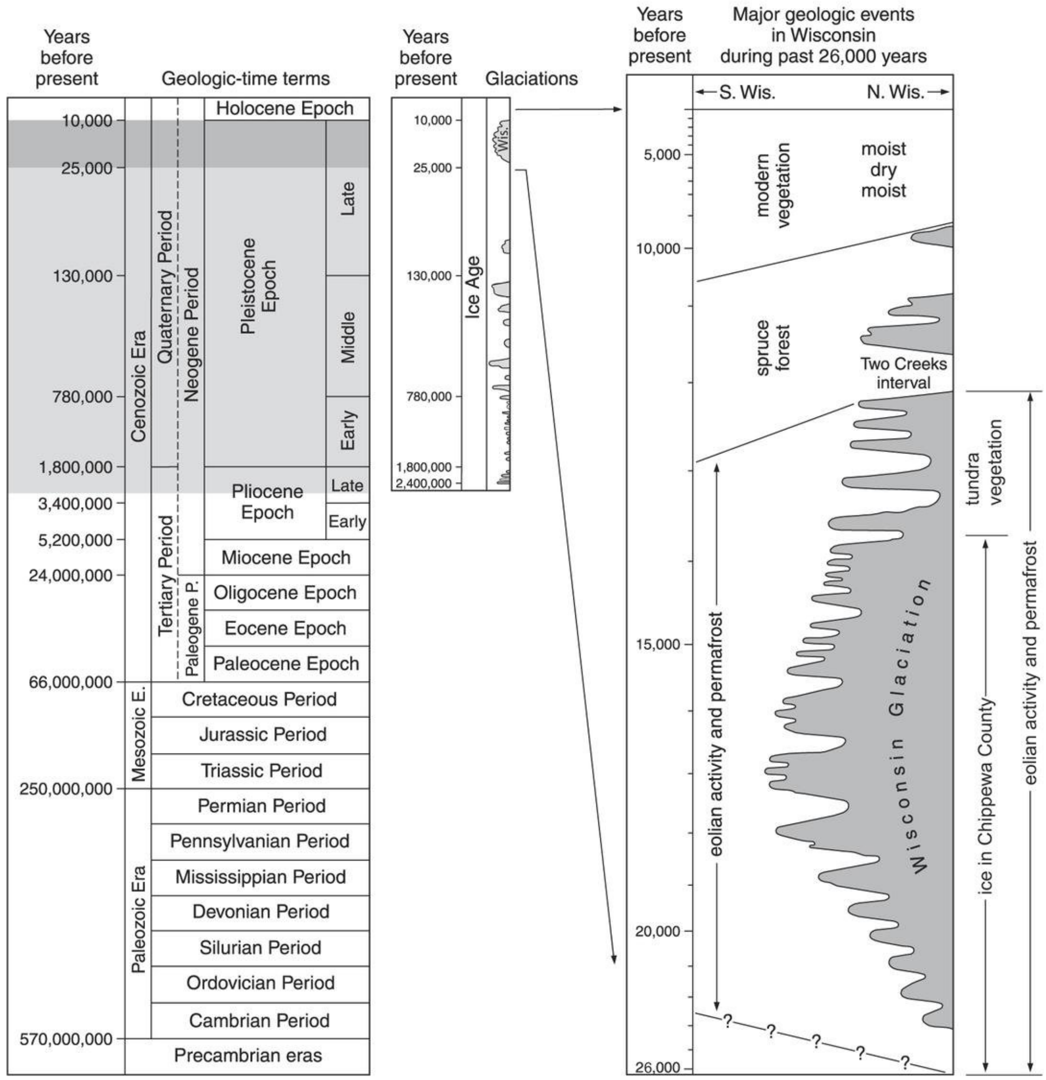


Figure 3. Geologic time scale (modified from Clayton and others, 2006). Geologic time terms are given in the left part of the diagram. The center column shows times of major glaciations during the past 2.5 million years, based on oxygen isotopes in deep sea sediment. Some of the less extensive glaciations may not have reached Wisconsin. The past 26,000 years is expanded in the right column, which shows the phases of the last part of the Wisconsin Glaciation and the conditions south of the glacier. The horizontal axis represents the approximate distance from southern to northern Wisconsin, and the curves represent the ice-margin position at any given time. The time of ice cover in Chippewa County during the last part of the Wisconsin Glaciation is indicated.

Many workers in western and central Wisconsin have used clay mineralogy to investigate till stratigraphy, but they have used a variety of methods that make quantitative comparisons impossible (Stewart and Mickelson, 1976; Baker and others, 1983; Johnson, 1986; Sutherland, 1989). I collected till samples during this study, and I was also granted access to samples from prior studies conducted elsewhere in western and north-central Wisconsin. The clay minerals in these till samples were evaluated using internally consistent laboratory procedures to collect data from which direct clay mineralogy comparisons could be made. Semi-quantitative clay mineralogy determinations were conducted on the less-than 1 µm clay fraction using methods outlined in Moore and Reynolds (1997). Vacuum-mounted, oriented clay mineral samples were analyzed using the Rigaku Biplanar D-MaxB Automated Powder Diffraction diffractometer with CuKα radiation at the University of Wisconsin–Eau Claire Geochemistry Laboratory (Thornburg and others,

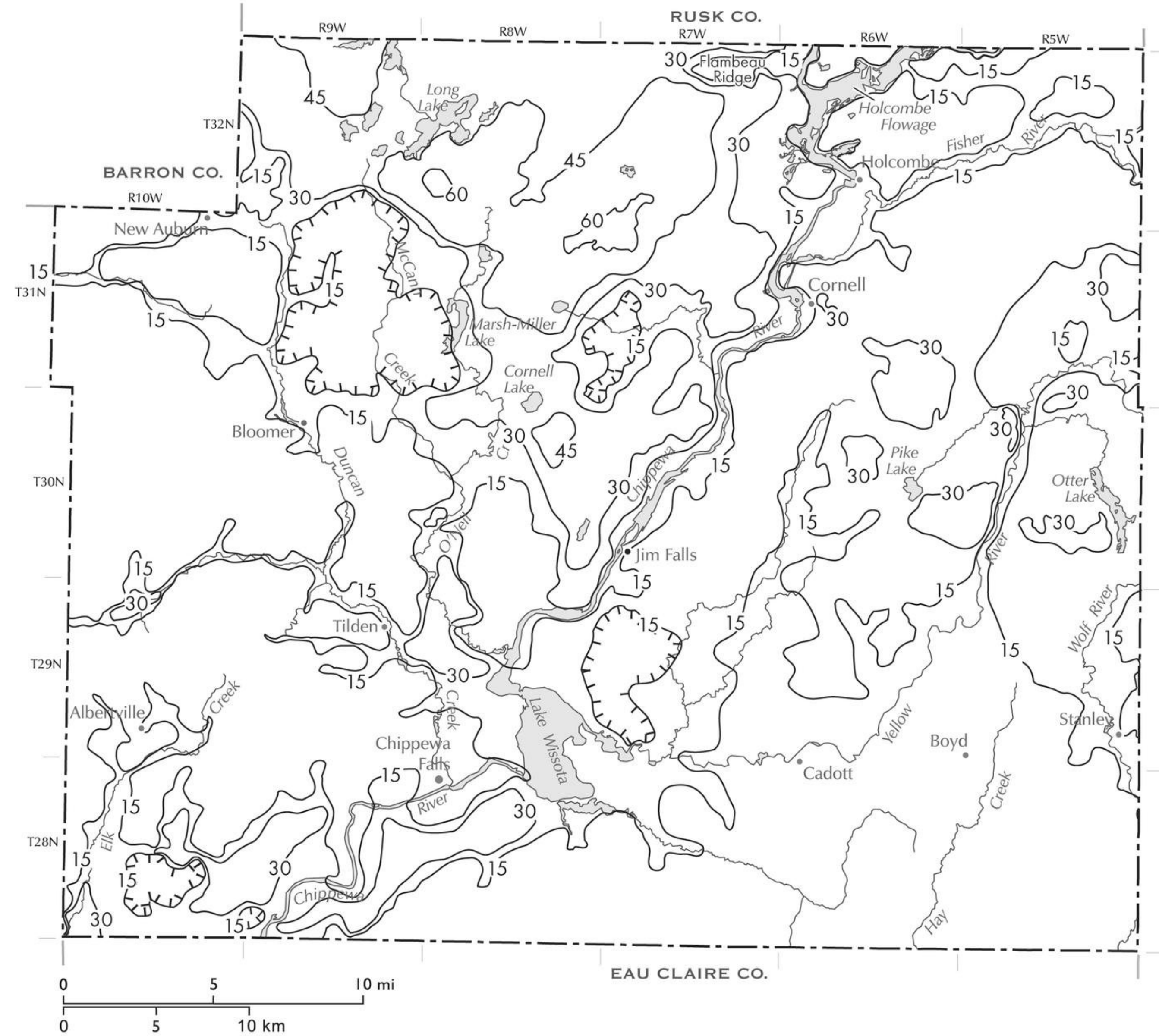


Figure 4. A. Thickness of Pleistocene sediment over bedrock in Chippewa County. Contour interval, 15 m. Flambeau Ridge is indicated. Hachured areas indicate closed depressions. Modified from Lippelt (1988b), using borings from this study.

2000). Mounts were scanned using air-dry conditions, ethylene glycol solvation, and acid digestions. Peak intensities were deconvoluted using JADE (v. 3.1) and mineral intensity factors determined using NEWMOD (v. 2.02). All clay mineral values were normalized to 100 percent.

Previous work

The Laurentide Ice Sheet entered Chippewa County during the most recent glaciation, and this ice shaped the northern and eastern parts of the county, where landforms are relatively fresh and young, but not the western and southern parts of the county, where older glacial deposits are deeply eroded (fig. 2). The earliest studies in westernmost Wisconsin (Strong, 1882; Wooster, 1882; T.C. Chamberlin, 1883; R.T. Chamberlin, 1905, 1910; Leverett, 1932; Mathiesen, 1940) and north-central Wisconsin (Weidman 1907, 1913; Hole, 1943) developed a broad understanding of the glacial stratigraphy, provenance, and history represented by these units. Subsequent studies have built upon the work of earlier researchers and incorporated these units into a

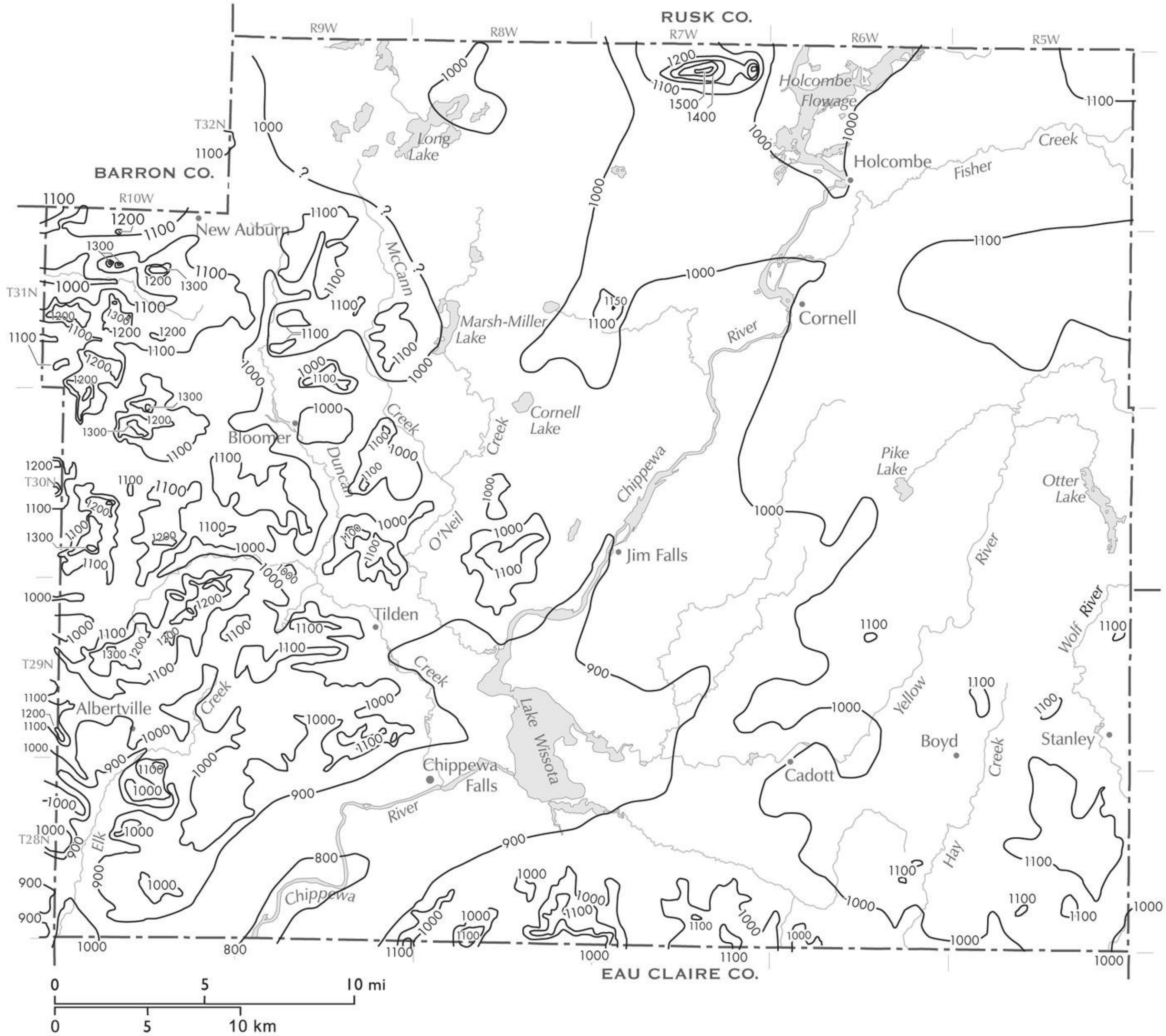


Figure 4 *(continued)*. **B.** Elevation of bedrock surface in Chippewa County, based on field observations, domestic well construction reports, and boreholes. Contour interval, 100 ft (30 m).

new lithostratigraphic framework for glacial deposits in Wisconsin (Mickelson and others, 1984; Attig and others, 1988; Johnson, 2000).

Recent glacial geology research near the county has focused on areas to the west near the Minnesota border and to the east in north-central Wisconsin. To the west, events of the Superior, Des Moines, and Chippewa Lobes have been described by Baker and others (1983, 1987), Clayton (1984), Johnson (1984, 1986, 1999, 2000), Johnson and others (1995), Johnson and Mooers (1998), Hinke (2003), and Syverson and others (2005). To the east, numerous researchers have refined the till stratigraphy and our understanding of the glacial history (Stewart, 1973; Stewart and Mickelson, 1976; Mode, 1976; Attig and Muldoon, 1989; Sutherland, 1989; Clayton, 1986, 1991; Attig, 1993; Ham and Attig, 1996a, 1997; Attig and others, 1998). The permafrost history of the region has been addressed by Black (1965, 1976a), Johnson (1986), Holmes and Syverson (1997), and Clayton and others (2001).

The glacial geology of Chippewa County has been explored by some workers. Mathiesen (1940) studied three townships in northwestern Chippewa County, and Andrews (1965) analyzed outwash terraces along the Chippewa River. The geomorphology of the Chippewa moraine has been studied by Black (1974), Cahow (1976), Syverson (1998b), and Syverson and others (2005). The origin of the high-relief Chippewa moraine and its relationship to ice-flow events during the last part of the Wisconsin Glaciation have been discussed by Ham and Attig (1996a, b), Attig and Ham (1997), Attig and others (1998), Waggoner and others (2001), and Syverson and others (2005). Lippelt (1988a, b) mapped the thickness of Pleistocene sediment as well as water-table elevations in Chippewa County.

Reliability of map and cross sections

All reasonable efforts have been taken to make the geologic contacts in plate 1 as accurate as possible. However, contact reliability is a function of the number of distinctive landforms, outcrops, gravel pits, or drillcores in an area. Contacts far from roads or accessible outcrops may be less accurate and have been interpreted on the basis of landscape morphology (determined from map and aerial photograph interpretation) and outcrops underlying similar landscapes.

Two cross sections were prepared (see plate 1 for locations). Surface topography was taken from digital versions of U.S. Geological Survey 7.5-minute topographic maps. Domestic well constructor's reports and drillcores 2 km on either side of a section line were used to draw the cross sections. Cross sections are not intended for site-specific determinations of the subsurface geology, but rather are intended to provide a generalized interpretation of the materials in that part of the county.

Acknowledgments

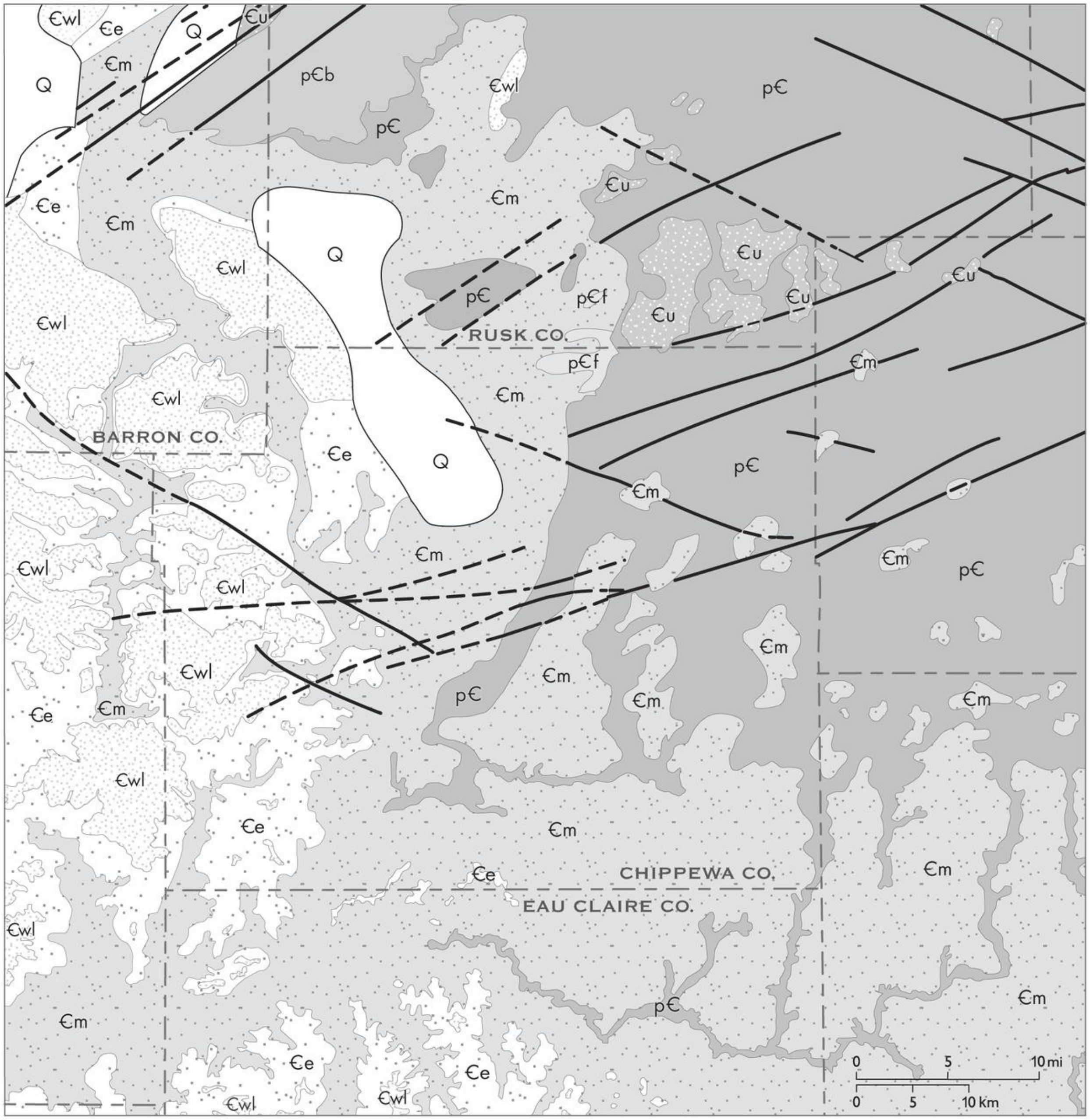
I thank Mark Johnson, Robert Baker, Adam Cahow, and David Mickelson for helpful discussions in the field; William Mode, Robert Baker, Nelson Ham, and Mark Johnson for supplying till samples and data; John Attig and William Mode for input at meetings; University of Wisconsin–Eau Claire undergraduate students Peter Bement, Kristie Franz, Kristen Hanson, Mark Holmes, Jeff Schels, Heather Spehle, Katie Thornburg, and Maria Waggoner for field research contributions to this project; William Batten and Scott Isberner for drilling support; Amy Jo Steffen, Katie Thornburg, and Robert Hooper for help with clay mineralogy; Kathleen Finder, Tyler Mace, Jeremy Treague, and Timothy Cummings for assistance with the till database; Daniel Masterpole, Richard Magyar, Joan Schemenauer, and Nancy Amdahl for logistical support; Deborah Patterson for production of plates 1 and 2; Gene Leisz, Richard Mickelson, and Debra Blanchard for assistance with figures; Susan Hunt for final graphics production and report layout; and Mark Johnson, Lee Clayton, Robert Baker, and Thomas Evans for their careful and complete reviews of the manuscript and map. Major funding for this project came from the Wisconsin Geological and Natural History Survey and the Chippewa County Land Conservation Department. Additional funding was provided by University of Wisconsin–Eau Claire Research and Creative Activity grants, Summer Research Experiences for Undergraduates grants, and the Sabbatical Leave Program. Lastly, I thank my wife, Lila Syverson, for giving me four summers to work on this project. To all of you, I am indebted for your help to complete this report.

PRE-PLEISTOCENE GEOLOGY

Pleistocene sediment in Chippewa County covers a deeply incised bedrock surface with more than 150 m of relief in places (fig. 4B). Precambrian metamorphic and igneous rock is exposed in Flambeau Ridge and in the major river valleys (fig. 3). This rock is overlain by Paleozoic sedimentary rock units and Pleistocene glacial sediment in much of the rest of the county (figs. 3 and 5) (Mudrey and others, 1987; Brown, 1988).

Precambrian rock

The oldest Precambrian rock units are exposed in the valleys of the Chippewa and Yellow Rivers and their tributaries, especially below the major dams on the Chippewa River at Chippewa Falls, Lake Wissota, Jim Falls, and Holcombe (Myers and others, 1980). The units are a part of



Q — Quaternary glacial sediment; too thick to determine type of bedrock

Єwl — Cambrian sandstone and shaly, glauconitic sandstone of the Wonewoc and Lone Rock Formations. Includes Eau Claire Formation where its outcrop pattern is too narrow to show.

Єe — Cambrian Eau Claire Formation, shaly sandstone

Єm — Cambrian Mount Simon Formation, sandstone, conglomerate, and shale

Єu — Cambrian sedimentary rock, undifferentiated

pЄf — Precambrian Flambeau Quartzite

pЄb — Precambrian Barron Quartzite

pЄ — Precambrian metamorphic and igneous rock units, undifferentiated

Fault, dashed where uncertain

Geologic contact

Figure 5. Generalized bedrock geology map of the Chippewa County region. Modified from Mudrey and others (1987) and Brown (1988).

the Wisconsin magmatic terrane, a sequence of Archean felsic gneisses and amphibolite, along with lesser amounts of Early Proterozoic metavolcanic and metasedimentary rocks, that were accreted to the proto-North American continent during the Penokean Orogeny. The Penokean Orogeny occurred approximately 1,850 Ma (million years ago), when a volcanic island arc collided with the proto-North American continent and formed mountains in a zone from central Minnesota to Michigan (Sims and Schultz, 1996; Holm and others, 1998a). The collision metamorphosed and deformed the rock, caused injection of granitic dikes, and then folded and faulted these units. Typical Precambrian rock units and related structures are accessible south of the abandoned County Highway Y bridge near Jim Falls (Myers and Maercklein, 1980). Erosional processes over millions of years reduced the elevation of the mountains.

The Flambeau Quartzite unconformably overlies Penokean rock and forms the 150 m high Flambeau Ridge west of Holcombe (figs. 2 and 6; plate 1). This Precambrian unit is approximately 700 m thick and contains extremely hard, cross-bedded, and maroon to pale-orange conglomeratic quartzite. Clasts with diameters up to 5 cm are composed of slate, white vein quartz, red granular iron formation, and pale-green metavolcanic rock. The Flambeau Quartzite contains more conglomerate and is more tightly folded (with a nearly vertical southern limb) than the relatively undeformed Barron Quartzite in Rusk and Barron Counties to the northwest (fig. 5; Campbell, 1986; LaBerge and others, 1991). Recent work has confirmed that the Flambeau, Barron, and Baraboo Quartzites were deposited in a shallow sea or in braided streams during the "Baraboo Interval" between 1,750 and 1,630 Ma (Holm and others, 1998b; Medaris and Dott, 2001). The Flambeau Quartzite was deformed during a plate collision to the south associated with the Mazatzal Orogeny (1,650 to 1,630 Ma), and the Barron Quartzite lay just outside the zone of deformation (Holm and others, 1998b; Romano and others, 2000).

