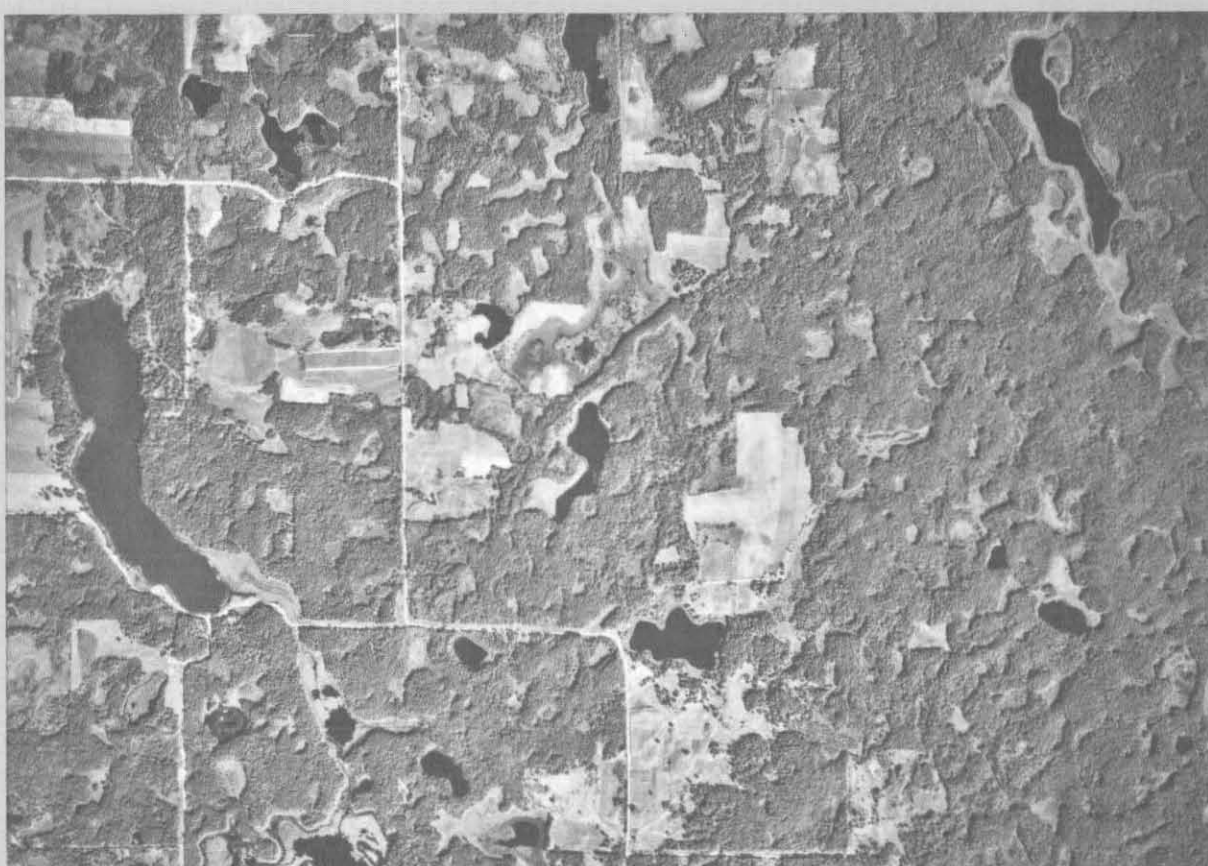
Pleistocene Geology of Barron County, Wisconsin

by Mark D. Johnson



UWEX UNIVERSITY OF WISCONSIN—EXTENSION
GEOLOGICAL and NATURAL HISTORY SURVEY

INFORMATION CIRCULAR
NUMBER 55 1986

Pleistocene Geology of Barron County, Wisconsin

by Mark D. Johnson

A study of the distribution, character, and origin of Pleistocene deposits in Barron County and a description of the glacial history

Wisconsin Geological and Natural History Survey
Information Circular 55

1986

UWEX UNIVERSITY OF WISCONSIN—EXTENSION

Published by and available from

WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY
3817 Mineral Point Road, Madison, Wisconsin 53705

M. E. Ostrom, Director and State Geologist

1986

ISSN: 0512-0640

PLATE

FIGURES

TABLES

Pleistocene Geology of Barron County, Wisconsin

by Mark D. Johnson

ABSTRACT

The Pleistocene geology of Barron County consists of sediment and landforms associated with at least seven glacial advances. The Des Moines Lobe advanced into Barron County (the Reeve Advance) probably several hundred thousand years ago and deposited olive-black loam till (of the Pierce Formation) in the western third of the county. Following a period of weathering, ice of the Superior Lobe advanced (the Baldwin Advance) and deposited yellowish red sandy-loam till (of an unnamed member of the River Falls Formation) at about the same time as the Chippewa Lobe (the Dallas Advance), which deposited yellowish red sandy-loam till (of the Prairie Farm Member of the River Falls Formation). Weathered magnetite and clay minerals indicate that River Falls till was weathered before the remaining four advances into Barron County that occurred during the last part of the Wisconsin Glaciation. Ice during the last four advances deposited yellowish red sandy-loam till (of the Copper Falls Formation) that is not as weathered as the River Falls till. The Early Chippewa Advance deposited till of the Pokegama Creek Member in eastern Barron County sometime between 25,000 and 15,000 years ago. Just before or during the Early St. Croix Advance, permafrost became established, and surface stones were abraded by wind-blown sediment. The Early St. Croix Advance deposited till of the Poskin Member in western Barron county after the Early Chippewa Advance, sometime between 25,000 and 15,000 years ago. The Late St. Croix and Late Chippewa Advances occurred around 15,000 B.P. and deposited the Sylvan Lake and Mikana Members. The sediment in these members makes up the St. Croix moraine and the Chippewa moraine in Barron County. The landforms in and behind these moraines include drumlins, tunnel channels, hummocks, ice-walled-lake plains, and outwash plains. Toward the end of or after the Late St. Croix and Late Chippewa Advances, loess was deposited in the county and permafrost abated, which allowed buried ice blocks to melt.

Gravel suitable for economic use is available in stream sediment beneath the outwash plains and in exposed older stream sediment. Fine sediment suitable for lining of waste pits occurs in the Pierce Formation and in lake sediment beneath ice-walled-lake plains.

INTRODUCTION

Glaciers advanced into Barron County many times during the Pleistocene Epoch and left a variety of landforms and sediment types. The character, distribution, and thickness of the sediment provide clues to the number of glacial advances, their relative ages, and the character of the ice that formed them. Though the glacial history is in itself fascinating, these deposits need to be understood because people live and work upon them. This report has a dual purpose. First, it is intended to aid in the planning and development of the county. The development of agriculture and industry, the siting of solid-waste disposal sites, the availability of aggregate and fill material, and the construction of buildings and roads all require a basic knowledge of the surface materials. The development of Barron County's groundwater resources and the preservation of groundwater quality depend on knowledge of the character and distribution of materials in the county. In Barron County, the surface materials consist primarily of glacial and stream sediment. These materials are described in the Pleistocene deposits section of this report.

Secondly, the purpose of this report is to interpret the glacial history from these deposits. The glacial-history section of this report is written so that it may be read separately from the Pleistocene-deposits section.

Relief in Barron County is generally low, but it can be as much as 80 m in the deeply dissected sandstone hills of southern Barron County or as much as 115 m in the Blue Hills. The highest point in the county occurs in the Blue Hills near the Rusk County line and has an elevation of 494 m. The lowest points (just below 305 m) in the county occur where the Hay and Red Cedar Rivers cross Barron County's southern border. The major rivers in the county, the Hay, Red Cedar, Brill, Vermillion, and Yellow Rivers, all have headwaters in the northern part of Barron County or southern Washburn County (fig. 1).

Precambrian quartzite and Cambrian sand and sandstone is deeply buried by glacial and stream deposits in most of the county. However, quartzite exposures are common in the Blue Hills, and sandstone exposures are extensive in the uplands of south-central Barron County

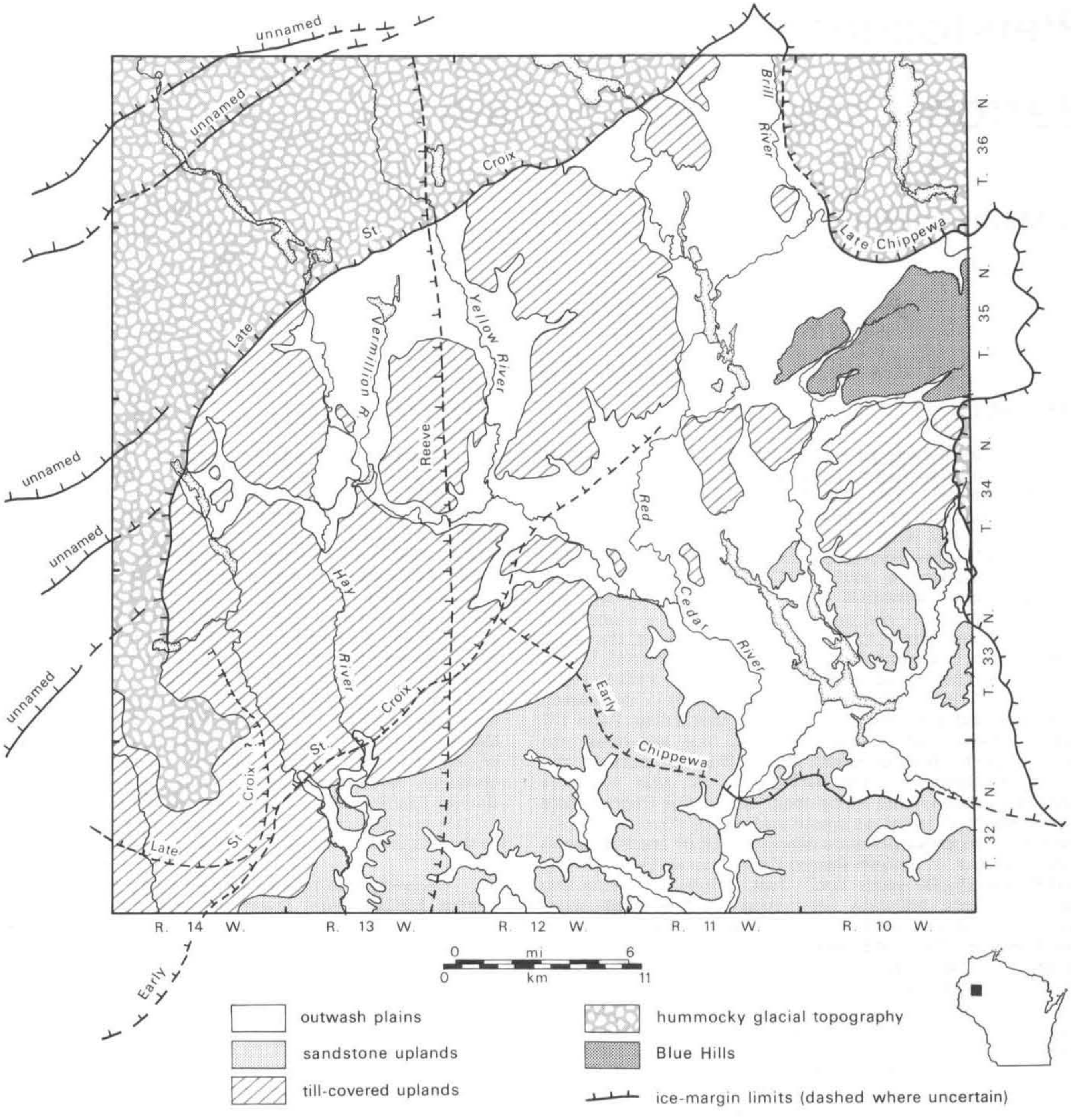


FIGURE 1. Map of Barron County showing principal landform regions, ice-margin limits, and major rivers.

(fig. 1). In regions where glacial and stream deposits are thick, three distinct landform regions predominate: flat plains composed of stream sediment, gently rolling uplands composed largely of till, and hummocky topography in the northwest and northeast sections of the county composed of till and stream sediment (fig. 1).

Field work for this report was completed during the summers of 1981, 1982, and 1983. The report was compiled and written during 1983 and 1984. Many people have provided assistance, ideas, and encouragement while I worked on this report. I wish to thank David M. Mickelson for first introducing me to Barron County and providing advice and constructive criticism. Lee Clayton extensively edited drafts and offered stimulating ideas concerning this project. For help in the field, in the lab, and in the office, I wish to thank John Attig, Heather Macdonald, Steve Kite, Galen Kenoyer, Todd Rayne, Chris Peters, Betty Socha, Doug Connell, Jim Goldberg, Kathy Erdmann, Robert Jones, Greg Jones, Gail Ptacek, Randy Mills, Mike Seifert, and Sue Boley-May. Lou Maher, Jim Knox, Sturges Bailey, Charles Byers, Ron Hennings, Thomas Evans, John Attig, and Alex Zaporozec made valuable criticisms of earlier drafts, and Doug Brew gave time, encouragement, and understanding. Lastly, I wish to thank the Wisconsin Geological and Natural History Survey for providing the support needed.

PRE-PLEISTOCENE GEOLOGY

The pre-Pleistocene geology of Barron County consists of Barron Quartzite of Precambrian age and several sand and sandstone formations of Cambrian age. The Barron Quartzite underlies the Blue Hills in east-central Barron County, and the Cambrian formations underlie the rest of the county (fig. 2).

Barron Quartzite

The Barron Quartzite was deposited as quartz-rich sand in a shallow, strongly agitated sea before it was buried, lithified, and metamorphosed. The Barron Quartzite is dominantly pink, medium-grained (average grain size of samples ranges from between 0.2 to 0.5 mm), and highly resistant to erosion (Dott and Dalziel, 1972). The color is pink, purple, gray, or white. Iron stains the sand grains and helps to emphasize sedimentary structures. Horizontal bedding and cross bedding are common. Locally interbedded with the quartzite is claystone that has gained significance because of its use by Indians in the making of claystone pipes. An outcrop of this claystone, which has been called pipestone or catlinite, occurs in a shallow quarry in the SE1/4 sec. 27, T. 35 N., R. 10 W., where the claystone was mined by Indians.

The Barron Quartzite underlies a broad area in Barron, Rusk, and Sawyer Counties, with a few outliers in Washburn County (fig. 2) (Mudrey, Brown, and Greenberg, 1982). The Barron Quartzite is only 180 m thick, but several northeast-trending faults have brought this resistant rock to the surface so that its areal extent is quite large (Hotchkiss, 1915). The southwesterly oriented drainage in the Blue Hills (fig. 1) is a reflection of the orientation of this structure. Based on isotopic age dates from rock associated with the Baraboo Quartzite, considered to be equivalent in age to the Barron Quartzite (Dott and Dalziel, 1972), the Barron Quartzite was deposited between 1,700,000 and 1,500,000 years ago (Brown and Greenberg, 1983). Folding and metamorphism of the quartzite occurred 1,630,000 or 1,500,000 years ago or at both these times (Geiger, Guidotti, and Petro, 1983; Brown and Greenberg, 1983).

Very few outcrops of in-place quartzite occur. During deformation, the brittle quartzite was highly fractured. Most exposures, especially those on south-facing slopes in

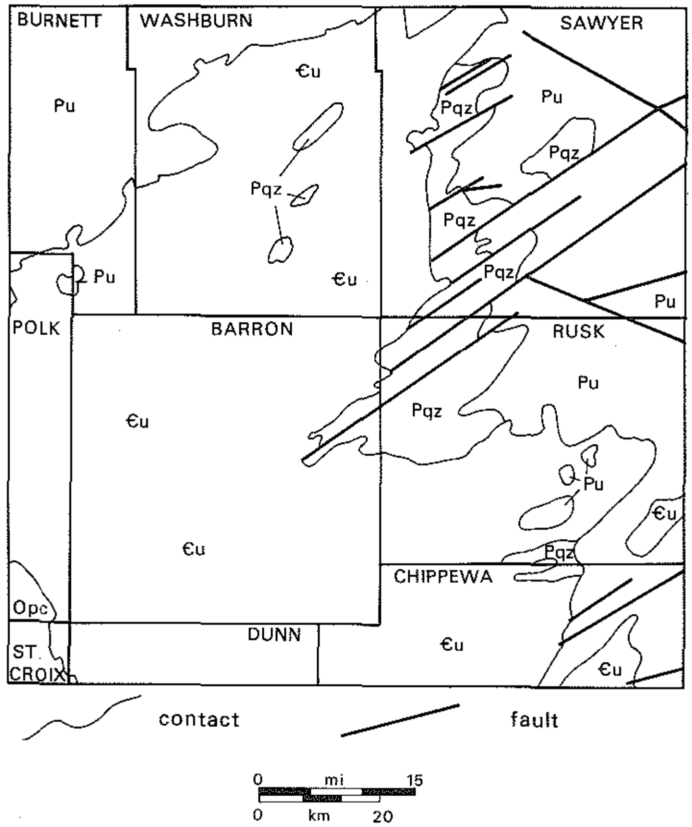


FIGURE 2. Pre-Pleistocene geology of Barron County area. Pqz = Precambrian Barron Quartzite; Pu = undifferentiated Precambrian granite, basalt, metasedimentary rock, and metavolcanic rock; €u = Cambrian sand and sandstone; Opc = Ordovician Prairie du Chien Group (from Mudrey and others, 1982).

the Blue Hills, are covered with coarse talus (map unit Mbt, plate 1). The talus blocks are 0.1 to 0.5 m in diameter, similar in length to the fracture spacings in quartzite outcrops (Hotchkiss, 1915). Streams cutting through bedding, which dips to the northwest, have exposed the edges of quartzite beds. Streams tend to migrate down the dip slope and undercut south-facing slopes. North-facing slopes tend to be less steep because they are dip slopes. Other factors (erosion by ice, frost movement, and southern exposure) have influenced the position and amount of talus but are of lesser importance. Presumably, downslope movement of talus was greater in the past when permafrost was present.

When ice flowed over the Blue Hills, quartzite was incorporated into the ice and deposited to the south and west. Cobbles and boulders of quartzite are commonly found in outcrops of glacial deposits and in farmers' boulder piles at the edges of fields. These cobbles and boulders are in the same size range as the fracture spacing in the quartzite, which indicates that little attrition of these clasts occurred. This is also suggested by a small amount of quartzite in the very-coarse-sand (1 to 2 mm), very-fine-pebble (2 to 4 mm), and fine-pebble (4 to 8 mm) fractions of glacial deposits.

<table>
<tr><td>Pre-cambrian</td><td colspan="11">PHANEROZOIC</td><td>Eon</td></tr>
<tr><td></td><td colspan="6">CAMBRIAN</td><td colspan="5">QUATERNARY</td><td>Period</td></tr>
<tr><td>Barron Quartzite</td><td>Mt. Simon</td><td>Eau Claire</td><td>Wonewoc</td><td>Mazomanie
Lone Rock</td><td>St. Lawrence</td><td>Jordan</td><td>Pierce</td><td>River Falls</td><td colspan="3">Copper Falls</td><td>Formation</td></tr>
<tr><td colspan="7" rowspan="3"></td><td rowspan="3">unnamed</td><td rowspan="2">unnamed</td><td rowspan="3">Pokegama Creek</td><td rowspan="3">Poskin</td><td>Sylvan Lake</td><td rowspan="3">Member</td></tr>
<tr><td>Chetek</td></tr>
<tr><td>Prairie Farm</td><td>Mikana</td></tr>
</table>

FIGURE 3. Lithostratigraphic units of Barron County (from Ostrom, 1970; Mickelson and others, 1984; and this paper).

Cambrian sand and sandstone

Cambrian sand and sandstone is composed primarily of quartz grains that range from very-fine (0.062 to 0.125 mm) to very-coarse (1 to 2 mm) sand with some very-fine pebbles (2 to 4 mm). In places, the quartz-rich sand is interbedded with green, glauconitic sandstone and shale. The relative abundance of glauconite is a characteristic used to distinguish different Cambrian formations (fig. 3). Fossils are present and include trilobites, brachiopods, burrows, and trails. Fossils are rare in the sandstone layers and are more common in the glauconitic units. Sedimentary structures preserved in these rocks include planar and trough cross bedding, horizontal lamination, ripple marks, and mudcracks (Berg, 1959; Ostrom, 1970). Locally, the sandstone contains calcareous cement. In numerous exposures, the sandstone is stained and cemented in places with iron and manganese oxides. These layers may form resistant ledges. However, in most exposures, the sediment is poorly cemented and can be excavated with a shovel.

The thickness of the Cambrian sediment ranges from 0 at its contact in eastern Barron County with the Barron Quartzite to over 215 m in the western part of the county (Bell and Hindall, 1975). In the northern two-thirds of the county, the sand and sandstone is buried beneath glacial deposits. Only in the southern part of the county, where sandstone is commonly exposed along valley sides, does the sandstone have a pronounced influence on the surface topography (fig. 1 and plate 1).

Because of their gentle southwest dip, different Cambrian formations occur at the surface at different locations in the county. The oldest Cambrian formation, the Mt. Simon Formation, occurs in the eastern part of the county near the Blue Hills. The youngest Cambrian unit, the Jordan Sandstone, occurs in southwestern Barron County. The sandstone in different formations varies in resistance to erosion. In the southeastern part of the county and south into Dunn County, isolated, steep-sided hills occur amidst the smooth, rolling topography. Based on the elevation of formation contacts recorded in well reports, the steep sides of the hills are most likely composed of rock of the Mazomanie Formation. The surrounding rolling topography is underlain by less-resistant rocks of the Eau Claire Formation and the lower part of the Wonewoc Formation (fig. 3). In Barron County, the base of these steep-sided hills decreases in elevation to the west and southwest with the dip of these units.

The topographic expression of the Cambrian sandstone formations in Barron County did not have as pronounced an effect on ice flow as that of the Barron Quartzite. Locally, however, sandstone knobs probably diverted the ice and influenced the position of ice margins.

PLEISTOCENE DEPOSITS

Glaciers, streams, and lakes were responsible for the character of the Pleistocene sediment in Barron County. Pleistocene deposits form an almost continuous cover in the northern two-thirds of the county, in places burying the Cambrian sediment to depths as much as 90 m. Little sediment has been deposited since glaciers left Barron County. A dusting of loess (wind-blown silt) covered the county shortly after ice melted. At present, silt, sand, and gravel are being deposited by streams in Barron County (map unit Msu, plate 1) and organic sediment is accumulating in marshes and bogs (map unit Mpm, plate 1).

Various procedures were used to analyze sediment (see Johnson, 1984, for description of analytical techniques). Grain size was analyzed using sieve and hydrometer techniques. Clay mineralogy of the less-than-0.002-mm fraction was analyzed using an X-ray machine. Lithology of grains present in till was determined by counting 150 to 300 grains in the very-coarse-sand fraction and 100 pebbles in the pebble fraction. Carbonate content of the 0.037-to-0.063-mm fraction was determined using a Chittick apparatus. Relative magnetic susceptibility was determined using a Bison 3101A Magnetic Susceptibility Meter. Moist color was determined in the field using a Japanese color book, but listed by their corresponding Munsell name. Pebble fabric was determined on 25 to 50 elongate pebbles that had at least a 2:1 long-to-short axis ratio.

Forty-five holes were drilled using a truck-mounted auger. In addition, reports of domestic water wells on file at the Wisconsin Geological and Natural History Survey are used in this report. The term "drill holes" refer to holes drilled by the author, and "well reports" refer to domestic water well reports. Description of material found in drill holes is included in the Appendix.

Till, stream sediment, and lake sediment are included in a stratigraphic framework that includes three formations and seven members (fig. 3). In this report, only the formations will be described in detail. Sedimentologically, the various members are similar to each other and can be distinguished from each other using only a few minor characteristics. The distribution of the members is shown on plate 1. Type sections of the seven members are described by Johnson (in Attig and others, in press).

Thickness of Pleistocene sediment

The thickness of the Pleistocene sediment that overlies the Cambrian and Precambrian material varies greatly in the county (fig. 4). In the southern part of the county, Pleistocene sediment occurs primarily in stream valleys. In the valley of the Red Cedar River, well reports show stream sediment as thick as 85 m. Prior to the last glaciation, this valley was deeper than today and contained

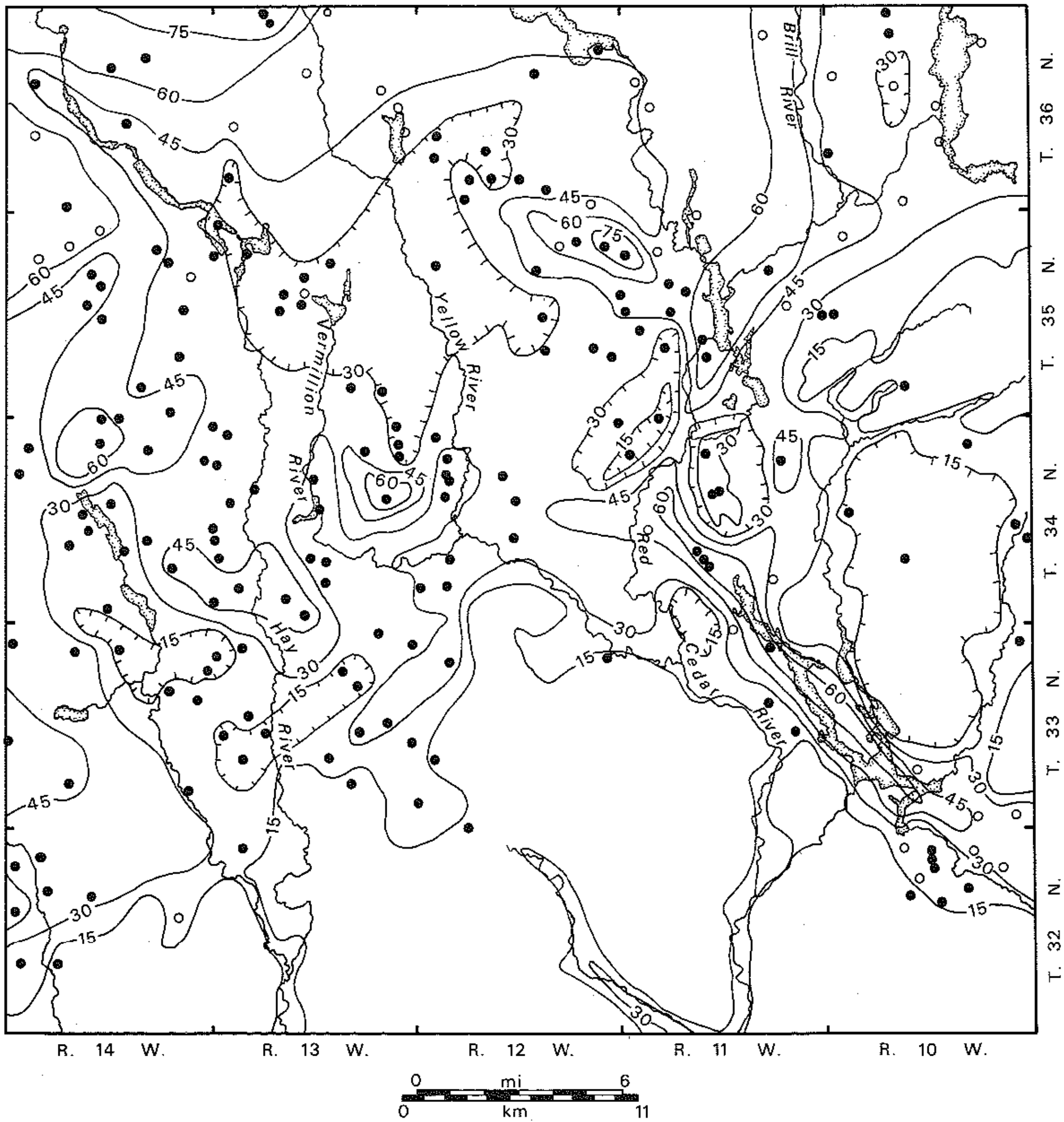


FIGURE 4. Thickness of Pleistocene sediment in Barron County. Contour intervals 15 m. Closed dot = well penetrating Cambrian or Precambrian material; open dot = well not penetrating Cambrian or Precambrian material. Contour lines in south-central Barron County based on outcrops.

a river that flowed to the southeast out of Barron County. The Red Cedar River was diverted by sediment from glaciers and streams and now flows to the south in a shallower valley. Much of the northwest quarter of the county is buried by over 45 m of Pleistocene sediment. Well reports near Barronett record over 93 m of Pleistocene sediment.

