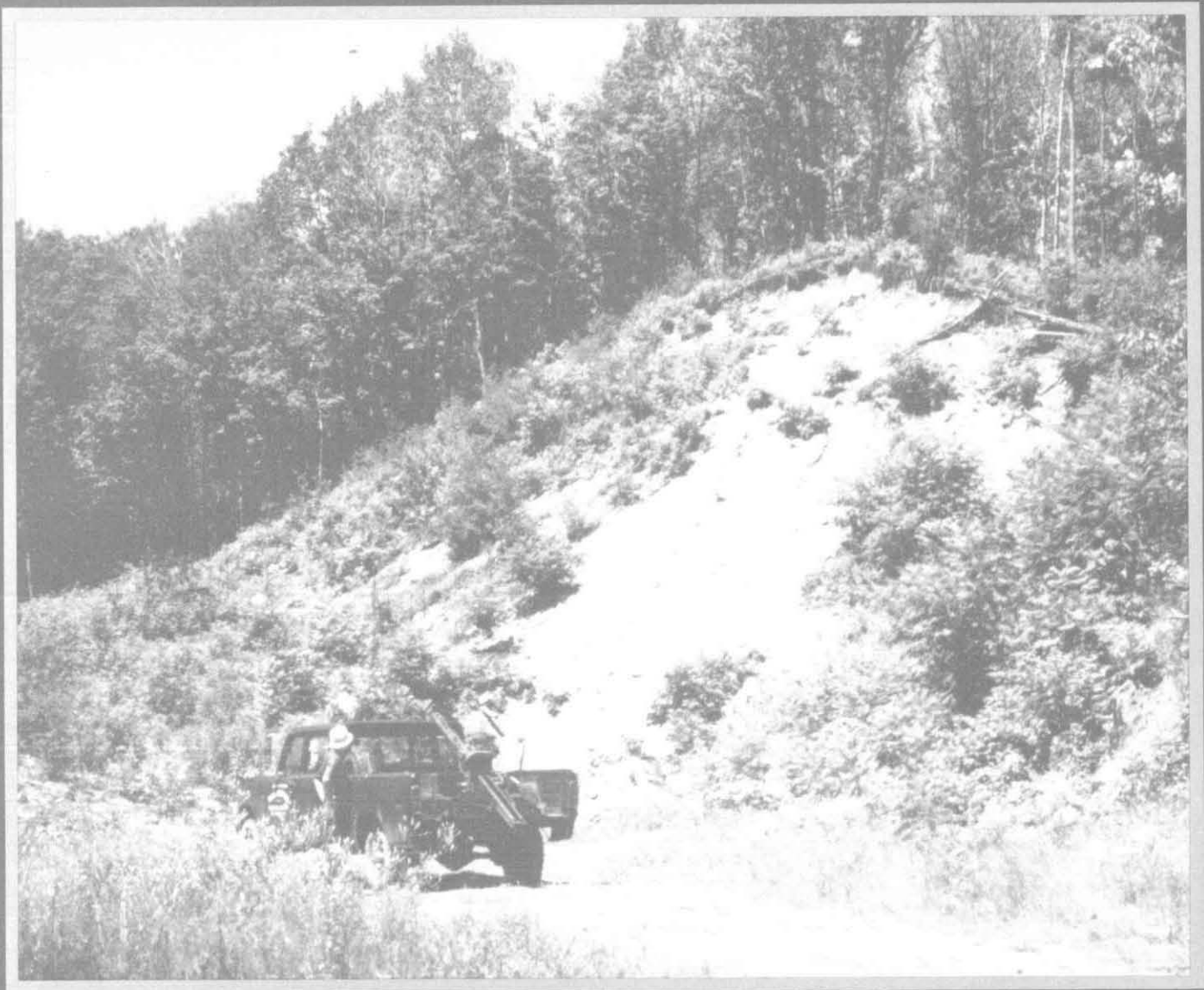


Information Circular 61  
1987

# Pleistocene Geology of Forest County, Wisconsin

W.W. Simpkins, M.C. McCartney, and D.M. Mickelson



Wisconsin Geological and Natural History Survey

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*A description of the Pleistocene sediment  
and a discussion of the glacial history  
of Forest County, Wisconsin*

Wisconsin Geological and Natural History Survey  
Information Circular 61

1987

Published by and available from

**UWEX** University of Wisconsin-Extension  
Geological and Natural History Survey  
M.E. Ostrom, Director and State Geologist  
3817 Mineral Point Road, Madison, Wisconsin 53705

1987

ISSN: 0512-0640

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# Pleistocene Geology of Forest County, Wisconsin

W.W. Simpkins, M.C. McCartney, and D.M. Mickelson

## ABSTRACT

Up to 90 m of Pleistocene sediment (including till and sand and gravel deposited by pre-, early, and late Wisconsin ice) overlies Precambrian igneous and metamorphic rock in Forest County, Wisconsin. Pleistocene stratigraphic units recognized include the Nashville Member of the Copper Falls Formation, the Mapleview Member of the Horicon Formation, Marathon Formation (undifferentiated), and Lincoln Formation (undifferentiated).