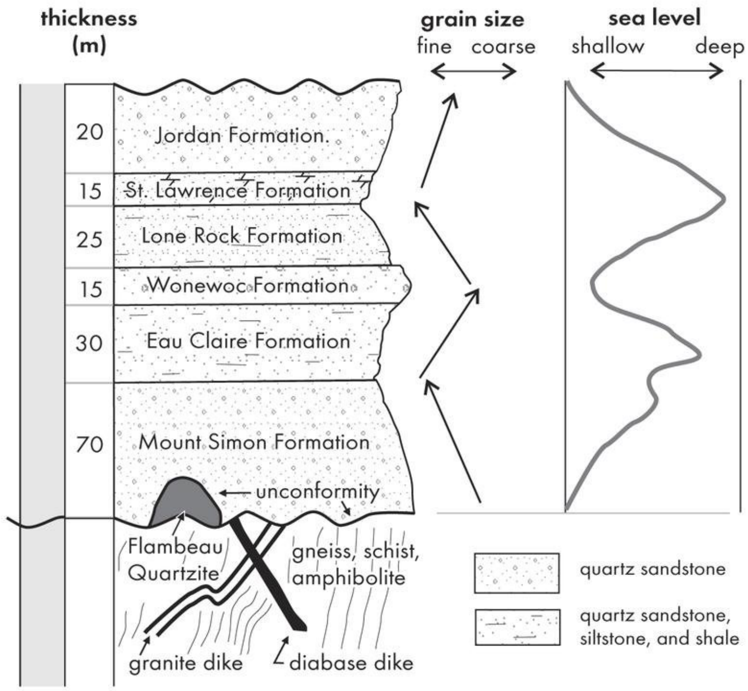


Figure 6. Simplified geologic column illustrating the Precambrian and Cambrian bedrock units in Chippewa County. The unconformity between the Precambrian and Cambrian rock formed during more than 1 billion years of net erosion. Thicknesses are representative for the area; sea level curve is schematic. Modified from Ostrom (1978) and Havholm (1998).

Diabase dikes that are associated with the 1,100 Ma midcontinental rifting event also are found in the county. These dikes trend northeast to southwest, are up to 50 m wide, and are well exposed downstream from the Wissota dam (Myers and others, 1980; Underwood and Miller, 1997).

A long period of stability and erosion followed. The erosionally resistant Flambeau Quartzite became the high Flambeau Ridge, which later exerted a strong control on glacial flow and landform development (see section entitled *Origin of the high-relief Chippewa moraine)*.

Precambrian–Cambrian unconformity

The unconformity between the Precambrian rock and the overlying Cambrian Mount Simon Formation represents a period of net erosion approximately 1,300 million years long (fig. 6). This unconformity is best exposed in Irvine Park in Chippewa Falls (Ostrom, 1987). Pale green clay (commonly called "soap rock" by well drillers) marks the top of the unconformity in places and grades downward into unaltered Precambrian rock. The clay might be saprolite (a soil-derived chemical weathering product) formed during the last part of the Precambrian Era and earliest part of the Cambrian Period (fig. 3; Duffin, 1989). However, because the geochemistry of the pale green clay does not suggest the action of soil-forming processes, hot fluids expelled from neighboring sedimentary basins after the development of the Precambrian–Cambrian unconformity might have chemically altered the Precambrian rock (Bethke, 1986; Haupt and Hooper, 1994; Hooper, 1998). Springs are commonly found at the unconformity because groundwater seeping downward through the permeable Mount Simon Formation cannot easily penetrate the low-permeability Precambrian rock.

Paleozoic rock

Paleozoic rock units in Chippewa County represent multiple fluctuations in sea level on the North American continent during the earliest part of the Paleozoic Era (figs. 3 and 6). Seas transgressed across the county during the Cambrian Period approximately 520 Ma, and sand was deposited in shallow water over the Precambrian rock units in the area. The sand is pebbly and coarse grained with cross-beds up to 1 m high near the base, but is finer and more shaly toward the top part of the formation. The sandstone is included in the Mount Simon Formation and is an important aquifer for domestic and municipal water supplies in Chippewa County.

As sea level continued to rise, the Eau Claire Formation was deposited above the Mount Simon (fig. 6). The Eau Claire is exposed in the westernmost part of the county (fig. 5) and contains pale brown, fine-grained sandstone, greenish-gray siltstone and shale, numerous trace fossils, and marine fossils such as brachiopods and trilobites (Havholm, 1998; Havholm and others, 1998). The sand grades upward from the lower part of the Eau Claire Formation into the fine- to coarse-grained sandstone of the Wonewoc Formation (fig. 6). This represents a relative decrease in sea level and deposition of sand in shallower water.

Sea level once again began to rise and the finer-grained Lone Rock and St. Lawrence Formations were deposited above the Wonewoc (fig. 6). The Lone Rock contains thin- to medium-bedded, fine-grained glauconitic sandstone interbedded with green-gray shale. The St. Lawrence Formation is very thin (to absent) in the area and contains thin-bedded, fine-grained sandstone, siltstone, and shale where present (Havholm, 1998). The Jordan Formation, a fine- to coarse-grained sandstone, is found more commonly west of Chippewa County, but it may underlie the highest bedrock hills in the westernmost part of the county (Mudrey and others, 1987; Brown, 1988).

Many other types of sedimentary rock must have been deposited in Chippewa County after the Cambrian Period, but over millions of years, dendritic streams have eroded and deeply dissected the entire Paleozoic section. Erosion in the eastern part of the county has removed most of the Paleozoic rock once located above the Precambrian basement (fig. 5). In the rest of the county, the Chippewa and Yellow Rivers have cut through the Paleozoic rock and tend to follow the Precambrian and Paleozoic rock contact, which dips to the west at approximately 2.3 m/km (12 ft/mi, see cross-section A–A′, plate 2; Mudrey and others, 1987; Brown, 1988).

PLEISTOCENE GEOLOGY

Pleistocene sediments cover much of the land surface in Chippewa County (fig. 4A; plate 1). These sediments are important for agricultural uses, engineering applications, aggregate resource development, and groundwater management. Four lithostratigraphic units are represented in the county (fig. 7). Each will be discussed separately, starting with the oldest formation.

Kinnickinnic Member of the Pierce Formation

Lacustrine sediment of the Kinnickinnic Member of the Pierce Formation is present in major river valleys of western Wisconsin, including the Chippewa River and Elk Creek valleys of Chippewa County. Although I did not observe the Kinnickinnic at the surface during this study, domestic well construction reports in the Elk Creek valley show that 15 to 25 m of this sediment is buried by approximately 16 m of sandy stream sediment. The following description is based on work by Baker and others (1983) and Baker (1984a, b) in areas to the west and south of Chippewa County.

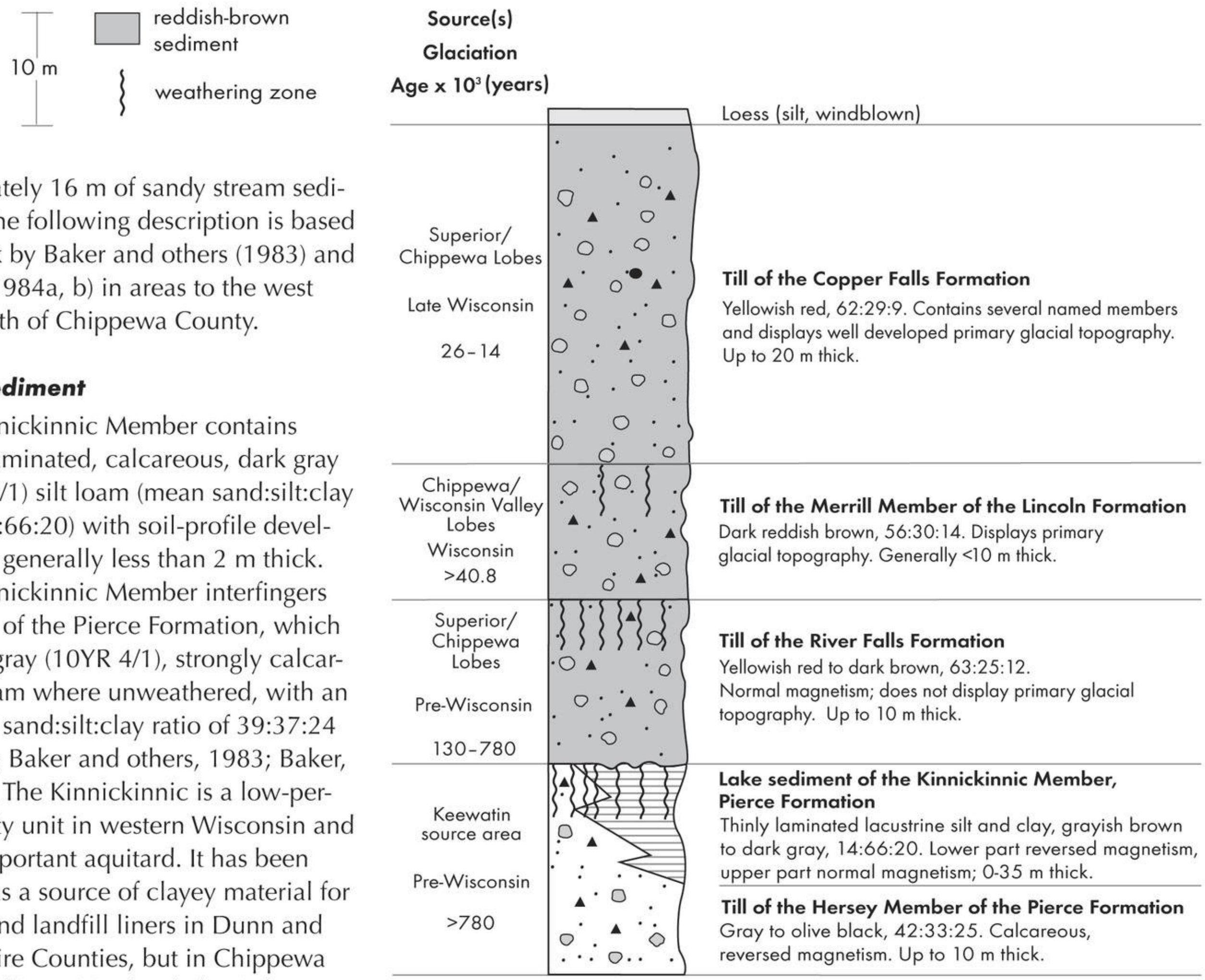


Figure 7. Glacial lithostratigraphy in the Chippewa County region (modified from Syverson and Colgan, 2004). The Keewatin source area was to the northwest near Winnipeg and associated with the Keewatin ice dome. Proposed ages for units are also shown. Vertical scale is approximate; mean grain size is reported as sand:silt:clay percentages.

Lake sediment

The Kinnickinnic Member contains thinly laminated, calcareous, dark gray (10YR 4/1) silt loam (mean sand:silt:clay ratio 14:66:20) with soil-profile development generally less than 2 m thick. The Kinnickinnic Member interfingers with till of the Pierce Formation, which is dark gray (10YR 4/1), strongly calcareous loam where unweathered, with an average sand:silt:clay ratio of 39:37:24 (table 1; Baker and others, 1983; Baker, 1984b). The Kinnickinnic is a low-permeability unit in western Wisconsin and is an important aquitard. It has been mined as a source of clayey material for bricks and landfill liners in Dunn and Eau Claire Counties, but in Chippewa County this unit is deeply buried.

Glacial history

The history of the lake sediment of the Kinnickinnic Member is intimately associated with that of the till of the Pierce Formation. Keewatin ice flowing from the Winnipeg region advanced from the northwest and deposited sediment of the Pierce Formation in western Wisconsin (Baker and others, 1983; Mickelson and others, 1984; Johnson, 1986; Attig and others, 1988; Syverson and others, 2005). This ice crossed Cretaceous shale and deeply weathered crystalline rock—both sources of the clay mineral kaolinite (Morey and Setterholm, 1997)—as well as Paleozoic limestone. Thus, till of the Pierce Formation is gray, calcareous, and has an elevated percentage of kaolinite (Baker and others, 1983; Thornburg and others, 2000; Syverson and others, 2005; table 1).

Keewatin ice flowed southeast across the Mississippi River, as shown by the easterly extent of the Pierce till in Barron and Dunn Counties (Johnson, 1986). This ice blocked major tributaries of the Mississippi River, such as the Chippewa and Red Cedar Rivers, and large ice-dammed lakes formed (fig. 8; Baker and others, 1983). The silty and clayey lake sediment of the Kinnickinnic Member has been observed at elevations up to 366 m (1,200 ft) within the Rush River drainage of northeastern Pierce County (Baker, 1984a; R.W. Baker, University of Wisconsin–River Falls, verbal communication, 2002). On the basis of lake-sediment elevations and the number of annual layers in the sediment, Baker (1984a) esti-

Table 1. Summary of till characteristics in Chippewa County and the region outside of Chippewa County. Chippewa County values (in italics) and regional values are provided. Clay mineralogy data are from Thornburg and others (2000). All grain-size and magnetic susceptibility analyses were performed at the University of Wisconsin–Madison Quaternary Laboratory.

Lithostratigraphic unit	Sand:silt:clay percentage (n)	Magnetic susceptibility (SI units) (n)	Clay mineralogy[1] (K:I:S:V %) (n)	V:K ratio ±std dev (n)	Munsell color
Copper Falls Formation (Chippewa County)	*62:29:9 (60)*	*2.9×10^{-3} (59)*	*4:30:43:23 (5)*	*6.0±3.9 (5)*	*Reddish brown to brown (5YR 4/4 to 7.5YR 4/4)*
Copper Falls Formation	68:22:10 (425)	2.9×10^{-3} (387)	7:45:28:19 (6)	4.3±2.6 (6)	Reddish brown to brown (5YR 4/4 to 7.5YR 4/4)
Merrill Member Lincoln Formation (Chippewa County)	*56:30:14 (64)*	*1.8×10^{-3} (64)*	*6:31:38:25 (13)*	*4.7±1.9 (13)*	*Reddish brown to brown (5YR 4/4 to 7.5YR 4/4)*
Merrill Member Lincoln Formation	55:31:14 (87)	2.6×10^{-3} (71)			Reddish brown to strong brown (5YR 4/3 to 7.5YR 4/6)
River Falls Formation (Chippewa County)	*63:25:12 (37)*	*1.7×10^{-3} (37)*	*19:26:37:17 (15)*	*1.0±0.6 (15)*	*Reddish brown to yellowish red (5YR 4/4-6)*
River Falls Formation	69:19:12 (51)	1.3×10^{-3} (38)	15:31:34:20 (12)	1.7±1.4 (12)	Reddish brown to yellowish red (5YR 4/4-6)
Marathon Formation	40:41:19 (359)	1.5×10^{-3} (352)	8:21:54:17 (9)	2.3±1.0 (9)	Yellowish brown to gray (10YR 5/6 to 2.5Y 5/1) and reddish brown (5YR 4/4)
Pierce Formation	39:37:24 (41)	1.1×10^{-3} (38)	23:25:40:12 (13)	0.5±0.1 (13)	Dark gray to yellowish brown (10YR 4/1 to 10YR 5/4)

[1] Clay minerals: K = kaolinite, I = illite; S = smectite; V = vermiculite

mated that the lakes might have covered an area of 5,800 km^2 for more than 1,200 years. Several domestic well construction reports show the Kinnickinnic lake sediment in southwestern Chippewa County extending to an elevation of 259 m (850 ft), so the former lake surface in the Elk Creek and Chippewa River valleys was at least that high. The absolute lake-surface elevation cannot be determined in Chippewa County, but it seems likely that the water level could have reached an elevation of 274 to 290 m (900 to 950 ft).

Baker and others (1983) and Baker (1984b) stated that till of the Hersey Member of the Pierce Formation and the lower part of the Kinnickinnic Member have reversed remanent magnetization, and the uppermost part of the Kinnickinnic Member has normal remanent magnetization. These researchers suggested, on the basis of these data, that the Kinnickinnic Member was deposited prior to the Wisconsin Glaciation at the Emperor–Brunhes polarity epoch boundary 460,000 years ago or the Matuyama–Brunhes polarity epoch boundary 780,000 years ago. Johnson (1986) proposed that the ice margin extended north–south through Barron and Dunn Counties during one of these reversals, an event he called the Reeve Phase (fig. 8; table 2), but the easterly extent of this ice is poorly constrained.

The Medford and Edgar Members (both calcareous loam till units) of the Marathon Formation were deposited in Marathon County to the east (fig. 8) during the Stetsonville and Milan Phases, respectively (Attig and Muldoon, 1989). These till units are similar to the magnetically reversed Hersey Member of the Pierce Formation (Baker and others, 1983, table 1), and Baker and others (1987) proposed that markedly expanded Keewatin ice deposited the Medford and Hersey tills at the same time. They cited evidence such as boulder trains, similar grain size, similar stratigraphic position, and carbonate and black shale sources to the northwest. In addition, Baker and others (1987) and Syverson and others (2005) have shown that the Medford till also has reversed remanent magnetization. If these till

Figure 8. Ice-margin positions (hachured lines), ice-flow directions from pebble fabrics (arrows), and ice-dammed lakes (stippled areas) associated with Keewatin ice flowing from the northwest during the Reeve Phase (modified from Baker and others, 1983, and Johnson, 2000). The Kinnickinnic Member of the Pierce Formation was deposited in the ice-dammed lakes. Pebble-fabric and lake-distribution data are from Baker and others (1983); ice margin A, from Baker and others (1983) and Johnson (1986). Ice margin B may represent the approximate location of the ice margin when much of the Kinnickinnic Member was deposited (Baker and others, 1983). Prior to deposition of the Kinnickinnic Member, this ice may have extended as far east as Marathon County (Baker and others, 1987; Syverson and Colgan, 2004).

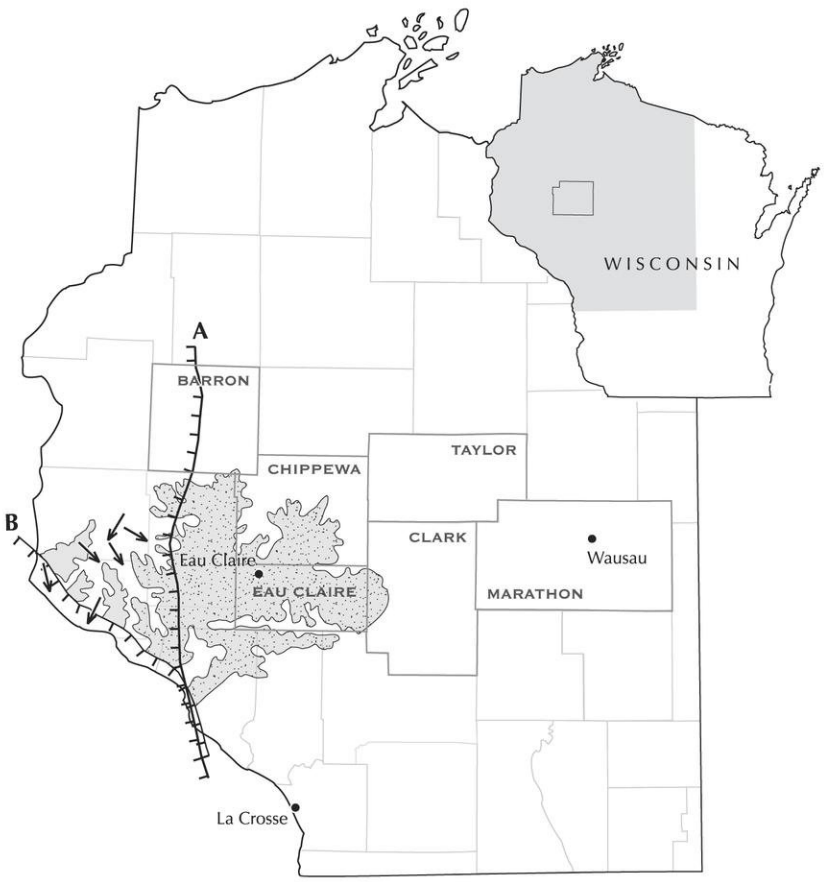


Table 2. Glacial phases represented in the sedimentary record of Chippewa County.

Years before present	Phase name	Lithostratigraphic units associated with phases in Chippewa County
18,000	Late Chippewa Phase Perkinstown Phase Early Chippewa and Stanley Phases	Copper Falls Formation
>40,800	Hamburg Phase	Merrill Member of the Lincoln Formation
>130,000	Baldwin and Dallas Phases Foster Phase	River Falls Formation
>780,000	Reeve Phase	Kinnickinnic Member of the Pierce Formation

members are time correlative, then all Chippewa County must have been covered by glacial ice during the Stetsonville Phase (and probably during the Milan Phase as well). I did not discover any Pierce or Marathon till in Chippewa County during this study, but these units may have been completely removed by erosion.

Thornburg and others (2000) reported that Marathon till contains much less kaolinite than Pierce till (table 1). Syverson and Johnson (2001) proposed that the Hersey and Medford tills might have been deposited at approximately the same time by lobes flowing from the northwest. These lobes incorporated different amounts of kaolinite along their flow lines. If the Hersey and Medford till units are time equivalent, it seems likely that the Reeve Phase and the deposition of the Kinnickinnic Member lake sediment occurred after the Stetsonville Phase (Syverson and Colgan, 2004).

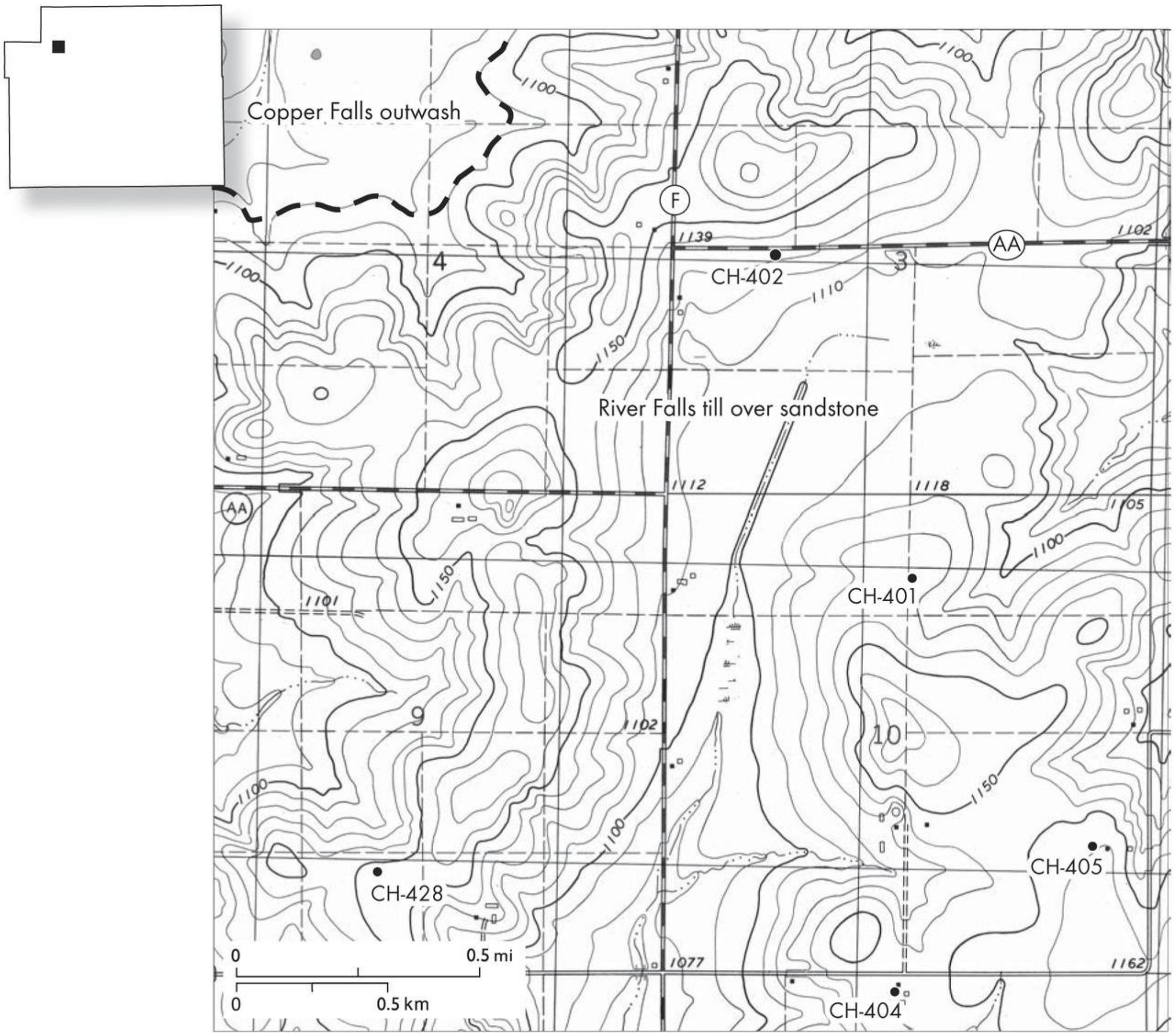


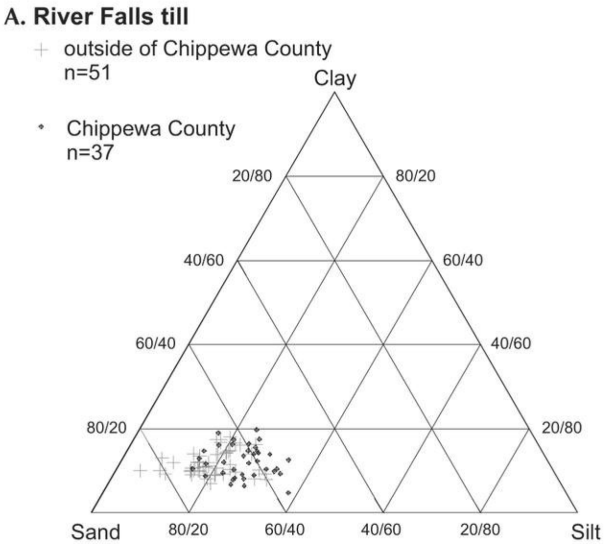
Figure 9. Part of the Marsh–Miller Lake Quadrangle, Wisconsin (U.S. Geological Survey, 7.5-minute series, topographic, 1975), showing the morphology of the River Falls Formation till plain north of Bloomer. Boreholes CH-401, CH-402, CH-404, CH-405, and CH-428 penetrated 3 to 12 m of till of the River Falls Formation over sandstone. Contour interval, 10 ft (3 m).