Till

Pierce till

The Pierce Formation (Mickelson and others, 1984) in Barron County contains olive-black, loam till that occurs several meters below the surface in the western third of the county. This member is named for exposures in Pierce County to the southwest of Barron County. In the type area, the Pierce Formation includes two till units, the Hersey Member and the Woodville Member (Baker and Lively, 1984). At this time, Pierce till in Barron County cannot be confidently correlated to either of these members. The following description is based on samples from Barron County.

The till is slightly gravelly loam with a gravel content (larger than 2 mm) of usually less than 5 percent. Samples of this till have an average sand:silt:clay ratio of 35:43:22 (fig. 5; table 1). The till is gray to olive-black (7.5YR 4/1 to 10YR 3/1) where unweathered and yellowish brown (10YR 5/4) where oxidized. The maximum depth of oxidation is difficult to determine because the upper part of the till is buried and may have been truncated by erosion. At one site, the depth of the oxidized zone was 2.0 m from the top of the unit. The clay minerals typically consist of 14 percent kaolinite, 16 percent illite, and 70 percent expandable clay (fig. 6). Clay heated to 550°C shows that it contains no chlorite in the oxidized zone and little, compared to kaolinite, in the unweathered zone. Except for a slight increase (less than 5 percent) in expandable clay in the oxidized zone, the clay mineralogy does not change greatly with depth. The 0.037-to-0.062-mm fraction has a typical carbonate (calcite plus dolomite) content of 4.6 percent with a calcite:dolomite ratio ranging from 0.3 to 1.4, with a typical value of 0.6. The very-coarse-sand fraction of the Pierce till contains 5 to 11 percent carbonate. The relative magnetic susceptibility of the till has a typical value of 4.2, but shows a marked change with depth that is attributed to weathering of magnetite in the upper part of the till. A summary of the very-coarse-sand lithologies is shown in table 2. Pierce till contains abundant organic material. Wood fragments can be observed in hand samples. The till of the Pierce Formation can be easily distinguished from till in other units on the basis of color, grain size, and carbonate content. Table 1 provides a comparison with other units.

TABLE 1.-- Characteristics of till in Barron County

Lithostratigraphic unit	sand:silt:clay	relative magnetic susceptibility	kaolinite:illite: expandable clay	kaolitine: illite	typical color
Copper Falls Formation	71:20:9	9.8	12:35:54	1.2	5YR 4/6
n(number of samples)=	126	126	65	65	
Sylvan Lake Member	71:21:8	11.8	12:31:57	1.1	5YR 4/4
n=	33	33	19	19	
Mikana Member	71:21:8	9.7	11:35:54	1.0	5YR 4/4
n=	26	26	12	12	
Poskin Member	71:20:9	9.3	10:30:60	1.4	5YR 4/6
n=	36	35	15	15	
Pokegama Creek Member	69:20:11	8.3	13:41:45	1.2	5 to 7.5YR 4/6
n=	31	31	19	19	
River Falls Formation	71:18:11	4.8	20:40:41	2.3	5YR 4/6
n=	33	33	21	21	
unnamed member in Barron County	69:20:11	4.7	19:33:48	2.6	5 to 7.5YR 4/6
n=	15	15	14	14	
Prairie Farm Member	73:16:11	4.9	21:53:26	1.7	5YR 4/6
n=	18	18	7	7	
unnamed member in St. Croix and Pierce Counties	66:22:13	2.2	14:21:65	2.5	5YR 4/6
n=	14	14	14	14	
Pierce Formation	35:43:22	4.2	14:16:71	2.4	7.5YR 4/1 (unoxidized)
n=	14	12	8	8	10YR 5/4 (oxidized)

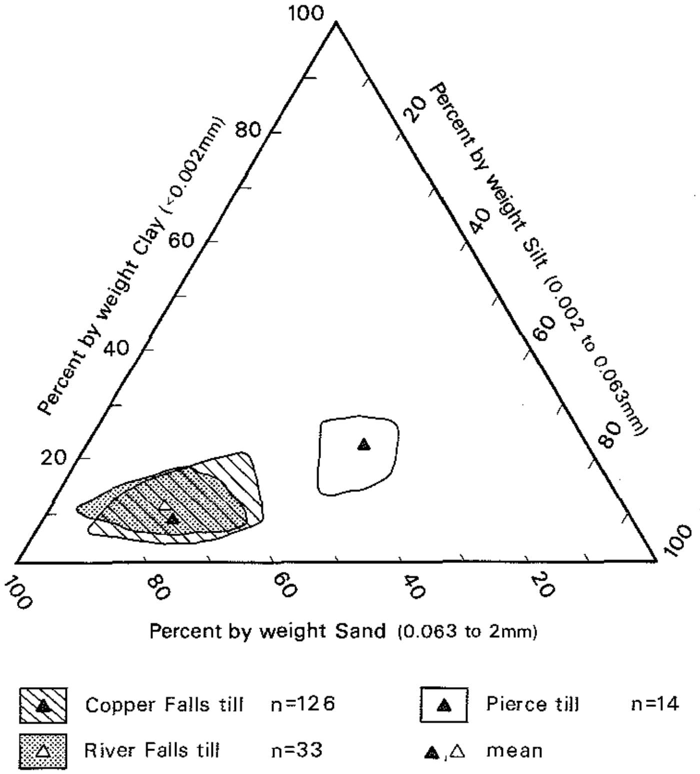


FIGURE 5. Grain-size distribution of the less-than-2-mm fraction of till from Barron County; n = number of samples.

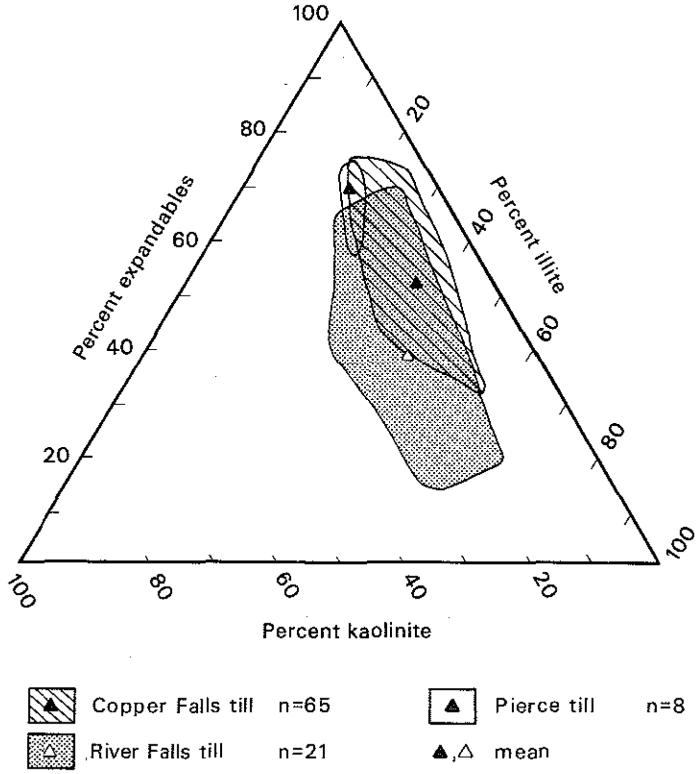


FIGURE 6. Clay-mineral composition of samples of the less-than-0.002-mm fraction of till from Barron County; n = number of samples. "Kaolinite" may include small amounts of chlorite.

TABLE 2.--Very-coarse-sand lithologies of till in Barron County

Lithostratigraphic unit	quartz	fine-grained mafic rock	granite	coarse-grained mafic rock	quartz with feldspar	rhyolite	Barron quartzite	red sandstone	non-red sandstone	limestone	other
Copper Falls Formation	48 n =43	12	6	14	3	8	2	5	1	0	2
Sylvan Lake Member	44 n = 12	16	6	14	2	8	2	5	0	2*	2
Mikana Member	50 n = 10	11	7	13	3	9	2	4	0	1*	2
Poskin Member	47 n = 10	12	6	16	3	7	2	5	0	0	2
Pokegama Creek Member	51 n = 11	9	5	13	4	8	2	5	1	0	2
River falls Formation	61 n = 18	6	4	10	3	6	1	5	2	0	2
Prairie Farm Member	59 n = 12	6	5	10	4	6	1	5	2	0	2
unnamed member in Barron County	65 n = 6	6	4	9	3	7	1	4	1	0	1
Pierce Formation n = 7	68	5	3	5	4	2	0	4	0	5	4

*limestone percent from unleached till, not included in total

TABLE 3.--Pebble lithologies of till and stream sediment in Barron County

Lithostratigraphic unit	fine-grained mafic rock	granite and gneiss	rhyolite	coarse-grained mafic rock	Barron quartzite	Precambrian sandstone	Cambrian sandstone	other
Copper Falls till n = 25	35	9	10	22	5	8	3	6
Sylvan Lake till n= 5	42	11	9	25	2	6	3	3
Sylvan Lake stream sediment n = 1	48	9	8	25	0	9	1	1
Mikana till n = 7	35	10	13	22	4	7	1	7
Mikana stream sediment n = 2	35	7	12	29	3	9	1	4
Poskin till n = 9	35	11	8	21	1	10	4	8
Poskin stream sediment n = 1	38	9	4	40	0	3	4	2
Pokegama Creek till n = 4	26	11	8	23	19	6	3	4
Pokegama Creek stream sediment n = 5	24	12	7	16	22	7	3	9
River Falls till								
River Falls-unnamed member till n = 1	39	10	3	23	1	13	4	8
Prairie Farm till n = 5	22	9	6	15	9	17	14	8

The Pierce Formation is found in the western third of the county. A few surface exposures occur in the southwest corner of the county, but its distribution (see figure 7) is known mostly from drill holes and well reports. This unit is described in well reports as "yellow clay" or "blue clay" or in places as "yellow clay" over "blue clay." Drill holes at three localities where "yellow" or "blue clay" is mentioned in well reports confirm that the clay reported in the well logs is till of the Pierce Formation. A good surface exposure occurs in the Vance Creek Township dump 2.5 km north of Reeve, Wisconsin. Here, only the upper oxidized and leached portion of the till is exposed. A drill hole at this site shows that the thickness of the leached zone is 2 m and that more than 10 m of unoxidized and unleached Pierce till is present. Not all well reports from western Barron County that attain depths at which the Pierce Formation is commonly found actually report finding "blue clay." Thus, the Pierce Formation seems to have a patchy distribution and is not a continuous sheet (see cross sections, unit Pt, plate 1).

The depth to the Pierce Formation over the western part of the county is variable. South of Highway 8, it is generally less than 30 m; north, it is close to or greater than this depth. One well in Maple Plain Township shows the Pierce Formation at 53 m. Figure 7 shows the areal variation in depth to the Pierce Formation.

The thickness of the Pierce Formation also varies from location to location (fig. 7), from 1 m resting on Cambrian sandstone in surface exposures (for example, the quarry south of Reeve, Wisconsin, SE1/4 sec. 32, T. 32 N., R. 14 W.) to over 27 m in a well 3 km northwest of Reeve. The average thickness in 24 well reports is 12.3 m. The thickness tends to be greatest along the western edge of the county and least near its eastern limit.

In over half of the water wells, and in all the surface exposures, the Pierce Formation rests directly on Cambrian sand or sandstone. In the other wells, it generally overlies Pleistocene sand and gravel that, in turn, overlies sandstone. Material occurring beneath the Pierce till that could represent an earlier ice advance was not mentioned in well reports. The Pierce Formation is overlain by sand and gravel or yellowish red, sandy-loam till.

River Falls till

The River Falls Formation (Mickelson and others, 1984) contains yellowish red, sandy-loam till and occurs at the surface in the south-central part of Barron County (plate 1). It is named for exposures near the community of River Falls, Wisconsin, and is described in its type area by Baker and others (1983). In Barron County, the River Falls Formation includes the Prairie Farm Member and an unnamed member. The Prairie Farm Member is named for exposures near the community of Prairie Farm, Wisconsin, and its type section is described by Johnson (in Attig and others, in press). The unnamed member correlates to till in the type area. The following description of the River Falls till is based on samples from Barron County and includes both members.

The till is slightly gravelly to gravelly sandy loam with a few samples being slightly gravelly to gravelly loamy sand (fig. 5), and samples have an average sand:silt:clay ratio of 71:18:11. Gravel (larger than 2 mm) content is 5 to 15 percent. Moist field color of the till is yellowish red to brown (5YR 4/6, 4/8, to 7.5YR 4/8). The clay mineralogy is quite variable in this unit as can be seen in figure 6. The average clay-mineral content is 20 percent kaolinite, 40 percent illite, and 41 percent expandable clay. The kaolinite peak (fig. 8) is typically sharp and much higher than the illite peak. Heating of clay samples to 550°C shows that the 0.7-nm peak shows only kaolinite and no chlorite (fig. 8). The kaolinite:illite ratio is consistently large in this unit with a typical value of 2.3. Values of relative magnetic susceptibility for the Prairie Farm till are typically 4.8. Near-surface till has a magnetic susceptibility of 3 to 4 whereas till from 3 to 5 m in depth has values of 5 to 7.

Most exposures of the River Falls till are very shallow and only samples leached of carbonate were available for analysis. The unleached till probably contains very little

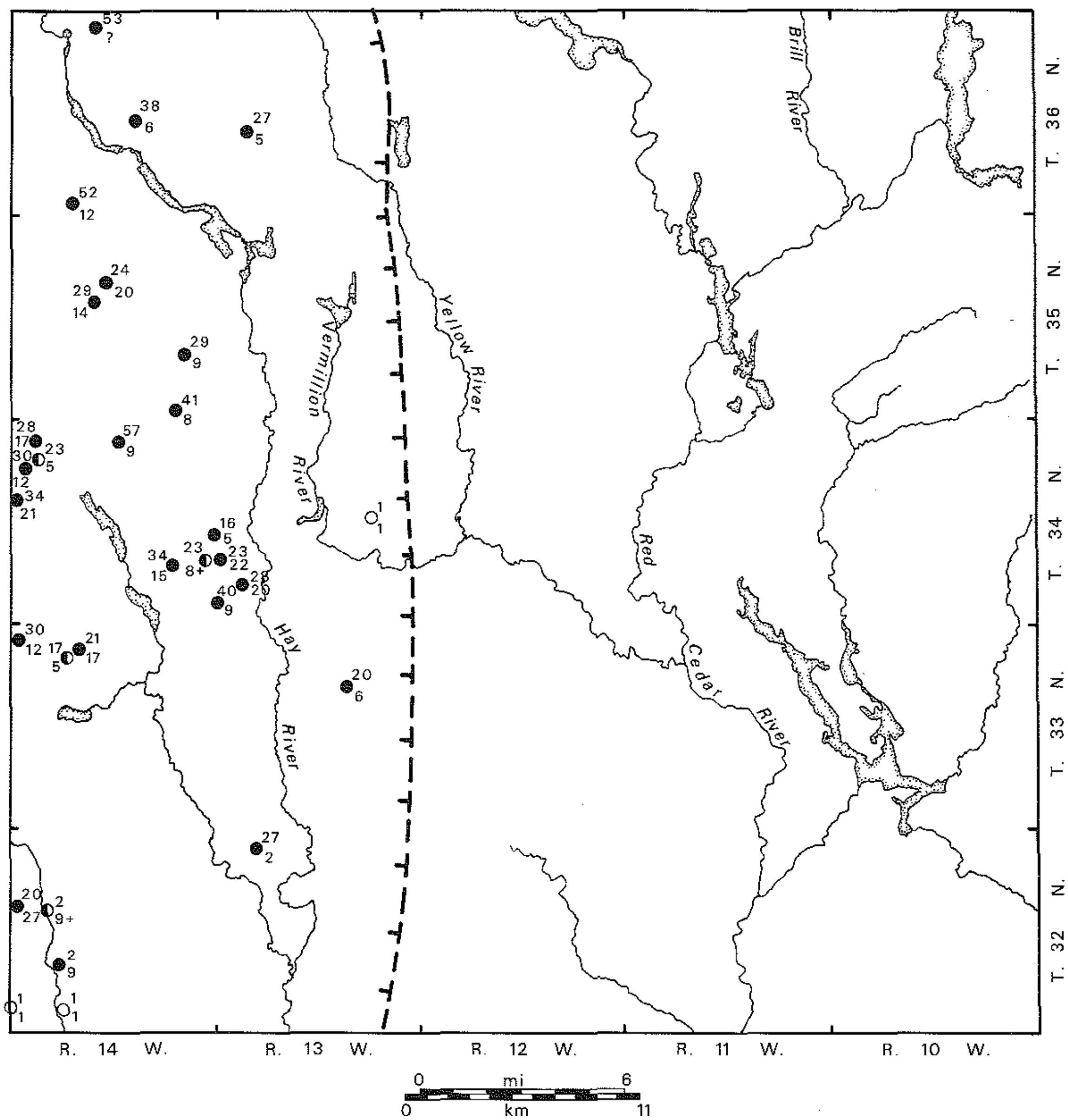


FIGURE 7. Distribution of till of the Pierce Formation in Barron County as indicated by well reports, drill holes, and outcrops. Closed circle = water well; open circle = outcrop; half-closed circle = drill hole. Upper number = depth in meters to top of Pierce till; lower number = thickness in meters of Pierce till. Dashed hachured line is the approximate position of the ice-margin limit during the Reeve Advance.

carbonate because this till was derived from the Superior basin. Table 2 shows the very-coarse-sand lithology of River Falls till. The mafic lithologies are more scarce in the River Falls till than in other Superior-basin till in the county. This may be due to either weathering or differences in the unweathered till. The pebble fraction includes Barron Quartzite and lithologies typical of the Superior basin (table 3). The presence of Barron Quartzite helps distinguish till of the Prairie Farm Member of the River Falls Formation (map unit R1tn, plate 1) from till of the unnamed member of the River Falls Formation (map unit R2tn, plate 1) that was derived from the northwest.

The region in which this till occurs is shown in plate 1, but its actual distribution within this area is patchy. Next to the Pierce Formation, this till unit is the oldest in the county. It occurs predominantly in the region of high relief in south-central Barron County, and as a result it has been removed in places by stream erosion or hillslope processes. Commonly, roadcuts show only a few pebbles overlying sandstone. Hillslope processes may have been especially active during the period of permafrost that occurred in the county during the last glaciation. Much of this area is mapped as Cambrian sand and sandstone (see plate 1) because of the lack of continuous till exposure. In areas where till exposure is more continuous, the topography is gently rolling (map units R1tn and R2tn, plate 1).

Thickness of the River Falls Formation in Barron County ranges from a few centimeters to no more than 10 m. Well logs show that the till is commonly about 5 m thick. However, no surface exposures were found in which the till was more than 3 m thick. The till is nearly everywhere on Cambrian sand and sandstone but overlies Pierce till or undifferentiated sand and gravel in places. The till is overlain by Copper Falls till and is widespread in the subsurface in western Barron County (fig. 14 and unit R2t in cross sections, plate 1). Elsewhere, River Falls till may be overlain by sand and gravel, or loess.

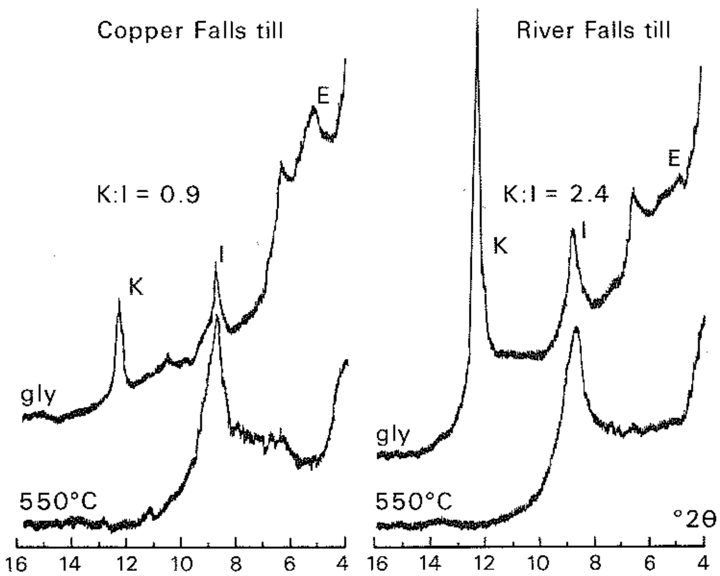


FIGURE 8. X-ray diffractograms of typical samples of River Falls and Copper Falls till. K = kaolinite; I = illite; E = expandable clay; K:I = kaolinite:illite ratio; gly = glycolated samples; 550°C = heated-to-550°C samples.

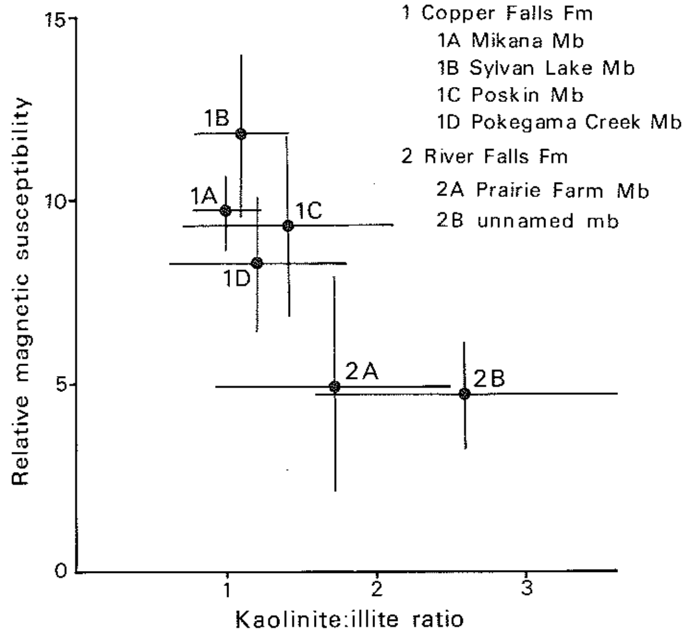


FIGURE 9. Relative magnetic susceptibility and kaolinite:illite ratio of River Falls and Copper Falls till in Barron County. The mean and standard deviation are plotted.

The till of the River Falls Formation in Barron County can be easily distinguished from Pierce till on the basis of color, grain size, and carbonate content. Differentiation from other till in the county is difficult because River Falls and Copper Falls till is consistently yellowish red (table 1) and sandy loam (fig. 5). Relative magnetic susceptibility, kaolinite:illite ratio (fig. 9), and quartzite content (table 3) serve to differentiate the six till units contained in these two formations. River Falls till tends to have smaller relative magnetic susceptibility values and larger kaolinite:illite ratios than Copper Falls till (fig. 9). Values of both these parameters vary with depth in the River Falls till but not in the Copper Falls till (Johnson, 1984). This indicates that the River Falls till is more weathered and therefore older than Copper Falls till. Within the River Falls Formation, the Prairie Farm Member can be distinguished from the unnamed member by the abundance of quartzite and the presence of northeast ice-flow indicators.

Copper Falls till

The Copper Falls Formation (Mickelson and others, 1984) contains yellowish red, sandy-loam till and covers much of the northern two-thirds of the county (plate 1). The till is included in four members of the Copper Falls Formation: the Pokegama Creek, Poskin, Mikana, and Sylvan Lake Members. Type sections of these four members have been described by Johnson (in Attig and others, in press). Characteristics of till of each member and of the Copper Falls Formation as a whole are shown in tables 1, 2, and 3. Well reports in the northern half of the county commonly mention layers of "hard pan" beneath the surface till. All buried till encountered in the author's drill holes is River Falls till. However, buried "hard pan" may in places be Copper Falls till.