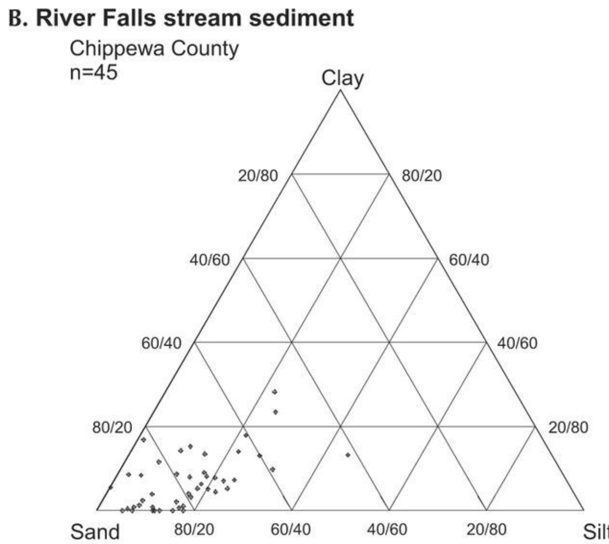
River Falls Formation

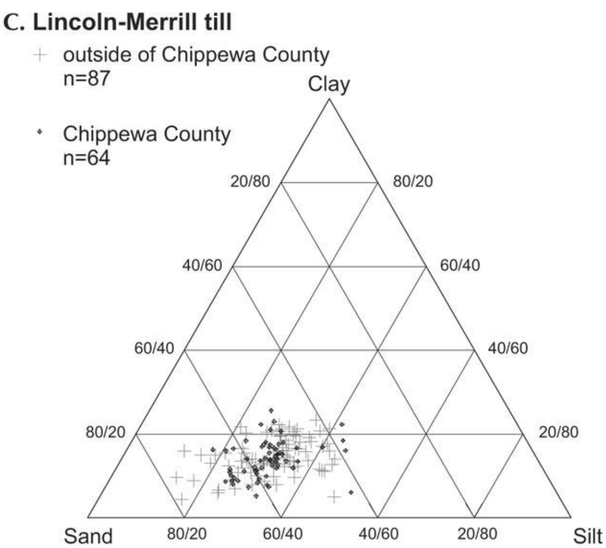
The River Falls Formation unconformably overlies weathered Pierce Formation sediment in western Wisconsin. The River Falls Formation contains reddish-brown, sandy loam till and yellowish-red stream sediment that commonly drape over sandstone uplands in western Chippewa County (fig. 2; map units **gr** and **sr**, plate 1). Sediments are extensively eroded, do not preserve original glacial topography, and vary markedly in thickness over short distances (fig. 9). Outcrops are rare, so the following descriptions are largely from drillcores and gravel pits in Chippewa County.

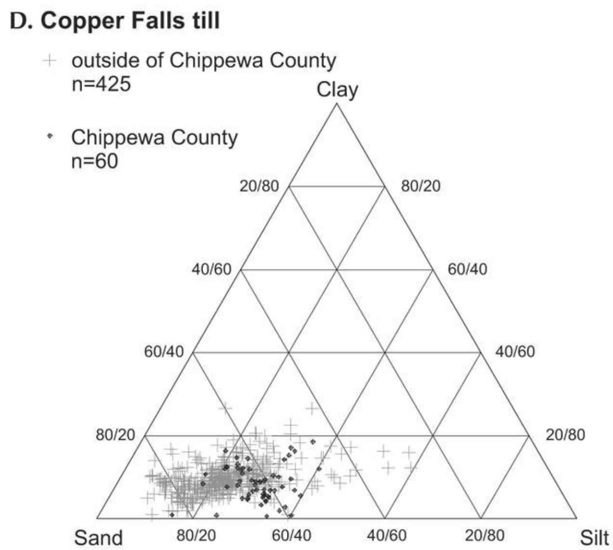
Till

Till of the River Falls Formation is reddish-brown (5YR 4/4), gravelly, matrix-supported, sandy loam (map unit **gr**, plate 1). The average sand:silt:clay ratio for River Falls till in Chippewa County is 63:25:12, the average magnetic susceptibility is 1.7×10^{-3} (SI units), and the average kaolinite percentage in the clay fraction is 19 percent (figs. 10A and 11; table 1). The mean field and laboratory hydraulic conductivity value for this till in St. Croix County to the west is 6.5×10^{-3} cm/s (Hinke, 2003). Dominant rock types in the pebble fraction include Keweenawan basalt, gabbro,









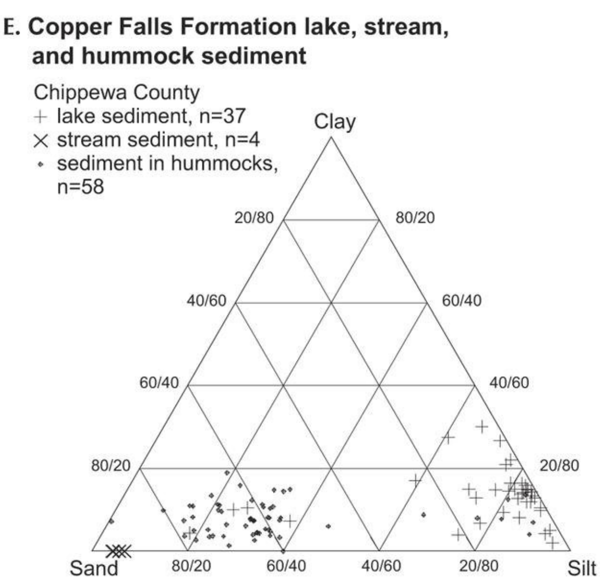


Figure 10. Grain-size distribution of the less-than 2 mm fraction for Chippewa County Pleistocene sediment units. Samples of the same unit from outside Chippewa County are plotted for comparison. Size ranges: sand 0.0625–2.0 mm, silt 0.002–0.0625 mm, and clay less than 0.002 mm. **A.** Till of the River Falls Formation. **B.** Stream sediment of the River Falls Formation. Most of the clay in this sediment is derived from weathering. **C.** Till of the Merrill Member of the Lincoln Formation. **D.** Till of the Copper Falls Formation (excludes till collected in hummocks). **E.** Copper Falls Formation lake sediment, stream sediment, and sediment in hummocks in Chippewa County.

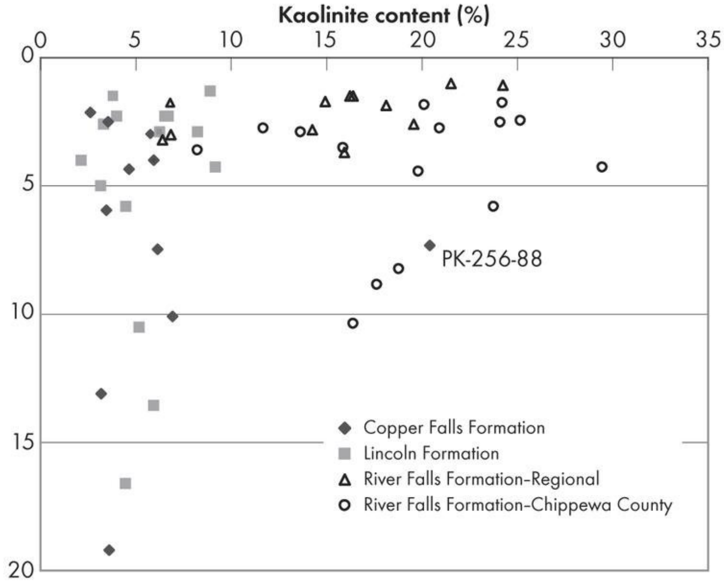


Figure 11. Kaolinite values in the less-than 1 µm clay fraction for reddish-brown, sandy till units in western Wisconsin (modified from Thornburg and others, 2000). The Copper Falls and Lincoln Formation datasets include samples from Chippewa County and western Wisconsin, but the River Falls Formation samples are separated in two groupings: those from Chippewa County and those from the region outside Chippewa County. In general, the Lincoln and Copper Falls Formations have low kaolinite values and the River Falls Formation has high kaolinite values. Note: The Copper Falls Formation sample PK-256-88 with approximately 20 percent kaolinite was collected directly above Pierce Formation till. Although Johnson (2000) interpreted this as part of the Copper Falls Formation, it is likely that this is till of the River Falls Formation.

and rhyolite in addition to sandstone, granite, quartzite, and gneiss, which indicate deposition by ice flowing out of the Lake Superior lowland. Soil-profile development extends to depths of 1.5 to 2.4 m, similar to values reported by Baker and others (1983). The till unit is up to 12 m thick, but is generally less than 5 m thick over Cambrian sandstone or glacial stream sediment.

Stream sediment

Stream sediment of the River Falls Formation is common in western Chippewa County (River Falls dissected outwash, fig. 2; map unit **sr**, plate 1). The unit contains horizontally bedded sandy gravel, gravelly sand, and sand with a distinctive oxidized, yellowish-red (5YR 4/6) color. Cobbles (and, in some places, boulders) are commonly found within the stream sediment. In one locality cross sets up to 3 m high have climbing ripple lamination and thin, red clay drapes that suggest deposition in a proximal deltaic environment. Pebble lithology is similar to that of the River Falls till, and large Lake Superior agates can be found within this unit (fig. 12). Extensive sediment weathering has produced clay that reaches concentrations up to 28 percent and soil textures that range from sandy loam to sandy clay loam (fig. 10B). The stream sediment is cemented in places by the weathering-derived clay to depths of 5 m (fig. 13), but then grades downward into material retaining the permeable, well washed attributes of stream sediment. Soil-derived clay

Figure 12. Lake Superior agate found in stream sediment of the River Falls Formation in southwestern Chippewa County. Photograph by Richard Mickelson.

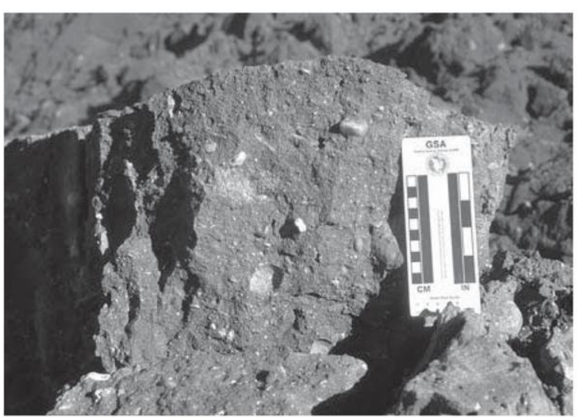


Figure 13. Clay cementation of stream sediment of the River Falls Formation in the soil B horizon (SE¼ sec. 26, T28N, R10W, Albertville Quadrangle, Wisconsin, U.S. Geological Survey, 7.5-minute series, topographic, 1972).

near the surface reduces the permeability of the sediment and makes the resulting soils “heavier.” For this reason, most western Chippewa County soils mapped as “till” in the soil survey (Jakel and Dahl, 1989) are actually very weathered River Falls stream sediment that grades downward into highly permeable stream sediment. In northern Chippewa County the upland stream sediment appears less weathered.

River Falls stream sediment is up to 35 m thick in the southwestern part of the county (Albertville area, fig. 2), but in many areas this unit is discontinuous and only 3 to 5 m thick above the Cambrian bedrock. The landscape underlain by River Falls stream sediment is eroded and does not preserve the original outwash plain (fig. 14). The thickest stream sediment is in “shoulder” positions adjacent to higher sandstone hills. This material is an important source of aggregate in the region, but clay accumulations give it higher plasticity, making its less usable than younger glacial stream sediment in Chippewa County.

Glacial history

The ice that deposited the material of the River Falls Formation flowed out of the Lake Superior basin. A thick weathered zone in the underlying Pierce Formation suggests that a long time elapsed before the deposition of the River Falls till (Baker and others, 1983; Johnson, 1986). In addition, the River Falls Formation seems quite old on the basis of the eroded nature of the landscape and the deep surficial weathering and clay enrichment observed within River Falls sediment. It has been proposed that the River Falls Formation was deposited during the Illinoian Glaciation (300,000 to 130,000 years ago), on the basis of its stratigraphic position, normal remanent magnetization, and thick soil development (Baker and others, 1983; Johnson, 1986; Syverson and Colgan, 2004). However, marine oxygen isotope records indicate two glaciations during that time interval and several others during the rest of the most recent normal magnetic polarity epoch, the Brunhes (Shackleton and Opdyke, 1973; Lowe and Walker, 1997). For these reasons, it is not possible to assign an age to the River Falls Formation with confidence (Syverson and others, 2005).

The River Falls till in southwestern Chippewa County was deposited during an event in which the Superior Lobe covered most of Dunn County and the adjacent Chippewa Lobe reached as far south as the Foster area in southern Eau Claire County (fig. 15A). Bement and Syverson (1995) found reddish-brown, sandy till and weathered glacial stream sediment that they used as evidence for an ice-margin position near Foster (fig. 15A), similar to the one proposed by Baker and others (1983) (fig. 15D) for the Chippewa Lobe. I call this event the Foster Phase of the Chippewa Lobe (new name; fig. 15A; table 2).

The presence of cobbles and boulders in the River Falls stream sediment in southwestern Chippewa County indicate ice-proximal deposition. In addition, the common presence of agates in the stream sediment outwash suggests a strong Superior Lobe contribution to this stream sediment, not simply a Chippewa Lobe influence (Syverson, 2004; Syverson and others, 2005). The extensive River Falls stream sediment may have been deposited in an interlobate junction or a reentrant between the Superior and Chippewa Lobes during retreat from the Foster Phase ice margin (fig. 15B). The till upland between New Auburn and Bloomer may have been deposited during the Dallas Phase (table 2; Johnson, 1986), but the extremely eroded nature of River Falls till in Chippewa and Dunn Counties makes the extent of glacial ice uncertain (fig. 15C).

This interpretation for the deposition of the River Falls Formation differs from that of Baker and others (1983) and Johnson (1986). According to Johnson (1986), the River Falls Formation was deposited during the Baldwin Phase of the Superior Lobe and the Dallas Phase of the Chippewa Lobe. The Baldwin Phase ice-margin position proposed by Johnson (1986) was based on the work of Baker and others (1983). They proposed that the Chippewa Lobe margin during the Baldwin Phase ran north–south along the Chippewa–Dunn County border, with a pronounced embayment between the Chippewa and Superior Lobes, roughly coinciding with the Red Cedar River valley (fig. 15D). The Lake Superior agates in

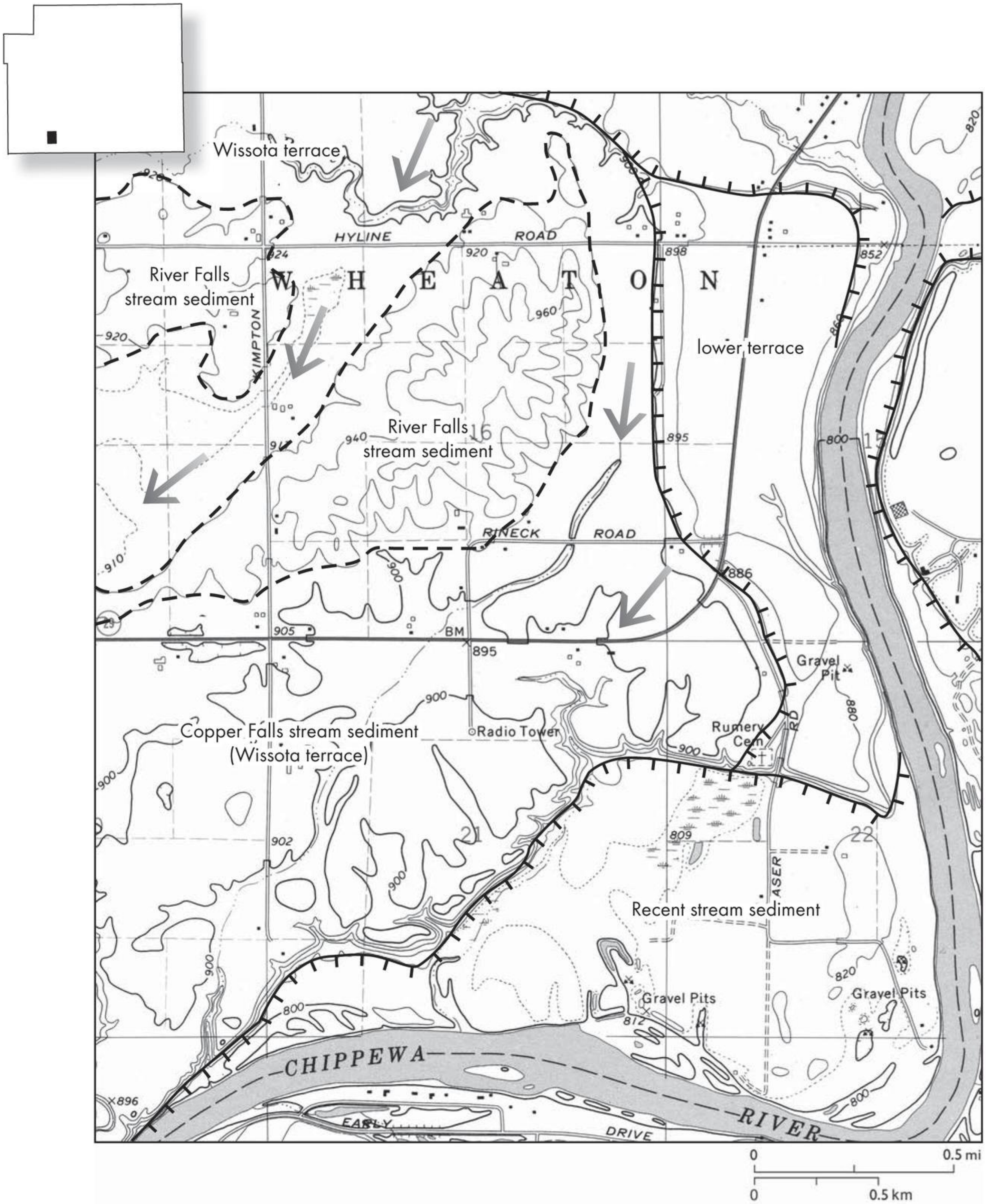


Figure 14. Part of the Chippewa Falls Quadrangle, Wisconsin (U.S. Geological Survey, 7.5-minute series, topographic, 1972), showing uplands of dissected stream sediment of the River Falls Formation surrounded by stream sediment of the Copper Falls Formation. Meltwater-flow directions are indicated by arrows; hachures indicate stream-cut banks. As ice wasted from Chippewa County, the Chippewa River downcut and the Wissota terrace remained perched above the younger Chippewa River sediment. Contour interval, 10 ft (3 m).

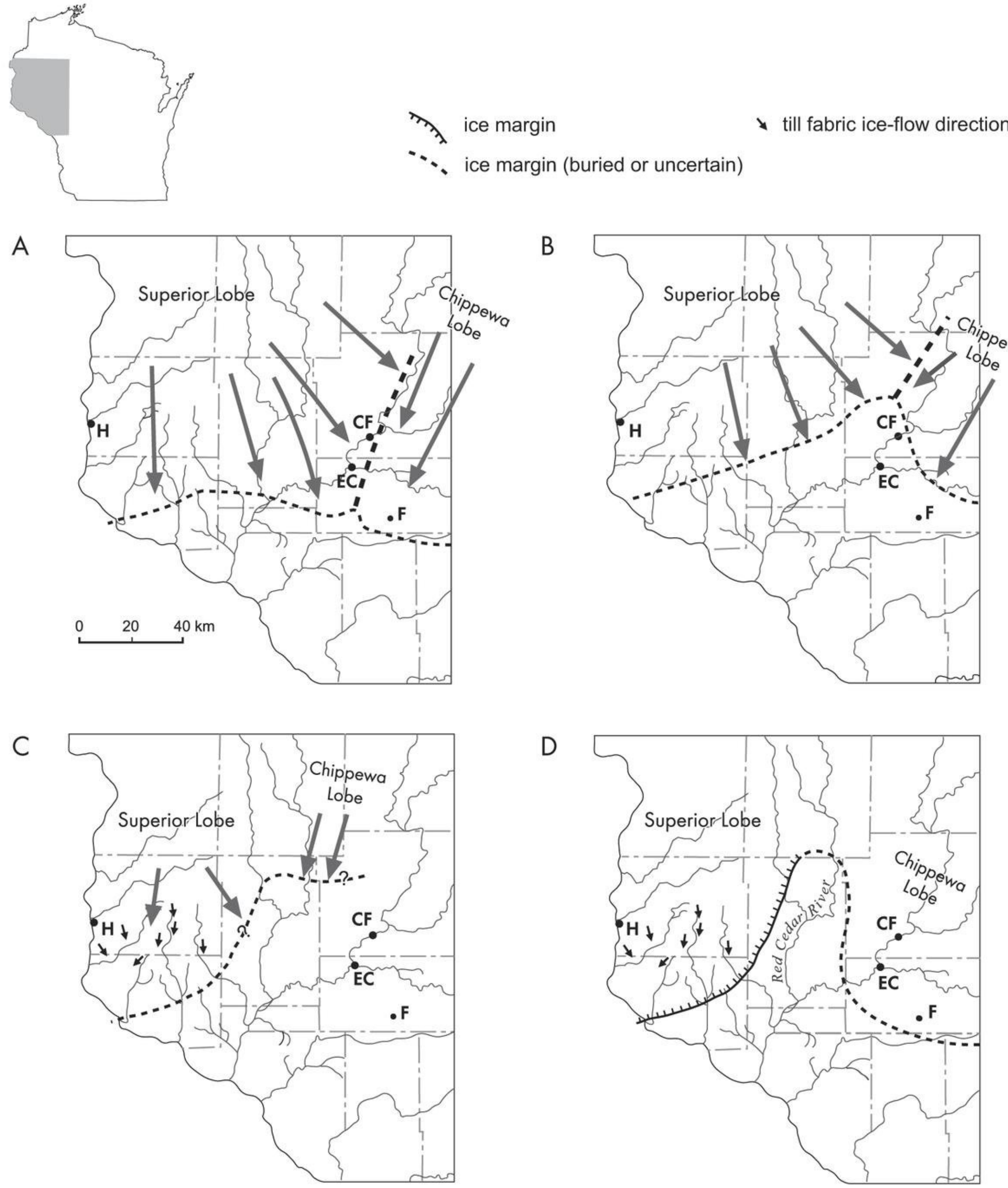


Figure 15. Events during which till and stream sediment of the River Falls Formation were deposited. Reference locations include the following: CF = Chippewa Falls, EC = Eau Claire, F = Foster, H = Hudson. **A.** During the Foster Phase, the Superior Lobe flowed across western Chippewa County and deposited proximal stream sediment in Eau Claire County that contains Lake Superior agates. Meltwater was concentrated along the interlobate zone between the Superior and Chippewa Lobes (thick dashed line). **B.** Ice margin wasted back into Chippewa County. Much stream sediment was deposited in the interlobate reentrant. **C.** Superior Lobe (Baldwin Phase) and the Chippewa Lobe (Dallas Phase) deposited River Falls till in southern Barron County and northwestern Chippewa County. These phases might have occurred at different times. **D.** Alternative hypothesis of Baker and others (1983) for the distribution of till of the River Falls Formation during the Baldwin Phase. They proposed that River Falls till was deposited on either side of an ice-free "embayment" centered on the Red Cedar River. I suggest that the embayment was actually glaciated and that the Red Cedar River eroded the glacial sediment in that region. Modified from Syverson and others (2005).

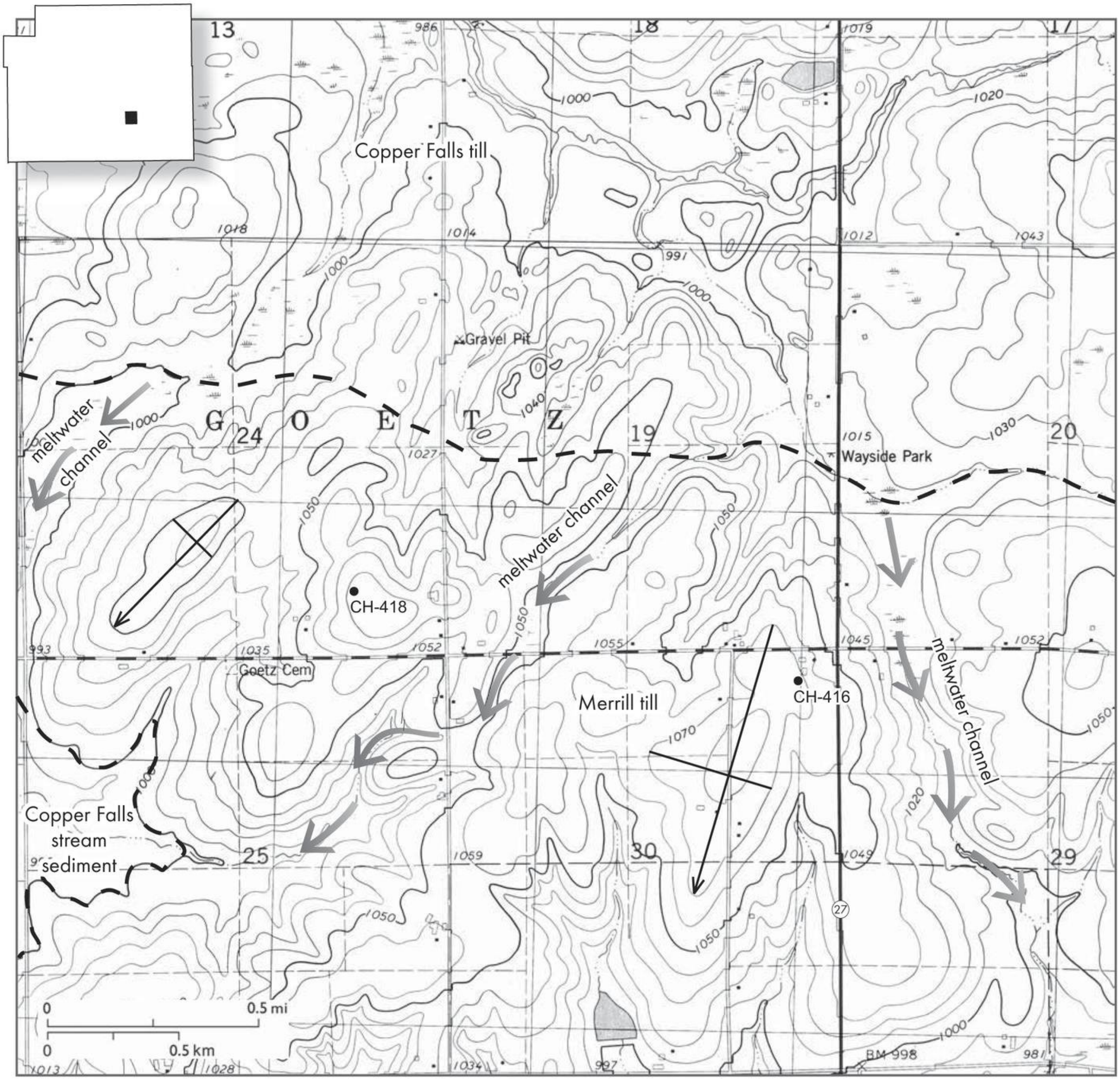


Figure 16. Part of the Cadott Quadrangle, Wisconsin (U.S. Geological Survey, 7.5-minute series, topographic, 1979), showing the subtle morphologic difference between the rolling, streamlined till surface of the Merrill Member of the Lincoln Formation (drumlins indicated by crosses; arrows indicate direction of flow) and the more irregular topography associated with the Copper Falls Formation till surface north of Cadott. The contact between these units marks the southernmost extent of Chippewa Lobe during the Stanley Phase of the last part of the Wisconsin Glaciation. Stanley Phase meltwater flowed through low valleys into the Yellow River. The two boreholes (CH-416 and CH-418) penetrated 5 m of Merrill Member till over bedrock. Contour interval, 10 ft (3 m).