Copper Falls till is dominantly gravelly sandy loam with some gravelly loamy sand. Gravel (larger than 2 mm) content is 5 to 20 percent. Samples have an average sand:silt:clay ratio of 71:20:9 (fig. 5, table 1). Moist field color of the Copper Falls till is usually yellowish red (5YR 4/6), but may be duller (5YR 4/4), darker (5YR 3/4), or yellower (7.5YR 4/6). The typical clay-mineral content is 12 percent kaolinite, 35 percent illite, and 54 percent expandable clay although there is great variability within this unit (fig. 6). Clay heated to 550°C shows small amounts of chlorite present in the deeper parts of the Copper Falls till, but not within the upper 3.5 to 5.0 m. The Copper Falls till has a kaolinite:illite ratio less than 1.8, typically around 1.2. This distinguishes this unit from the more weathered till of the River Falls Formation. The typical value of relative magnetic susceptibility of the Copper Falls till is 9.8. Relative magnetic susceptibility does not vary with depth as seen in the River Falls till, which suggests that the Copper Falls till is not as weathered as the River Falls till (Johnson, 1984).

Unleached Copper Falls till contains a small amount of carbonate. The 0.037-to-0.062-mm fraction of unleached till contains 0.5 to 1.5 percent carbonate. Copper Falls till of the Sylvan Lake and Mikana Members is leached to depths of 3.5 to 5.0 m. No unleached samples were collected from the Poskin and Pokegama Creek Members. The lithologies of the very-coarse-sand and pebbles fractions are shown in tables 2 and 3 respectively. Barron Quartzite is an important indicator lithology in the pebble fraction (table 3). The larger amount of quartzite in the till of the Pokegama Creek Member helps to distinguish it from till of the Sylvan Lake and Poskin Members, which were deposited by ice flowing southeast.

The distribution and thickness of the till of the four members of the Copper Falls Formation vary across the county.

Pokegama Creek till.--The Pokegama Creek till occurs in a triangle-shaped area in east-central Barron County (map unit C1tn, plate 1). The west and east boundaries of the Pokegama Creek till occur where the Pokegama Creek till is overlapped by till of later ice advances. The southern limit of the till coincides with an outwash head south of Chetek and the limit of pitting in adjacent outwash plains. In the area south and east of Chetek, immediately north of the Pokegama Creek margin (plate 1), sandstone is commonly found in surface exposures, and outcrops of till are not numerous. The till rarely exceeds 1 m in thickness, although isolated occurrences of till up to 7 m are recorded in well reports.

In the upland area between Cameron and Rice Lake, the Pokegama Creek till overlies a thick (as much as 30 m) layer of gravelly stream sediment. Much of the till has been eroded in this region and is found only capping the hill tops (plate 1). The till is commonly 2 m thick but in places is as thick as 7 m. On the eroded slopes of these hills, the older underlying sand and gravel is exposed (map unit Css, plate 1).

Pokegama Creek till overlies quartzite in the Blue Hills region. On the north sides of the hills, the till tends to be continuous and 4 to 7 m thick. On the south side of the hills, the slopes are commonly talus covered, and till thickness is not known. South of the Blue Hills in Sumner Township, quartzite is at the surface in places, but the land has a more rolling topography. Here the till is roughly 3 to 5 m thick.

Pokegama Creek till is buried by stream sediment beneath the outwash plain to the east of Cameron. Elsewhere, it probably underlies Poskin and Mikana till, although no occurrences were found. Where the till is at the surface, it is covered by less than a meter of loess.

Poskin till.--The Poskin till occurs at the surface from the north-central to the southwest parts of Barron County (map unit C2tn, plate 1). Poskin till is thick and forms a continuous cover, although sandstone exposures are not uncommon in the southwestern part of the county. The till occurs in the subsurface farther to the northwest where it is buried by till of the Sylvan Lake Member. The eastern margin of the Poskin till is based on several lines of evidence: a marked change in till characteristics (quartzite content, magnetic susceptibility, kaolinite:illite ratio, fabric), geomorphic evidence (limit of pitting in outwash, diverted drainages), and changes in till thickness. There is no moraine along this boundary. To the north, the eastern margin of the Poskin till lies buried beneath younger stream sediment.

The Poskin till is generally very thick. The typical thickness of "hard pan" recorded in well reports and interpreted to be Poskin till in this region is about 15 m and is as much as 50 m in places. Only a few surface exposures were found during field work that show the base of this unit. Though well reports are not always accurate, a typical thickness of 15 m seems reasonable for this unit.

The Poskin till rests almost everywhere on sand and gravel except in the southwest part of the county where it overlies Cambrian sand and sandstone. The till overlies a very thick (about 10 m) unit of sandy stream sediment in the upland area north of Poskin between the Hay and Yellow Rivers.

Poskin till is overlain by stream sediment to the northwest of Cameron and by Sylvan Lake sediment in the northwest part of the county. Poskin till at the surface is covered by a meter or less of loess.

Mikana till.--The Mikana till occurs in the northeastern part of the county and along the east edge of the county (map unit C3uh, plate 1). Some of the hummocks in the region mapped as C3uh contain stream sediment, but many contain mostly till. Till is commonly exposed in the hummocky region between Brill and Mikana and along the east edge of the county south of Rock Creek and north of Highway D.

Where the Mikana Member overlies quartzite, as in the Blue Hills, the till is generally less than 5 m thick. In the hummocky region east of Brill, the till commonly overlies stream sediment and may be as thick as 20 m. Mikana till is buried, in places, beneath stream sediment (map units C3sp and C3sh, plate 1) and lake sediment (map unit C3li, plate 1).

Sylvan Lake till.--The Sylvan Lake till occurs in the northwestern part of the county (map units C4uh, plate 1).

Some of the hummocks in the area mapped as C4uh are composed of stream sediment, but many hummocks are composed almost entirely of till.

The distribution of the Sylvan Lake Member south of Turtle Lake is not known at the present time. Low-relief hummocks composed of till of the Sylvan Lake Member (map unit C4uh, southwest Barron County, plate 1) lie well in front of the regional trend of the St. Croix moraine. A discussion of this sediment is included in the glacial-history section.

The thickness of the till of the Sylvan Lake Member is known from drill holes, outcrops, and well reports. In three drill holes in hummocks containing till, 8 m, 9 m, and 26 m of till occur over sand and gravel. In two outcrops near the Sylvan Lake ice margin, one near Lake Thirty and one near Long Lake (in southwest Barron County), 1.5 and 0.8 m, respectively, of till of the Sylvan Lake Member overlies till of the Poskin Member. Well reports give till thickness of 5 to 45 m with an average value of 18 m.

Sylvan Lake till generally overlies sand and gravel but, as noted above, it may overlie Poskin till. The till occurs in places beneath stream sediment (map units C4sp and C4sh, plate 1) and lake sediment (map units C4ni, C4oi, and C4li, plate 1).

Stream sediment

Stream-deposited sand and gravel occurs at the surface in many parts of Barron County. These areas are mapped on plate 1 in shades of red and are differentiated on the basis of lithostratigraphy and surface topography. Many of the sand and gravel units are associated with the till units described above and are included within the corresponding members. Sand and gravel occurs in the Pokegama Creek, Poskin, Mikana, Sylvan Lake, and Chetek Members of the Copper Falls Formation and in the River Falls Formation. The Chetek Member of the Copper Falls Formation contains stream sediment derived from both the Chippewa and Superior Lobes and is equivalent in age to the Sylvan Lake and Mikana Members (fig. 3). Layers of stream sediment buried by till and other younger sediment are extensive in Barron County and no attempt was made to differentiate them lithostratigraphically (unit s on cross sections, plate 1).

Copper Falls stream sediment

Numerous gravel pits in the county show that grain-size distribution and sedimentary structures of stream sediment are similar in all the members of the Copper Falls Formation. Though this sediment was not analyzed in detail, much of it can be classified as slightly gravelly sand and gravelly sand. Gravel is present in amounts varying from a few pebbles scattered in beds of sand to coarse-cobble layers. Near former ice-margin positions, the stream sediment is coarser. Stream sediment exposed in several gravel pits near Haugen shows a pronounced coarsening toward the ice-margin limit.

The stream sediment is characteristically horizontally bedded. Gravelly beds commonly show imbrication and sandy beds may contain trough or planar cross beds. Rock types of pebbles in the stream sediment are similar to those found in corresponding till units (table 3).

Copper Falls stream sediment occurs predominantly in outwash plains. In Barron County, outwash plains are extensive and underlie the communities of Brill, Rice Lake, Barron, Cameron, and Chetek. Some outwash in the county is unpitted (map units Csu, C1su, C5su; plate 1), but most outwash is pitted (map units C1sp, C2sp, C3sp, C4sp, C5sp; plate 1). In places, especially behind the Sylvan Lake and Mikana ice-margin limits, streams deposited sediment on nearly continuous ice. After melting of this buried ice, little primary surface topography remained, and the sand is now hummocky (map units C3sh and C4sh, plate 1). The thickness of the sediment beneath the outwash plains is as great as 85 m in the buried valley that runs from Brill through Rice Lake and southeast to Chetek (fig. 4). Elsewhere, sand and gravel is commonly 30 m thick.

Older units of Copper Falls stream sediment occur deeply buried beneath the outwash plains and in upland areas north of Cameron and north of Poskin. In the upland areas, stream sediment is buried by till of the Copper Falls Formation and has been exposed in hillsides and gravel pits (for example, sec. 1 and 2, T. 34 N., R. 11 W. and sec. 2, T. 34 N., R. 13 W.). This sediment is over 30 m thick in places and is mapped as unit Css on plate 1.

River Falls stream sediment

Stream sediment of the River Falls Formation occurs in southeastern Barron County (map unit R1ss, plate 1). This sediment is broadly similar to Copper Falls stream sediment, but it typically contains 3 percent silt and 10 percent clay in the fraction smaller than gravel. The pebbles and cobbles in this sediment are commonly coated with a thin layer of silt and clay. The silt and clay in this sediment were probably illuviated into the sand following deposition, perhaps during the period of weathering that altered River Falls till. Drill holes show that this sediment is interbedded, in places, with till or till-like sediment that may be glacial or slope deposits.

Lake sediment

Ice-walled-lake plains are a common feature in northwestern and northeastern Barron County and their sediments are included in the Sylvan Lake and Mikana Members (map units C4ni, C4oi, C4li, and C3li, plate 1). As ice melted following the advance of ice that deposited the Sylvan Lake and Mikana till, lakes formed that were flanked by debris-covered ice. After the ice melted, the sediment deposited in these lakes was left as dish-shaped plateaus (see section on ice-walled-lake plains in the section on the Late St. Croix and Late Chippewa Advances). The rims of the ice-walled-lake plains are composed dominantly of sand and slightly gravelly sand (map unit C4ni, plate 1). The sediment in the rims is bedded in topset, foreset, and bottomset beds typical of coarse-grained delta deposits. Associated with these lake-margin deposits is till-like sediment that flowed off surrounding ice into the lake. Bedded silt is common, draped on the foresets at the margin or in thick sequences in the center of ice-walled-lake plains. Drill holes in the center of ice-walled-lake plains (map unit C4oi, plate 1) show 7 to 10 m of lake sediment and debris-flow sediment overlying till. The lake sediment fines upward and is silty in the upper few meters. An analysis of this sediment shows that it contains 15 percent 0.05-to-2.0-mm grains, 67 percent 0.002-to-0.05-mm grains, and 18 percent clay (less than 0.002 mm) (Robinson and others, 1958). Carbonate has been leached to a depth of 3.6 m in one drill hole.

Loess

Following the last glacial advance, loess (wind-blown silt) was deposited throughout Barron County. The loess forms a thin cap on all types of sediment. The thickness is fairly uniform throughout the county although variations exist. North of Almena, loess is commonly 1 m thick. Most of the county, however, is blanketed by 0.4 to 0.6 m of loess. On the outwash plains, the loess is patchy. Either outwash was being deposited simultaneously with the loess, or the outwash was already deposited but provided a setting in which silt was easily deflated.

GLACIAL HISTORY

During the Pleistocene Epoch, from 1,600,000 to 10,000 years ago, glaciers advanced into Barron County many times, eroded pre-existing rock and sediment, and deposited till. Some of the debris released from the ice was deposited in streams and lakes. The till deposited during at least six of the advances is red and sandy, whereas the till of the earliest known glaciation is gray and clayey. Till was deposited by ice advancing into the county at different times from the northwest (the Superior Lobe), the northeast (the Chippewa Lobe), and the west (the Des Moines Lobe) (fig. 10). The youngest deposits in the county are around 15,000 years old; the oldest glacial deposits are several hundred thousand years old. The variety of deposits, the interaction of different lobes, and the long time span of glacial activity indicate the complexity and variety of the glacial geology of Barron County. In this section, the sequence of glacial advances and their deposits and landforms will be described, beginning with the oldest. Two figures that may be helpful to refer to throughout this section are the map of the Pleistocene geology of Barron County (plate 1) and figure 11, which is a time-distance diagram showing a summary of the different ice advances, their extent, age, and sequence.

Sediment deposited during the Pleistocene Epoch is included in several lithostratigraphic units (fig. 3). Table 4 shows the age of each lobe's various advances and the associated lithostratigraphic units. A detailed description

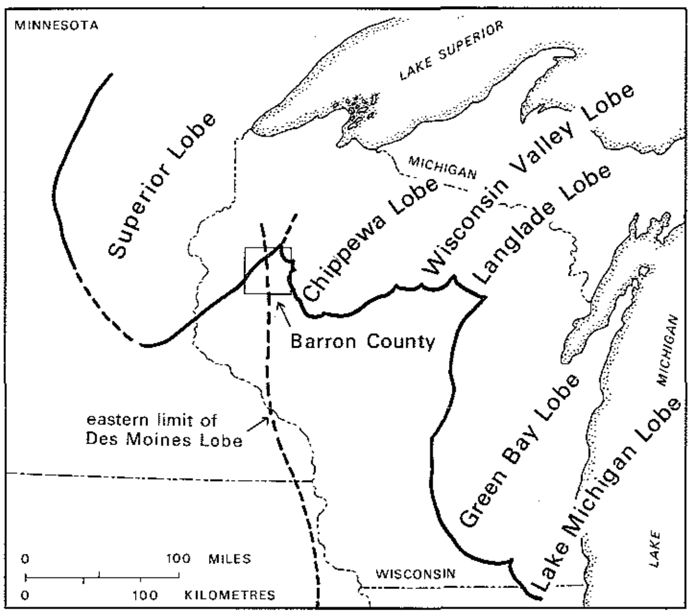


FIGURE 10. Glacial lobes and ice-margin limits of the Upper Midwest. The extent of the lobes, except the Des Moines Lobe, is shown as it occurred about 15,000 years ago. The Des Moines Lobe is shown as it might have been during the Reeve Advance, several hundred-thousand years ago.

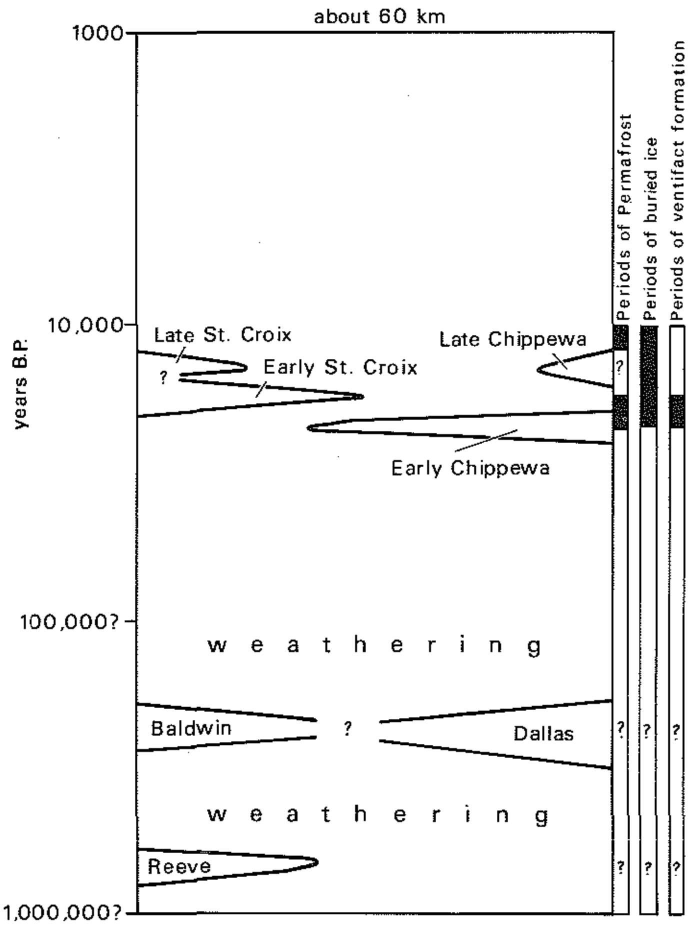


FIGURE 11. Time-distance diagram of Pleistocene events in Barron County. Time scale at left is logarithmic. Timing of the advances is not well known. Horizontal scale from left to right is roughly from the northwest corner of Barron County to the southeast corner. Advances shown originating from the northwest are of the Superior Lobe with the exception of the Reeve Advance, which was of the Des Moines Lobe. Horizontal scale from right to left is roughly from the northeast corner to the southwest corner. Advances shown originating from the northeast are of the Chippewa Lobe.

TABLE 4.--Relationship of lithostratigraphy, event stratigraphy, lobes, and suggested ages

Formation	Member	Event	Lobe	Suggested age
Copper Falls	Sylvan Lake	Late St. Croix Advance	Superior Lobe	around 15,000 years
	Mikana	Late Chippewa Advance	Chippewa Lobe	around 15,000 years
	Chetek	Late St. Croix and Late Chippewa Advances	Superior and Chippewa Lobes	around 15,000 years
	Poskin	Early St. Croix Advance	Superior Lobe	between 15,000 and 25,000 years
	Pokegama Creek	Early Chippewa Advance	Chippewa Lobe	between 15,000 and 25,000 years
River Falls	unnamed	Baldwin Advance	Superior Lobe	older than deposits of the Wisconsin Glaciation
	Prairie Farm	Dallas Advance	Chippewa Lobe	older than deposits of the Wisconsin Glaciation
Pierce	unnamed	Reeve Advance	Des Moines Lobe	probably several hundred thousand years

of the sediment in these units is found in the Pleistocene deposits section of this report. Lithostratigraphic names are also used to refer to the sediment contained in a particular member or formation (for example, Pierce till, Mikana sand and gravel, and Sylvan Lake lake sediment) or to landforms composed of sediment contained in a particular member or formation (for example, Chetek outwash plain, Sylvan Lake hummock).

Pleistocene sediment was deposited during seven glacial advances: the Reeve Advance, the Baldwin Advance, the Dallas Advance, the Early and Late Chippewa Advances, and the Early and Late St. Croix Advances (table 4). Other glacial advances may have occurred in the county prior to or interspersed with those recorded by the sediments described in this report, but deposits they left have either been eroded or are deeply buried. Part of the thick unit of sand and gravel that underlies the outwash plains near Chetek and Rice Lake may date from pre-Pleistocene time. Other than these units, no sediment exists in the county that represents the time between the Cambrian and Quaternary Periods (fig. 3). Prior to the onset of glaciation, as well as during later periods when glaciers were absent from Barron County, streams formed the drainage network now present. This drainage network was modified by glaciers but many valleys have persisted through several glacial advances.

Reeve Advance

During the earliest known glacial advance, the Des Moines Lobe (fig. 10) flowed into the county from the west and deposited olive-black, loam till of the Pierce Formation. The maximum extent of the ice during this advance, here called the Reeve Advance, was first suggested by Leverett (1932, p. 20) who said it advanced "as far east as the border of St. Croix and Dunn Counties and the eastern part of Pierce County." Baker and others (1983) recognized the margin farther east (fig. 12). In Barron County, the extent of the ice is suggested by the eastern extent of till of the Pierce Formation (fig. 7). The Des Moines Lobe may have advanced farther east during the Reeve Advance, although evidence to support this idea is lacking. Pleistocene sediment is thick in north-central Barron County (fig. 4), yet wells that reach Cambrian material do not encounter Pierce till. The shape of this margin indicates ice flow to the east and east-southeast. Eastern ice flow is indicated by the lithologic and fabric data of Baker and others (1983) (fig. 12). The Des Moines Lobe advanced more than once at about this time. A drill hole near Woodville, Wisconsin, contains two gray till units of the Pierce Formation (Baker and Lively, 1984). Only one advance can be recognized in Barron County at the present time.

Characteristics of the Pierce till are described in figures 5 and 6, tables 1 and 2, and the section on Pleistocene deposits. The characteristics of till of the Pierce Formation in Barron County and till of the Hersey Member of the Pierce Formation to the southwest are compared in table 5. Grain-size distribution and leached and unleached color are similar, and both contain abundant organic matter. In Barron County, wood can be seen in hand samples. Pierce till in Barron County lacks the Cretaceous shale common in gray till deposited during the late Wisconsin advance of the Des Moines Lobe (Matsch and others, 1972; Kemmis and others, 1981). Absence of Cretaceous shale is characteristic of older gray till in Iowa (Alburnett and Wolf Creek Formations) (Hallberg, 1980), southwest Minnesota (Granite Falls till) (Matsch and others,

TABLE 5.--Comparison of Pierce till in Barron and St. Croix Counties

	sand:silt:clay	kaolinite	illite	expandable clay	quartz	oxidized color	unoxidized color
Pierce till in Barron County	35:43:22	14	16	70	-	10YR 5/4	7.5YR 4/1
Pierce till in St. Croix County	42:33:25	25-30	15	50-60	5-10	10YR 5/4 to 6	10YR 4/1

St. Croix County data from Baker and others (1983)

1972), and Pierce till in the type area (Baker and others, 1983). These authors suggest that the glacier bypassed the Cretaceous shale of eastern North and South Dakota and northwest Minnesota. Alternatively, comminution may have been sufficient during the Reeve Advance to grind the shale to silt and clay. A comparison of till described in these studies with the Pierce till in Barron County shows that they are broadly similar.

Because Pierce till is buried (see cross sections, unit Pt, plate 1) in Barron County, there are no topographic features that can be attributed to the activity of the ice during this advance.

During the Reeve Advance and also as the Reeve ice margin retreated, ice blocked the mouths of numerous valleys and proglacial lakes formed (fig. 12). Thick (greater than 13 m), rhythmically laminated beds of dark-gray silt and clay occur in the valleys of several rivers to the southwest of Barron County (Kinnickinnick, Trimbelle, Rush, Chippewa, and Buffalo Rivers) (Baker and others, 1983). This lake sediment is included in the Kinnickinnick Member of the Pierce Formation (Mickelson and others, 1984) and covers an area of over 5800 km^2. The elevation of the lakes, around 320 m as shown by Baker and others (1983, fig. 2), indicates that a lake may have extended into southern Barron County in the valleys of the Red Cedar and Hay Rivers. These valleys are now occupied by outwash of the Copper Falls Formation. Prior to the deposition of this outwash, the floors of these valleys would have been lower and the valleys could have contained lakes at the elevation suggested by Baker and others (1983). Neither drill holes nor well reports in this area record the presence of material that could be lake sediment. If it existed, it has been eroded by streams. It is not known what effect rebound of the crust after retreat had on the elevation of the lake deposits. Elevations determined west of Barron County, where ice was thick during this advance, may be too high for lake levels to the east where ice was thin or absent.

The age of the Pierce Formation is known from radiocarbon and paleomagnetic dating. Dates of wood in the Pierce till indicate it is more than 40,000 years old (Baker and others, 1983). Pierce till has a magnetic polarity that is opposite of the polarity of the earth's magnetic field at present (Baker and others, 1983). Before 40,000 B.P., short periods of reversed polarity occurred at about 110,000 B.P., 180,000 B.P., 295,000 B.P., 400,000 B.P., 460,000 B.P., and 620,000 B.P. (Champion and others, 1981; Rampino, 1981). A long period of reversed polarity (the Matuyama Reversed Polarity Epoch) occurred between 2,500,000 B.P. and 730,000 B.P. (Bowen, 1978). Champion and others (1981) considered the reversed period that occurred around 460,000 B.P. to have lasted between 5,000 and 10,000 years. The other reversed periods may have been less than 5,000 years long (Champion and others, 1981). Baker and others (1983) considered that the Pierce till was probably deposited around 460,000 B.P. or before 730,000 B.P. because only at these times was the polarity reversal complete. The other polarity events listed above were only excursions and not complete reversals. However, the non-existence of these other periods has not been proven and there are other periods of reversed polarity that occurred prior to the Matuyama. The Pierce till may have been deposited during any of the reversed events and its age is unclear, although it is likely, based on age estimates of younger sediment, that it is several hundred thousand years old.

A period of weathering

Following the Reeve Advance, a period of weathering took place during which the upper part of the Pierce till was oxidized and leached of carbonate. This is known from the

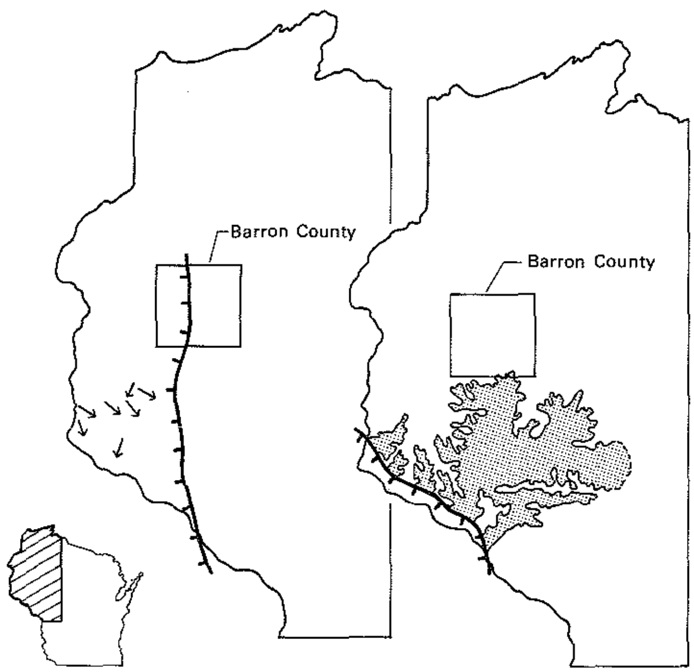


FIGURE 12. Ice-flow direction, ice-margin position (hachured line), and lakes (dotted pattern) of the Reeve Advance in western Wisconsin. Data from Baker and others (1983) with Barron County ice-margin position. Arrows represent ice-flow direction determined from pebble fabric.

change of color and carbonate content with depth in the till. Weathering also depleted magnetite in the upper part of the till (fig. 13). This weathering took place after the retreat of the Reeve ice margin but prior to the advance of the Baldwin and Dallas glaciers because weathered till of the Pierce Formation can be found underlying River Falls till. Based on age estimates of the Pierce and River Falls till, the time available for weathering may have been as long as several hundred thousand years.