Chippewa County suggest a more southeasterly expansion of the Superior Lobe than previously recognized. The lack of River Falls till in the proposed ice-margin embayment of Baker and others (1983) may have been caused by intense erosion associated with the Red Cedar River drainage system (fig. 15D). The Dallas and Baldwin Phases may represent recessional phases of the same glaciation, or these events may represent different, later glaciations.

Till of the River Falls Formation is correlated to till of the Bakerville Member of the Lincoln Formation in Marathon and Clark Counties to the east (Johnson, 2000). The Bakerville till was deposited during the Nasonville Phase and has similar characteristics to the River Falls till: It is reddish-brown, sandy loam to loam, and is found in a highly eroded landscape with no original glacial topography preserved (Attig and Muldoon, 1989). High kaolinite values in River Falls till do not decrease with depth, suggesting that the kaolinite is derived from the erosion of kaolinite-rich material, not simply in situ weathering of the till. However, the Bakerville till does not have elevated kaolinite values (Thornburg and others, 2000). The low kaolinite values in the Bakerville till might reflect an ice flow line that did not cross as much kaolinite-rich saprolite or till as the ice that deposited the more westerly River Falls Formation.

Merrill Member of the Lincoln Formation

The Merrill Member of the Lincoln Formation contains reddish-brown to brown, sandy loam to loam till that commonly drapes over sandstone uplands in the Merrill till plain of southeastern Chippewa County (fig. 2). Unlike the extensively eroded River Falls Formation, some rolling till surfaces and drumlins are preserved on surfaces underlain by the Merrill Member (fig. 16). Few outcrops are present; the following descriptions are largely based on information from drillcores and roadcuts in Chippewa County.

Till

Till of the Merrill Member of the Lincoln Formation is a reddish-brown to brown (5YR 4/4 to 7.5YR 4/4), gravelly, matrix-supported, sandy loam to loam (map unit **gm**, plate 1). The average sand:silt:clay ratio for Merrill till in Chippewa County is 56:30:14, average magnetic susceptibility is 1.8×10^{-3} (SI units), and the average kaolinite percentage in the clay fraction is 6 percent (figs. 10C and 11; table 1). The mean field hydraulic conductivity value for this till in north-central Wisconsin is 2.2×10^{-4} cm/s (Muldoon and others, 1988). Dominant rock types in the pebble fraction are derived from the Lake Superior lowland. Tan sandstone pebbles become abundant near the basal contact with the Cambrian sandstone surface. In two drillcores near the city of Stanley, the till became finer with increasing depth, a characteristic observed by Attig (1993) in Taylor County; soil-profile development extends to depths of 1.2 to 1.7 m. The till is generally less than 6 m deep, but one borehole south of Boyd (CH-421) penetrated 23 m of Merrill till. Cambrian sandstone commonly crops out in areas of the Merrill till plain.

Merrill till is differentiated from the River Falls till by its lower sand and kaolinite values, thinner soil development, and till surfaces that display original glacial topography (figs. 10A, 10C, 11; table 1).

Stream sediment

Stream sediment of the Merrill Member is present in small remnants above the highest stream surfaces from the last part of the Wisconsin Glaciation (map unit **sm**, plate 1). This sediment in southeastern Chippewa County contains brown to pale brown (7.5YR 4/4 to 10YR 6/3) gravelly sand and sand. Limited observations revealed pebble lithology similar to that in River Falls stream sediment, although I have not found any Lake Superior agates in Merrill stream sediment. Soil profiles tend to be 1.0 to 1.2 m thick. Merrill stream sediment is easily distinguished from stream sediment of the River Falls Formation by its brown color and lack of a thick, clay-enriched weathering zone (table 3).

Glacial history

The Merrill till was deposited in north-central Wisconsin during the Hamburg Phase (table 2; Attig and Muldoon, 1989), when ice flowed out of the Superior region for the final time prior to the last part of the Wisconsin Glaciation. Johnson (1986) used relative weathering observations to argue that the Merrill Member of the Lincoln Formation is younger than the River Falls Formation. The Merrill till is the only till unit in western

Table 3. Summary of meltwater-stream sediment characteristics in Chippewa County.

Lithostratigraphic unit	Munsell color	Landform expression	Distinguishing characteristics
Copper Falls Formation	Pale brown to brown (10YR 6/3 to 7.5 YR 4/4)	Underlies outwash plains and terraces relatively unmodified by erosion.	Soil profiles thin (1 to 1.2 m); underlies outwash surfaces with minor erosional modification.
Merrill Member Lincoln Formation	Brown to pale brown (7.5YR 4/4 to 10YR 6/3)	Small eroded terrace remnants higher than the Copper Falls Formation terraces.	Soil profiles thin (1 to 1.2 m); higher than Copper Falls Formation terraces.
River Falls Formation	Yellowish red (5YR 4/6)	Extensively eroded surfaces high on the landscape.	Soil profiles thick (2 to 5 m); original stream surfaces removed by erosion; more gravel-rich (on average) than other stream units.

Wisconsin deposited before the last part of the Wisconsin Glaciation that displays original glacial topography (such as drumlins and low-relief hummocky topography), so the Merrill till plain appears younger than the River Falls till plain. Stewart and Mickelson (1976) reported a 40,800 ±2,000 BP radiocarbon age (IGS-256) on organic material overlying the Merrill till. The Merrill till may have been deposited during the early part of the Wisconsin Glaciation (Attig and Muldoon, 1989; Syverson and Colgan, 2004).

Copper Falls Formation

Sediment of the Copper Falls Formation underlies much of the landscape in northern and western Wisconsin, including the Copper Falls till plain in the northern part of Chippewa County (fig. 2; map units starting with **gc**, **lc**, and **sc**, plate 1). Glacial, gravity-flow, lake, and stream sediment of the Copper Falls Formation underlie well preserved glacial landforms throughout much of Chippewa County. The Copper Falls Formation contains reddish-brown to brown sandy loam till that is exposed in excavations and many small outcrops throughout the county.

Till

Till of the Copper Falls Formation is a reddish-brown to brown (5YR 4/4 to 7.5 YR 4/4), gravelly, matrix-supported, sandy loam (map unit **gc**, plate 1). The average sand:silt:clay ratio for Copper Falls till in Chippewa County is 62:29:9, the average magnetic susceptibility is 2.9×10^{-3} (SI units), and the average kaolinite percentage in the clay fraction is 4 percent (figs. 10D and 11; table 1). The mean field and laboratory hydraulic conductivity value for this till in St. Croix County to the west is approximately 10^{-3} cm/s (Hinke, 2003). Dominant rock types in the pebble fraction are derived from the Lake Superior lowland. Soil-profile development extends to depths of 1.0 to 1.2 m. The till is generally 10 to 20 m thick in the northeastern part of the county and forms an almost continuous sheet.

Copper Falls till looks similar to other reddish-brown till units in Chippewa County (table 1). Copper Falls and River Falls tills have similar grain sizes (figs. 10A and 10D). However, the Copper Falls till underlies a relatively unmodified glacial landscape, unlike the highly eroded River Falls till surface (fig. 9). Copper Falls till has less kaolinite, higher magnetic susceptibility, and thinner soil development than River Falls till (fig. 11; table 1). The Copper Falls and Merrill tills have similar grain sizes, low kaolinite values, similar color and magnetic susceptibility values, and their till surfaces exhibit original glacial topography (figs. 10C, 10D, and 11; table 1). In Lincoln and Langlade Counties, Stewart and Mickelson (1976) reported that illite concentrations increased with depth in the Merrill till and proposed that the Merrill till was more weathered than the Copper Falls till. Thornburg and others (2000) did not observe this trend in Merrill till in Chippewa County. Thus, the Merrill and Copper Falls tills cannot be differentiated in Chippewa County on the basis of physical characteristics.

Lake sediment

The Copper Falls Formation includes lake sediment deposited in ice-walled lakes and ice-dammed lakes. Ice-walled-lake plains in the

Figure 17. Deltaic foreset bedding in the Bob Lake ice-walled-lake plain, SE¼SW¼ sec. 14, T31N, R8W. Foresets dip southward into the former ice-walled lake. Field notebook and shovel indicated for scale (see arrow).

Perkinstown and Chippewa moraines contain coarse, poorly sorted sandy gravel deltaic sediment along the edges (fig. 17; map unit **lci**, plate 1; Syverson and others, 2005). In places the deltaic sediment is interbedded with sandy loam gravity-flow sediment derived from the surrounding ice surface. This shore and nearshore sediment can be extremely coarse and is mined in places for aggregate. Farther from the former lake margins, the sediment becomes sandier and contains some silt beds. Offshore lake sediment is rarely exposed, but a drillcore in an ice-walled-lake plain north of Plummer Lake penetrated 23 m of laminated silt and silt loam (figs. 18 and 19; Syverson and others, 2005). This drillcore as well as domestic well construction reports suggests that ice-walled-lake plain sediment is approximately as thick as the lake plain is high.

Ice-dammed-lake sediment is also present in the county. Glacial ice blocked river valleys in Chippewa County, and stream valleys were filled with ice-dammed lakes of various sizes as the ice melted. These lakes served as sediment traps where fine-grained sediments were deposited in low-lying areas (map unit **lcp**, plate 1). Wave- and stream-sorted sand and gravel was deposited along the margins of the lakes. This sediment tends to be less coarse and more sorted than nearshore sediment in ice-walled-lake plains, but it still may contain sandy loam gravity-flow beds derived from till highlands. Sediment grades to laminated silt loam and silty clay loam farther from the former shoreline, but pebbles and sandy loam beds with gravel are present in places and may represent iceberg dump deposits. Ice-dammed-lake sediment thickness varies markedly with position in the valley, but a sediment thickness of 10 m was observed in core from borehole CH-445 north of Stanley.

Stream sediment

Stream sediment of the Copper Falls Formation is present in broad outwash plains along the major rivers in Chippewa County (figs. 2 and 14) as well as tributary valleys (map unit **sc**, plate 1). The sediment contains pale brown to brown (10YR 6/3 to 7.5 YR 4/4) sandy gravel, gravel, gravelly sand, and sand. Four representative samples of the less-than 2 mm matrix revealed more than 90 percent sand (fig. 10E).

Copper Falls stream sediment in pitted outwash plains (map unit **scp**, plate 1) was deposited on isolated blocks of stagnant ice relatively close to the ice margin; the stream sediment deposited

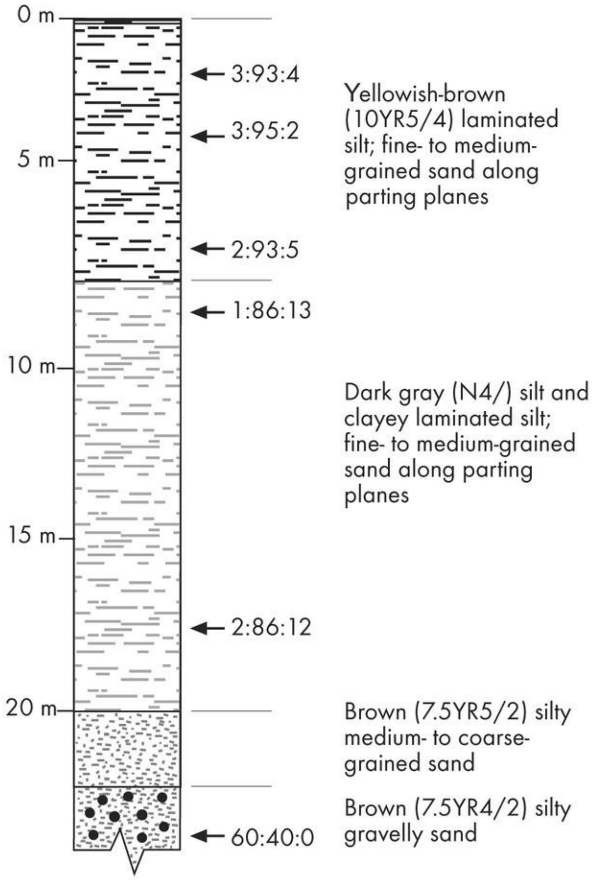


Figure 18. Offshore sediment log for the Plummer Lake ice-walled-lake plain, Chippewa Moraine Ice Age National Scientific Reserve (borehole CH-436; see fig. 26 for location). Sand:silt:clay ratios are indicated at the appropriate sample depths. The laminated silt and clay settled from suspension in the ice-walled lake, and the two lower units may represent gravity-flow sediment. The ice-walled-lake plain rises 25 to 34 m above surrounding kettles, so the lake sediment is nearly as thick as the landform is high.

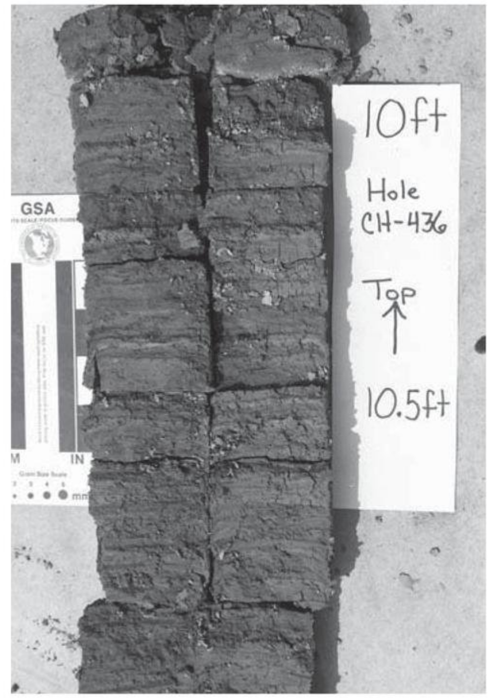


Figure 19. Laminated silt and silt loam deposited in an offshore environment, Plummer Lake ice-walled-lake plain, Chippewa Moraine Ice Age National Scientific Reserve (borehole CH-436, depth 10 ft (3 m), see fig. 26 for location).

within 0.5 km of former ice-margin positions tends to contain clast-supported cobble gravel and sandy gravel that is crudely stratified and poorly sorted (fig. 20). The stream sediment also may contain boulders and have chaotic bedding. This material is valuable for aggregate and has been mined extensively in Chippewa County.

Stream sediment deposited farther from the ice margin is more sand dominated and horizontally bedded with cross sets up to 1 m high. Pebble lithology is similar to River Falls and Merrill stream sediment (abundant Precambrian igneous and metamorphic clasts). Small fragments of Lake Superior agates are present, but relatively rare. Soils tend to be 1.0 to 1.2 m thick. This permeable stream sediment is commonly greater than 30 m thick and is an important surficial aquifer for domestic and municipal water use in Chippewa County.

Copper Falls stream sediment initially deposited on glacial ice is also present in hummocks (map unit **sch**, plate 1). This stream sediment tends to be highly variable and may contain clean sand to boulder-rich sandy gravel as well as local inclusions of sandy silt lake sediment and interbeds of reddish-brown, sandy loam gravity-flow deposits. Bedding is contorted from the melting of underlying glacial ice.

Copper Falls stream sediment is easily distinguished from stream sediment of the River Falls Formation by its brown color and lack of a thick, clay-enriched weathering zone (table 3). Copper Falls and Merrill stream sediment contain similar rock types and a similar degree of weathering (table 3). It is likely that some River Falls and Merrill stream sediments are present beneath Copper Falls stream sediment, but these sediments cannot be distinguished in domestic well construction reports.

Figure 20. Coarse proximal stream sediment of the Copper Falls Formation, NW¼SW¼ sec. 5, T30N, R8W. The gravel and sandy gravel fines upward and was deposited within 100 m of the former ice margin by water flowing from right to left. This gravel-rich sediment is an ideal source of commercial aggregate. Shovel and clipboard at base of outcrop for scale (enclosed in circle).

Hummocky sediment

Copper Falls Formation sediment underlies the hummocks in Chippewa County (map units **gch**, **sch**, plate 1). Much of this material was at one time sediment that accumulated on the ice surface before it was deposited. Because multiple processes acted at the ice surface, the grain size and hydraulic conductivity values for sediment in hummocks tend to be extremely variable vertically and laterally (figs. 10E and 21). Meltout till, gravity-flow sediment, stream sediment, and lake sediment are found within hummocks in Chippewa County. This sediment is greater than 30 m thick in the highest relief part of the Chippewa moraine in northwestern Chippewa County, but is more typically 5 to 20 m thick in other parts of the county.

Windblown silt

While sediment of the Copper Falls Formation was being deposited in Chippewa County, windblown silt (loess) was being deposited on the land surface (fig. 22), as described by Cahow (1976). The silt is massive to weakly laminated, stone poor, and generally less than 0.5 m thick, although Cahow (1976, p. 184) described silt up to 3.8 m thick southeast of Lake Wissota and up to 3 m thick northwest of Lake Wissota. During this study I observed windblown silt 3 m thick on bedrock hills immediately west of the Chippewa River valley (SE¼SE¼ sec. 12, T28N, R10W). The silt is commonly 0.5 to 1.5 m thick in the eastern part of the county near Stanley. Generally, windblown silt is very thin to absent in areas covered by glacial ice during the last part of the Wisconsin Glaciation.

Sources for this silt included silt-laden meltwater streams draining the ice margins, such as the Red Cedar River, Duncan Creek, O'Neil Creek, Chippewa River, Yellow River, and Hay Creek. In addition, blowing sand was common in the areas beyond the ice margin during the last part of the Wisconsin Glaciation, as indicated by numerous wind-abraded ventifacts in western Chippewa County and in Barron County (see Johnson, 1986, p. 22, for photograph of a venti-

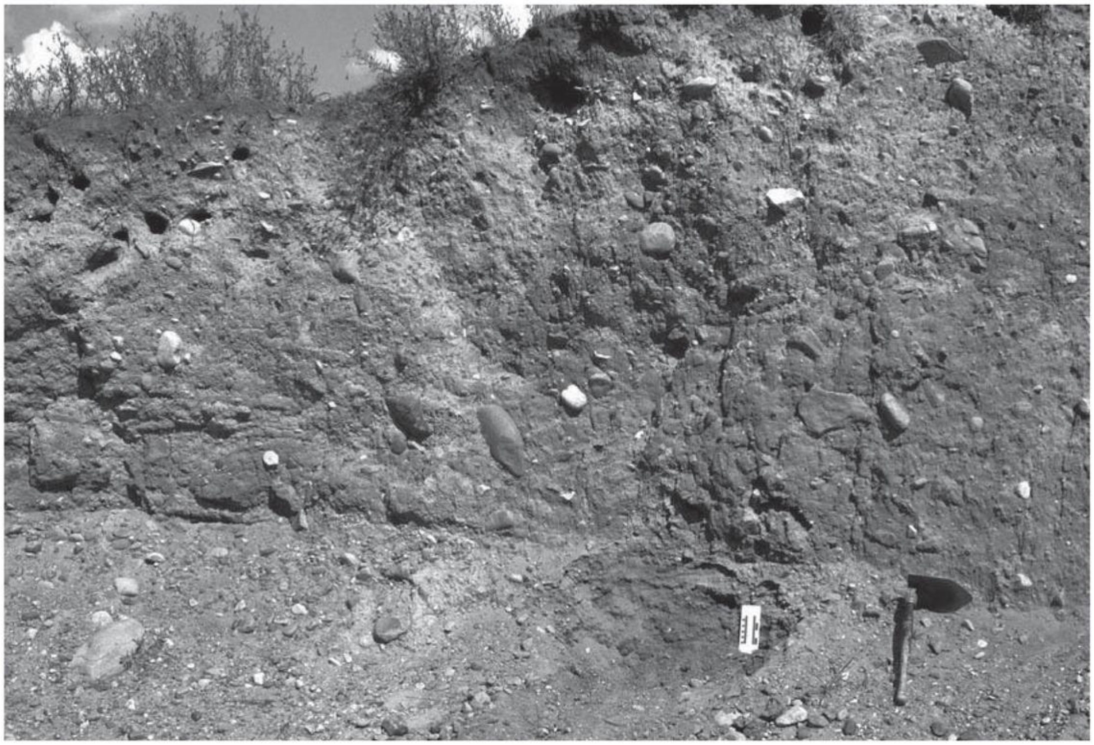


Figure 21. Variable sediment of the Copper Falls Formation in a hummock, SW¼SW¼ sec. 34, T30N, R7W. Blade of shovel marks the contact between matrix-supported, gravelly sandy loam (top) and well washed sandy gravel (bottom). Crude stratification in the upper unit is typical for gravity-flow sediment.

Figure 22. Windblown silt (loess), 1.2 m thick, overlying stony till of the Copper Falls Formation, sec. 36, T31N, R7W. The silt source was the Chippewa River outwash plain 2 km west of the site. Shovel and bucket auger for scale. From Cahow (1976, p. 186).

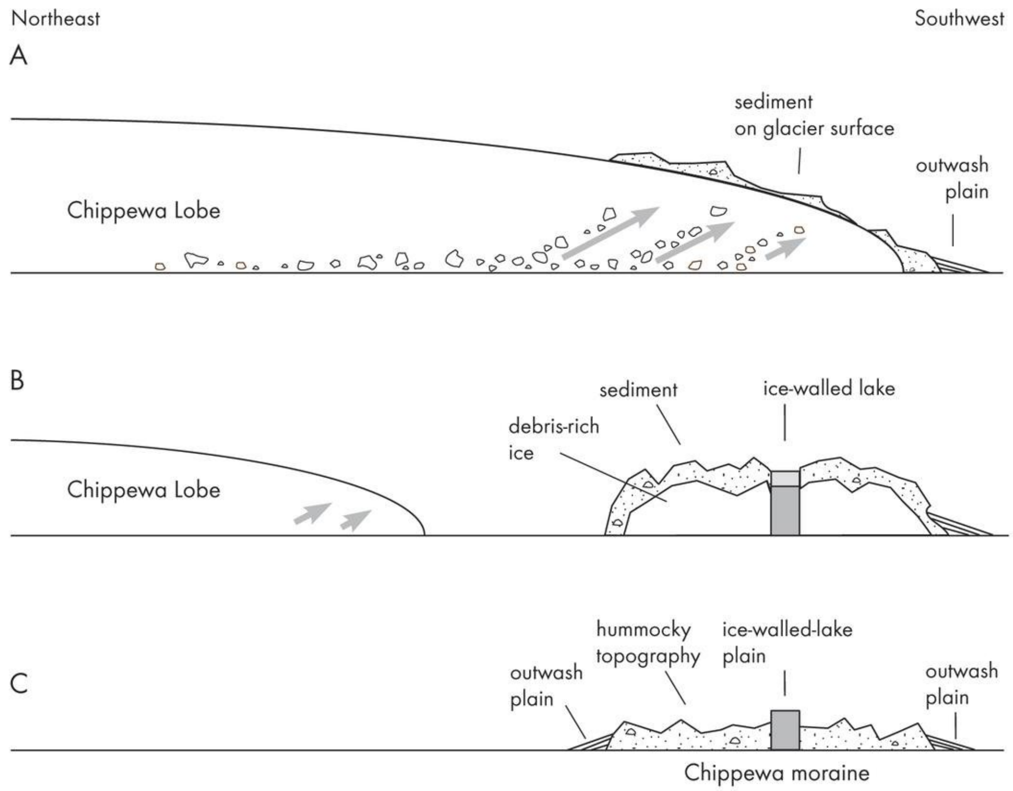


Figure 23. Formation of the Chippewa moraine (modified from Ham and Attig, 1997). **A.** Chippewa Lobe margin remains in same position for a period of time. Compressive ice flow occurs as ice slows at the margin. This carries sediment from the base of the glacier into the ice where the sediment later melts out at the ice surface. Meltwater deposits sand and gravel in an outwash plain sloping away from the ice margin. **B.** Debris-covered ice melts slowly, stagnates, and eventually separates from the active ice of the Chippewa Lobe. Low areas fill with water (ice-walled lakes) or sediment. Ham and Attig (1997) proposed that this occurred during permafrost conditions. **C.** Stagnant ice melts, perhaps over a period of several thousand years, after permafrost conditions end. Meltwater-stream sediment is deposited in outwash plains sloping away from the moraine in all directions. Hummocky topography and ice-walled-lake plains mark the moraine.

fact). Blowing sand grains impacting the ground also would have generated airborne silt grains.