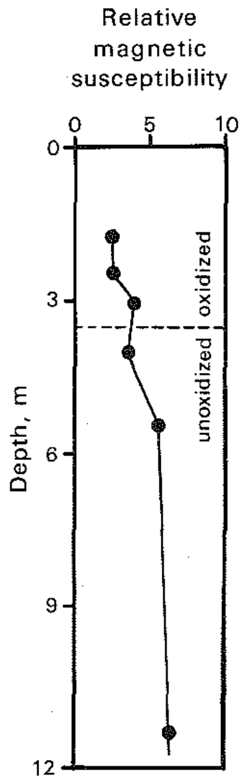


FIGURE 13. Relative magnetic susceptibility of Pierce till at the Vance Creek dump site (sec. 17, T. 32 N., R. 14 W.).

Baldwin and Dallas Advances

After a period of time, during which the Pierce till was weathered, ice of the Superior and Chippewa Lobes advanced into Barron County and deposited yellowish red, sandy-loam till that is included in the River Falls Formation (fig. 3) (Mickelson and others, 1984). River Falls till occurs at the surface in the southern part of the county (fig. 14 and plate 1). The advance of the Superior Lobe is called the Baldwin Advance and the advance of the Chippewa Lobe is called the Dallas Advance.

The River Falls till is old and no evidence of primary topography remains. The history of this advance must be gleaned solely from the distribution and characteristics of the till. Abundant Keewenawan basalt, rhyolite, and sandstone indicate much of the till was derived from the Lake Superior region. To the west of the community of Prairie Farm, till has a southeast fabric (fig. 14) and is included in an unnamed member of the River Falls Formation. This till was deposited by the Superior Lobe. East of Prairie Farm, the till has a southwest fabric and is rich in Barron Quartzite (table 3). This till unit is included in the Prairie Farm Member of the River Falls Formation and was deposited by the Chippewa Lobe (table 4).

The boundary between the two till units is near Prairie Farm (fig. 14), but is poorly defined because few outcrops exist. The distribution of the till where it is at the surface in south-central Barron County is patchy. Many roadcuts consist only of sandstone with little or no till and perhaps a line of pebbles capped by a few centimeters of loess. Mass wasting during periods of permafrost (fig. 11) may be responsible for the patchy distribution. The River Falls till can be mapped to the north and northwest of its surface occurrence where it occurs buried beneath till of the Poskin Member (fig. 14).

The till is very similar in composition to the yellowish-red, sandy-loam till in the Copper Falls Formation (see fig. 5 and 6, table 1, and the section on Pleistocene deposits), but can be distinguished by relative magnetic susceptibility and kaolinite:illite ratio, which are lower and higher respectively in River Falls till than in Copper Falls till (fig. 9). In addition, relative magnetic susceptibility and kaolinite:illite ratio show a relationship

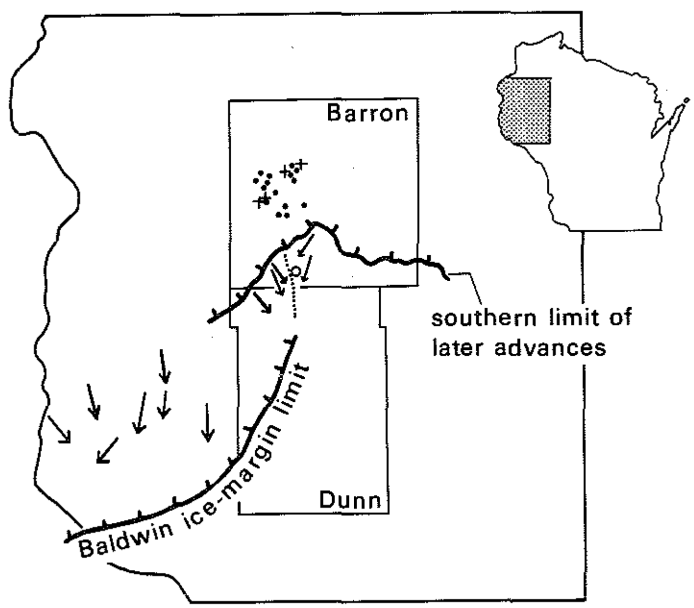


FIGURE 14. Ice-flow direction, ice-margin position, and till distribution associated with the Baldwin and Dallas Advances. Dotted line marks approximate boundary between till derived from the northeast (Prairie Farm Member of the River Falls Formation) and till derived from the northwest (unnamed member of the River Falls Formation). Ice-margin limit of the Dallas Advance is not known, but is south of Barron County. Arrows indicate ice-flow direction determined from pebble fabric. Data from Baker and others (1983) with Barron and Dunn County data added. Crosses = drill holes containing River Falls till buried beneath Poskin till, closed circles = well reports in vicinity of drill holes that mention buried till, open circle = community of Prairie Farm.

with depth in River Falls till but not in Copper Falls till (see fig. 15 and 16). These characteristics indicate that the River Falls till is more weathered than the Copper Falls till (Johnson, 1984). Because they have similar weathering characteristics, the two members of the River Falls Formation are likely of similar age. The synchroneity of the Baldwin and Dallas Advances is not known because the two members have not been found together.

The Chippewa Lobe must have advanced south of Barron County during the Dallas Advance because Prairie Farm till occurs in northern Dunn County. Mathieson (1940) placed the "probable limits of (First Wisconsin) ice" in southern Barron County between two till units, "pre-Wisconsin drift" and "Iowan Drift," as shown in figure 17. I know of no geomorphic or stratigraphic evidence to support this. Till from either side of this boundary has the same characteristics. Rather, the ice-margin limit of the Dallas Advance must be south of the county.

The Superior Lobe also advanced to a position south of Barron County at this time. River Falls till deposited during the Baldwin Advance was deposited in northwestern Dunn

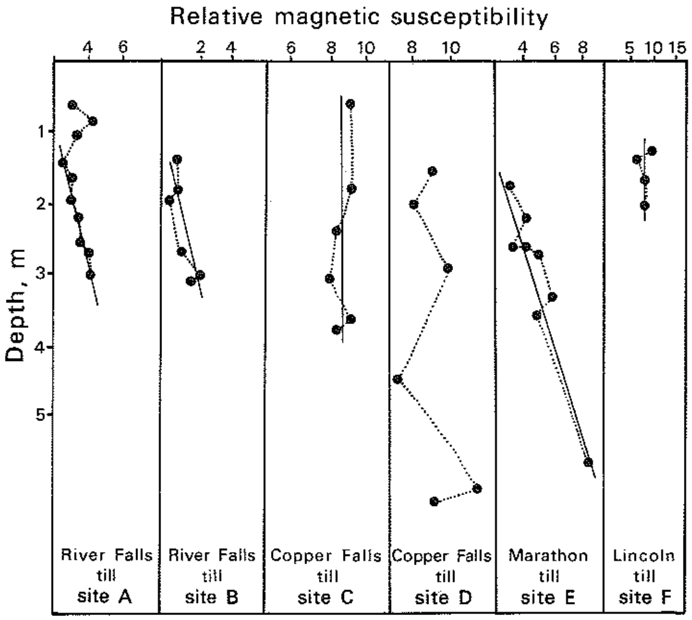


FIGURE 15. Relative magnetic susceptibility of River Falls and Copper Falls till. Site A = River Falls till (Prairie Farm member), NE1/4NW1/4SE1/4 sec. 13, T. 32 N., R. 13 W.; site B = River Falls till from two sites in St. Croix County, SE1/4NE1/4NE1/4 sec. 18, T. 29 N., R. 16 W. and NW1/4SW1/4SW1/4 sec. 6, T. 28 N., R. 17 W., samples provided by Robert W. Baker, University of Wisconsin-River Falls; site C = Copper Falls till (Pokegama Creek Member), NW1/4NE1/4SW1/4 sec. 1, T. 34 N., R. 11 W.; site D = Copper Falls till (Sylvan Lake Member), SE1/4SW1/4NW1/4 sec. 14, T. 36 N., R. 13 W.; site E = Marathon till (Edgar Member), from several sites in east-central Wisconsin, samples collected by William N. Mode, University of Wisconsin-Oshkosh; site F = Lincoln till (Merrill Member), from several sites in east-central Wisconsin, samples provided by David M. Mickelson, University of Wisconsin-Madison.

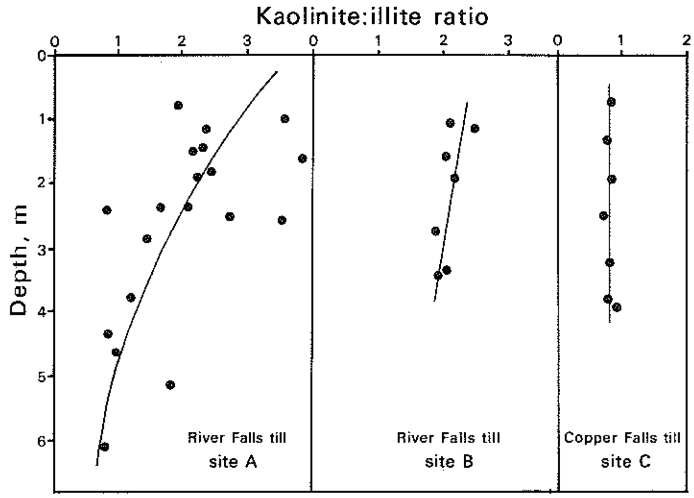


FIGURE 16. Kaolinite:illite ratio of River Falls till and Copper Falls till. Site A = River Falls till (unnamed member and Prairie Farm Member) from several sites in Barron County; site B = River Falls till from St. Croix County (site B in figure 15); site C = Copper Falls till from Barron County (site C in figure 15).

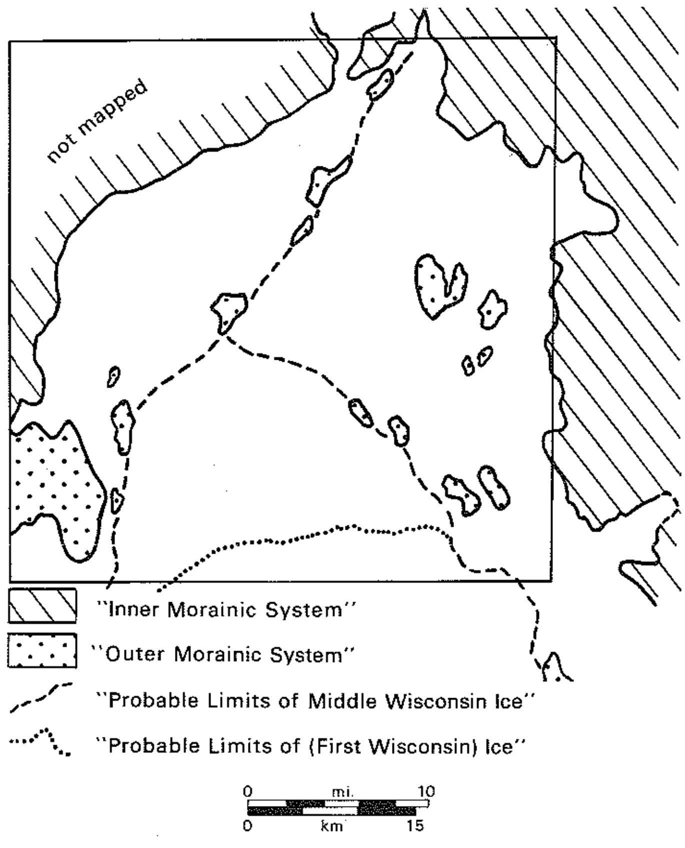


FIGURE 17. Mathieson's (1940) interpretation of the glacial geology of Barron County.

County as well as parts of St. Croix and Pierce Counties (Baker and others, 1983). The limit of this advance (fig. 18) may also coincide with the Hampton moraine of eastern Minnesota (Ruhe and Gould, 1954).

During the Baldwin and Dallas Advances, melt water deposited sand and gravel. Patches of sand and gravel (map unit R1ss, plate 1) that are weathered and contain illuviated clay are common in the southeast part of the county above the level of the outwash plain of the Copper Falls Formation (map unit C5sp and C5su, plate 1). This stream sediment was deposited during or sometime after retreat of the River Falls ice margin.

Ice advances to the east of Barron County may have occurred at this time, but dates that would provide a means of correlation are lacking. Mode (1976) and Stewart (1973) worked on till stratigraphy in Clark, Wood, and Marathon Counties, but field studies are lacking in Dunn, Chippewa, and Eau Claire Counties. Attempts to correlate to the east and to till deposited by other lobes are difficult. However, the relationship of relative magnetic susceptibility and depth in River Falls till is present in till of the Edgar Member of the Marathon Formation (fig. 15, site E), but not in till of the younger Merrill Member of the Lincoln Formation (fig. 15, site F) or in till of the Lincoln Formation occurring in late-Wisconsin moraines of eastern Wisconsin. The Edgar till probably experienced the same period of weathering as the River Falls till.

The time of the Baldwin and Dallas Advances is unknown. Because the upper part of the Pierce till is weathered where overlain by River Falls till, the maximum age of the River Falls Formation is probably considerably less than the age of the Pierce till. Similarly, because the upper part of the River Falls till is weathered where overlain by Copper Falls till, the River Falls till is probably considerably older than the Copper Falls till. Baker and others (1983) interpret the River Falls Formation to be pre-Wisconsin based on solum thickness and comparison to soils developed in pre-Wisconsin till in northern Illinois. They report solum thickness three times as thick in till of the River Falls Formation as in till in the St. Croix moraine (Copper Falls till). However, this difference in solum thickness was not apparent in Barron County. A pre-Wisconsin age may be suggested by correlations with till in eastern central Wisconsin. The Merrill till (fig. 18), which occurs in eastern Wisconsin, contains unweathered magnetite (fig. 15, site F), but is probably older than 40,000 years based on radiocarbon dating (Stewart and Mickelson, 1976). This suggests that the Merrill till was deposited during the early part of the Wisconsin Glaciation. Because the Merrill till is not as weathered as the River Falls till, the weathering of the River Falls till could not have occurred during the relatively warm middle part of the Wisconsin Glaciation. The weathering of the River Falls till, and thus the deposition of the River Falls till, must have occurred before the Wisconsin Glaciation.

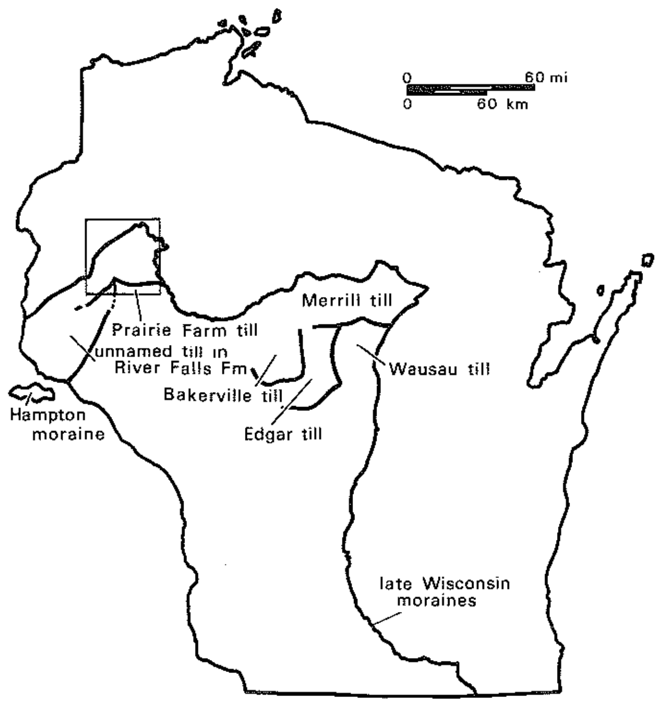


FIGURE 18. Till deposited prior to the last part of the Wisconsin Glaciation in central Wisconsin. Distribution of Wausau, Edgar, Bakerville, and Merrill Members from Stewart (1973) and Mode (1976). Distribution of River Falls Formation southwest of Barron County from Baker and others (1983). Location of Hampton moraine from Ruhe and Gould (1954).

Early Chippewa Advance

Following the period during which the River Falls till was weathered, ice of the Chippewa Lobe advanced into the county from the north and northeast and deposited yellowish red, sandy-loam till that is included in the Pokegama Creek Member of the Copper Falls Formation. It is distinguished from the River Falls till by relative magnetic susceptibility and kaolinite:illite ratio (see fig. 5 and 6, tables 1, 2, and 3, and section on Pleistocene deposits).

The southern limit of this advance (fig. 1 and plate 1) is south of Chetek and is indicated by geomorphic features and the distribution of the Pokegama Creek till. The most prominent geomorphic feature at the ice-margin limit is a large fan of sand and gravel that is bounded on the north side by a now-eroded ice-contact face. This feature is located in sec. 14, 15, and 16, T. 32 N., R. 10 W. and is mapped as C1su on plate 1. Immediately behind the ice-contact face, sand and gravel is pitted and collapsed (map units C1sp and C3sp, plate 1). To the west, the ice margin is marked by two ridges that are draped over sandstone hills. The ridge running northwest from the SW1/4 sec. 8, T. 32 N., R. 10 W. to the E½sec. 7, T. 32 N., R. 10 W. is made of gravelly sandy loam, and the ridge in the northwest corner of sec. 13, T. 32 N., R. 11 W. is made of sand (map unit C1su, plate 1). These three features mark the Early Chippewa ice margin in the southeastern part of the county. This margin is also the southern limit of pitting in the outwash plains (fig. 19). The boundary between pitted outwash (map units C1sp and C5sp, plate 1) and unpitted outwash (map units C1su and C5su, plate 1) marks the Early Chippewa ice-margin limit. Ice from the Early Chippewa Advance remained in valleys and was buried by stream sediment before it melted.

To the west, no geomorphic evidence is present that marks the Early Chippewa ice margin. The ice-margin limit in this area is drawn in plate 1 along the boundary between the Pokegama Creek till (map unit C1tn) and the Prairie Farm till (map unit R1tn). Farther west, the Early Chippewa ice-margin position is buried by till deposited during the Early St. Croix Advance.

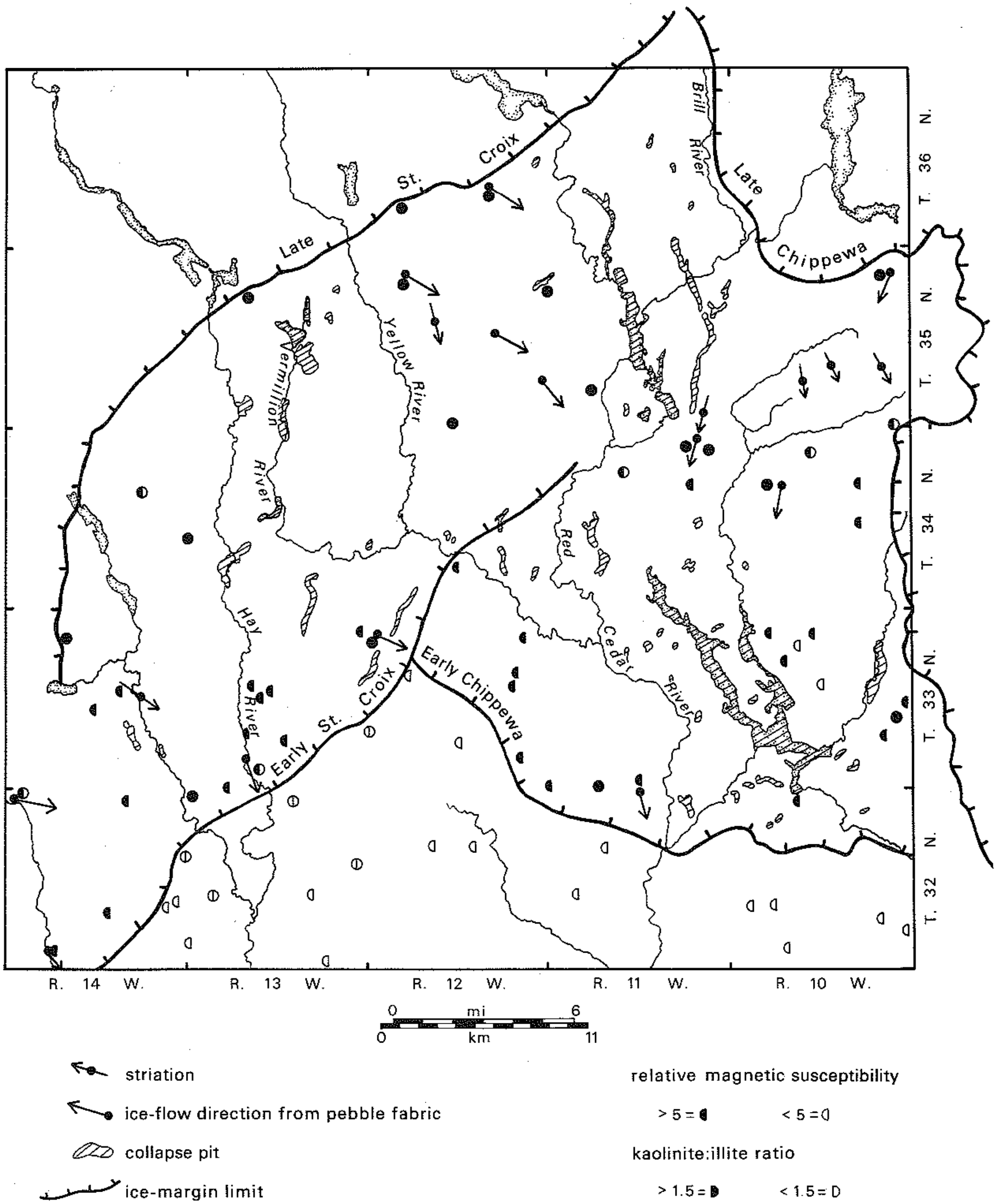


FIGURE 19. Fabric, striations, collapse pits, and till characteristics associated with the Early Chippewa and Early St. Croix Advances. Not all collapse pits north of the ice-margin positions or all samples from the northern half of the county are shown.

The extent of the Early Chippewa Advance outside of Barron County is not known. To the east, the ice margin is buried by stream sediment of the Mikana Member of the Copper Falls Formation, which makes up the Chippewa moraine. However, farther to the east, it is possible that till equivalent in age to the Pokegama Creek till is present at the surface, emerging from beneath the deposits of the Late Chippewa Advance. Till units deposited before the formation of the Chippewa moraine occur in east-central Wisconsin (Stewart, 1973; Mode, 1976) and perhaps the Pokegama Creek till is of the same age as one of these.

The large amount of quartzite in the Pokegama Creek till indicates that ice-flow direction was southerly. Fabric measurements and striation orientations on quartzite in the Blue Hills (fig. 19 and plate 1) also indicate flow to the southeast, south, and southwest. Northeast-southwest oriented, drumlin-like, till-covered, sandstone hills are present 1 to 2 km south of the community of Barron. These hills may have been shaped by ice during this advance. Elsewhere, there are few geomorphic features that can be attributed to the action of ice during this advance. Parts of the landscape are gently rolling and underlain by relatively thick (about 5 m) till, whereas parts, west and northeast of Chetek, consist only of patchy till on sandstone.

Sand and gravel was deposited by streams as the glacier margin advanced and retreated. Much of the stream sediment cropping out in the uplands between Cameron and Rice Lake (map unit Css, plate 1) was probably deposited in front of the advancing Chippewa Lobe. Exposures of this unit show a coarsening-upward sequence of outwash (gravel pits in sec. 1 and 2, T. 34 N., R. 11 W.) that is capped with Pokegama Creek till. During retreat, sand and gravel was deposited by streams in the valleys and later buried by outwash of the Chetek and Mikana Members.

The date of this advance is not known. The Pokegama Creek till deposited during this advance does not have the weathered character of the River Falls till. The Pokegama Creek till is more like till of the Mikana Member, which was deposited during the Late Chippewa Advance. The persistence of buried Early-Chippewa ice until after the deposition of the late Wisconsin Sylvan Lake, Chetek, and Mikana Members of the Copper Falls Formation, suggests that the Pokegama Creek Member cannot be much older. Clayton (1967) cited evidence that ice can remain buried for as much as 3,000 years. Pokegama Creek till was not likely deposited during the early part of the Wisconsin Glaciation because buried ice would have to remain through the warm middle part of the Wisconsin. The Early Chippewa Advance most likely occurred during the latter part of the Wisconsin Glaciation, but may be a few thousand years older than the Late Chippewa and Late St. Croix Advances. This advance probably occurred at some time between 25,000 and 15,000 years ago (Johnson, 1984).

A period of permafrost activity and wind abrasion

Ice-wedge casts are common in Barron County and are primary evidence for a period of permafrost activity in the county following the Early Chippewa Advance. Figure 20 shows the distribution of ice-wedge casts in the county. The ice-wedge casts that formed in Barron County during this period occur in Cambrian sand and sandstone, Prairie Farm stream sediment, and Pokegama Creek till. Figure 21 shows a photo of an ice-wedge cast formed in Cambrian sand. The ice-wedge casts occur predominantly on surfaces older than those containing sediment of the Poskin Member of the Copper Falls Formation. This distribution suggests that the period of permafrost activity was either before or at the same time as the Early St. Croix Advance, and that the Early Chippewa Advance occurred before the Early St. Croix Advance. However, two sites contain ice-wedge casts developed in stream sediment deposited during the Late St. Croix and Late Chippewa Advances. This suggests permafrost existed (1) at two different times during the last part of the Wisconsin Glaciation (fig. 11), (2) continuously through the last part of the Wisconsin Glaciation, or (3) only towards the end of the Late St. Croix and Late Chippewa Advances.

The presence of permafrost at this time would have accelerated rates of mass wasting on hillslopes and may explain the lack of thick Pleistocene sediment on the uplands of south-central and southeastern Barron County.

Ventifacts are common in Barron County. They occur on surfaces older than the Poskin Member. Many ventifacts are composed of Barron Quartzite, although ventifacts composed of other lithologies occur (fig. 22). Prevailing wind direction during wind abrasion at two sites (fig. 20) was N. 80°W. and N. 45°W. Though the ventifacts did not necessarily form under permafrost conditions, both the ventifacts and the ice-wedge casts are of similar age.

Early St. Croix Advance

Following or during the period of permafrost activity, ice of the Superior Lobe advanced into Barron County from the northwest and deposited yellowish red, sandy-loam till of the Poskin Member. Fabric measurements and striations indicate that the ice-flow direction of the Superior Lobe varied between S. 30°E. and S. 80°E. (fig. 19).

The maximum position to which the ice advanced (fig. 1 and plate 1) is not immediately obvious and is known only from the limit of the Poskin till and certain geomorphic features. There are no ice-margin ridges at the Early St. Croix ice-margin limit and there are no extensive outwash plains associated with this advance.

Three geomorphic features remain that indicate the ice-margin position. First, the ice-margin is shown by the southern limit of pitted sand and gravel in the valleys of the Vermillion, Yellow, and Hay Rivers (fig. 19). Ice was left in the stream valleys and buried by stream sediment as the Early St. Croix ice margin retreated. Ice must have advanced at least as far as the limit of pitting. Second, disruption of drainage while the ice was at its limit is shown by the sharp bend in Fourmile Creek at the northeast corner of sec. 17, T. 33 N., R. 12 W. (fig. 23). As the ice advanced, the stream was diverted from its original northwest course to a northeast course. Upstream from this bend a lake formed, and now the valley is broad and flat and filled with a marsh. Third, the valley of Dority Creek, which lies near the features mentioned above, contains stream-deposited sand and gravel with abundant basalt but no quartzite, suggesting that Early St. Croix ice advanced as far as the Dority Creek drainage basin. Perhaps the steepening of the valley walls along Dority Creek occurred at this time as glacial melt water flowed from the Early St. Croix ice.

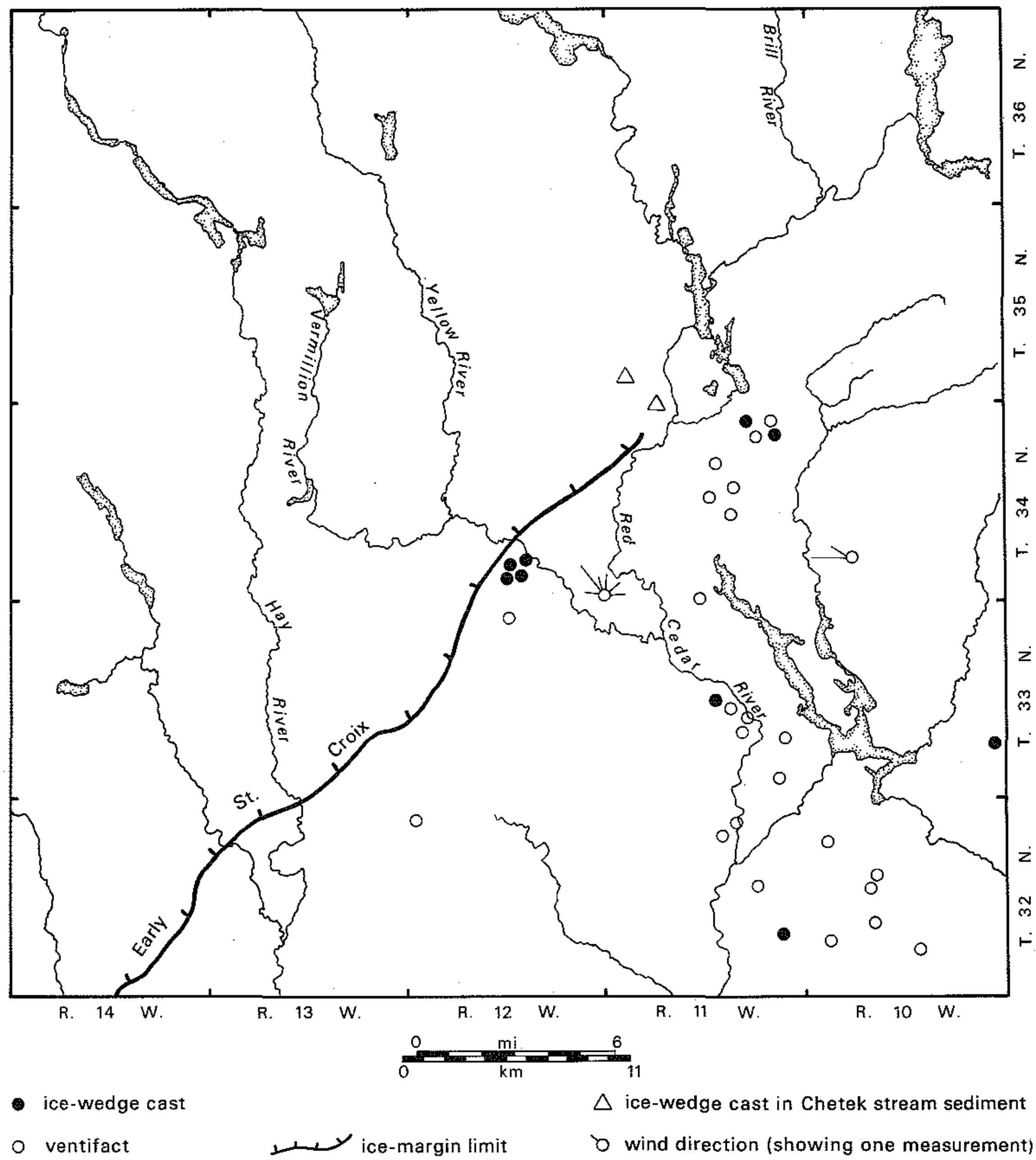


FIGURE 20. Distribution of ice-wedge casts and ventifacts in Barron County. Wind direction determined from elongated pits on in-place ventifacts.

These geomorphic features coincide with the mapped limit of the Poskin till. The Poskin till is sufficiently distinct from River Falls till and Pokegama Creek till that the surface extent of the Poskin till can be easily determined (see section on Pleistocene deposits). To the northwest of the Early St. Croix ice-margin limit, the surface till (the Poskin till) is thick and continuous, whereas to the southeast, the surface till (the River Falls and Pokegama Creek till) is patchy and thin over Cambrian sand and sandstone hills (cross section D-D', plate 1).

Northeast of the community of Barron, the margin lies buried beneath stream-deposited sand and gravel. Southwest of Barron County, the River Falls till has been mapped by Baker and others (1983), but Poskin till probably occurs in part of this area.

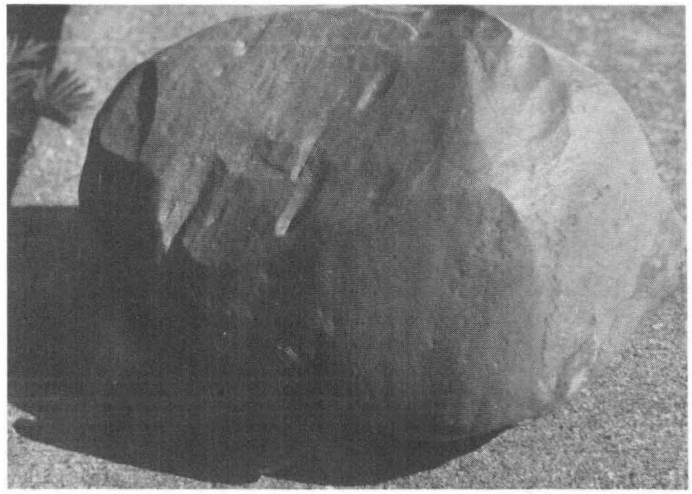
The Early St. Croix ice-margin limit is located 10 to 20 km southeast of and concentric to the Late St. Croix ice-margin limit. The position of Mathieson's "Outer Morainic System" is similar to the limit of the Early St.

FIGURE 21. Photograph of ice-wedge cast in Cambrian sand, 2.5 km south of Barron, Wisconsin in an abandoned sandstone quarry, SW1/4SW1/4SE1/4 sec. 4, T. 33 N., R. 12 W.

Croix Advance (compare fig. 17 and 19). However, most of the areas within his "Outer Morainic System" are not distinct from the surrounding landscape geomorphically or stratigraphically, and they lie west of the Early St. Croix limit. An exception is the low-relief hummocky landscape of Vance Creek and Turtle Lake Townships in southwestern Barron County (part of map unit C4uh, plate 1). This hummocky region, however, was formed during the Late St. Croix Advance.

The Late St. Croix ice-margin limit is located at the southern edge of a band of hummocky topography that has been generally referred to as the "St. Croix Moraine," and which Mathieson (1940) referred to as the "Inner Morainic System." Mathieson believed that the "Inner" and "Outer Morainic Systems" were formed during a single advance towards the end of the Wisconsin Glaciation. He suggested that the Superior Lobe exceeded the position of the "St. Croix Moraine" and built the "Outer Morainic System." The "Inner Morainic System," or "St. Croix Moraine," was merely a "recessional moraine." However, field evidence indicates that the Late St. Croix ice-margin limit is not a "recessional moraine," but represents a later advance of the Superior Lobe. Outcrops and drill holes in the "St. Croix Moraine" reveal Poskin till buried beneath Late St. Croix deposits.

Behind the Early St. Croix ice-margin limit, the surface is gently rolling and underlain by loess-covered Poskin till. A well established drainage network with a relief of up to 75 m has been developed in the region. In the southwest part of Barron County, the Poskin Member is thin and overlies sandstone. Exposures of sandstone are common along stream valleys. An esker, first mentioned by Mathieson (1940) and now almost completely gone due to gravel mining, occurs in NE1/4NE1/4 sec. 20, T. 35 N., R. 12 W. This feature was formed during retreat of the ice and is now partially buried by younger stream sediment.



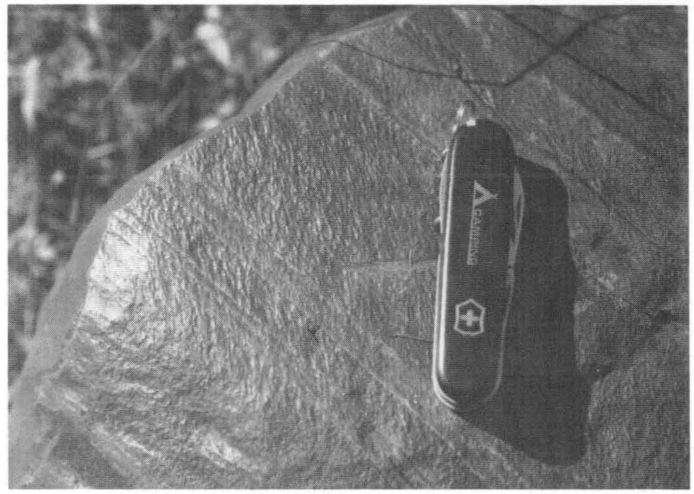


FIGURE 22. Photographs of ventifacts from Barron County. Upper photograph shows facets and pits on a cobble of Precambrian Barron Quartzite. Lower photograph shows fine elongate pits on a boulder of Precambrian argillite.

Ice-margin fluctuations during general retreat may have occurred and caused Early St. Croix ice to be covered by Poskin till. Melting of the ice and collapse of the overlying Poskin till created the valleys in which Sweeney Pond, Lake Desair, Quaderer Creek, and parts of the Hay River are located. Barbed tributaries near the headwaters of Quaderer Creek and Sweeney Pond (fig. 23) indicate capture of south-flowing streams after the collapsed valleys were formed. Ice must have remained buried long enough to allow southern drainage to be established.

The date of this advance is unknown. As during the Early Chippewa Advance, buried ice was left during the Early St. Croix Advance and did not melt until after the Late St. Croix and Late Chippewa Advances. Maintenance of buried ice by permafrost following Early St. Croix retreat, indicates that the Early St. Croix Advance could have occurred several thousand years before the Late St. Croix Advance. However, the period between these two advances may have been short. The Early St. Croix Advance probably occurred between 25,000 and 15,000 years ago.

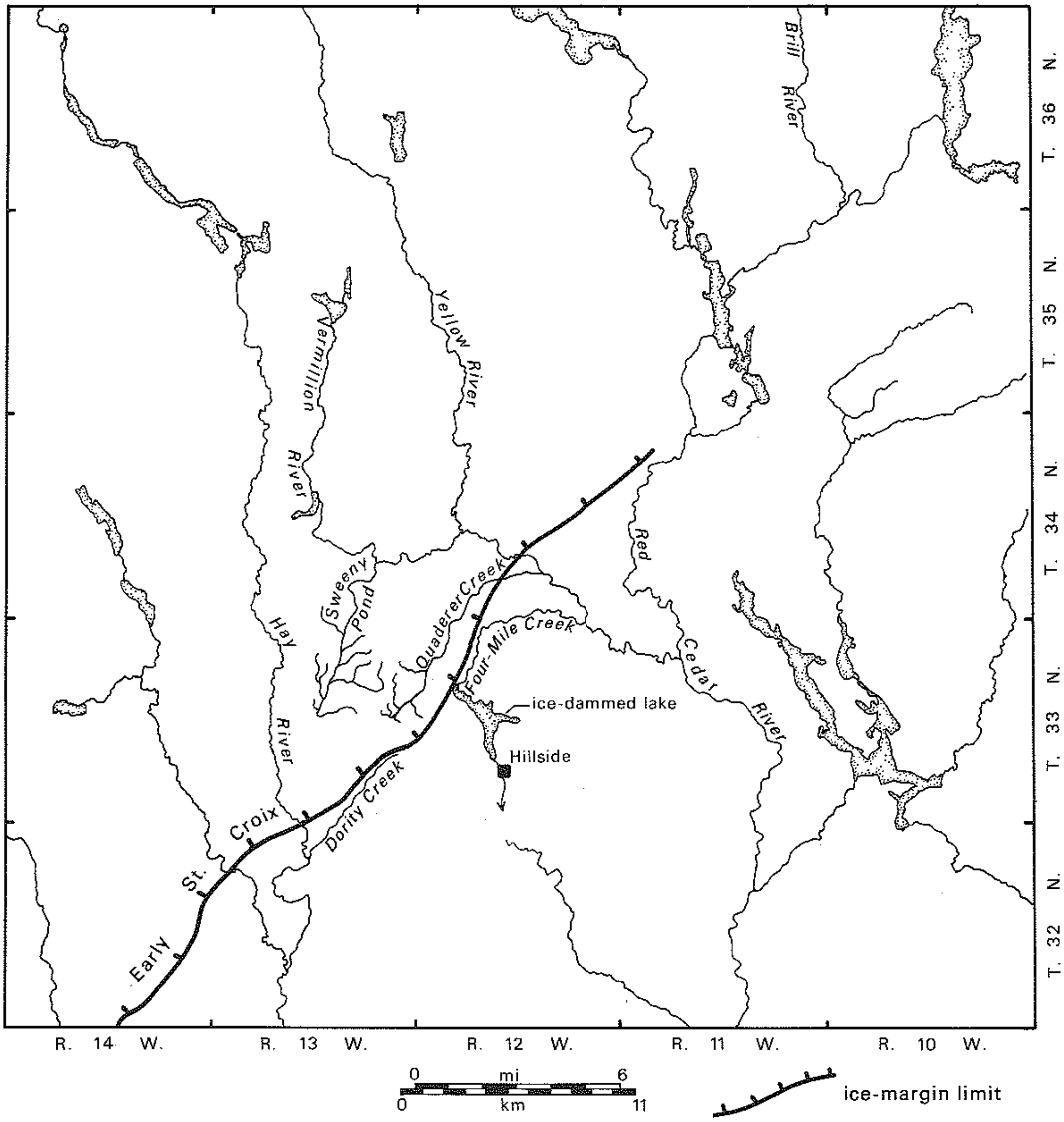


FIGURE 23. Geomorphic features near the Early St. Croix ice-margin limit. Sweeney Pond and Quaderer Creek lie in collapsed valleys. Tributaries to these collapsed valleys originally flowed south but were captured after the melting of buried ice and now flow north. Fourmile Creek was dammed by Early St. Croix ice forming a lake that may have drained through a low point located at Hillside, Wisconsin.

Late St. Croix and Late Chippewa Advances

The last period of glacial activity in Barron County consisted of the Late St. Croix Advance of the Superior Lobe and the concurrent Late Chippewa Advance of the Chippewa Lobe (fig. 11). Both lobes deposited yellowish red, sandy-loam till. The ice-flow direction of each lobe is known from pebble fabric, the trace of the ice-margin limit, striations (Strong, 1880), and drumlin trends. The landforms formed during this glacial episode make up a landscape sharply distinct from the rest of the county. A well-defined boundary occurs between this forested, hummocky landscape and the gently rolling, largely cultivated land in the remainder of the county.

Ice-margin limits

The ice-margin limits of the Late St. Croix and Late Chippewa Advances are shown in figure 1. Only in a few places is there a ridge that marks the former ice-margin position. More typically, there is a change from

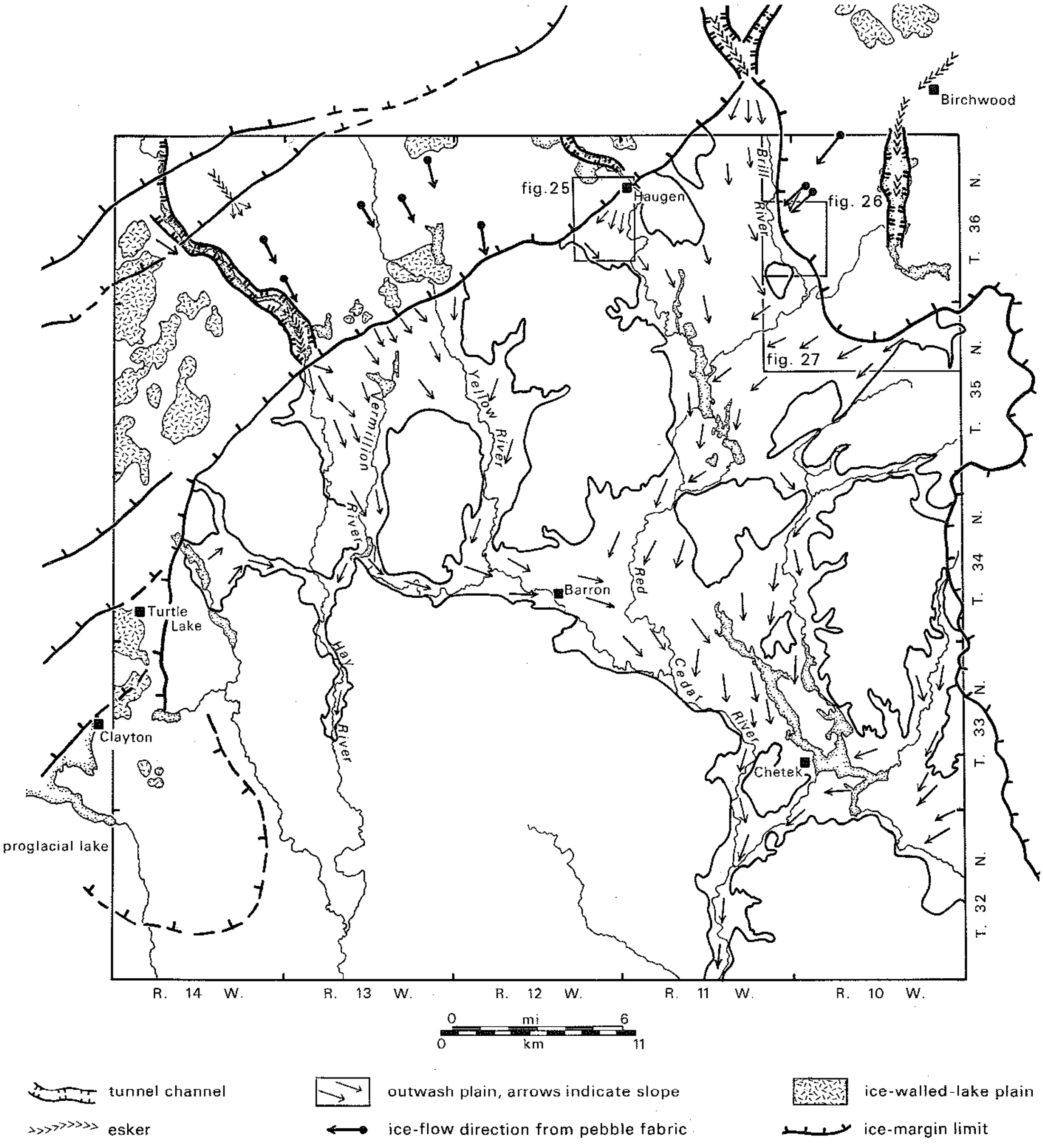


FIGURE 24. Ice-flow direction, ice-margin limits (dashed were uncertain), and geomorphic features associated with the Late St. Croix and Late Chippewa Advances. Location of area in figures 25, 26, and 27 shown in the north part of the map.

non-hummocky to hummocky topography. The hummocky character of the landscape behind the former ice-margin position and the lack of an ice-margin ridge suggests that ice was stagnant at the glacier margin.

Late St. Croix ice-margin limit.--Along the northern boundary of Barron County, the Late St. Croix ice-margin limit occurs in sec. 4, T. 36 N., R. 11 W. and is marked by a narrow low-relief ridge. To the southwest, the limit is roughly a straight line to Haugen and is marked by a series of short ridges from Haugen to sec. 22, T. 36 N., R. 12 W (fig. 25). From there, it lacks strong definition in the upland area to the west. From sec. 31, T. 36 N., R. 12 W. to the community of Cumberland, the ice-margin limit is straight, bordered by a pitted plain to the south and hummocks to the north. In this area, melt water flowed off the ice and deposited sand and gravel in broad fan-shaped deposits. Southwest of Cumberland, the former ice-margin limit is marked by a change from the rolling topography found on the Poskin till surface to the hummocky topography behind the margin. This limit can be followed south through the community of Comstock and east of the community of Turtle Lake to the north side of Big Moon Lake (plate 1).

South of Big Moon Lake the margin is obscure. Well defined margin features are present to the west in Polk County, running parallel to Highway 63 for several kilometers southwest of the community of Clayton (fig. 24), but this does not represent the maximum extent of ice that occurred during the Late St. Croix Advance. The ice margin at the northern edge of Big Moon Lake was too far east to be a continuation of the margin that passed through Clayton. In addition, Sylvan Lake till occurs east of the Clayton ice-margin limit in sec. 6, T. 32 N., R. 14 W. In T. 32 and 33 N., R. 14 W., the upland area contains several small ice-walled-lake plains (map unit C4li, plate 1) and many low-relief hummocks (1 to 4 m high) composed of till and stream sediment (map unit C4uh, plate 1). This area was recognized by Mathieson (1940) as part of his "Outer Morainic System" (fig. 17). The origin of this topography is not clear but it contains sediment most likely of the Sylvan Lake Member. The hummocks may have been deposited by a small tongue of ice that protruded from the main body of the Superior Lobe. This advance may have been possible because of the presence of a small proglacial lake that occurred in sec. 24, 25, 26, 34, and 35, T. 32 N., R. 15 W. in Polk County (fig. 24), and which overflowed down the South Fork Hay River. Tunnel channels to the north along the Late St. Croix ice-margin limit suggest that the ice margin was frozen at its toe (Mickelson and Clayton, 1981). However, the water in the proglacial lake probably

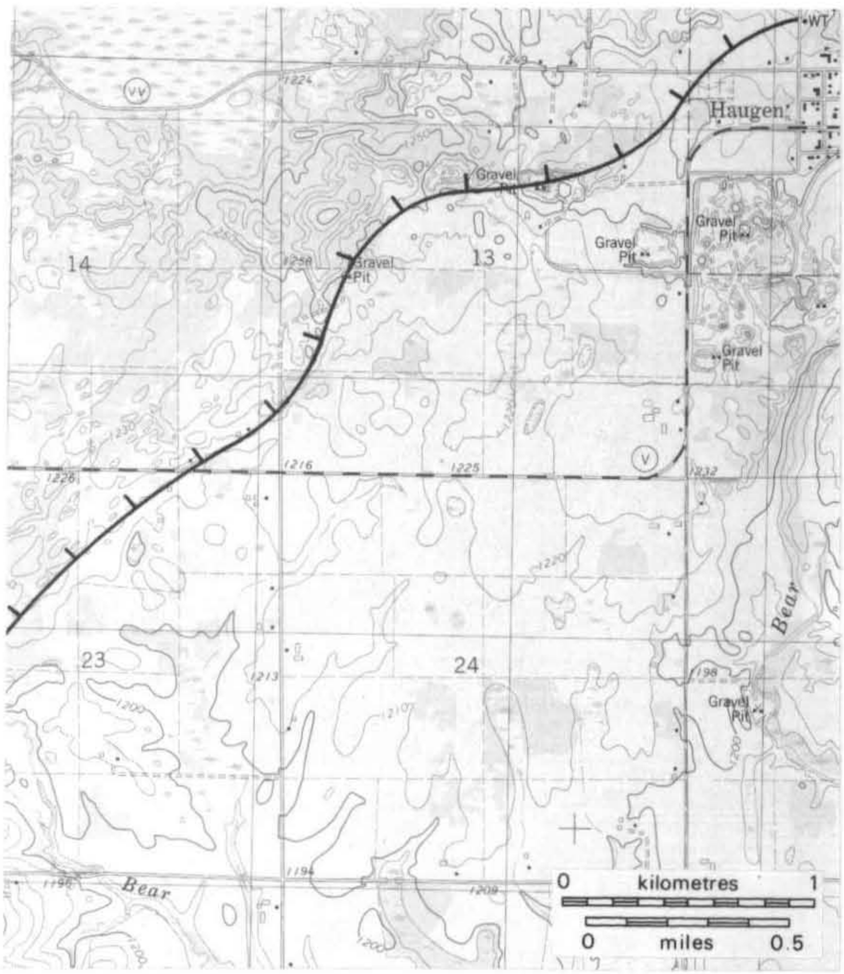


FIGURE 25. Part of the St. Croix moraine shown on the U.S. Geological Survey Haugen 7.5-minute Quadrangle. This is one of the few places in Barron County where the Late St. Croix ice margin is marked by a ridge. Central part of the area shown on this map is underlain by stream sediment derived from a tunnel channel that lay just north of Haugen. Note that surface slope is towards the southwest and not away from the adjacent ice margin. Location shown in figure 24.

maintained an unfrozen margin and allowed a small part of the glacier to flow beyond the regional trend of the ice margin and deposit the sediment in the hummocks of southwest Barron County. Similar features do not occur farther north in the county because drainage was away from the ice and no lakes would have formed.