Landforms of the Chippewa Lobe

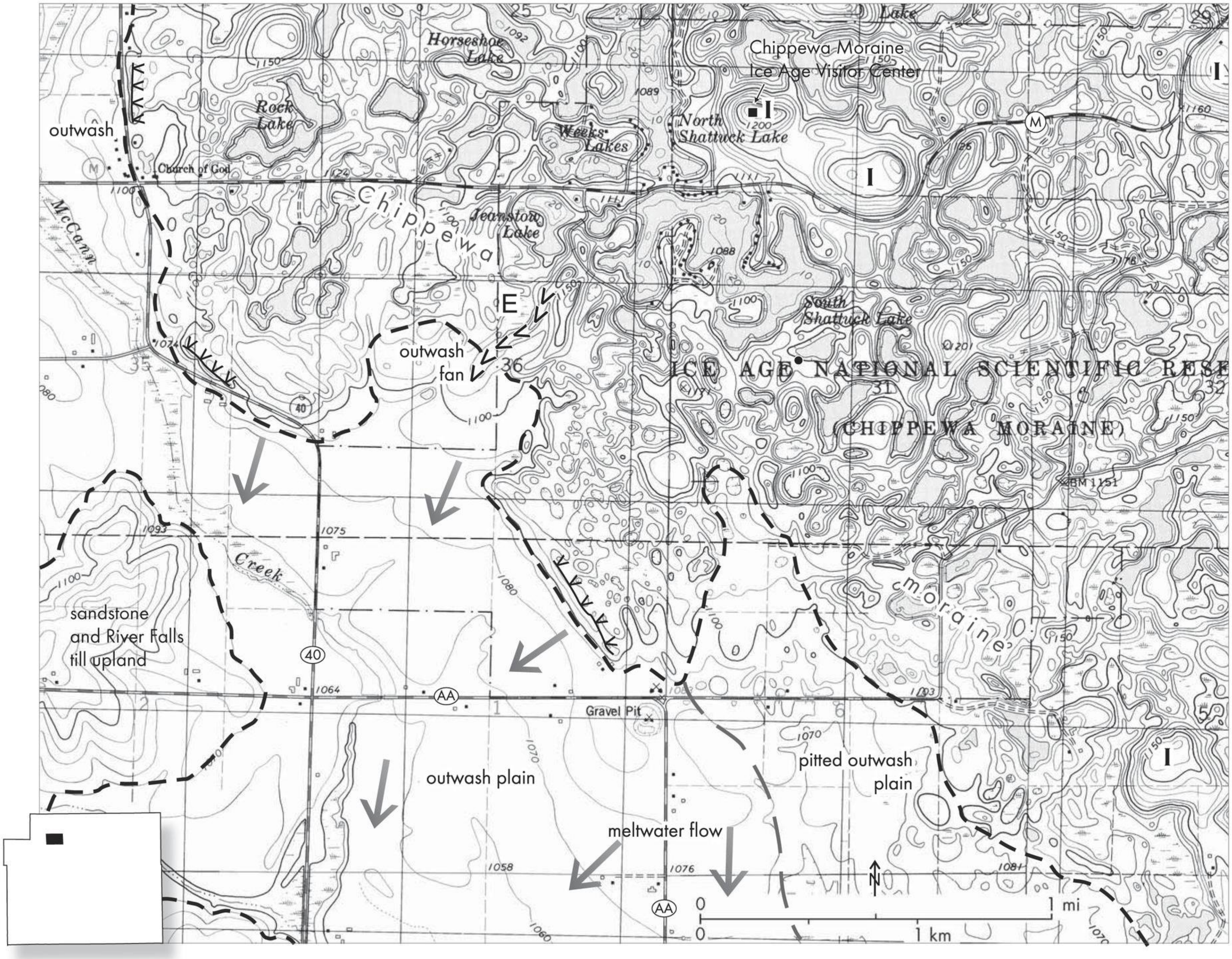
The Chippewa Lobe formed textbook examples of glacial features such as end moraines, kettle lakes, hummocks, ice-walled-lake plains, outwash plains, tunnel channels, and eskers. Syverson and others (1995) presented a field introduction to these landforms; this publication is available at the Chippewa Moraine Ice Age Visitor Center near New Auburn, Wisconsin.

End moraines

An end moraine is a ridge or band of hummocky topography that marks the former position of a glacier margin, as shown in figures 23 and 24. Several moraines are present in Chippewa County. These include the poorly developed Stanley moraine, the Perkinstown moraine, and the high-relief, prominent Chippewa moraine. These moraines contain hummocks, kettles, and ice-walled-lake plains (see the following sections). Details about the formation of these moraines are discussed in the section entitled *History of the last part of the Wisconsin Glaciation.*

Hummocks and kettles

The most common landforms in the moraines—hummocks and kettles—are thought to have formed by the process of topographic reversal. This occurred when sediment on the ice surface was deposited as the underlying stagnant glacial ice melted to produce irregularly shaped hills


outwash
Chippewa Moraine
Ice Age Visitor Center
Horseshoe Lake
Rock Lake
Weeks Lakes
North Shattuck Lake
Church of God
McCann
Chippewa
Jeanstow Lake
E
outwash fan
South Shattuck Lake
ICE AGE NATIONAL SCIENTIFIC RESE
(CHIPPEWA MORAINE)
Creek
moraine
sandstone
and River Falls
till upland
Gravel Pit
outwash plain
pitted outwash
plain
meltwater flow
0
1 mi
0
1 km

◀ **Figure 24.** Part of the Marsh–Miller Lake Quadrangle, Wisconsin (U.S. Geological Survey, 7.5-minute series, topographic, 1975), showing the high-relief hummocks (irregular hills) and kettles (depressions largely filled with water) of the Chippewa moraine, in the western part of the Chippewa Moraine Ice Age National Scientific Reserve. Ice-walled-lake plains (I), eskers (E), the former meltwater-flow direction (arrows), ice-marginal ridges (arrowheads attached by their tips) and the Chippewa Moraine Ice Age Visitor Center are indicated. Coarse, proximal stream sediment of the Copper Falls Formation was mined at the gravel pits on County Highway AA near the contact between the moraine and outwash plain. Contour interval, 10 ft (3 m).

(hummocks) and depressions (kettles) (fig. 25; Gravenor and Kupsch, 1959; Clayton, 1967; Cahow, 1976; Johnson and Clayton, 2003).

The variable nature of sediment within Chippewa County hummocks (figs. 10E and 21) suggests that numerous processes were acting on the ice surface as hummocks were forming. Supraglacial processes such as gravity flows, stream flow, water ponding, and passive meltout from glacial ice produce color, bedding, and grain-size variations vertically and laterally within hummocks. Some hummock exposures within the Chippewa Moraine Reserve contain Copper Falls till, but many hummocks in Chippewa County contain extremely variable sediment assemblages, including stream and lake sediment (map units **gch** and **sch**, plate 1; figs. 10E and 21).

Johnson (1984) described very uniform till from a borehole through a hummock in the Chippewa moraine of Barron County; the till showed strong pebble fabric parallel to the former ice-flow direction. This has been described in hummocks elsewhere in Wisconsin (Ham and Attig, 1993, 1996a, 1997; Johnson and others, 1995). The sediment in these uniform-till hummocks has been interpreted as little-modified flow till (Ham and Attig, 1993) or meltout till (Johnson and others, 1995).

Some hummocks in Chippewa County contain lake sediment, as observed elsewhere in northern Wisconsin by Attig (1993) and Ham and Attig (1997). Some of these hummocks might have formed in small ice-walled lakes (see next

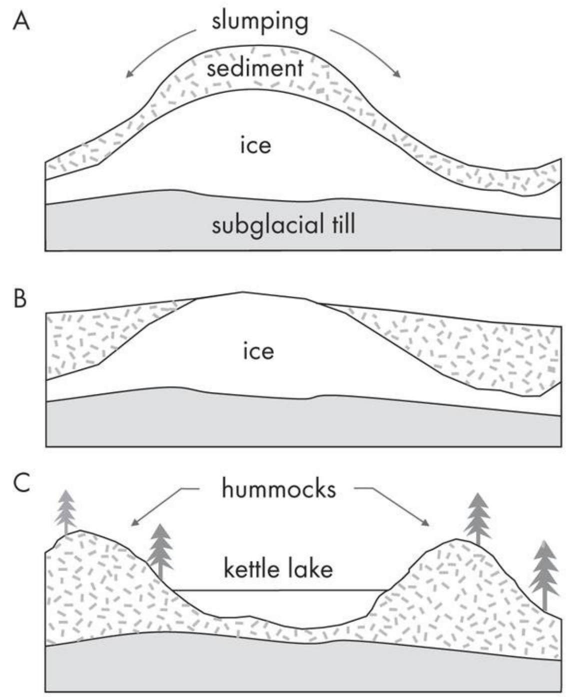


Figure 25. Process of topographic reversal and the formation of hummocks and kettles (modified from Syverson, 1998b). **A.** Ice melts slowly where sediment on the ice is thickest, so this becomes a high area on the ice surface. Water-saturated sediment slumps into adjacent low areas. **B.** Exposed clean ice in the center melts rapidly. **C.** All ice has melted. A depression called a kettle (commonly filled with water) remains where the ice surface was formerly high. Hummocks (hills) surrounding the kettle mark the former low areas on the ice surface. Thus, topographic reversal has occurred.

section). Others formed as lake sediment was deposited in larger ice-walled lakes on the ice surface. As the underlying ice melted, the lacustrine sediment underwent collapse and topographic reversal to form hummocks.

Ice-walled-lake plains and ice-dammed-lake plains

Another common landform in the Chippewa and Perkinstown moraines of Chippewa County is the ice-walled-lake plain (Cahow, 1976; Syverson, 2000; Syverson and others, 2005). Some ice-walled-lake plains are flat to concave, circular, and may have raised rims around the outer parts of the lake plain (fig. 26). Other ice-walled-lake plains tower above the surrounding landscape, are convex, and are circular to oval (fig. 24). Because of their gentle slopes, good drainage, and low concentration of surficial rocks, ice-walled-

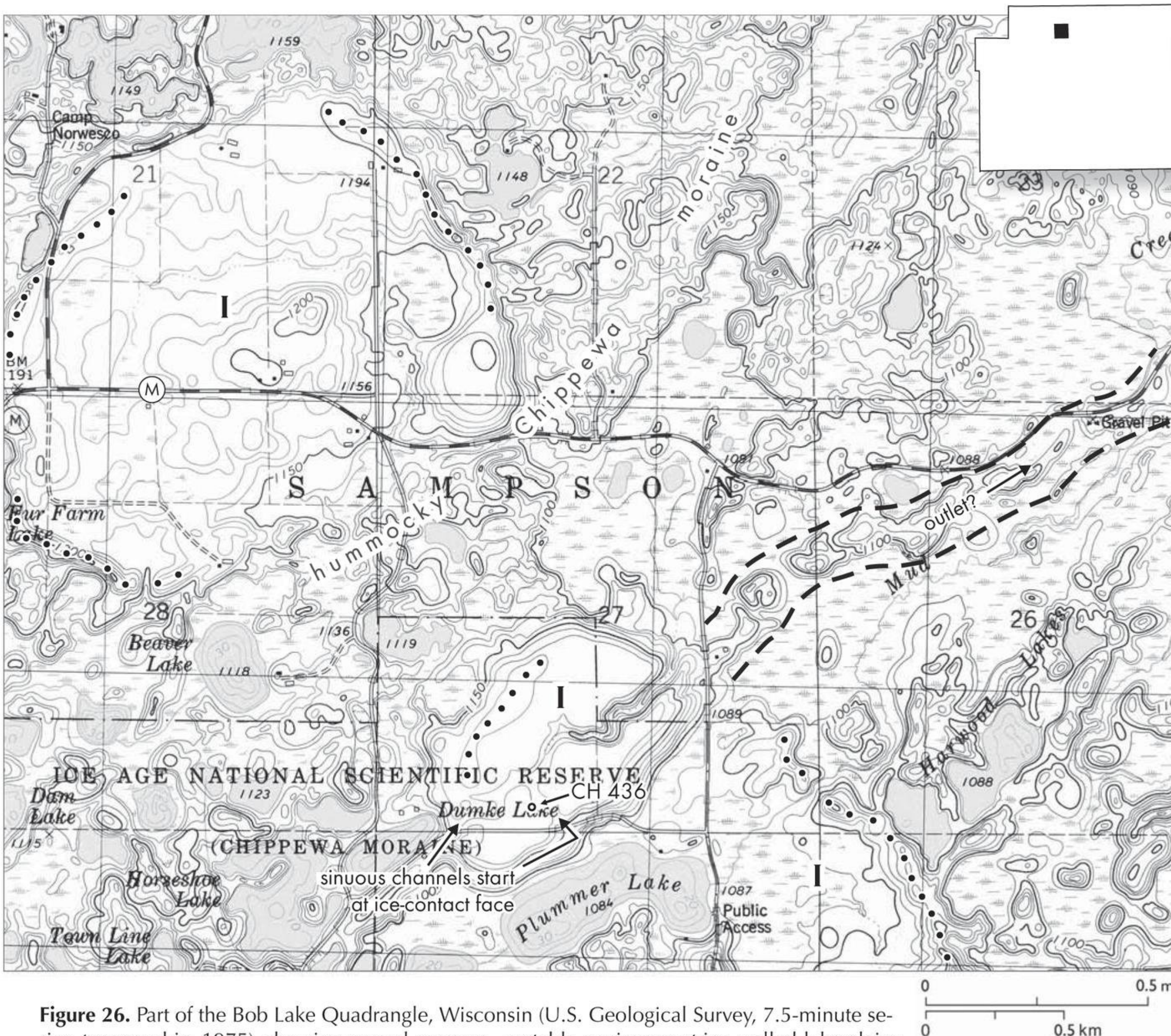


Figure 26. Part of the Bob Lake Quadrangle, Wisconsin (U.S. Geological Survey, 7.5-minute series, topographic, 1975), showing several concave, unstable-environment ice-walled-lake plains (I) with rim ridges (dots) in the easternmost part of the Chippewa Moraine Ice Age National Scientific Reserve. Borehole CH-436 penetrated 20 m of lake sediment over gravity-flow sediment in the oval ice-walled-lake plain north of Plummer Lake (figs. 18 and 19). That same plain is incised by several sinuous, dry stream channels that head at the top of a steep ice-contact face. These channels formed as meltwater flowed directly off glacial ice onto the lake plain soon after lake drainage. The linear zone of hummocky sandy gravel (stream sediment) to the northeast within heavy dashed lines may mark an outlet for the former ice-walled lake. Contour interval, 10 ft (3 m).

lake plains are farmed. Thus, they are commonly treeless and contrast markedly with the wooded, steep, and rocky slopes of the surrounding hummocks.

Ice-walled-lake plains form in areas of stagnant, debris-covered glacial ice (Clayton and Cherry, 1967; Johnson and Clayton, 2003; Clayton and others, in press). Ice that has thin debris cover melts rapidly and forms low areas on the ice surface that may fill with water (fig. 27). The water absorbs heat, melts its way to the glacier bed, and forms a lake surrounded by debris-covered glacial ice. Sediment from the surrounding glacial surface is deposited in the lake, and this forms an ice-walled-lake plain that remains perched above the surrounding landscape after the ice melts (fig. 27).

The concave plains (figs. 26 and 27A) are classified as unstable-environment ice-walled-lake plains (Clayton and Cherry, 1967). The for-

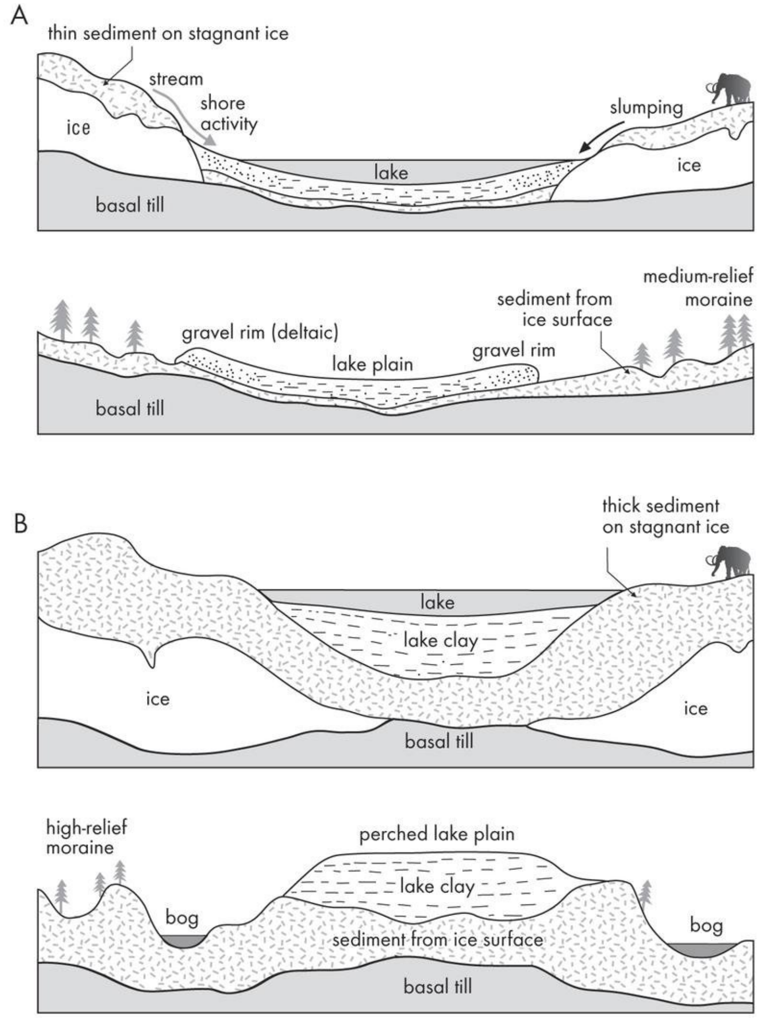


Figure 27. Formation of ice-walled-lake plains (modified from Clayton and Cherry, 1967). **A.** Unstable-environment ice-walled-lake plain. Because sediment is thin on the ice surrounding the lake, the ice melts rapidly and produces much water that carries large quantities of sediment into the lake. Coarse sediment is deposited near the shore in deltas, and silt is deposited in more quiet-water conditions near the center of the lake. After ice melts and the lake drains, gravel rim ridges may remain around the outer parts of the ice-walled-lake plain. **B.** Stable-environment ice-walled-lake plain. Thick sediment on ice prevents the ice that confines the lake from melting quickly. Little meltwater is produced, so little coarse sediment is transported into the lake. Silt and clay are deposited in the long-lived lake. When the surrounding ice melts, the former lake plain remains perched high in the landscape.

mer ice-walled lakes were surrounded by stagnant ice overlain by relatively thin sediment. Ice beneath the thin sediment melted quickly because it was poorly insulated. In addition, Ham and Attig (1996a, 1997) proposed that unstable-environment ice-walled-lake plains formed after the end of permafrost (approximately 13,000 years before present), when the ice could melt more rapidly. This melting ice created an unstable, dynamic environment in which ice-walled-lake plains and surrounding hummocks formed low in the landscape. Melting produced numerous streams and gravity flows that transported much coarse- and fine-grained sediment into the lakes. Coarse-grained sediment was deposited in deltas around the outer margins of lakes (figs. 17 and 27). These deltas are commonly parts of rim ridges observed around the outer lake-plain margins following lake drainage (figs. 27 and 28).

Fine-grained sediment was transported into offshore areas, where it settled from suspension (figs. 19 and 27). Most offshore sediment in unstable-environment ice-walled-lake plains lacks abundant clay, so many lakes had outlets that selectively removed clay from the system. These outlets may have removed water through an englacial or subglacial ice karst system or possibly through streams flowing over the ice surface. A linear zone of hummocky sand and gravel extending northeast from the Plummer Lake ice-walled-lake plain (fig. 26) may represent stream sediment deposited in an englacial outlet from the former ice-walled lake.

Several unstable-environment ice-walled-lake plains in Chippewa County are incised by sinuous, 3 to 6 m deep, v-shaped stream valleys that in some cases head at the tops of ice-contact faces (Cahow, 1976; Syverson and others, 2005; fig. 26, plate 1). These formed soon after the ice-walled lakes drained and water flowed directly from the surrounding ice masses onto the exposed ice-walled-lake-plain sediment and rapidly eroded the material.

The convex hills (such as the Chippewa Moraine Ice Age Visitor Center hill, Pikes Peak, and Baldy Mountain) are stable-environment ice-walled-lake plains (figs. 24 and 27B). According to Clayton and Cherry (1967), this type of ice-walled-lake plain forms in areas with thick sediment on top of thick stagnant ice. The sediment prevents the underlying ice from melting rapidly. Ham and Attig (1996a, 1997) proposed that the permafrost conditions that existed until approximately 13,000 years before present also prevent-

Figure 28. A. Parts of the Bob Lake and Jim Falls Quadrangles, Wisconsin (U.S. Geological Survey, 7.5-minute series, topographic, 1975), showing an unstable-environment ice-walled-lake plain (I) with a sharp-crested rim ridge near Himple Lake. The ice-walled lake probably had drained before sediment from the ice surface slumped onto the lake plain and formed the steep rim ridge. Contour interval, 10 ft (3 m). **B.** Photograph looking northeast at the easternmost part of the sharp-crested rim ridge. The flat ice-walled-lake plain is in the foreground (location of photograph shown by arrow in **A**).

ed rapid melting of ice in northern Wisconsin. Because melting rates were low, the lake position remained stable for a long time and water-supply rates and stream velocities into the lake were low. In addition, low rates of meltwater production reduced sediment saturation, so sediment was not as susceptible to gravity flows into the lake. The permafrost also would have inhibited the formation of subglacial and englacial tunnels to drain water from the ice-walled lake. Thus, stable-environment ice-walled-lake plains tend to contain fine-grained sediment and lack rim ridges. Drilling for the well at the Chippewa Moraine Ice Age Visitor Center penetrated 86 m of sediment, much of it fine-grained and not useful for supplying water, and did not encounter bedrock (see fig. C-6 of Syverson, 1998b).

The Visitor Center ice-walled-lake plain has two crests (fig. 24). This suggests that two ice-walled lakes coalesced as the ice walls confining the lakes slowly melted back, and then more lacustrine sediment was deposited at lower levels within the new ice-walled lake. Attig (1993, p. 14) observed coalesced ice-walled-lake plains in Taylor County.

As ice of the Chippewa Lobe melted back from moraines, ice dammed low-lying areas to the east and north of the former ice-margin positions (fig. 29; map unit **lcp**, plate 1). With melting of the ice dams and reintegration of the drainage system, these ice-dammed lakes ceased to exist. The lake plains today are flat, swampy lowlands underlain by peat, silt, clay, and fine-grained sand. Specific ice-dammed-lake plains are discussed in the section entitled *History of the last part of the Wisconsin Glaciation*.

Drumlins

Drumlins are elongate, streamlined hills that form subglacially through a poorly understood erosional process (Benn and Evans, 1998, p. 431). Because the long axis of a drumlin is oriented parallel to the former ice-flow direction, a drumlin is a valuable tool to decipher the glacial history of an area. A few drumlins are present south of Cadott and Stanley (fig. 16). These drumlins contain till of the Merrill Member of the Lincoln Formation and indicate ice flow from north to south (see symbol on plate 1). Drumlins in northeastern Chippewa County are not well defined (plate 1), but they contain till of the Copper Falls Formation and indicate ice flow from the northeast.

Tunnel channels and eskers

Tunnel channels (also referred to as tunnel valleys) are troughs formed subglacially by meltwater erosion (O'Cofaigh, 1996; Clayton and others, 1999). Although numerous tunnel channels are present along ice-margin positions in Wisconsin from the last part of the Wisconsin Glaciation (Attig and others, 1989; Clayton and others, 1999; Cutler and others, 2002), the only clear example of a tunnel channel in Chippewa County is the one occupied by Otter Lake (fig. 30). The Otter Lake tunnel channel cuts the Perkinstown moraine and is approximately 13 km long, 400 to 1,100 m wide, 25 to 40 m deep, and oriented approximately north to south parallel to the former ice-flow direction.

Eskers are sinuous ridges of stream sediment deposited in contact with glacial ice on at least two sides, and most preserved eskers probably formed in subglacial tunnels. Several eskers are present in Chippewa County (see plate 1), although most eskers have been mined away for aggregate. The largest esker in Chippewa County extends approximately 4 km north of the Otter Lake tunnel channel and then follows the tunnel channel to Brownsville. The esker branches numerous times and forms elongate islands and peninsulas on the western side of Otter Lake (including parts of Otter Lake County Park, fig. 30; plate 1).

All mechanisms for tunnel-channel formation invoke subglacial meltwater erosion. Wright (1973) proposed that tunnel channels formed as subglacially derived meltwater was trapped behind the frozen margin of the glacier. Water pressure eventually became sufficient to break through the frozen bed "dam," and a sudden, catastrophic meltwater release incised the tunnel channel beneath glacier. A similar mode of formation has been accepted by numerous workers in the Midwest (Attig and others, 1989; Patterson, 1994; Clayton and others, 1999; Cutler and others, 2002). Other possible mechanisms include erosion by low-discharge subglacial streams fed by a supraglacial meltwater source (Mooers, 1989) or meltwater erosion of a deforming glacial bed (Boulton and Hindmarsh, 1987). The esker at the base of a tunnel channel represents a change from subglacial water erosion to deposition.