The Late St. Croix ice-margin position continues southwest of Barron County through Polk and St. Croix Counties and crosses the St. Croix River near Hudson.

Late Chippewa ice-margin limit.--The north end of the Late Chippewa ice-margin limit in Barron County occurs in sec. 6, T. 36 N., R. 10 W. Southward, it lies on the east side of Brill and is marked by a change in topography from a flat outwash plain on the west to high-relief hummocks on the east. The outwash on the adjacent plains was not deposited by melt water from the immediately adjacent ice but rather by streams emanating from a tunnel channel at the interlobate junction to the north and now occupied by Long Lake in Washburn County (fig. 24). Stream sediment buried the outer part of the glacier and obscured the actual ice margin (fig. 26).

The most clearly defined portion of the ice margin in northeastern Barron County is the edge of a fluvial surface that occurs in sec. 1, 2, 9, 10, and 11, T. 35 N., R. 10 W. and is shown in figure 27. The slope of this surface indicates that streams flowed between Chippewa Lobe ice to the north and the Blue Hills to the south. A few collapse pits are present on this surface. The ice that bordered the north edge of this surface was later covered by sand and gravel deposited by streams emanating from the mouth of a tunnel channel that was located at the present position of the south end of Red Cedar Lake. This stream sediment was collapsed as underlying ice melted, producing a hummocky topography

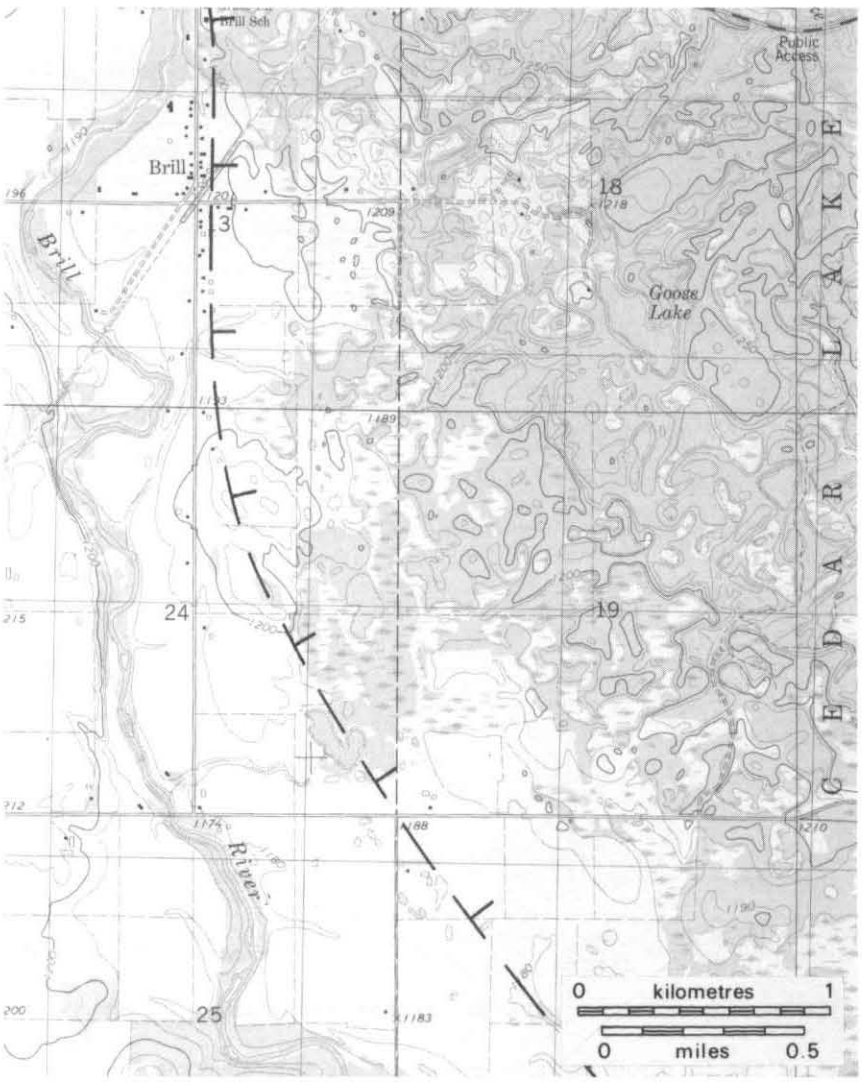


FIGURE 26. Part of the Late Chippewa ice-margin position shown on U.S. Geological Survey Rice Lake North 7.5-minute Quadrangle. The actual ice-margin position is buried by stream sediment. Note hummocky topography northeast of ice-margin limit. Location shown in figure 24.

(map unit C3sh, plate 1). The restored surface slope of this hummocky region indicates the former position of the tunnel-channel mouth (fig. 27).

A short distance to the east of the fluvial surface mentioned above, the ice-margin limit crosses the county line into Rusk County. A large re-entrant in the margin (fig. 24) formed when the apparently thin ice of the Chippewa Lobe flowed around rather than over the Blue Hills. The ice-margin limit is in Rusk County for several kilometers but is present again in Barron County at the southern edge of the Blue Hills in the northeast corner of T. 34 N., R. 10 W. South of this point, the ice-margin limit is roughly straight and is marked by a change in topography, but no prominent ice-margin ridge is present. The ice-margin limit does not extend farther than a kilometer into the county south of the Blue Hills. The southern extent of the ice-margin limit in Barron County is in sec. 12, T. 33 N., R. 10 W. (fig. 24, plate 1). The Late Chippewa margin continues southeast of Barron County into Rusk and Chippewa Counties (fig. 10).

North of the county, the Superior and Chippewa Lobes merged at Long Lake in Washburn County (fig. 24). Mathieson (1940) believed that the Chippewa Lobe advanced somewhat earlier than the Superior Lobe. He concluded that the unpaired terrace scarp west of the Brill River (plate 1) was formed by melt water from the Chippewa Lobe cutting into pre-existing stream sediment deposited by melt water from the Superior Lobe. This means that stream sediment from the Superior Lobe was deposited first, and therefore the Superior Lobe must have advanced first. Because the scarp is unpaired, the cutting cannot be attributed to postglacial dissection (Mathieson, 1940). However, this scarp may also be explained as having been formed during a simultaneous advance of the Superior and Chippewa Lobes. The following sequence of events most likely occurred. (1) Both lobes advanced to their maximum positions. (2) A tunnel in the ice located at their junction, and now occupied by Long Lake, became a major outlet for melt water and sediment. This sediment formed a broad outwash fan extending south from the mouth of the tunnel channel (fig. 24). The shape of the fan and position of the tunnel channel indicates that both lobes must have been present at the same time. (3) Following deposition of much of the stream sediment, but while ice was still present, the Brill River cut down through the outwash surface and formed the prominent terrace scarp. To the east, the river cut down through sand and gravel and stagnant ice of the Chippewa Lobe. (4) After some time, the ice melted, collapsing the east side of the original outwash surface leaving only the west terrace. Non-collapsed remnants of the east terrace occur on the east side of the Brill River in sec. 24, 25, and 36, T. 37 N., R. 11 W., in Washburn County and in sec. 24, T. 36 N., R. 11 W., 1 km south of Brill. Based on this interpretation, the two ice lobes must have reached their maximum positions simultaneously.

Behind the outer ice margin

The surface topography behind the ice-margin limit of each lobe is characterized by four major types of landforms: tunnel channels with eskers, hummocks, ice-walled-lake plains, and outwash plains. In addition, a few drumlins are present.

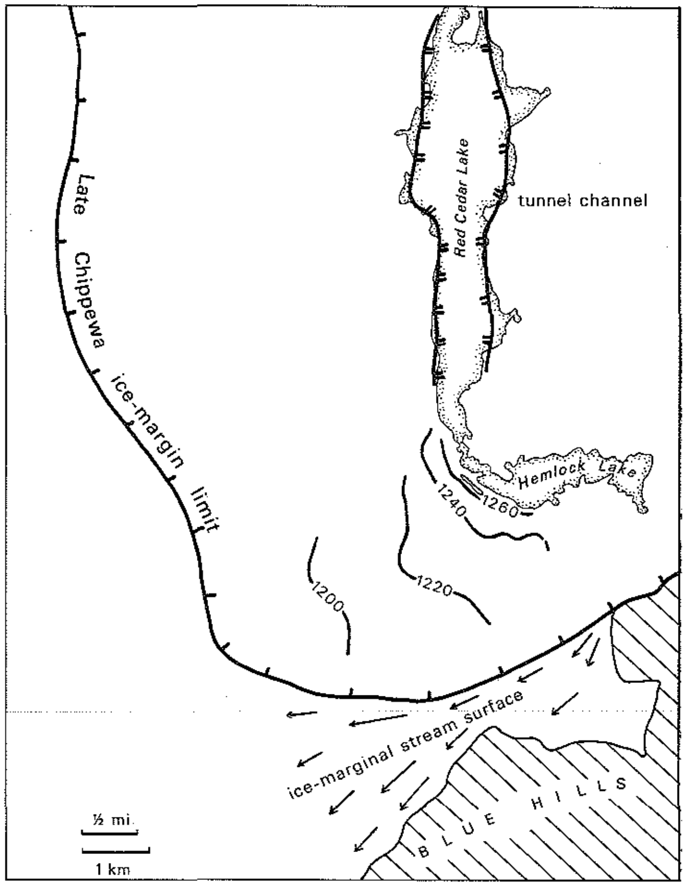


FIGURE 27. Part of the Late Chippewa ice-margin features in northeast Barron County. Ice margin was at the north side of the stream surface immediately north of the Blue Hills. During retreat, stagnant ice was covered with stream sediment deposited by meltwater emerging from the tunnel channel now filled by Red Cedar Lake. Outwash fan surface reconstructed from hummock tops (map unit C3sh, plate 1). Location shown in figure 24.

Drumlins.--Drumlins are not common in Barron County and are found only behind the limit of the Late St. Croix Advance. The Late St. Croix drumlins are found in the southwestern part of Barron County (fig. 28). They are about 0.5 km in length and 0.2 km in width. Their distribution coincides with the part of the Sylvan Lake Member that was deposited by a sublobe of the Superior Lobe (see section on Late St. Croix ice-margin position).

Tunnel channels with eskers.--Tunnel channels are stream-eroded channels that were formed subglacially by water flowing toward the glacier margin. Tunnel channels are associated with the St. Croix Advance in Minnesota (Wright, 1973) and have been mapped along the late-Wisconsin margin in Wisconsin (Mickelson and Clayton, 1981). The presence of tunnel channels indicates that the margins of the Superior and Chippewa Lobes may have been frozen to their beds (Mickelson and Clayton, 1981).

In Barron County, four large tunnel channels occur at the Late St. Croix and Late Chippewa ice-margin limits (fig. 24 and plate 1). In all places, the channels are now occupied by lakes: Red Cedar Lake, Bear Lake, Long Lake (in Washburn County), Beaverdam Lake, and Sand Lake. Evidence that these features are tunnel channels and that they were active when the ice was at its furthest extent is the large fan-shaped outwash surfaces found at the point where the tunnel channel meets the ice-margin limit (fig. 24). Water from the Red Cedar Lake tunnel deposited sand on ice, and the fan that was formed collapsed as ice melted (fig. 27). The other three tunnel channels are associated with uncollapsed outwash fans (note outwash slopes at tunnel-channel mouths, plate 1 and fig. 24).

At some time, the water that cut the tunnel channels diminished in quantity and allowed the ice to flow into the channel and partly close the tunnel. As the tunnels decreased in size, water flowing through them deposited sand and gravel and filled the tubes. These deposits are left as eskers along the axes of some of the tunnel channels. The community of Cumberland is built on one of these eskers. The string of islands in Red Cedar Lake, including Stout Island, is an esker that is partly submerged in the lake. This esker is more conspicuous outside the county where it forms a long ridge running northeast of Birchwood. The total length of this esker is more than 13 km, and in places it is over 25 m high.

Hummocks.--The most common landform type behind the Late St. Croix and Late Chippewa ice-margin limits is the hummock. Hummocky topography consists of isolated knobs or small hills separated by depressions that are now filled with marshes and lakes. Hummocky topography (figs. 26 and 29) makes up most of the landscape behind the ice margin (map units C4uh and C3uh, plate 1) and is underlain by a variety of sediments including stream sediment, till, and mixtures of these.

Hummocky topography forms by the collapse of supraglacial debris as underlying stagnant ice melts. Commonly, supraglacial debris will become mobilized and flow during collapse. Some of the hummocky topography in

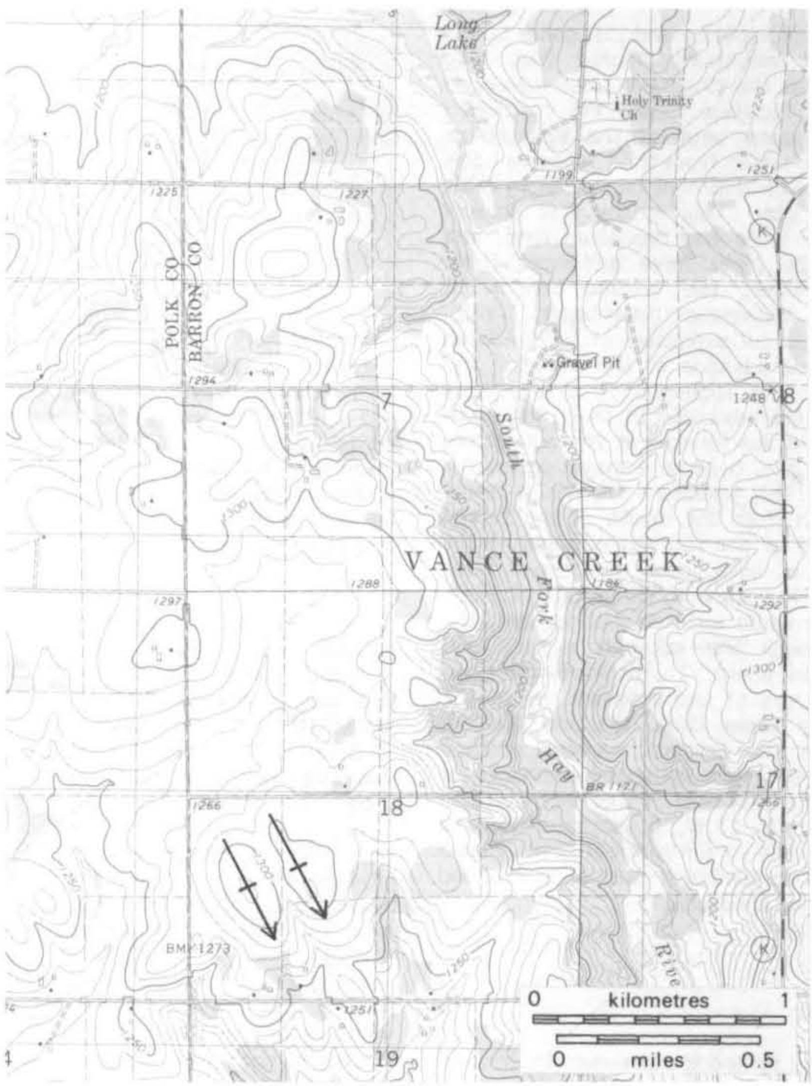


FIGURE 28. Late St. Croix drumlins near Clayton shown on the U.S. Geological Survey Clayton 7.5-minute Quadrangle. These drumlins were formed during the Late St. Croix Advance but probably contain sediment deposited earlier.

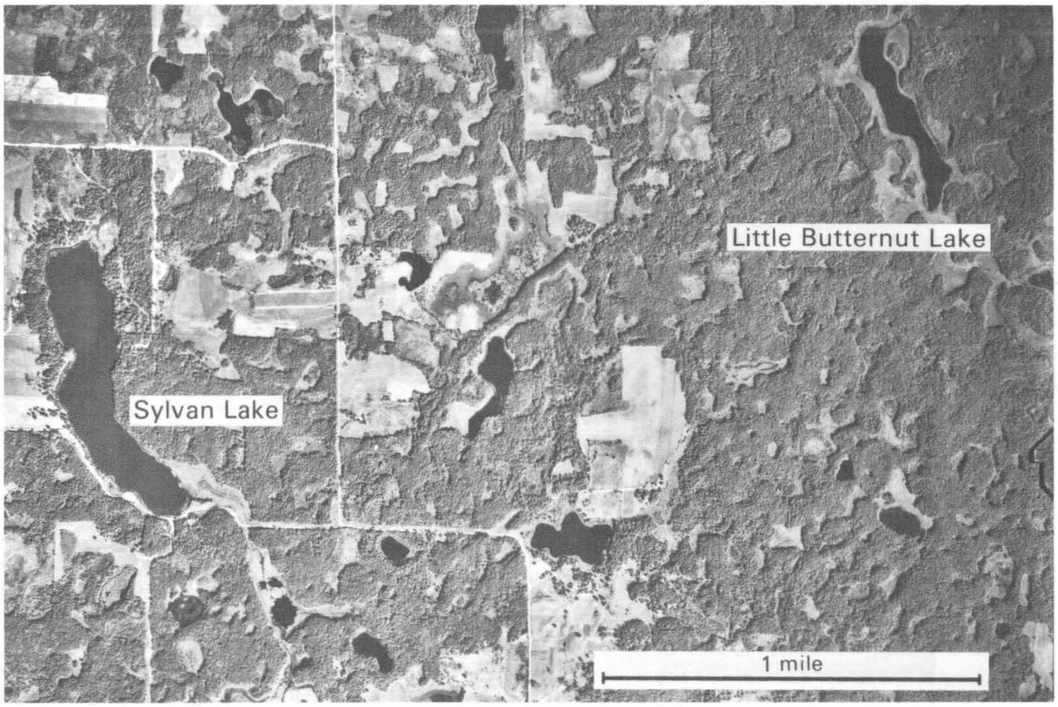


FIGURE 29. Photograph of hummocky topography behind the Late St. Croix ice-margin limit. Part of T. 36 N., R. 13 W., Agricultural Stabilization and Conservation Service, Department of Agriculture photo, October 17, 1961, flight no. BRO 2AA, frame 94.

this region most likely formed in this way because some hummocks are composed of sediment that shows signs of collapse and flowage. However, many hummocks in this area are composed of till that has the characterisitics of till that has not flowed. The till in these hummocks has a strong pebble fabric that is parallel to the regional ice-flow direction (Johnson, 1984). The till in these hummocks may have been deposited by melt out or lodgement. Subsequent collapse only faulted this sediment and did not cause it to flow.

Other interpretations suggest that the hummocks were not formed by collapse. The hummocks may have been formed by patchy deposition of lodgement till at the base of active ice. This would produce a layer of till with a variable thickness. Hummocks would occur where the till was thick, and swales would occur where the till was thin. Alternatively, the hummocks may have been formed by ice that had a variable concentration of debris in the basal ice layers. As ice became stagnant and released debris as melt-out till, hummocks would form where concentrations had been high, and swales would form where concentrations had been low (Johnson, 1984).

Ice-walled-lake plains.--Perhaps the most fascinating landform associated with the Late St. Croix and Late Chippewa Advances is the ice-walled-lake plain (fig. 30). Ice-walled-lake plains are formed by deposition of sediment in a lake surrounded by stagnant ice. With the melting of the ice, the deposit is left as a rimmed, dish-shaped plain. Hummocky topography and ice-block lakes generally surround the ice-walled-lake plains (fig. 30). Where present, the rim is generally 5 to 15 m above the level of the central depression and composed of sand and gravel with silt beds and occasional layers of debris-flow sediment (fig. 31). The center of the plains are flat and underlain by silt and fine sand 6 to 8 m thick. These centers contain fertile soil and are actively cultivated. Drill holes indicate that till lies beneath the lake sediment. Figure 32 shows a cross section through an ice-walled-lake plain.

Several ice-walled-lake plains occur in Barron County. About twenty-five are associated with Late St. Croix deposits, while only three occur amongst the Late Chippewa deposits (map units C4ni, C4oi, C4li, and C3li, plate 1). The community of Turtle Lake is located on the northeast edge of an ice-walled-lake plain approximately 8 km in diameter (fig. 24). Outside of the county, Late Chippewa ice-walled-lake plains occur to the northeast around Birchwood (fig. 24) and to the southeast (Cahow, 1976).

Ice-walled-lake plains may show collapse features indicating that they were formed on stagnant ice (Clayton and Cherry, 1967; Parizek, 1969). None of the plains in Barron County show evidence of collapse within the centers of the plains. This indicates that the lakes penetrated the entire thickness of the ice. Through time, and as flanking ice melted, ice-walled lakes expanded and coalesced with adjacent lakes. Expansion is shown by older rims present toward the centers of some ice-walled-lake plains. As ice melted, these rims were abandoned and left isolated in the center of the lake (fig. 33).

Ice-walled lakes form in stagnant ice and must have formed towards the end of the last period of glacial activity. One ice-walled-lake plain truncates the trace of an ice-margin limit younger than and to the northwest of

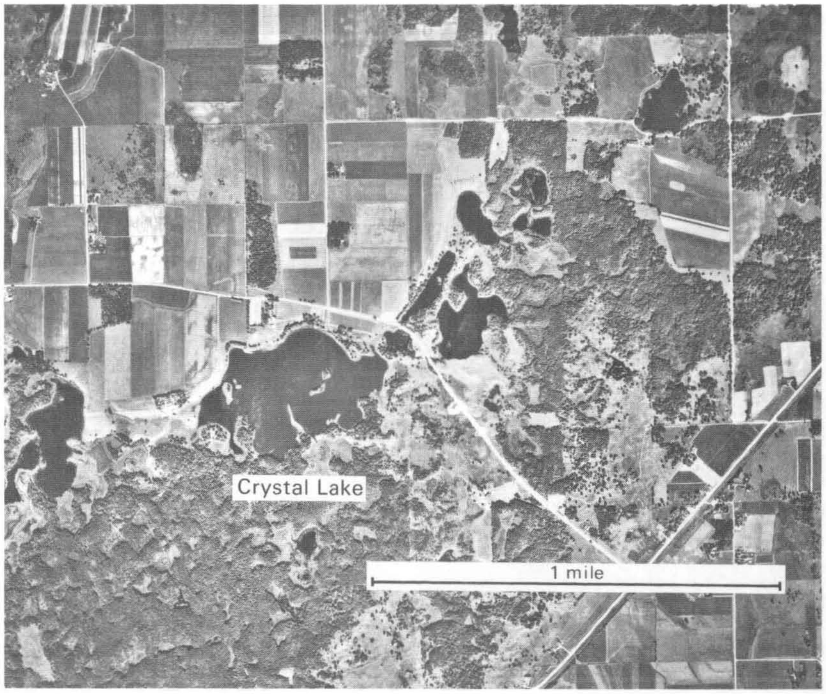


FIGURE 30. Photograph of ice-walled-lake plain behind the Late St. Croix ice-margin limit. Note the contrast between the forested, hummocky topography and the flat, cultivated ice-walled-lake plain in the upper left part of the photograph. This lake plain is north of Turtle Lake in sec. 21 and 28, T. 35 N., R. 14 W., Agricultural Stabilization and Conservation Service, Department of Agriculture photo, October 17, 1961, flight no. BRO 2AA, frame 269.

the Late St. Croix ice-margin limit (fig. 24). The ice-walled lake formed in stagnant ice that was left from both advances.

The distribution and elevation of the ice-walled-lake plains suggests that the glacier had an integrated groundwater system. The elevation of ice-walled-lake-plain centers, which are only a few meters below former lake levels, decreases towards the southwest and towards the ice margin. This surface was graded to the ice-marginal lake near Clayton (see fig. 24), which may have acted as a local control on the groundwater level in the ice.

Other ice-margin positions.--Behind both the Late St. Croix and Late Chippewa ice-margin limits are bands of landforms that indicate several ice-margin positions that occurred shortly after these two advances. These later ice-margin positions are shown by the presence of outwash plains graded to bands of hummocks, ice-marginal ridges, ice-contact faces, and, in one instance, an esker leading into an ice-marginal fan (fig. 24). These ice margins and their associated landforms may represent stillstands of the ice margin during overall retreat or they may represent advances. Wright (1973) suggested that the Superior Lobe surged several times during the latter part of the Wisconsin Glaciation. The various ice-margin positions in Barron County behind the Late St. Croix ice-margin limit may each represent a surge of the Superior Lobe.

Bands of hummocky topography occur behind the Late Chippewa ice-margin limit southeast of Barron County (Cahow, 1976). These may represent ice-margin positions or piles of debris left from debris-rich bands in the Chippewa glacier (Cahow, 1976).

Outwash plains

Stream sediment is found in many areas behind the Late St. Croix and Late Chippewa ice-margin limits. Because much of this stream sediment was deposited on stagnant ice, the outwash plains are pitted (for example, map unit C4sp surrounding Beaverdam Lake, plate 1). Elsewhere, buried ice was of sufficient extent that subsequent collapse of overlying sand and gravel has left little evidence of the original plain surface and the surface is hummocky (for example, map unit C3sh surrounding Red Cedar Lake, plate 1).

By far the greatest extent of stream sediment lies in front of the Late St. Croix and Late Chippewa ice-margin limits. These outwash plains cover a large part of the county (map units C4sp, C3sp, C4sh, C3sh, C5sp, C5su, Csu, plate 1), and upon them are located the communities of Chetek, Cameron, Rice Lake, and part of Barron, Haugen, and Brill. The surface of the plain is generally flat, interrupted only by stream valleys, abandoned channels, terraces, lakes, and ice-block depressions. Many of the lakes occurring in the outwash plain (Rice Lake, the Chetek lakes) and numerous pits are due to the persistence of buried ice left by the Early St. Croix and Early Chippewa Advances that was buried by outwash deposited during the Late St. Croix and Late Chippewa Advances.