Outwash plains and pitted outwash plains

During the last part of the Wisconsin Glaciation, meltwater flowed away from the outermost ice-

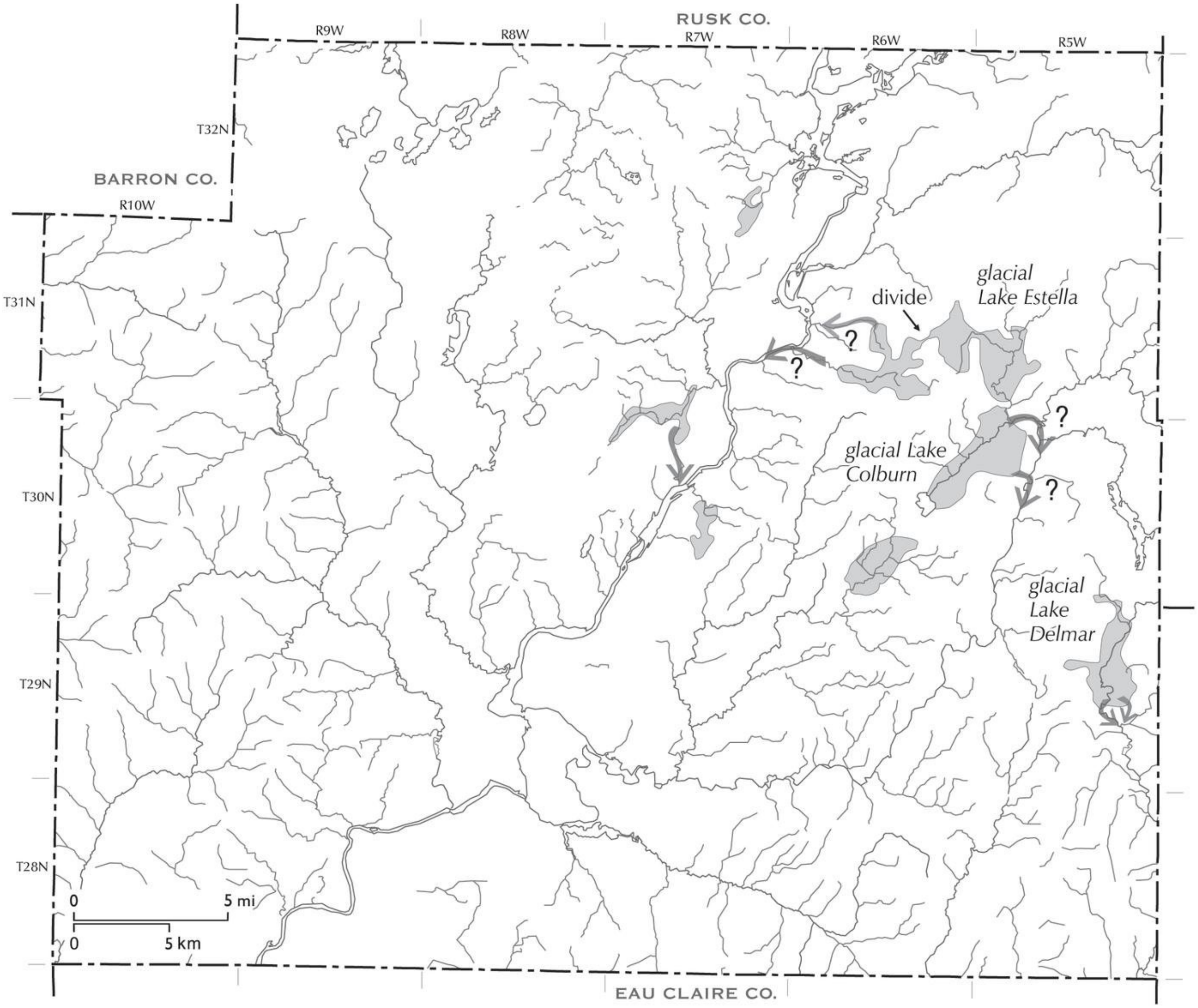


Figure 29. Locations of ice-dammed lakes and lake outlets in relation to present-day rivers and streams in Chippewa County. Outlets for some lakes are uncertain because they drained through areas underlain by stagnant ice. Glacial Lake Estella separated into two lakes as the lake level lowered and exposed the divide between the two basins. The eastern basin of glacial Lake Estella likely merged with glacial Lake Colburn and drained eastward.

margin positions in valleys containing broad floodplains. Most meltwater flowed through the Chippewa and Yellow Rivers, although some water flowed out of northwestern Chippewa County into the Red Cedar River and some out of southeastern Chippewa County by way of Hay Creek and the Wolf River (tributaries of the Eau Claire River). Between New Auburn and Chippewa Falls, meltwater flowed around numerous Cambrian sandstone highlands (fig. 2; plate 1).

Meltwater-stream sediment was deposited in broad, gently sloping outwash plains throughout these valleys (map unit **sc**, plate 1). As glacial ice disappeared from the drainage basins, less sediment was supplied to the river systems, and the rivers began to downcut. The former meltwater floodplains were left as elevated terraces along the river valleys. Numerous terraces along the Chippewa and Yellow Rivers represent several stream incision events.

The Wissota terrace is the name given to the highest stream surface formed during the last part of the Wisconsin Glaciation in the Chippewa River valley and its tributaries (Andrews, 1965). The

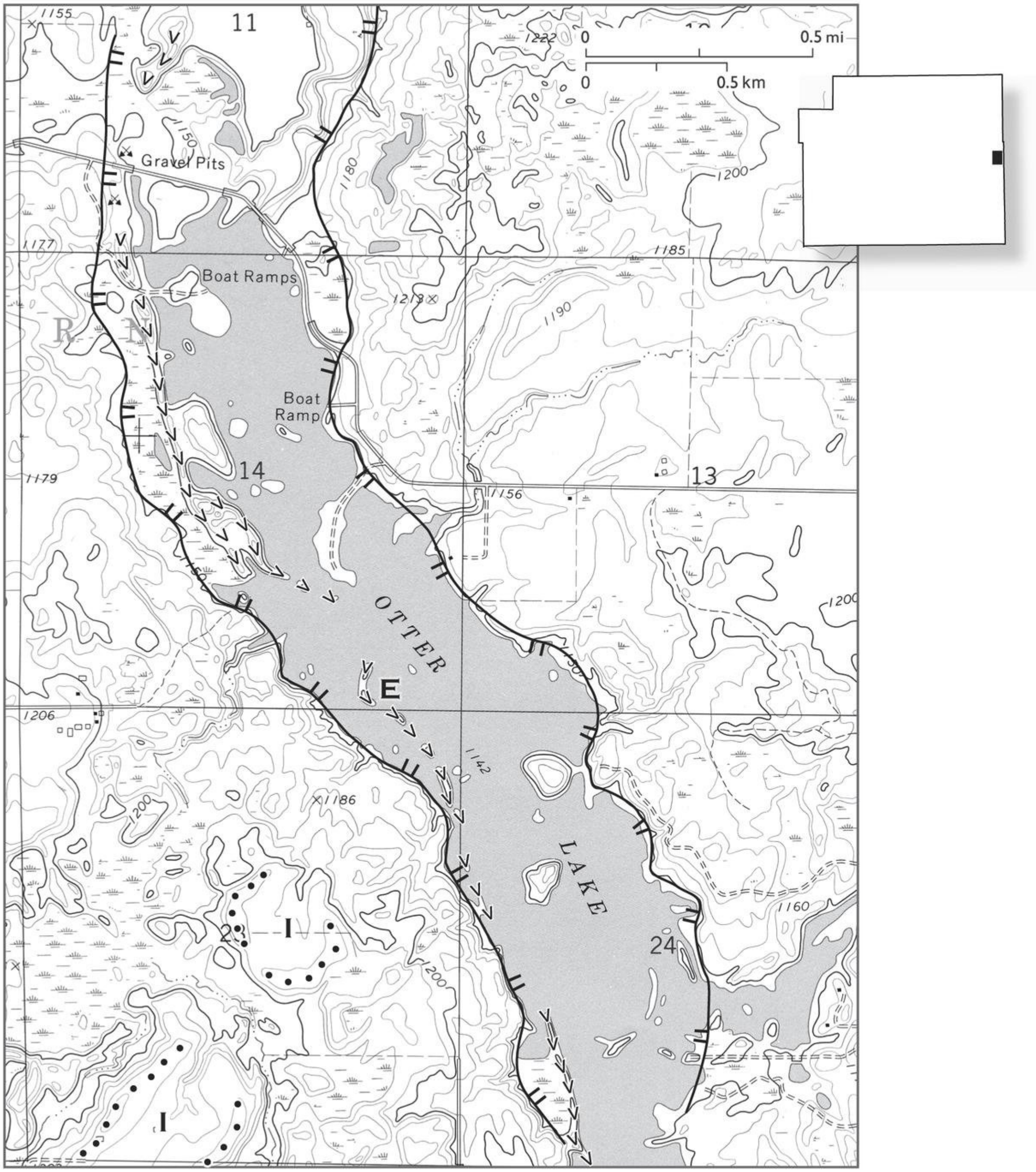


Figure 30. Part of the Huron Quadrangle, Wisconsin (U.S. Geological Survey, 7.5-minute series, topographic, 1973), showing a tunnel channel (indicated by hachures) now occupied by Otter Lake and an esker **(E).** Ice-walled-lake plains **(I)** are surrounded by rim ridges (indicated by dots) within the hummocky Perkinstown moraine. Contour interval, 10 ft (3 m).

head of this terrace may be marked by a pitted outwash plain with isolated depressions (fig. 24; map unit **scp**, plate 1) and areas of hummocky topography (map unit **sch,** plate 1). In these areas stream sediment was deposited on stagnant ice that later melted and caused sediment collapse.

The Wissota terrace can be traced from the Chippewa and Perkinstown moraines to the Mississippi River. The fact that the high terrace surface along the Yellow River grades to the high terrace along the Chippewa River implies that buried ice in the Perkinstown moraine melted at the same time as ice in the younger Chippewa moraine, perhaps after permafrost conditions ended.

Valleys that start in the Cambrian sandstone uplands or sediment-covered uplands that were not glaciated during the last part of the Wisconsin Glaciation (River Falls Formation till plain and dissected outwash in fig. 2) contain terraces underlain by stream and gravity-flow sediment. These terraces grade to the Wissota terrace. Andrews (1965) proposed that high aggradation rates associated with sediment-laden, glacier-fed streams would have dammed rivers flowing from unglaciated drainages and caused backflooding. However, material from borehole CH-439 and domestic well-construction reports did not reveal the presence of lake sediment in these tributary valleys. Enhanced sediment supply caused by permafrost conditions and lack of vegetation may have allowed the small drainage basins not containing glacial ice to aggrade at rates similar to the Chippewa River system.

The outwash plains typically slope south and west, away from the hummocky moraines in Chippewa County. However, Cahow (1976) recognized that the outwash plains slope northward on the western side of Flambeau Ridge (sec. 12, T32N, R8W, Fireside Lakes Quadrangle, Wisconsin, U.S. Geological Survey, 7.5-minute series, topographic, 1972; plate 1) and southeastward near Cornell (secs. 3 and 10, T31N, R7W, Cornell Quadrangle, Wisconsin, U.S. Geological Survey, 7.5-minute series, topographic, 1973; plate 1). These areas are adjacent to the highest relief parts of the Chippewa moraine and indicate that as the Chippewa Lobe wasted, thick sediment protected the underlying ice in the marginal area. Eventually, the Chippewa moraine region was separated from the main part of the Chippewa Lobe, and meltwater flowed radially away from the stagnant, debris-covered glacier remnant, as recognized elsewhere in Wisconsin (fig. 23; plate 1; Attig, 1993; Ham and Attig, 1997).

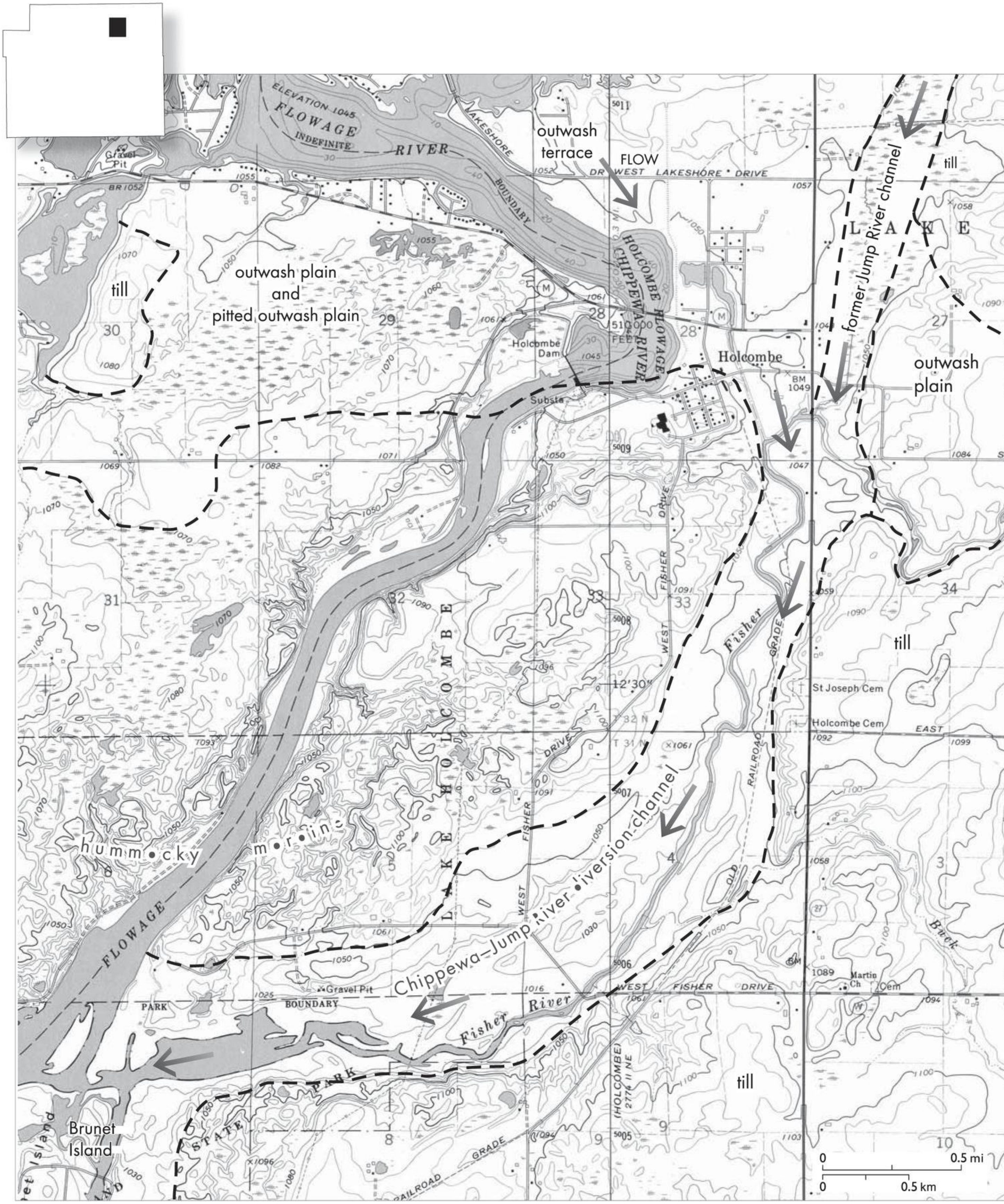
Chippewa and Jump River diversion channels

Ice-cored moraine ridges formed high areas in the landscape for hundreds to thousands of years after the ice margin wasted northward out of Chippewa County. The Chippewa and Jump Rivers initially flowed through large channels east of their present positions near Holcombe (figs. 2 and 31), but as ice melted, the rivers moved to their present positions. The Jump River (and perhaps the Chippewa River) was diverted down a north–south trending channel through secs. 15, 22, 27, T32N, R6W, just east of the Holcombe Flowage (fig. 31; plate 1). This channel, now largely filled with peat, was used when stagnant ice blocked the central part of the modern Lake Holcombe (Cahow, 1976, p. 195). The Chippewa and Jump Rivers followed the broad valley of the Fisher River from the present location of the village of Holcombe to the Brunet Island area north of what is now Cornell (Cahow, 1976, p. 196; plate 1). This segment of the valley is largely filled with glacial outwash, but there are areas where scoured Precambrian bedrock is exposed. The narrow, modern Chippewa River valley between Holcombe and Brunet Island State Park near Cornell was occupied after most of the ice had melted out of that hummocky area.

History of the last part of the Wisconsin Glaciation

Following the deposition of the Merrill Member of the Lincoln Formation, the ice melted in the Chippewa County region and might have disappeared entirely from the state. After a period of weathering, the ice began to readvance across the drainage divide south of Lake Superior basin approximately 26,000 years before present, reached its maximum extent by approximately 18,000 to 21,000 years before present, and started to recede by about 15,000 years before present (Black, 1976b; Clayton and Moran, 1982; Attig and others, 1985; Syverson and Colgan, 2004). Organic material is lacking for much of

▶ **Figure 31.** Parts of the Cornell and Holcombe Quadrangles, Wisconsin (U.S. Geological Survey, 7.5-minute series, topographic, 1973), showing the early postglacial paths of the Chippewa and Jump Rivers. The ice-cored hummocky moraine diverted water flow into the Fisher River valley, perhaps for thousands of years, until sufficient ice melted to allow the Chippewa River to erode a narrow, steep-sided valley through the moraine. Contour interval, 10 ft (3 m).


outwash terrace
FLOW
till
outwash plain and pitted outwash plain
former Jump River channel
outwash plain
Holcombe
Holcombe Dam
Fisher River
hummocky moraine
Chippewa–Jump River diversion channel
Brunet Island
St Joseph Cem
Holcombe Cem
LAKE HOLCOMBE
FLOWAGE
HOLCOMBE FLOWAGE
CHIPPEWA RIVER
WEST LAKESHORE DRIVE
WEST FISHER DRIVE
0.5 mi
0.5 km

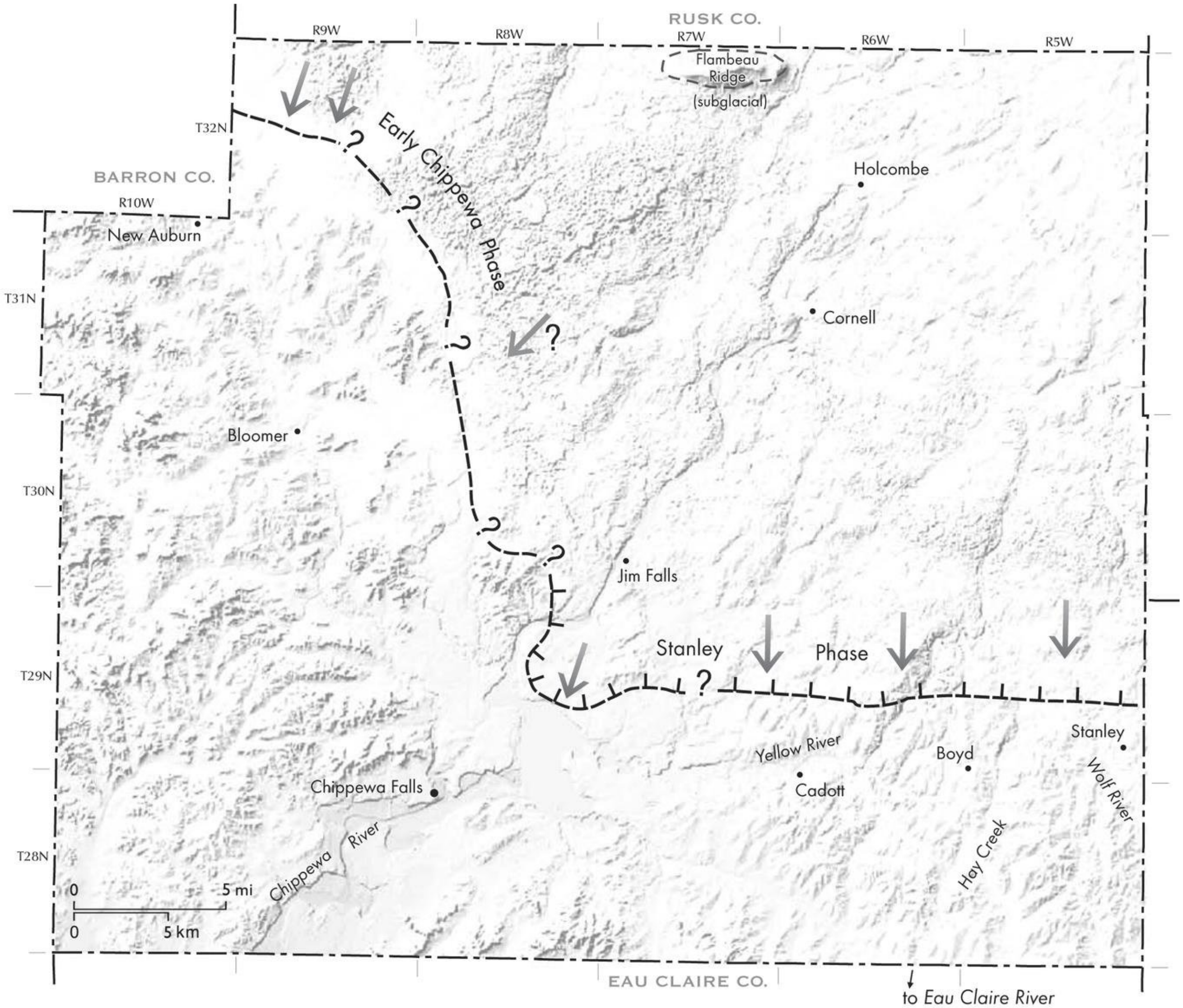


Figure 32. History of the last part of the Wisconsin Glaciation in Chippewa County. Meltwater flow is shown by arrowheads; arrows indicate direction of ice flow; hachures indicate stream-cut bank. **A.** Early Chippewa and Stanley Phases. Early Chippewa Phase ice-margin position and its extension toward the Stanley Phase ice-margin position is poorly constrained in Chippewa County.

the last part of the Wisconsin Glaciation, so the ages presented for the following phases are only rough estimates. Sediment of the Copper Falls Formation was deposited at the surface throughout much of Chippewa County at this time (plate 1). I discuss events in Chippewa County in order from oldest to youngest.

Early Chippewa Phase

The Chippewa Lobe advanced from the north during the Early Chippewa Phase (table 2; Johnson, 1986). The ice deposited till of the Pokegama Creek Member of the Copper Falls Formation in southeastern Barron County and an ice-contact fan north of New Auburn (secs. 14, 15, 16, T32N, R10W). Ice must have extended into Chippewa County at this time, and Johnson (1986) extrapolated the Chippewa Lobe ice margin eastward into the Bass and Loon Lakes area of northwestern Chippewa County (fig. 32A). Any evidence for the Early Chippewa Phase in Chippewa County has been buried by younger stream and glacial sediment of the Late Chippewa Phase.

The date of the Early Chippewa Phase is poorly constrained. Johnson (1986) observed that stagnant ice from this phase still remained in the

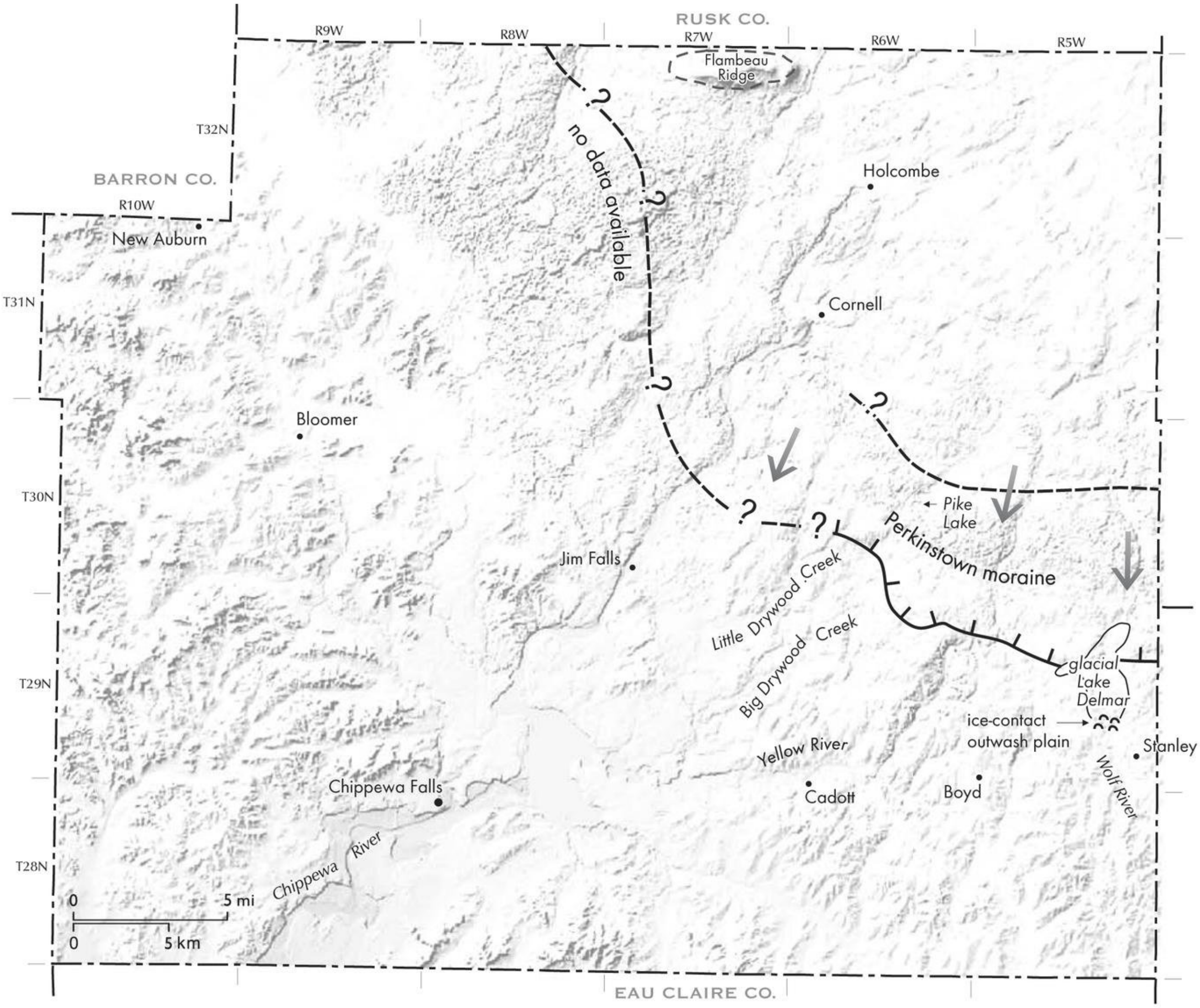


Figure 32 *(continued).* **B.** Perkinstown Phase of the Chippewa Lobe. Perkinstown moraine is formed. Glacial Lake Delmar was trapped behind the Stanley moraine and the ice-contact outwash plain face. Ice extent to the northwest is uncertain because landforms associated with this phase have been obscured by the younger, high-relief Chippewa moraine.

landscape during younger events of the last part of the Wisconsin Glaciation. Florin and Wright (1969) showed that stagnant ice remained buried for up to 3,000 years beneath sediment in Minnesota, and Henriksen and others (2003) reported that buried, stagnant glacial ice has survived at a high latitude (northern Russia) for approximately 80,000 years. It seems unlikely that ice from a previous glaciation could have survived in the mid-latitudes until the last part of the Wisconsin Glaciation. Thus, Johnson (1986) estimated that the Early Chippewa Phase occurred sometime between 15,000 and 25,000 years before present. I suggest that this phase occurred during the earliest part of that range (between approximately 20,000 and 25,000 years before present).