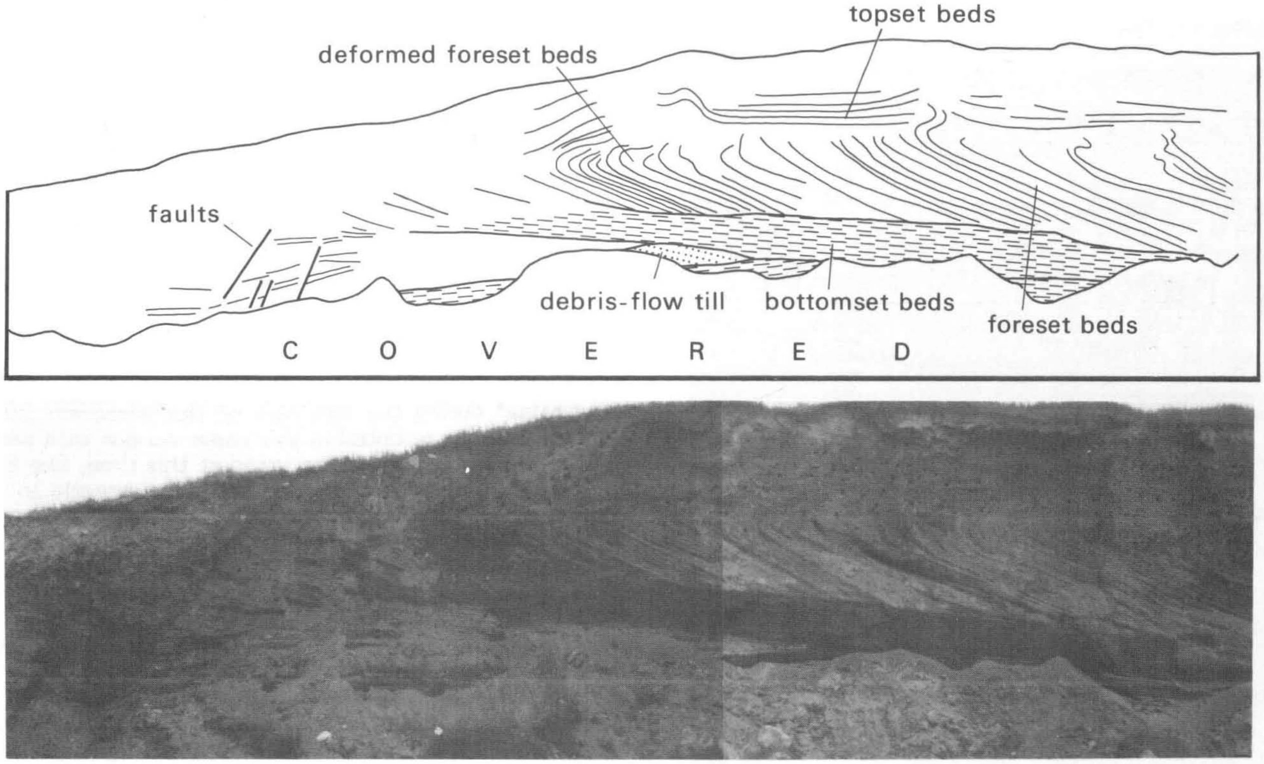


FIGURE 31. Photograph and sketch of a delta making up the rim of the ice-walled-lake plain south of Turtle Lake, Wisconsin. The delta sediment, generally slightly gravelly sand, occurs in topset, foreset, and bottomset beds. Bottomset beds are silty. Normal faults occur at left near the ice-contact face. Deformation flow of topset beds has produced folds whose axes are roughly horizontal and parallel to the strike of foreset beds.

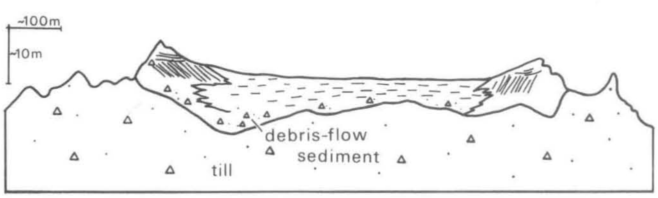


FIGURE 32. Cross section through ice-walled-lake plain. Rims are composed of stream, wave, grain-flow, and debris-flow sediment. Centers are composed of turbidity-current and fall-out sediment. Lake overlies supraglacial debris-flow sediment that was deposited as lake formed. Sylvan Lake till underlies rim and center sediment.

The amount of sand and gravel deposited is not known but great thicknesses, as much as 84 m, are known to occur beneath the plains surrounding Rice Lake, Cameron, and Chetek. In places, the vertical sequence of sand and gravel is interrupted by a layer of till indicating that only a part of the sand and gravel was deposited during the Late St. Croix and Late Chippewa Advances. Units of sand and gravel below till layers are older and were deposited during earlier glacial advances.

The surface slope of the outwash plain (marked by arrows, plate 1) slopes away from the Late St. Croix and Late Chippewa ice-margin positions. Near the former ice-margin position, it is clear that much of the sediment

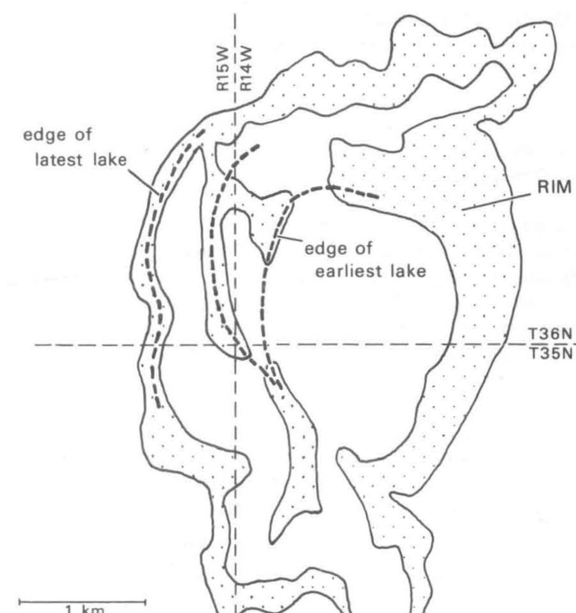


FIGURE 33. Ice-walled-lake plain with several rims within the center of the plain. These rims indicate that the lake grew laterally during its existence. Relative age of the rims is indicated.

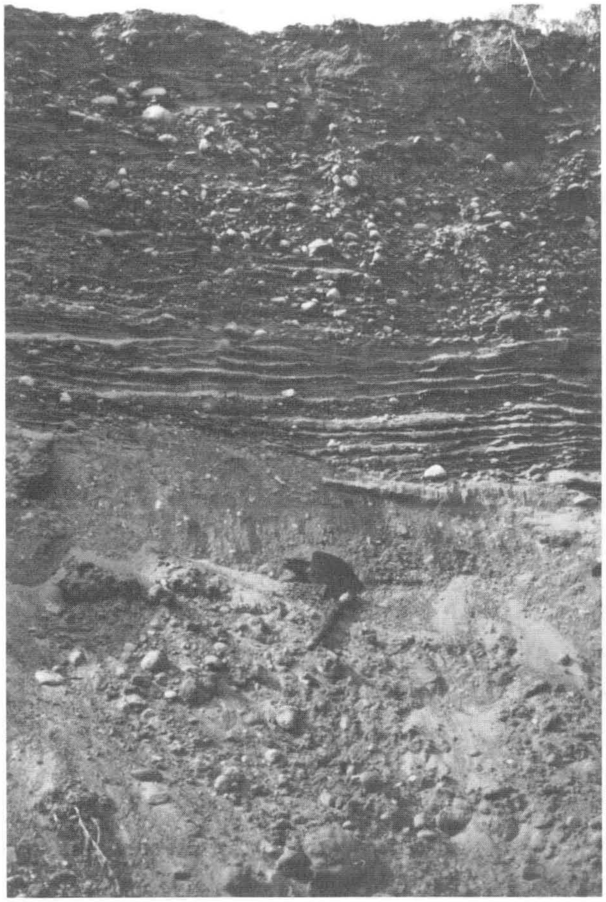


FIGURE 34. Photograph of stream sediment of the Mikana Member, north of Mikana, Wisconsin.

was carried by melt water emanating from tunnel channels along the ice margin.

Where the surface of the outwash plain is clearly graded to the Late St. Croix ice margin, it is mapped as C4sp (plate 1). Similarly, Late Chippewa stream sediment is mapped as C3sp (plate 1). In areas where the stream sediment comes from both lobes and is mixed, it is mapped as stream sediment of the Chetek Member (map unit C5sp or C5su, plate 1).

Exposures in numerous gravel pits reveal trough and planar cross bedding, horizontal bedding, and imbricated gravel. Vertical variation in grain-size is great (fig. 34). The stream sediment was probably deposited in a braided-stream environment.

Date of the Late St. Croix and Late Chippewa Advances

The date of the Late St. Croix and Late Chippewa Advances is not well known. No radiocarbon dates exist for deposits in Barron County. The Sylvan Lake and Mikana Members were deposited at about the same time as sediment contained in a broad band of moraines that occur across Wisconsin from Minnesota to Illinois (fig. 10). Wright and others (1973), based on dated lake sediment on St. Croix till in Minnesota, suggested that the Late St. Croix Advance occurred before 16,000 B.P. Clayton and Moran (1982) caution against using dates from lake sediment because they may be contaminated. They estimate this advance to have occurred around 15,000 B.P.

Character of the Superior Lobe during Early and Late St. Croix Advances

Mathieson (1940) concluded that the margin of the Superior Lobe exceeded the position of the "St. Croix Moraine" during the last part of the Wisconsin Glaciation. The findings presented in this paper concur with Mathieson. The two advances that occurred at this time, The Early and Late St. Croix Advances, do not differ greatly in age, yet the landforms they left are quite distinct from each other. This relationship is similar to that described adjacent to the "St. Croix Moraine" in Minnesota (Leverett, 1932; Schneider, 1961; Savina and others, 1979; Hobbs, 1983).

The difference in the surface topography may be attributed to extensive erosion by streams and hillslope processes following the Early St. Croix Advance and prior to the Late St. Croix Advance. Erosion did occur as indicated by a well-developed stream network. The presence of permafrost prior to and during the Late St. Croix Advance may have accelerated mass wasting of hillslopes.

Alternatively, the difference in landforms left by each advance may be attributed to a change in the depositional style of the ice. Early St. Croix deposits consist primarily of homogeneous till, whereas Late St. Croix deposits include till, stream sediment, and lake sediment. The Early St. Croix deposits are indicative of active ice, whereas the Late St. Croix deposits are indicative of stagnant ice. This suggests that the difference in the landforms produced by these two advances can be attributed more to a change in the character of the depositional style of the ice rather than to a great difference in age.

Wright (1973) suggested that the Superior Lobe may have surged several times during the last part of the Wisconsin Glaciation. Perhaps the Superior Lobe advanced at normal rates during the Early St. Croix Advance, deposited thick till from active ice, and left a rather subdued topography. The Superior Lobe later advanced at surging rates during the Late St. Croix Advance and left large amounts of stagnant ice that, upon melting, formed a hummocky landscape.

A period of permafrost, ice melting, lake formation, and loess deposition

Following the final advance of the Superior and Chippewa Lobes and deposition of sediment of the Sylvan Lake and Mikana Members, a number of events occurred that influenced the landscape of the county.

Ice-wedge casts in sediment of the Chetek Member (equivalent in age to the Sylvan Lake and Mikana Members) (fig. 35) at two locations in Barron County (fig. 20) indicate that permafrost was present in the county following the St.

Croix and Chippewa Advances. This period of permafrost may have been a continuation of the period of permafrost that occurred during or prior to the Early St. Croix Advance, or it may have been separated in time from the earlier permafrost period by a time of no permafrost. The ice-wedge cast in figure 35 is developed in stream sediment on the main surface of the outwash plain in sec. 28, T. 34 N., R. 11 W.

The duration of the permafrost formed after the Late St. Croix and Late Chippewa Advances is suggested by a site at sec. 32, T. 35 N., R. 11 W. Here, ice-wedge casts are found in a terrace of the Red Cedar River cut about 3 m below the main outwash surface. Therefore, permafrost occurred sometime during or after outwash deposition and continued until after the Red Cedar River had established a course and cut into the outwash plain. Permafrost most likely kept buried ice from melting prior to this time. Most of the pits and lakes present on the outwash plain did not form until this ice melted and probably did not form until the end of the Pleistocene.

Ice melting is known to have occurred late because of the relationship of the collapse features and the modern drainage system. The pattern formed by pits and lakes suggests that ice remaining after the Early St. Croix and Early Chippewa Advances was concentrated in pre-existing channels cut in an older outwash surface. Apparently, stagnant ice of these two earlier advances was buried quickly in topographic lows allowing more ice to remain in channels than on intervening interfluves, which only show minor pitting. This is shown by the branching pattern formed by Rice Lake, a marshy tract east of Rice Lake, and Dietz Lakes (fig. 36). Other lakes in the county that have similar origins are Poskin, Vermillion, and Upper and Lower Turtle Lakes. The pre-existing drainage system (fig. 36), revealed by the pattern of collapse pits, is crossed by the modern Red Cedar River channel. The pattern of these two drainage systems superimposed on each other is striking. This pattern indicates that buried ice persisted not only until after the Sylvan Lake and Mikana stream sediment was deposited, but also after this surface was cut and the modern drainage system developed. By the time the ice

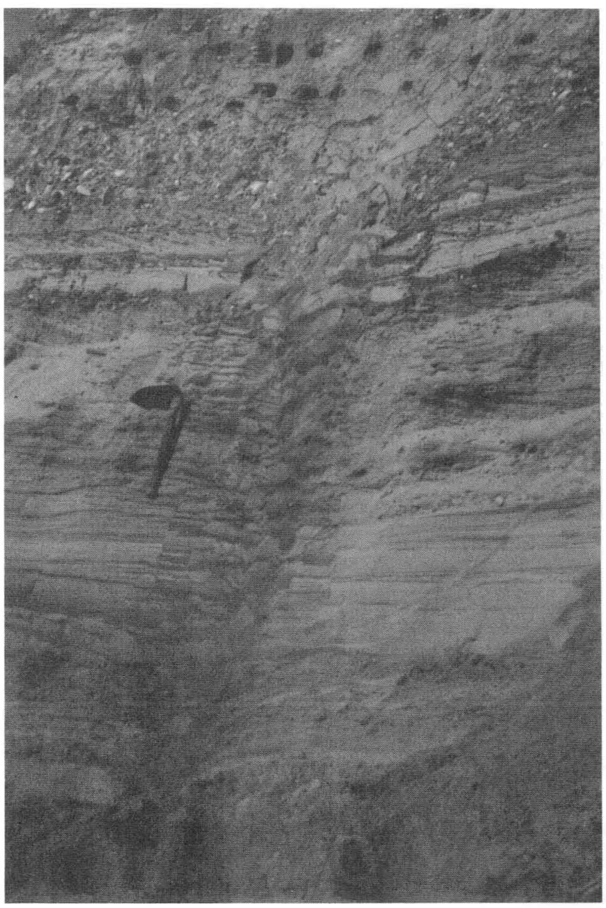


FIGURE 35. Photograph of ice-wedge cast in Chetek stream sediment located in landfill, sec. 28, T. 34 N., R. 11 W.

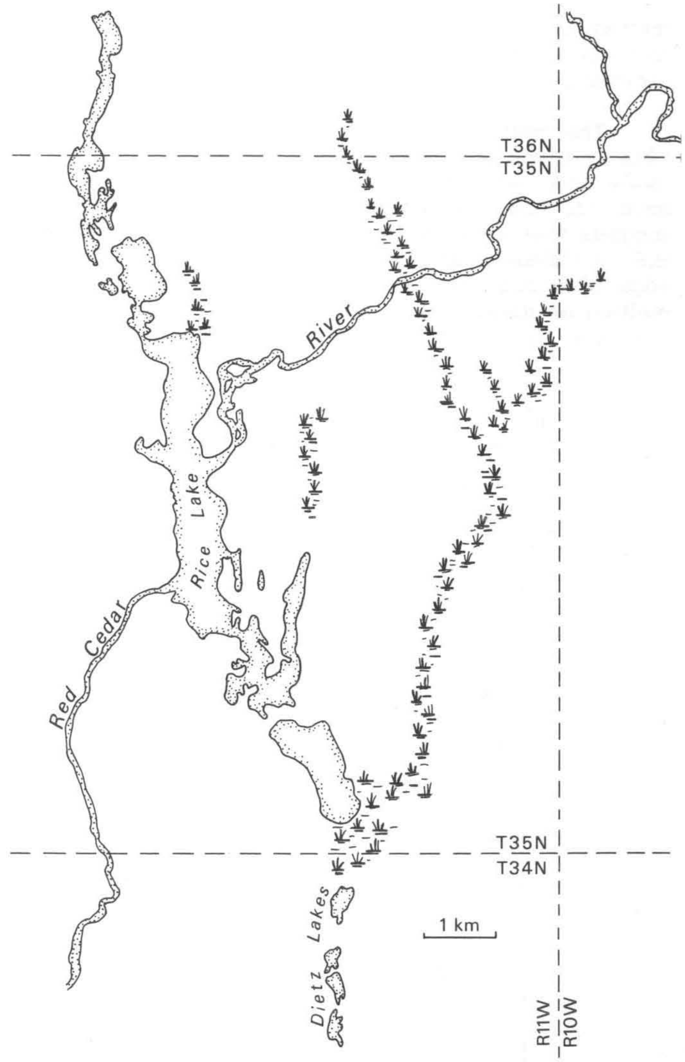


FIGURE 36. Rivers, lakes, and marshes on the Late St. Croix and Late Chippewa outwash plain. The lakes and marshes are in collapse pits that outline the pre-existing drainage system. Collapse did not occur until after the establishment of the modern course of the Red Cedar River.

melted, the modern drainage network had been established and was not diverted when the ice collapsed the surrounding sediment.

The melting of buried ice in front of and behind the Late St. Croix and Late Chippewa ice-margin positions most likely occurred simultaneously. Though no absolute dates exist for the melting of buried ice, indirect evidence suggests that some melting had taken place by about 10,500 B.P. A Paleo-Indian site in Chippewa County occurs on the edge of a bog that, at one time, was a lake formed by melting of stagnant ice. The oldest artifacts found at this site are thought to be 10,500 years old (Jeff Behm, University of Wisconsin, Department of Anthropology, unpublished report). Some of the artifacts found at this site, especially the older ones, relate to open water use (Behm, same as above). The ice at this site must have melted by this time.

A blanket of loess (wind-blown silt) covers the county and is generally around 0.5 to 1.0 m thick. In places on the outwash plain and on steep slopes, loess was either never deposited or has been subsequently eroded. The greatest thickness of loess is generally more than a meter, for example, north of Almena, but in places, local ponding has concentrated the silt to greater thicknesses.

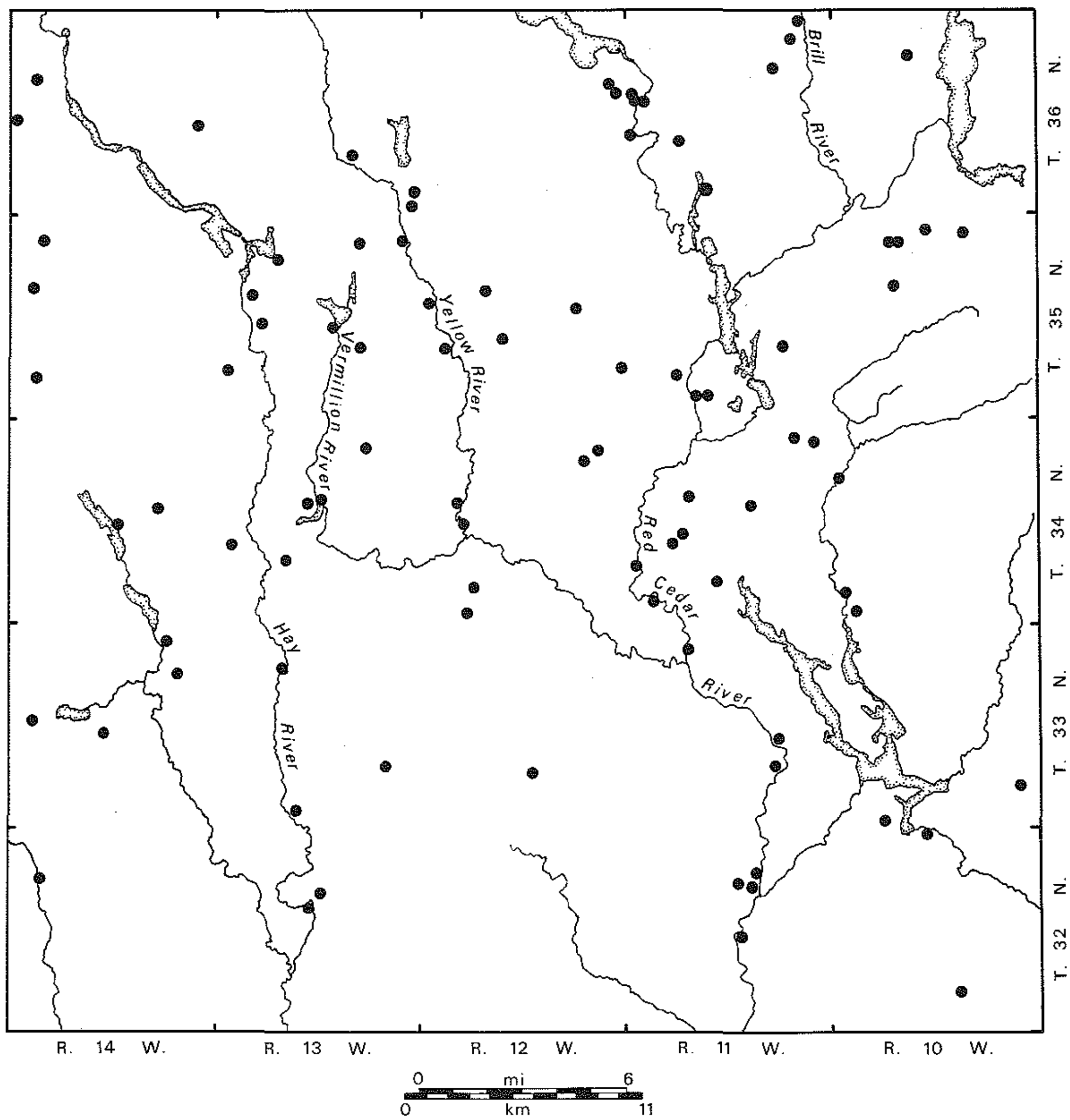


FIGURE 37. Location of gravel pits shown on U.S. Geological Survey 7.5-minute quadrangles in Barron County.

ECONOMIC GEOLOGY OF GLACIAL DEPOSITS

Gravel

Stream sediment is widespread in Barron County (map units Msu, Csu, C5su, Clsu, Csp, C5sp, C4sp, C3sp, C2sp, Clsp, C4sh, C3sh, Css, and Rlss, and parts of map units C4uh and C3uh, plate 1). Much of this sediment is composed of slightly gravelly to gravelly sand (see section on Pleistocene deposits) and screening is required to extract the gravel. Gravel pits in the county, shown in figure 37, are primarily in the Chetek, Sylvan Lake, and Mikana Members of the Copper Falls Formation.

Close to the Late St. Croix and Late Chippewa ice-margin limits, the average grain size of the stream sediment in the outwash plains is larger and gravelly sand is more dominant. Gravel pits near Haugen (map unit C4sp, plate 1) show the change in grain size away from the ice-margin limit. One of these pits occurs at the late St. Croix ice-margin limit and several beds of till are exposed. Farther away from the ice-margin limit (a few kilometers), the stream sediment in the outwash plains is dominantly slightly gravelly sand. Here the sediment contains less than 10 percent gravel.

A high water table occurs in places on the outwash plains, which increases the cost of mining the gravel. The water table is only 1.5 m below the surface in many parts of the plains, but averages 8 m (Bell and Hindall, 1975). The thickness of the sand and gravel in the outwash plains is typically 15 m but is as much as 85 m around Rice Lake and Chetek and as a result, most of the sand and gravel is below the water table. Because of its great permeability, the outwash plains have the fastest groundwater recharge rate of any surface in the county. Annual recharge to the sand and gravel of the outwash plains is about 0.2 m (Bell and Hindall, 1975). For this reason, groundwater on the outwash plains is easily contaminated.

Several sand and gravel units of the Copper Falls Formation stratigraphically underlie the Sylvan Lake, Mikana, and Chetek Members. These units have not been assigned to any member and are included in the Copper Falls Formation undifferentiated (for example, map unit Css, plate 1). Because this sand and gravel crops out in the uplands above the outwash plain, the water table is generally lower. Stream sediment in these places is slightly gravelly sand to gravelly sand and screening is required to remove the sand. Gravel pits east of Rice Lake (sec. 2, T. 34 N., R. 11 W.) are in this unit. This unit is commonly covered by till, but in places the till has been removed by erosion.

Clay

Clay suitable for lining waste pits is not abundant in Barron County. Two possible sources of clay exist. These sources have not been analyzed in terms of their engineering properties and must be regarded as only potential sources.

The most clay-rich sediment in the county is the till of the Pierce Formation. This till contains about 35 percent sand, 43 percent silt, and 22 percent clay in the less-than-2-mm fraction (see table 1 and the section on the Pierce Formation in the Pleistocene deposits section for a complete description). The till is calcareous below a leached and oxidized zone that is 2 to 3 m thick. The clay minerals include a large proportion (70 percent) of expandable clay and smaller amounts of kaolinite and illite.

The Pierce till generally occurs several meters below the surface (fig. 7) although a few surface exposures occur in the southwestern part of the county. Pierce till is exposed in the Vance Creek Township dump located in sec. 17, T. 32 N., R. 14 W. A drill hole at this site shows that the Pierce till is more than 10 m thick. The extent of the surface exposure is not known. At this site, the till has about 24 percent clay and a P-200 content (less-than-0.074-mm fraction) of over 61 percent.

Another possible source of fine-grained sediment for use in lining waste-pits is the silty sediment beneath the centers of ice-walled-lake plains (map unit Croi, plate 1). Drill holes in the centers of two of the larger ice-walled-lake plains show 4 to 5 m of silty sediment at the surface. This lake sediment is calcareous below 3 m. Debris-flow sediment and till occur below the lake sediment. A size analysis of near-surface sediment shows that it contains about 15 percent sand (0.05 to 2.0 mm), 67 percent silt (0.002 to 0.05 mm), and 17 percent clay (less than 0.002 mm) (Robinson and others, 1958). The P-200 content is greater than 84 percent. The ice-walled-lake plains and their fertile central parts are used largely for agriculture at present.

REFERENCES

Attig, J. W., Clayton, Lee, and Mickelson, D. M., in press, Pleistocene stratigraphic units of Wisconsin, additions through 1985: Wisconsin Geological and Natural History Survey Information Circular.

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

Baker, R. W., and Lively, R. S., 1984, Pleistocene history of west-central Wisconsin: Wisconsin Geological and Natural History Survey Field Trip Guide Book 11, 76 p.

Bell, E. A., and Hindall, S. M., 1975, The availability of ground water for irrigation in the Rice Lake-Eau Claire area, Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 31, 65 p.

Berg, R. R., 1959, Franconia formation of Minnesota and Wisconsin: Geological Society of America Bulletin, v. 65, no. 9, p. 857-881.

Bowen, D. Q., 1978, Quaternary geology--a stratigraphic framework for multidisciplinary work: New York, Pergamon Press, 221 p.

Brown, B. A., and Greenberg, J. K., 1983,
Stratigraphic and depositional framework of the Baraboo Interval in Wisconsin: North-Central Section, Geological Society of America, 17th Annual Meeting, Madison, Wisconsin, 1983, Abstracts with Programs, v. 15, no. 4, p. 209.

Cahow, A. C., 1976,
Glacial geomorphology of the southwest segment of the Chippewa lobe moraine complex, Wisconsin [Ph.D. dissertation]: East Lansing, Michigan, Michigan State University, 217 p.

Champion, D. E., Dalrymple, G. B., and Kuntz, M. A., 1981,
Radiometric and paleomagnetic evidence for the Emperor reversed polarity event at 0.45 + 0.05 m.y. in basalt lava flows from the eastern Snake River Plain, Idaho: Geophysical Research Letters, v. 8, no. 10, p. 1055-1058.

Clayton, Lee, 1967,
Stagnant-glacier features of the Missouri Coteau in North Dakota, in Clayton, Lee, and Freers, T. F., eds., Glacial geology of the Missouri Coteau and adjacent areas: North Dakota Geological Survey Miscellaneous Series 30, p. 25-46.

Clayton, Lee, and Cherry, J. A., 1967,
Pleistocene superglacial and ice-walled lakes of west-central America, in Clayton, Lee, and Freers, T. F., eds., Glacial geology of the Missouri Coteau and adjacent areas: North Dakota Geological Survey Miscellaneous Series 30, p. 47-52.

Clayton, Lee, and Moran, S. R., 1982,
Chronology of late Wisconsinan glaciation in middle North America: Quaternary Science Reviews, v. 1, no. 1, p. 55-82.

Dott, R. H., Jr., and Dalziel, I. W. D., 1972,
Age and correlation of the Precambrian Baraboo Quartzite of Wisconsin: Journal of Geology, v. 80, no. 5, p. 552-568.

Geiger, C. A., Guidotti, C. V., and Petro, W. L., 1983,
Metamorphism of the Waterloo Quartzite and tectonic implications: North-Central Section, Geological Society of America, 17th Annual Meeting, Madison, Wisconsin, 1983, Abstracts with Programs, v. 15, no. 4, p. 209.

Hallberg, G. R., 1980,
Pleistocene stratigraphy in east-central Iowa: Iowa Geological Survey Technical Information Series 10, 168 p.

Hobbs, H. C., 1983,
Structure and geomorphology of the St. Croix moraine, Swanville area, Minnesota: North-Central Section, Geological Society of America, 17th Annual Meeting, Madison, Wisconsin, 1983, Abstracts with Programs, v. 15, no. 4, p. 251.

Hotchkiss, W. O., 1915,
Mineral land classification: Wisconsin Geological and Natural History Survey Bulletin 44, 378 p.

Johnson, M. D., 1984,
Glacial geology of Barron County, Wisconsin [Ph.D. dissertation]: Madison, Wisconsin, University of Wisconsin--Madison, 318 p.

Kemmis, T. K., Hallberg, G. R., and Lutenegger, A. J., 1981,
Depositional environments of glacial sediments and landforms of the Des Moines Lobe: Iowa Geological Survey Guidebook 6, 132 p.

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

Mathieson, J. T., 1940,
The Pleistocene of part of northwestern Wisconsin: Wisconsin Academy of Sciences, Arts, and Letters, v. 32, p. 251-272.

Matsch, C. L., Rutford, R. H., and Tipton, M. J., 1972,
Quaternary geology of northeastern South Dakota and southwestern Minnesota, in Field trip guide book for geomorphology and Quaternary stratigraphy of western Minnesota and eastern South Dakota: Geological Society of America, 6th Annual Meeting, Minneapolis, Minnesota, 1972, p. 1-34.

Mickelson, D. M., and Clayton, Lee, 1981,
Subglacial conditions and processes during middle Woodfordian time in Wisconsin: North-Central Section, Geological Society of America, 15th Annual Meeting, Ames, Iowa, 1981, Abstracts with Programs, v. 13, no. 6, p. 310.

Mickelson, D. M., Clayton, Lee, Baker, R. W., Mode, W. N., and Schneider, A. F., 1984,
Pleistocene stratigraphic units of Wisconsin: Wisconsin Geological and Natural History Survey Miscellaneous Paper 84-1, 57 p.

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

Mudrey, M. G., Jr., Brown, B. A., and Greenberg, J. K., 1982,
Bedrock geologic map of Wisconsin: Wisconsin Geological and Natural History Survey, scale 1:1,000,000.

Ostrom, M. E., 1970,
Sedimentation cycles in the Lower Paleozoic rocks of western Wisconsin, in Field trip guidebook for Cambrian-Ordovician geology of western Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 11, p. 10-34.

Parizek, R. R., 1969,
Glacial ice-contact rings and ridges, in United States contributions to Quaternary research: Geological Society of America Special Paper 123, p. 49-102.

Rampino, M. R., 1981,
Revised age estimates of Brunhes paleomagnetic events: support for a link between geomagnetism and eccentricity: Geophysical Research Letters, v. 8, no. 10, p. 1047-1050.

Robinson, G. H., Vessel, A. J., Erickson, R. A., and Hole, F. D., 1958,
Soil survey of Barron County, Wisconsin: U.S. Department of Agriculture, Series 1948, no. 1, 103 p.

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

Savina, Mary, Jacobson, Robert, and Rodgers, David, 1979,
Outwash deposits of central Dakota County, Minnesota: report to the Minnesota Geological Survey, 81 p.

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

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

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

Strong, Moses, 1880,
The geology of the upper St. Croix district: [Wisconsin Geological Survey], Geology of Wisconsin, v. 3, p. 363-428.

Wright, H. E., Jr., 1973,
Tunnel valleys, glacial surges, and subglacial hydrology, in Black, R. F., Goldthwait, R. P., and Willman, H. B., eds., The Wisconsin Stage: Geological Society of America Memoir 136, p. 251-276.

Wright, H. E., Jr., Matsch, C. L., and Cushing, E. J., 1973,
Superior and Des Moines Lobes, in Black, R. F., Goldthwait, R. P., and Willman, H. B., eds., The Wisconsin Stage: Geological Society of America Memoir 136, p. 153-185.

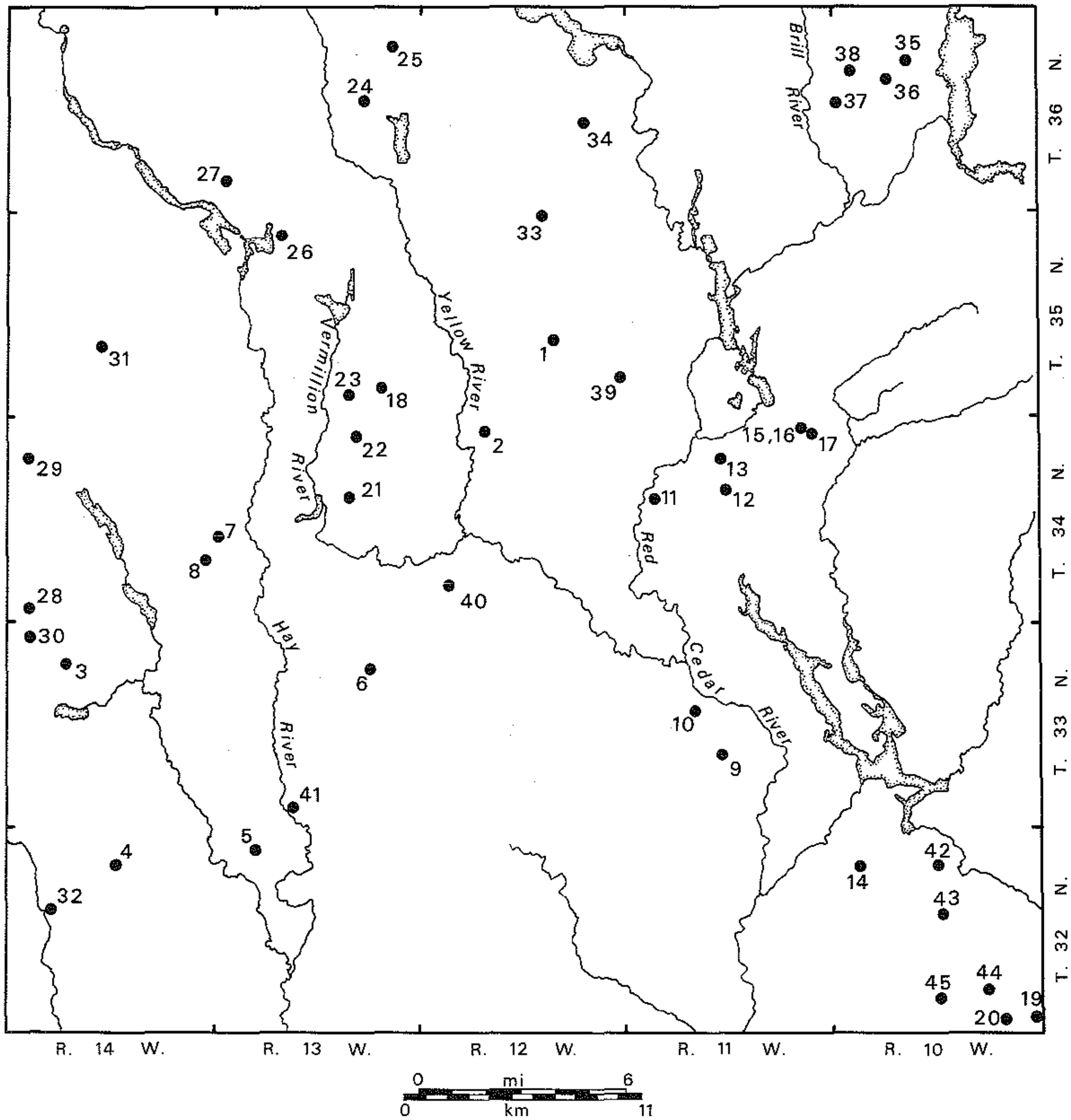


FIGURE A1. Location of drill holes in Barron County. Holes were drilled during the summer of 1982 using a truck-mounted auger.

APPENDIX: DRILL-HOLE LOGS

A truck-mounted auger aided field mapping and was a necessity for investigating the subsurface extent of many of the units described in this report. Forty-four drill holes (fig. A1) ranging in depth from 5 to 40 m were drilled during the summer of 1982.

Drill hole 1
Location: SE1/4NE1/4SE1/4 sec. 22, T. 35 N., R. 12 W.
Elevation: 1240 feet
0 - 3 ft silt
3 - 9 ft clean, brown sand
9 - 25 ft red, sandy loam, till (Poskin till)
25 ft rejected by tight sediment

Drill hole 2
Location: SE1/4NE1/4NE1/4 sec. 5, T. 34 N., R. 12 W.
Elevation: 1160 feet
0 - 4 ft silt with some sand
4 - 70 ft slightly gravelly sand
70 - 78 ft sandstone
78 ft end of drill hole

Drill hole 3
Location: NE1/4NE1/4NE1/4 sec. 8, T. 33 N., R. 14 W.
Elevation: 1220 feet
0 - 2 ft silt
2 - 8 ft slightly gravelly sand
8 - 55 ft red, sandy loam till (Poskin till), non-calcareous
55 - 72 ft gray, loam till (Pierce till), calcareous
72 ft end of drill hole

Drill hole 4
Location: SW1/4SW1/4NW1/4 sec. 10, T. 32 N., R. 14 W.
Elevation: 1283 feet
0 - 28 ft red, sandy loam till (Sylvan Lake till)
28 ft rejected by tight sediment

Drill hole 5
Location: SW1/4NE1/4SW sec. 5, T. 32 N., R. 13 W.
Elevation: 1250 feet
0 - 2 ft silt
2 - 15 ft red, sandy loam till (Poskin till), gravelly zone at 9 to 10 feet
15 ft rejected by tight sediment

Drill hole 6
Location: NE1/4NE1/4SW1/4 sec. 11, T. 33 N., R. 13 W.
Elevation: 1240 feet
0 - 4 ft silt
4 - 24 ft red, sandy loam till (Poskin till)
24 - 25 ft sandstone
25 ft end of drill hole

Drill hole 7
Location: SW1/4NW1/4SW1/4 sec. 19, T. 34 N., R. 13 W.
Elevation: 1210 feet
0 - 5 ft silt
5 - 14 ft red, sandy loam till (Poskin till), non-calcareous
14 - 16 ft slightly gravelly sand
16 - 29 ft red, sandy loam till (Poskin till), slightly calcareous
29 - 38 ft slightly gravelly sand
38 - 48 ft red, sandy loam till (River Falls till), non-calcareous
48 - 53 ft sandstone
53 ft end of drill hole

Drill hole 8
Location: NE1/4NE1/4NE1/4 sec. 25, T. 34 N., R. 14 W.
Elevation: 1210 feet
0 - 6 ft silt
6 - 22 ft red, sandy loam till (Poskin till), slightly calcareous
22 - 50 ft tan, orange, and yellow, slightly gravelly sand
50 - 78 ft red, sandy loam till (River Falls till), calcareous, browner and more calcareous 70 to 78 feet
78 - 103 ft gray, loam till (Pierce till), calcareous
103 ft end of drill hole

Drill hole 9
Location: SE1/4SE1/4SE1/4 sec. 21, T. 33 N., R. 11 W.
Elevation: 1110 feet
0 - 2 ft artificial fill
2 - 23 ft brown, sandy clay loam, non-calcareous, colluvium?
23 ft end of drill hole

Drill hole 10
Location: NW1/4SW1/4SW1/4 sec. 16, T. 33 N., R. 11 W.
Elevation: 1110 feet
0 - 2 ft silt
2 - 18 ft interbedded colluvium (?) and sand, colluvium is brown clay loam
18 - 40 ft clean, brown to tan, sand
40 ft end of drill hole

Drill hole 11
Location: SE1/4NE1/4NE1/4 sec. 18, T. 34 N., R. 11 W.
Elevation: 1110 feet
0 - 30 ft slightly gravelly sand
30 - 40 ft red, sandy loam till (Poskin or Pokegama Creek till)
40 - 58 ft slightly gravelly sand
58 ft end of drill hole

Drill hole 12
Location: NW1/4NE1/4NE1/4 sec. 16, T. 34 N., R. 11 W.
Elevation: 1240 feet
0 - 2 ft silt
2 - 16 ft red, sandy loam till (Pokegama Creek till), non-calcareous
16 - 55 ft yellow, slightly gravelly sand
55 - 60 ft red, sandy loam till (?), non-calcareous
60 - 74 ft slightly gravelly sand

Drill hole 13
Location: SW1/4NW1/4NE1/4 sec. 9, T. 34 N., R. 11 W.
Elevation: 1230 feet
0 - 3 ft silt
3 - 9 ft red, sandy loam till (Pokegama Creek till), non-calcareous
9 - 55 ft brown, orange, and tan sand
55 - 56 ft red, sandy loam till (?), non-calcareous
56 - 95 ft sand
95 - 103 ft sandstone
103 ft end of drill hole

Drill hole 14
Location: NE1/4SE1/4NE1/4 sec. 7, T. 32 N., R. 10 W.
Elevation: 1105 feet
0 - 28 ft sand
28 ft end of drill hole

Drill hole 15
Location: NW1/4SW1/4NW1/4 sec. 1, T. 34 N., R. 11 W.
Elevation: 1180 feet
0 - 28 ft gravelly sand
28 ft rejected by gravel

Drill hole 16
Location: NW1/4SW1/4NW1/4 sec. 1, T. 34 N., R. 11 W.
Elevation: 1180 feet
0 - 28 ft gravelly sand
28 ft rejected by gravel

Drill hole 17
Location: NW1/4NE1/4SW1/4 sec. 1, T. 34 N., R. 11 W.
Elevation: 1170
0 - 20 ft gravelly sand
20 ft rejected by gravel

Drill hole 18
Location: NW1/4NW1/4NW1/4 sec. 36, T. 35 N., R. 13 W.
Elevation: 1260 feet
0 - 3 ft organic-rich sediment
3 - 9 ft gray silt
9 - 36 ft slightly gravelly sand
36 - 43 ft red, sandy loam till (River Falls till), non-calcareous
43 ft end of drill hole

Drill hole 19
Location: SE1/4NW1/4SE1/4 sec. 36, T. 32 N., R. 10 W.
Elevation: 1120 feet
0 - 10 ft brown, sandy clay loam, colluvium (?), non-calcareous
10 ft rejected by gravel

Drill hole 20
Location: SE1/4NE1/4SW1/4 sec. 36, T. 32 N., R. 10 W.
Elevation: 1120 feet
0 - 15 ft brown, sandy clay loam, colluvium (?), non-calcareous
15 - 35 ft sand with some silt and clay
35 - 36 ft sandstone
36 ft end of drill hole

Drill hole 21
Location: SW1/4SW1/4NW1/4 sec. 14, T. 34 N., R. 13 W.
Elevation: 1270 feet
0 - 2 ft silt
2 - 4 ft slightly gravelly sand
4 - 30 ft red, sandy loam till (Poskin till), non-calcareous
30 ft rejected by tight sediment

Drill hole 22
Location: SE1/4NE1/4SW1/4 sec. 2, T. 34 N., R. 13 W.
Elevation: 1240 feet
0 - 125 ft tan sand, grayer from 75 feet to bottom
125 ft end of drill hole

Drill hole 23
Location: NW1/4SW1/4NW1/4 sec. 35, T. 35 N., R. 13 W.
Elevation: 1290 feet
0 - 20 ft red, sandy loam till (Poskin till), non-calcareous
20 - 83 ft sand
83 - 106 ft red, sandy loam till (River Falls till) interbedded with sand
106 ft end of drill hole

Drill hole 24
Location: SE1/4SW1/4NW1/4 sec. 14, T. 36 N., R. 13 W.
Elevation: 1270 feet
0 - 16 ft red, sandy loam till (Sylvan Lake till), non-calcareous
16 - 38 ft red loamy sand, non-calcareous, contains thin lenses of sand and gravelly sand
38 ft end of drill hole

Drill hole 25
Location: SW1/4SW1/4SW1/4 sec. 1, T. 36 N., R. 13 W.
Elevation: 1250 feet
0 - 74 ft red, sandy loam till (Sylvan Lake till), calcareous below 8 feet
74 - 88 ft gray sand
88 ft end of drill hole

Drill hole 26
Location: NW1/4SE1/4NE1/4 sec. 5, T. 35 N., R. 13 W.
Elevation: 1250 feet
0 - 60 ft gravelly sand
60 - 65 ft red, sandy loam till (Poskin till), non-calcareous
65 - 77 ft sand with layers of red, sandy loam till
77 - 78 ft sandstone or gravel
78 ft rejected by sandstone or gravel

Drill hole 27
Location: SW1/4NW1/4SW1/4 sec. 30, T. 36 N., R. 13 W.
Elevation: 1280 feet
0 - 15 ft red, sandy loam till (Sylvan Lake till), non-calcareous
15 - 58 ft yellow and gray sand
58 ft end of drill hole

Drill hole 28
Location: SW1/4NW1/4SE1/4 sec. 31, T. 34 N., R. 14 W.
Elevation: 1250 feet
0 - 16 ft laminated silt, calcareous below 11 feet, perched water zone from 8 to 11 feet
16 - 24 ft interbedded silt and sand with occasional pebbles
24 - 29 ft brown, pebbly, silt loam with sand lenses
29 - 37 ft red, sandy loam till (Sylvan Lake till), calcareous
37 ft end of drill hole

Drill hole 29
Location: SW1/4SW1/4NE1/4 sec. 7, T. 34 N., R. 14 W.
Elevation: 1250 feet
0 - 8 ft gravelly sand
8 - 12 ft red, sandy loam till (Sylvan Lake till), non-calcareous
12 - 62 ft slightly gravelly sand
62 - 84 ft yellow clay loam interbedded with sand (associated with Pierce till?), non-calcareous
84 ft end of drill hole

Drill hole 30
Location: SW1/4NW1/4SE1/4 sec. 6, T. 33 N., R. 14 W.
Elevation: 1250 feet
0 - 16 ft slightly gravelly sand
16 - 20 ft red, sandy loam till (Sylvan Lake till), non-calcareous
20 ft end of drill hole

Drill hole 31
Location: NW1/4NE1/4SE1/4 sec. 21, T. 35 N., R. 14 W.
Elevation: 1278 feet
0 - 12 ft interbedded silt and sand, non-calcareous
12 - 24 ft sand with a few pebbles with depth
24 - 48 ft red, sandy loam till (Sylvan Lake till), non-calcareous
48 ft end of drill hole

Drill hole 32
Location: NW1/4NE1/4SW1/4 sec. 17, T. 32 N., R. 14 W.
Elevation: 1220 feet
0 - 7 ft artificial fill and loess
7 - 38 ft gray loam till (Pierce till), yellow (oxidized) and non-calcareous from 7 to 11 feet, gray (unoxidized) and calcareous to 38 feet
38 ft end of drill hole

Drill hole 33
Location: SW1/4SW1/4SE1/4 sec. 34, T. 36 N., R. 12 W.
Elevation: 1400 feet
0 - 2 ft silt
2 - 4 ft sand
4 - 15 ft red, sandy loam till (Mikana till), non-calcareous
15 ft end of drill hole

Drill hole 34
Location: NE1/4NW1/4NE1/4 sec. 23, T. 36 N., R. 12 W.
Elevation: 1225 feet
0 - 10 ft slightly gravelly sand
10 - 60 ft tan sand
60 - 103 ft gray sand with some pebbles
103 ft end of drill hole

Drill hole 35
Location: SW1/4NW1/4NW1/4 sec. 9, T. 36 N., R. 10 W.
Elevation: 1230 feet
0 - 3 ft artificial fill
3 - 8 ft red, sandy loam till (Mikana till), non-calcareous
8 - 33 ft sand
33 ft end of drill hole

Drill hole 36
Location: SE1/4SW1/4SE1/4 sec. 8, T. 36 N., R. 10 W.
Elevation: 1290 feet
0 - 2 ft silt
2 - 20 ft red, sandy loam till (Mikana till), non-calcareous
20 ft end of drill hole

Drill hole 37
Location: NW1/4NW1/4SW1/4 sec. 18, T. 36 N., R. 10 W.
Elevation: 1230 feet
0 - 9 ft red, sandy loam till (Mikana till), non-calcareous
9 - 20 ft brown loam, non-calcareous
20 - 63 ft red, sandy loam till (Mikana till), calcareous
63 - 68 ft sand
68 ft end of drill hole

Drill hole 38
Location: NE1/4SE1/4SW1/4 sec. 7, T. 36 N., R. 10 W.
Elevation: 1260 feet
0 - 60 ft red, sandy loam till (Mikana till), calcareous below 13 feet
60 ft end of drill hole

Drill hole 39

Location: NE1/4NE1/4SW1/4 sec. 25, T. 35 N., R. 12 W.

Elevation: 1240 feet

0 - 7 ft sand
7 - 35 ft brown clay loam to sandy clay loam, non-calcareous, unit is sandier with depth
35 - 40 ft tight sand
40 ft end of drill hole

Drill hole 40

Location: NE1/4SE1/4SE1/4 sec. 30, T. 34 N., R. 12 W.

Elevation: 1200 feet

0 - 5 ft silt
5 - 41 ft red, sandy loam till (Poskin till), calcareous below 33 feet
41 ft rejected by tight sediment

Drill hole 41

Location: SE1/4NW1/4SW1/4 sec. 33, T. 33 N., R. 13 W.

Elevation: 1080 feet

0 - 29 ft slightly gravelly sand
29 - 32 ft sandstone
32 ft end of drill hole

Drill hole 42

Location: NW1/4NW1/4NW1/4 sec. 10, T. 32 N., R. 10 W.

Elevation: 1075 feet

0 - 25 ft slightly gravelly sand
25 - 26 ft sandstone
26 ft end of drill hole

Drill hole 43

Location: NW1/4NE1/4SW1/4 sec. 15, T. 32 N., R. 10 W.

Elevation: 1095 feet

0 - 3 ft artificial fill
3 - 9 ft gray-brown clay, non-calcareous
9 - 56 ft slightly gravelly sand
56 - 58 ft sandstone
58 ft end of drill hole

Drill hole 44

Location: SE1/4SE1/4SW1/4 sec. 26, T. 32 N., R. 10 W.

Elevation: 1110 feet

0 - 22 ft orange sand
22 - 38 ft interbedded loam (colluvium?) and sand, non-calcareous
38 - 43 ft slightly gravelly sand
43 ft end of drill hole

Drill hole 45

Location: SE1/4SW1/4SW1/4 sec. 27, T. 32 N., R. 10 W.

Elevation: 1120 feet

0 - 4 ft artificial fill
4 - 14 ft yellowish red, sandy clay loam till (Prairie Farm till), non-calcareous
14 ft end of drill hole