Stanley Phase (new)

The Stanley Phase marks the southernmost extent of the Chippewa Lobe in eastern Chippewa County and northern Clark County during the last part of the Wisconsin Glaciation (table 2), and it roughly coincides with the "middle Woodfordian advance" of Cahow (1976). The Chippewa Lobe advanced from the north during the Stanley Phase to a point 3 km north of what is now the village

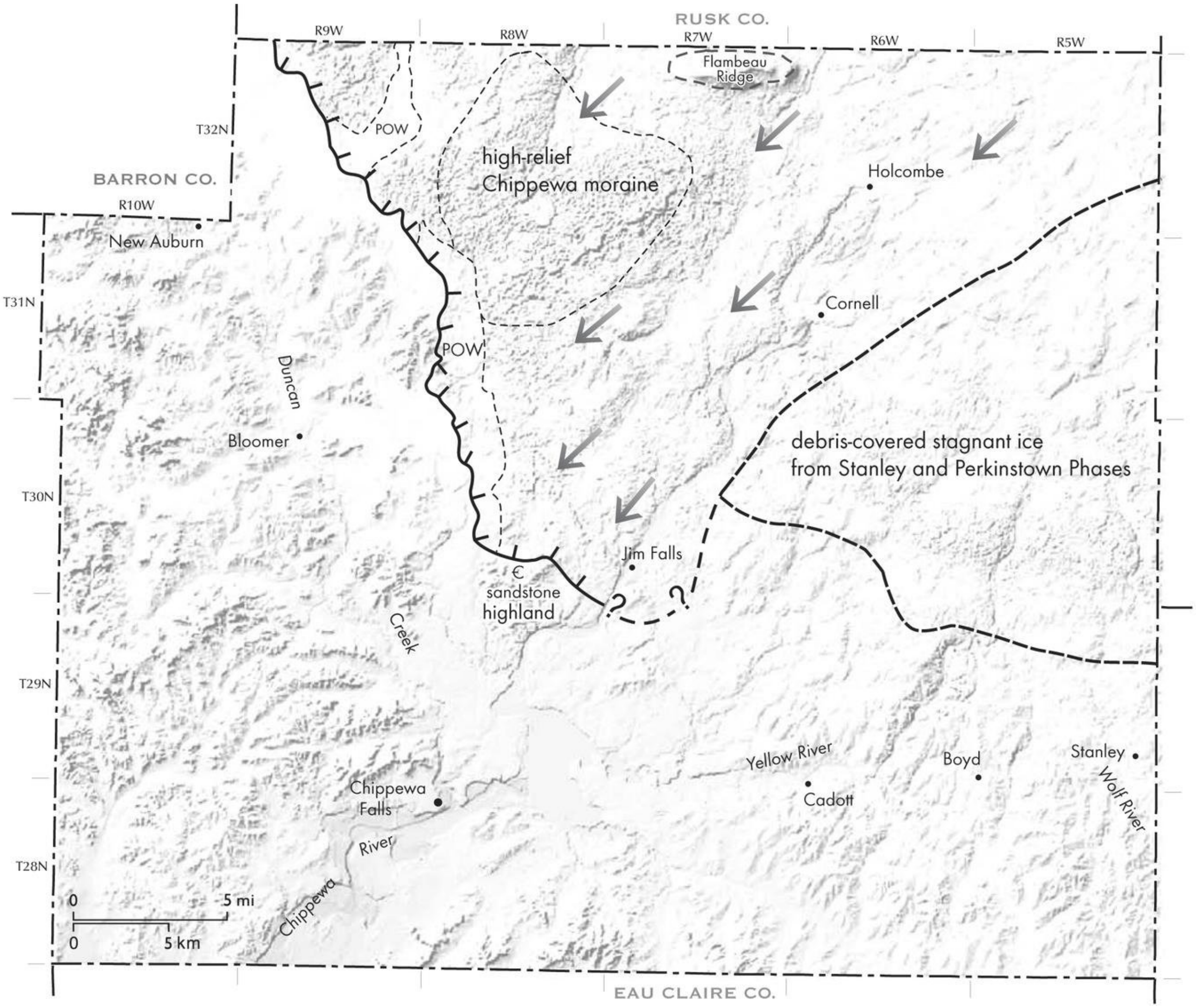


Figure 32 *(continued)*. **C.** Late Chippewa Phase of the Chippewa Lobe. Ice surges to the southwest; thick sediment accumulates on the ice surface downflow from Flambeau Ridge and becomes part of the high-relief Chippewa moraine. POW = pitted outwash plain.

of Stanley (fig. 32A). Evidence for this ice-margin position can be observed north of Lake Wissota, where kettles commonly interrupt the Wissota terrace (map unit **scp,** plate 1).

The Stanley moraine is marked by subdued glacial landforms located beyond the Perkinstown ice-margin position (see next section, *Perkinstown Phase)*. The Stanley moraine is composed of small hummocks northwest of Cadott (secs. 23 and 24, T29N, R7W) and the moraine continues to the east (fig. 2). The Stanley moraine has 2 to 6 m of local relief and is more irregular than the Merrill till surface to the south (figs. 16 and 33). An esker in the Coldwater Creek valley (secs. 16 and 17, T29N, R5W) extends beyond what is interpreted as the Perkinstown ice margin and terminates 1 km north of the Stanley Phase ice-margin position. Little meltwater-stream sediment is observed along this part of the Stanley ice margin until the area north of Stanley, where a prominent ice-contact outwash plain marks the Stanley Phase ice-margin position (fig. 33). This stream sediment has been mined extensively for high-quality aggregate. The Stanley Phase ice-margin position extends east to the area north of Thorp and then veers north to intersect the Perkinstown moraine in northern Clark County (sec. 8, T29N, R3W). The Stanley moraine is more poorly developed than the Perkinstown moraine and lacks the ice-walled-lake plains as-

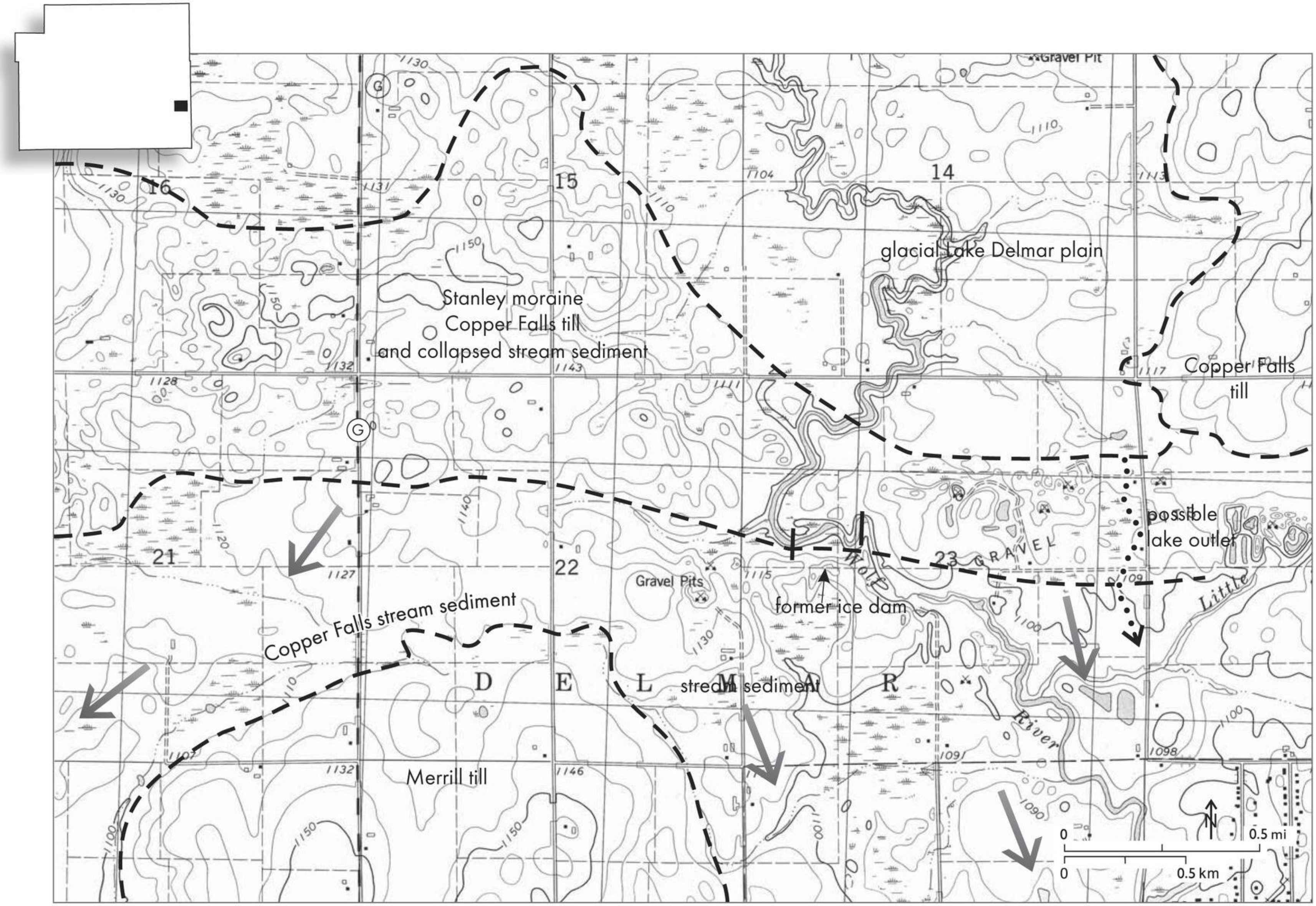


Figure 33. Part of the Stanley Quadrangle, Wisconsin (U.S. Geological Survey, 7.5-minute series, topographic, 1979), showing the low-relief Stanley moraine. As ice wasted from the Stanley Phase maximum, ice-cored stream sediment dammed the Wolf River drainage and formed glacial Lake Delmar. Arrows represent meltwater flow. Contour interval, 10 ft (3 m).

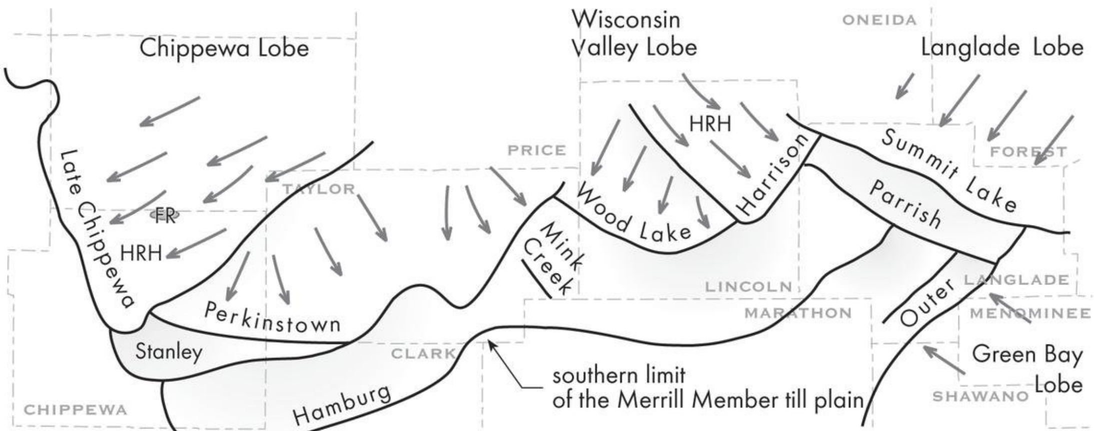


Figure 34. Ice-flow directions (arrows) and phases of the Wisconsin Glaciation. The Mink Creek moraine might be correlative to the Stanley moraine. The high-relief, hummocky (HRH) Chippewa and Harrison moraines formed after the Chippewa and Wisconsin Valley Lobes underwent major changes in ice-flow direction. These major changes of flow direction are thought to represent ice-surging events that contributed to the development of the high-relief moraines. Modified from Attig and others (1998) and Syverson and others (2005). FR = Flambeau Ridge.

sociated with the Perkinstown moraine.

The low-relief hummocks and the rolling Stanley till plain that formed during the Stanley Phase are underlain by reddish-brown sandy till. On the basis of geomorphic arguments, I interpret the Stanley Phase to be the first event of the last part of the Wisconsin Glaciation. First, although the ice-marginal topography tends to be subdued, it is relatively unmodified by erosion (unlike the Merrill till plain). Second, pitted outwash plains outside the Perkinstown and Late Chippewa Phase ice-margin positions suggest that stagnant ice from the Stanley Phase was still present during those younger events, thus indicating a younger age.

Attig (1993) described areas in eastern Taylor County that have relatively unmodified glacial landforms outside the prominent end moraines from the last part of the Wisconsin Glaciation (map units gu, guh, gmh on Attig's plate 1). In Taylor County Attig (1993, p. 7) also observed the Merrill till plain, the Mink Creek moraine to the north that displays similar morphology to the Stanley moraine, and the younger Perkinstown moraine (fig. 34). This geomorphic sequence is identical to the Merrill–Stanley–Perkinstown sequence observed in eastern Chippewa County. The Mink Creek moraine is underlain by reddish-brown, sandy till that Attig (1993) interpreted as Merrill till deposited before the last part of the Wisconsin Glaciation. Attig (1993, p. 8) stated that the Merrill and Copper Falls tills could not be clearly separated in Taylor County using physical characteristics, so he used surface expression to tentatively demarcate the units and infer ages. On the basis of the evidence in Chippewa County that the Stanley Phase occurred during the last part of the Wisconsin Glaciation and the Stanley moraine's morphologic similarities to the Mink Creek moraine, it is possible that the Mink Creek Phase of Attig (1993) and the Stanley Phase may be early, correlative events from the last part of the Wisconsin Glaciation.

The timing of the Stanley Phase can only be approximated. It is possible that it is correlative to the Early Chippewa Phase of the western part of the Chippewa Lobe (see previous section; fig. 32A; Johnson, 1986) and predates the Emerald Phase of the Superior Lobe (Johnson, 2000). The Stanley Phase definitely predates the Perkinstown Phase of the Chippewa Lobe, the event that constructed the large Perkinstown moraine in Chippewa and Taylor Counties (Attig, 1993). Ice may have reached the Perkinstown maximum position by approximately 18,000 to 20,000 years before present (Attig, 1993; Ham and Attig, 1996a). Given the parallel nature of the Stanley and Perkinstown ice-margin positions in eastern Chippewa County, I suggest that the Stanley Phase occurred shortly before the Perkinstown Phase, perhaps at some time between 20,000 and 25,000 years before present.

Perkinstown Phase

After the Stanley Phase, the Chippewa Lobe wasted back from its maximum position in eastern and central Chippewa County. During the Perkinstown Phase (table 2; Attig, 1993), the Chippewa Lobe restabilized approximately 3 to 14 km north–northeast of Stanley Phase ice-margin position (fig. 32B). The ice deposited the prominent Perkinstown moraine at this time. The moraine is a low- to moderate-relief (8 to 20 m) hummocky zone that is up to 9 km wide in a north–south direction. This moraine, named by Attig (1993, p. 20) in Taylor County, extends westward from Taylor County, through the Otter Lake area in eastern Chippewa County and toward Cornell, where the moraine becomes indistinct (figs. 2 and 32B). The northwest to southeast trend of the Perkinstown moraine near Cornell suggests that ice in eastern Chippewa County was flowing in a more southwesterly direction during the Perkinstown Phase than during the Stanley Phase.

The character of the Perkinstown moraine changes markedly from one place to another. In Chippewa County, the most pronounced part of the moraine topography is not typically evident at the southernmost part of the moraine. The most hummocky topography can be seen several kilometers upflow from the outermost ice-margin position, and an area of discontinuous low-relief hummocky topography connects the discrete areas. Cahow (1976, p. 64) mapped the Drywood and Pike Lake moraines in the eastern Chippewa County area; I refer to them as the Perkinstown moraine in this report. It seems likely that several ice-margin fluctuations occurred during the Perkinstown Phase to create the moraine.

During the Perkinstown Phase, stagnant ice was still present in the ice-contact outwash plain that formed north of Stanley during the Stanley Phase. Ice-cored stream sediment created a dam that blocked the southerly flow of the Wolf River. Glacial Lake Delmar formed north of that dam (lake-plain elevation, 335 to 341 m [1,100 to 1,120 ft], figs. 29, 32B , and 33). Chippewa Lobe ice may have terminated at a calving ice margin on the north side of the lake during the Perkinstown Phase.

Ice wasting back from the Perkinstown ice margin also dammed glacial Lakes Colburn and Estella in the Pike Lake and Cornell areas, respectively (fig. 29). Glacial Lake Colburn formed as the northeasterly draining Pike Creek was dammed by the retreating Chippewa Lobe margin (lake-plain elevation, 334 to 338 m [1,095 to 1,110 ft], fig. 29). This lake eventually drained east into the Yellow River (probably in sec. 8, T30N, R5W, Colburn Quadrangle, Wisconsin, U.S. Geological Survey, 7.5-minute series, topographic, 1973) once sufficient ice melted out of the Perkinstown moraine to allow the passage of the water.

Glacial Lake Estella was an irregularly shaped lake east–southeast of Cornell (lake-plain elevation, 332 to 347 m [1,090 to 1,140 ft]) that initially drained west into the Chippewa River by way of Clark and French Creeks. As the level of glacial Lake Estella decreased, the lake separated into eastern and western basins as a narrow divide emerged (fig. 29). The eastern basin probably merged with glacial Lake Colburn and drained to the east.

To the east, the Perkinstown Phase appears to correlate with the Wood Lake Phase of the Wisconsin Valley Lobe (fig. 34; Attig, 1993; Ham and Attig, 1997). Ice was certainly present in northwestern Chippewa County at this time, but features from the Perkinstown Phase are obscured by the high-relief Chippewa moraine formed during the Late Chippewa Phase (fig. 32B). This suggests that the Perkinstown Phase occurred before the Late Chippewa Phase (and the concurrent St. Croix Phase of the Superior Lobe, based on the interpretation of Johnson, 1986). Attig (1993) and Ham and Attig (1996a) proposed that the Chippewa Lobe may have reached the Perkinstown maximum position by approximately 18,000 to 20,000 years before present.

Late Chippewa Phase

The Chippewa Lobe flowed southwest into Chippewa County during the Late Chippewa Phase (table 2; Johnson, 1986) and formed the prominent Chippewa moraine in the northwestern part of the county as well as in Barron and Rusk

Counties (figs. 2, 32C, and 34). Parts of the Chippewa moraine were described by Mathiesen (1940), who called it the “Inner Morainic System,” Black (1974), who called it the “Bloomer moraine,” Cahow (1976), Johnson (1986), Syverson (1998a, b), and Syverson and others (2005). Extensive outwash plains head at the Chippewa moraine (Andrews, 1965).

The maximum extent of the Chippewa Lobe during the Late Chippewa Phase is marked by pitted outwash plains that extend up to 2 km beyond the Chippewa moraine. The Chippewa moraine in Chippewa County is dominated by a 16 km wide, triangular tract of high-relief hummocks and irregularly shaped lakes southwest of Flambeau Ridge (figs. 2 and 24). The hummocks are circular to elongate, 15 to 30 m high, 100 to 300 m in diameter, and 200 to 300 m apart. The most prominent hills in the Chippewa moraine (such as Baldy Mountain and the Chippewa Moraine Ice Age Visitor Center hill) are stable-environment ice-walled-lake plains that are 40 to 50 m high (fig. 24).

The southwesterly ice-flow direction during the Late Chippewa Phase is indicated by drumlins in northeastern Chippewa County (shown by symbol in map unit **gc,** plate 1), and in Rusk, Taylor, and Price Counties (Attig, 1993, p. 21). To the south, these Late Chippewa Phase drumlins truncate poorly developed, south–southeast trending drumlins that indicate flow toward the Perkinstown moraine in Taylor County (fig. 34; J.W. Attig, 2004, verbal communication). The truncation of this drumlin set indicates that the southwesterly ice flow during the Late Chippewa Phase occurred after the Perkinstown Phase.

In Taylor County the Late Chippewa Phase drumlins are roughly parallel to the Perkinstown moraine and extend quite close to it (Attig, 1993). This shows that the Chippewa Lobe was not fanning outward in the downflow direction, as is typical for glaciers, during the Late Chippewa Phase. Similar late-stage, atypical flow relationships associated with major changes in ice-flow direction have been described for the Harrison Phase of the Wisconsin Valley Lobe to the east (fig. 34, Ham and Attig, 1996b, 1997; Attig and others, 1998) and during phases of the Superior Lobe to the west (Johnson, 2000). These flow events may represent rapidly moving ice streams or surging glaciers where much subglacial water lubricated the bed and enhanced basal sliding and ice velocity (Clayton and others, 1985; Clark, 1992; Ham and Attig, 1996b, 1997; Attig and others, 1998, p. 43). If so, this would have impacted moraine morphology (see next section).

The Late Chippewa Phase ice maximum correlates with the St. Croix Phase of the Superior Lobe on the basis of the ice-marginal relationships in Barron and Washburn Counties (Johnson, 1986). Given estimates that the Laurentide Ice Sheet began wasting on a large scale approximately 15,000 years before present (Clayton and Moran, 1982; Attig and others, 1985), I propose that the Late Chippewa Phase probably occurred between about 15,000 and 18,000 years ago.

Origin of the high-relief Chippewa moraine

The difference in morphology between the older, low- to moderate-relief (8 to 20 m) Perkinstown moraine and the younger, high-relief (15 to 30 m) Chippewa moraine is striking. Such hummocky moraines are thought to require thick sediment on the ice surface (Gravenor and Kupsch, 1959; Clayton, 1967; Mickelson and others, 1983; Lagerbäck, 1988; Sollid and Sørbel, 1988; Johnson and others, 1995; Ham and Attig, 1996a, 1997; Colgan and others, 2003; Johnson and Clayton, 2003). Clayton (1967, p. 38) postulated that the relief of a hummocky moraine is similar to the sediment thickness originally present at the glacial surface as the moraine was forming. If so, this indicates that the sediment on top of the ice at the Late Chippewa ice margin was generally two to three times thicker than the sediment on top of the Perkinstown ice margin.

Several mechanisms have been proposed for the accumulation of thick supraglacial sediment in midcontinental areas, as summarized by Johnson and Clayton (2003). These include compression near the ice margin as the thinning ice slows (Paterson, 1994, p. 253), compressive ice flow caused by the glacier flowing over permafrost (Attig and others, 1989; Clayton and others, 2001; Johnson and Clayton, 2003), and enhanced compression at the margin of a surging glacier (Hambrey and others, 1996). The Perkinstown and Chippewa moraines formed at approximately the same latitude during permafrost conditions, although at different times, so it seems likely that many of these processes would have been at work in both areas.

The widest, highest-relief part of the Chippewa moraine is southwest (directly downflow) of Flambeau Ridge, a 150 m high Precambrian quartzite ridge (fig. 2, plate 1). This area also coincides with the thickest glacial sediment in the county (greater than 60 m; fig. 4A; Lippelt, 1988b) and a reentrant in the outermost part of the Chippewa moraine (plate 1). On the basis of these relationships, it seems likely that the high-relief Chippewa moraine is somehow related to Flambeau Ridge (Cahow, 1976; Waggoner and others, 2001). Waggoner and others (2001) and Syverson and others (2005) proposed that Flambeau Ridge formed a prominent obstacle to ice flow that slowed the ice, enhanced compressive ice flow (Paterson, 1994, p. 254) and the transportation of sediment into the ice, and eventually resulted in thicker than normal sediment accumulations on the ice surface.

As Flambeau Ridge emerged from the thinning ice, large-scale ice stagnation occurred in the Chippewa moraine region downflow from the obstruction. The thick sediment insulated the underlying ice, and eventually the active Chippewa Lobe separated from the stagnant ice mass southwest of Flambeau Ridge (fig. 23). Outwash plains formed, sloping away in all directions as this ice mass melted and the hummocky moraine topography developed.

Cahow (1976, p. 41, 173) proposed that this section of the Chippewa moraine formed as an interlobate moraine downflow from Flambeau Ridge. However, Waggoner and others (2001) noted that hummocks in this area are largely made of till-like sediment, not the glacial stream sediment that is common in interlobate moraines (Mickelson and Syverson, 1997).

The high-relief Chippewa moraine also might have been formed by different ice-flow conditions than those operating during the Perkinstown Phase. Attig and others (1998) proposed that the Perkinstown moraine formed during non-surging conditions as ice flowed south–southeast toward the margin (fig. 34). Perkinstown Phase ice in the western part of the Chippewa Lobe was flowing south–southwest near Cornell at this time (figs. 32B and 34). Truncated ice-flow indicators in the middle of the Chippewa Lobe show a marked change in flow direction from southeasterly to southwesterly during the Late Chippewa Phase.

Ham and Attig (1996b) and Attig and others (1998) attributed such major changes in ice-flow direction during the last part of the Wisconsin Glaciation to surging events. Attig and others (1998) recognized that the high-relief Chippewa and Harrison moraines are associated with major, late-stage changes in flow direction of the Chippewa and Wisconsin Valley Lobes, respectively (fig. 34). According to Attig and others (1998), the Chippewa Lobe surged rapidly toward the southwest over permafrost during the Late Chippewa Phase. This caused the ice to freeze to the bed near the margin and sliding stopped. This would have quickly reduced ice velocity, strengthened the compressive flow regime, enhanced upward ice flow and erosion, and produced thick sediment accumulations on the ice surface (Johnson and others, 1995; Clayton and others, 2001). The sharp, linear eastern boundary of the Chippewa moraine suggests that stagnant, debris-covered ice from the Perkinstown Phase might have prevented ice from flowing farther to the east during the Late Chippewa Phase (fig. 32C), as suggested by Attig (1993).

Permafrost history

Abundant ice-wedge casts in Wisconsin are indicative of former permafrost conditions (fig. 35; Black, 1965; Clayton and others, 2001). Black (1965) and Johnson (1986) described ice-wedge cast sites in western Wisconsin, and Holmes and Syverson (1997) described nine different sites in Eau Claire and Chippewa Counties (fig. 35). Most of these sites are outside the terminal moraines associated with the last part of the Wiscon-

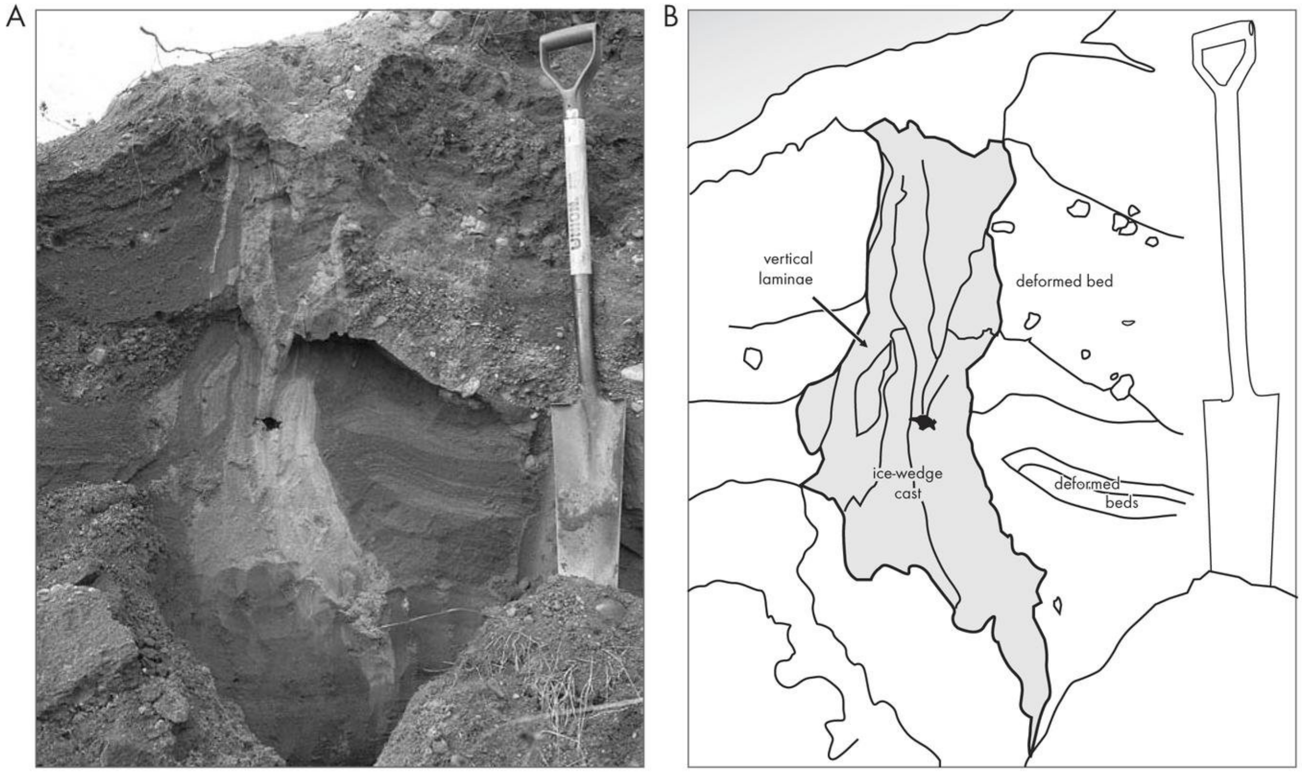


Figure 35. Photograph **(A)** of ice-wedge cast and line sketch **(B)** highlighting important features (NE¼ sec. 16, T28N, R10W). Weathered layers of stream sediment of the River Falls Formation are deformed upward adjacent to the ice-wedge cast. Modified from Holmes and Syverson (1997).

sin Glaciation, but the timing of ice-wedge-cast formation has been in doubt. Clayton and others (2001) cited abundant ice-wedge-cast polygon data from Wisconsin to suggest that permafrost existed in Wisconsin from approximately 10,000 to 25,000 years before present, and that permafrost melted in the Chippewa County region approximately 12,500 years before present. They also proposed that all ice-wedge casts in Wisconsin date from the last part of the Wisconsin Glaciation, arguing that older ice-wedge casts would have been destroyed by later permafrost activity. Holmes and Syverson (1997) used relative weathering differences in the ice-wedge casts and host sediment to conclude that the surficial ice-wedge casts in Eau Claire and Chippewa Counties formed during permafrost conditions associated with the last part of the Wisconsin Glaciation.

Post-Late Chippewa Phase history

No other ice-margin positions were found in Chippewa County northeast of the Chippewa moraine. Younger Chippewa Lobe ice-margin positions are nearer to Lake Superior in northern Sawyer and Price Counties (Clayton, 1984; Clayton and others, 2006). The last ice advance into northernmost Wisconsin from the Lake Superior basin occurred approximately 9,900 years before present, and the ice margin wasted from Wisconsin for the last time approximately 9,500 years before present (Clayton, 1984; Syverson and Colgan, 2004).

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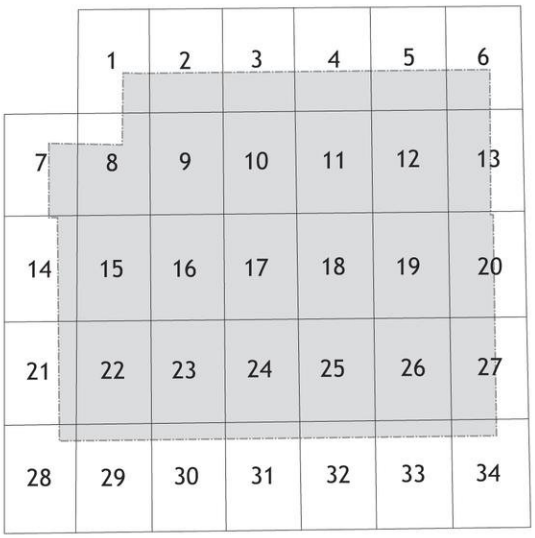

Index to 1:24,000-scale maps

1 Moose Ear Lake—1978
2 Chain Lake—1972
3 Fireside Lakes—1972
4 Flambeau Ridge—1971
5 Ladysmith SE—1971
6 Sheldon—1971
7 Sand Creek—1975
8 New Auburn—1975
9 Marsh-Miller Lake—1975
10 Bob Lake—1975
11 Cornell—1973
12 Holcombe—1973
13 Ruby—1973
14 Colfax North—1975
15 Como Creek—1975
16 Bloomer—1975
17 Jim Falls—1975
18 Crescent—1973
19 Colburn—1973
20 Huron—1973
21 Colfax South—1972
22 Albertville—1972
23 Chippewa Falls—1972
24 Lake Wissota—1972
25 Cadott—1979
26 Boyd—1979
27 Stanley—1979
28 Elk Creek Lake—1972
29 Eau Claire West—1972 (82 PR)
30 Eau Claire East—1972 (82 PR)
31 Fall Creek—1972
32 Lake Eau Claire West—1979
33 Lake Eau Claire East—1979
34 Simes Creek—1979

PR Photorevised

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COVER, CLOCKWISE, FROM RIGHT: Shaded-relief map of Chippewa County; laminated silt and silt loam from borehole, taken at a depth 10 ft; and sharp-crested rim ridge with flat ice-walled-lake plain in the foreground. (Photographs by K.M. Syverson.)

Wisconsin Geological and Natural History Survey
Bulletin 103
Pleistocene Geology of Chippewa County, Wisconsin
Plate 1

Kent M. Syverson

2007

Explanation

Postglacial Sediment

p — **Sediment of low, wet areas.** Peat or slope sediment covering the stream, lake, or glacial sediment indicated by adjacent map units; flat to low-relief surfaces.

sp — **Postglacial stream sediment.** Silty sand, sand, and gravelly sand deposited by postglacial streams; commonly contains peat; flat to low-relief floodplains. Mapped only where extensive; present but not shown along most streams.

Meltwater-Stream Sediment

sc, scp, sch — **Meltwater-stream sediment of the Copper Falls Formation.** Unit **sc:** brown to pale brown, sand, gravelly sand, and sandy gravel; typically more gravelly near former ice-margin positions; soil profiles 1 to 1.2 m thick; gently sloping, low-relief outwash plains; deposited by meltwater streams flowing away from the Chippewa Lobe or deposited in valleys by streams flowing off highlands. Contains some slope sediment. Unit **scp:** brown to pale brown, sandy gravel, gravel, gravelly sand, and sand, moderately to poorly sorted; gently sloping, low-relief plains interrupted by collapse depressions (pits) up to 10 m deep; deposited in outwash plains above isolated blocks of ice as meltwater streams flowed away from the Chippewa Lobe. Unit **sch:** brown sandy gravel, gravelly sand, and reddish-brown gravelly sandy loam, poorly sorted; chaotic bedding; moderate- to high-relief hummocky surfaces; deposited on surface of Chippewa Lobe by streams and gravity flows; as buried ice melted, original depositional surface was destroyed.

sm — **Meltwater-stream sediment of the Merrill Member of the Lincoln Formation.** Brown to pale brown sand, gravelly sand, and sandy gravel, moderately to well sorted; soil profiles 1 to 1.2 m thick; small, isolated, gently sloping terraces above Copper Falls Formation outwash plains; deposited by meltwater streams flowing away from the Chippewa Lobe.

sr — **Meltwater-stream sediment of the River Falls Formation.** Yellowish-red, gravelly sandy clay loam, gravelly sandy loam, sandy gravel, and sand; soil profiles up to 5 m thick with B horizons that are clay-cemented in areas; located high in the hilly, stream-dissected landscape or adjacent to bedrock hills; deposited in outwash plains by meltwater streams flowing away from the Superior and Chippewa Lobes, then extensively eroded and weathered. Unit thickness is extremely variable over the irregular Cambrian sandstone surface in the western part of the county; contains some small areas of Cambrian sandstone.

Lake Sediment

lcp, lci — **Lake sediment of the Copper Falls Formation.** Unit **lcp:** brown, yellowish-brown, to dark gray, laminated silt loam, silty clay loam, and gravelly sand; commonly contains peat; flat to low-relief, poorly drained surfaces; occupies low areas in landscape where glacial ice blocked valleys and formed ice-contact or proglacial lakes. Unit **lci:** brown, yellowish-brown, to dark gray, laminated silt and silt loam offshore sediment, sandier and more gravelly nearer to former shoreline; flat to broad, convex surfaces are commonly high areas in the moraine landscape; deposited in ice-walled lakes. Rim ridges contain poorly to well sorted sandy gravel, sand, and gravelly sandy loam deposited in nearshore environment.

Glacial Sediment

gc, gcf, gch — **Glacial sediment of the Copper Falls Formation.** Unit **gc:** reddish-brown to brown, gravelly sandy loam till, poorly sorted; low- to moderate-relief, rolling to streamlined surfaces deposited subglacially by the Chippewa Lobe. Unit **gcf:** reddish-brown, gravelly sandy loam till, poorly sorted, commonly draped by 1 to 2 m of poorly sorted, crudely bedded silty gravelly sand deposited in ice-marginal streams; steeply sloping, ramp-like topography influenced by Flambeau Quartzite present at shallow depths beneath the till. Unit **gch:** reddish-brown to brown, gravelly sandy loam gravity-flow sediment and meltout till, silt loam lake sediment, and sandy gravel meltwater-stream sediment; chaotic bedding; low- to high-relief hummocky surfaces; sediment deposited at the surface of the melting Chippewa Lobe, and sediment later collapsed and flowed as underlying ice melted.

gm — **Glacial sediment of the Merrill Member of the Lincoln Formation.** Reddish-brown to brown, gravelly sandy loam to loam till, poorly sorted; moderate-relief, rolling to glacially streamlined surfaces with a more integrated drainage network than found on surfaces of unit **gc;** deposited subglacially by the Chippewa Lobe. Unit thickness is extremely variable over the irregular Cambrian sandstone surface in the southeastern part of the county; contains some small areas of Cambrian sandstone.

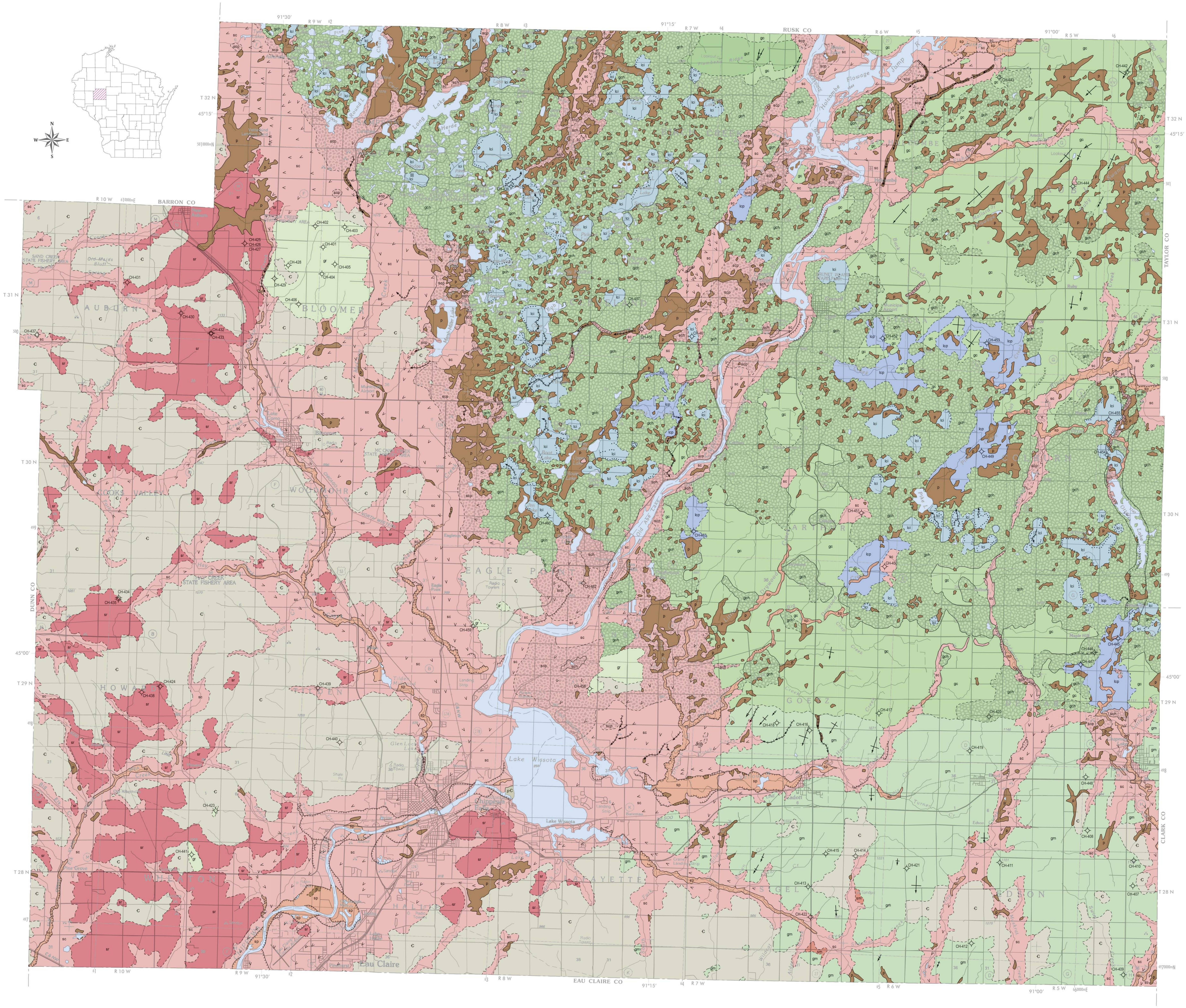
gr — **Glacial sediment of the River Falls Formation.** Yellowish-red to reddish-brown, gravelly sandy loam till, poorly sorted; surface is rolling with well integrated stream drainage; no original glacial landforms present; deposited subglacially by the Superior and Chippewa Lobes. Unit thickness is extremely variable over the irregular Cambrian sandstone surface in the western part of the county; contains some small areas of Cambrian sandstone.

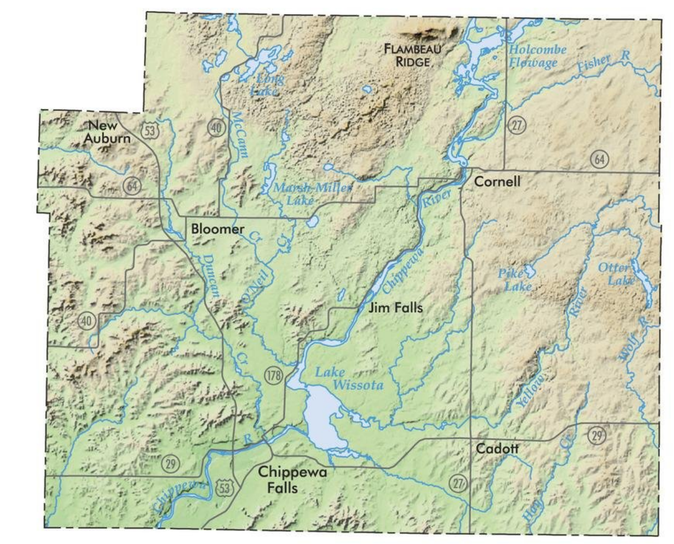
Cambrian Bedrock, Undifferentiated

Є — **Sand, quartz sandstone, conglomerate, siltstone, and shale of the Mount Simon, Eau Claire, Wonewoc, Lone Rock, St. Lawrence, and Jordan Formations.** Contains fine- to coarse-grained, light brown to yellow quartz sand and sandstone, conglomerate, glauconitic sandstone, and white to green siltstone and shale; thinly to thickly bedded; sandstone displays cross-beds and parting lineations; marine brachiopod shells, trilobite casts, and trace fossil burrows are common. Bedrock is exposed at surface or draped by scattered patches of weathered glacial outwash and till up to 2 m thick or windblown sandy silt up to 3 m thick. Topography is stream dissected with local relief up to 100 m.

Precambrian Bedrock, Undifferentiated

pЄ — **Precambrian metavolcanic, metasedimentary, and igneous rock–gniess, schist, amphibolite, Flambeau quartzite and metaconglomerate, granite, and diabase.** Uppermost 1 to 10 m of rocks other than quartzite and metaconglomerate is commonly altered chemically to greenish clay. Most outcrops are at river level along the major rivers and downstream from dams.





Shaded-relief map of Chippewa County.

10 0 20 40 Mi
10 0 20 40 60 Km

Symbols

Contact. Solid where position shown on map is generally within 0.1 km of the actual position; dashed where the position shown may be more than 0.1 km from actual position.

Esker

Tunnel-channel margin

Axis of small meltwater-stream channel. Arrow indicates water-flow direction.

Drumlin. Length of line is proportional to length of drumlin axis.

Glacial striation with arrow pointing in ice-flow direction. Dot marks location of measurement.

Stream-cut bank

Ice-marginal ridge

Major ice-contact face

Rim of ice-walled-lake plain

Direction of meltwater flow as indicated by modern surface slope and flow features observed on aerial photographs.

CH-420 Test-hole location and WGNHS Geologic Log number

Scale 1:100,000

MILES

KILOMETERS

This map 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 and cartographic principles; however, the map should not be used to guide site-specific decisions without verification. Proper use of the map is the sole responsibility of the user.

The base map was constructed from U.S. Geological Survey digital line graph files (1990, scale 1:100,000) and modified by the Wisconsin Department of Natural Resources (1992) and the Wisconsin Geological and Natural History Survey (2000).

Cartography by D.L. Patterson.

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Plate 1. Pleistocene geologic map of Chippewa County, Wisconsin.

Wisconsin Geological and Natural History Survey
Bulletin 103
Pleistocene Geology of Chippewa County, Wisconsin
Plate 2

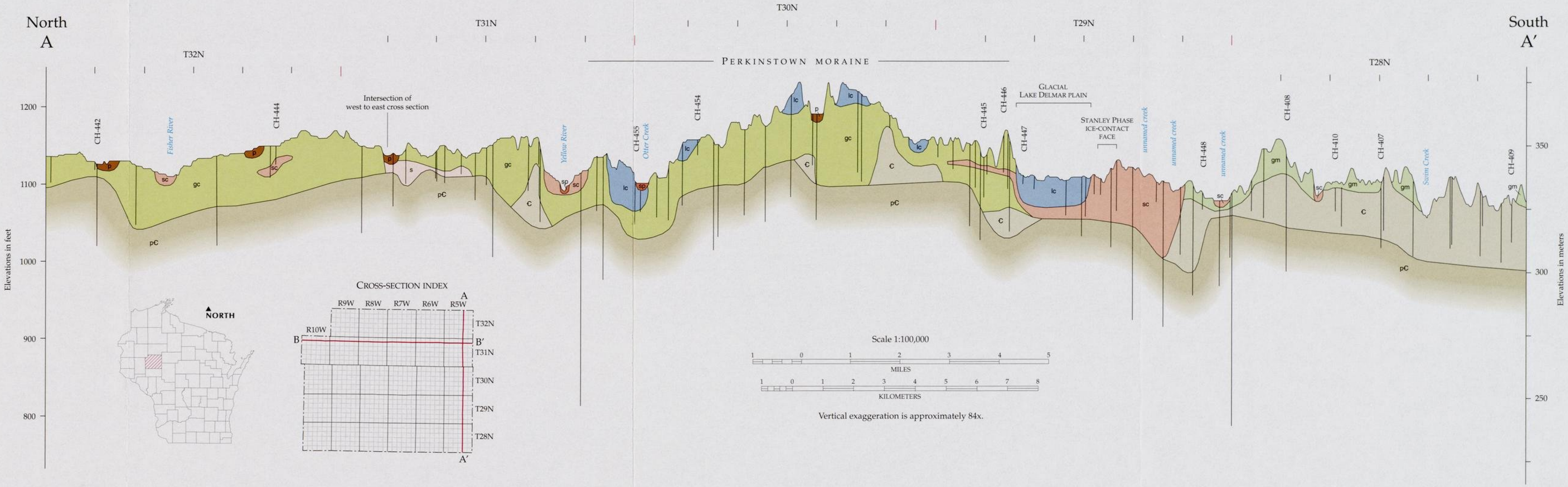
Kent M. Syverson

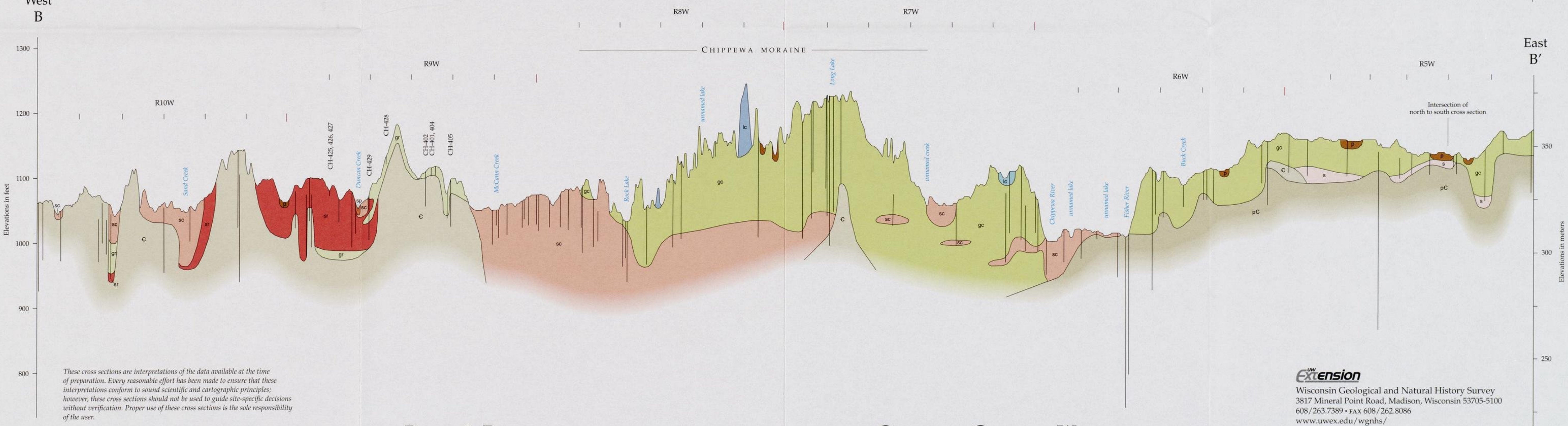
2007

Explanation

Cross-sections A–A′ and B–B′ show the generalized vertical relationships between geologic units. They are based on the surficial distribution of materials, logs of holes drilled for this study, and logs of domestic wells that are on file at the Wisconsin Geological and Natural History Survey. Unit designations are the same as those used on the map (plate 1), with the following exceptions:

- sc — Stream sediment of the Copper Falls Formation (map units **sc, scp,** and **sch**). This unit may include stream sediment of the River Falls and Lincoln Formations at depth.
- gc — Glacial sediment of the Copper Falls Formation (map units **gc, gcf,** and **gch**).
- s — Stream sediment, undifferentiated.
- lc — Lacustrine sediment of the Copper Falls Formation (map units **lci** and **lcp**).
- | — Well location. Symbol represents approximate elevation of well, which may be as far as 1.6 km from line of cross section.





These cross sections are interpretations of the data available at the time of preparation. Every reasonable effort has been made to ensure that these interpretations conform to sound scientific and cartographic principles; however, these cross sections should not be used to guide site-specific decisions without verification. Proper use of these cross sections is the sole responsibility of the user.

Cartography by D.L. Patterson.

PLATE 2. PLEISTOCENE GEOLOGIC CROSS SECTIONS OF CHIPPEWA COUNTY, WISCONSIN.

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