The surface sediment in Forest County was deposited by a southwestern advance and northeastern retreat of the Langlade Lobe between about 22,000 and 12,000 years ago. Till of the Nashville Member, a reddish brown to brown, noncalcareous, silty sand, is found primarily in drumlins. Retreat of the ice lobe produced meltwater that deposited large quantities of sand and gravel of the Nashville Member as pitted and unpitted plains, hummocks, and unpitted fans. Eskers formed by the melting out of subglacial tunnels filled with sand and gravel. Lacustrine sediment, primarily sand, marks the extent of former glacial lakes.

## INTRODUCTION

In this report and accompanying map we describe the Pleistocene sediments and landforms of Forest County, Wisconsin. The report provides geologists, hydrologists, engineers, regulators, planners, and others interested in the geologic resources of the county with a basic understanding of the type, origin, and distribution of Pleistocene sediments, which are an important economic resource for the county. Sand and gravel is a source of aggregate for highway construction and also composes the principal aquifer for municipal, industrial, and private water supply. Characterization of Pleistocene sediments has been an important part of the feasibility studies for mining a large zinc-copper deposit near Crandon (hereafter referred to as the Crandon site). Determination of the Pleistocene stratigraphy and properties of the glacial sediment, such as hydraulic conductivity, is necessary to determine possible impacts of the mining and waste disposal on local groundwater and surface-water resources.

Forest County covers 2,800 km<sup>2</sup> in northeastern Wisconsin and borders the Upper Peninsula of Michigan (fig. 1). Primarily federal land, the county contains parts of the Nicolet National Forest and the Mole Lake and Potawatamie Indian Reservations. Forest County contains the headwaters of two federally designated Wild and Scenic Rivers, the Pine and Popple Rivers (Oakes and Hamilton, 1973). Both drain eastward into the Menominee River, which drains into Lake Michigan. Surface water in the northern part of the county drains north to the Brule River, which also drains into the Menominee River. Pine Lake, near Hiles, contains the headwaters of the Wolf River, which flows southward and eventually empties into the Wisconsin and Mississippi Rivers.

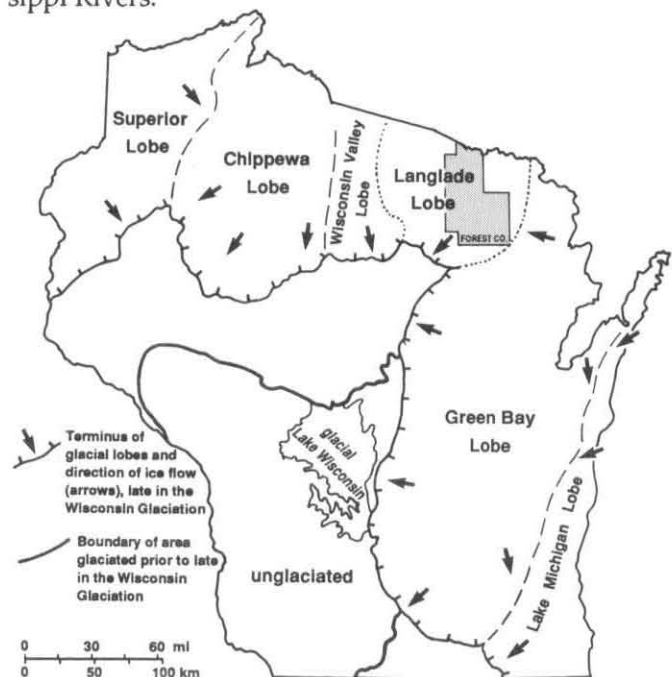


Figure 1 Location of Forest County, Wisconsin, showing maximum extent of the late Wisconsin Glaciation (between about 25,000 and 10,000 years ago in Wisconsin). Area covered by the Langlade Lobe is shown by the dotted line. Modified from Mode and Attig (in press).

The geologic map (plate 1) is based on data collected in the field during the summers of 1977 and 1978, laboratory analysis of sediment samples, well constructor's reports, and previous reports about the Pleistocene geology of the region. Field mapping was done on maps of the U.S. Geological Survey (7.5-minute series, topographic, scale 1:24,000). Field maps (one landform and one surficial materials map) were combined and compiled at a scale of 1:100,000 to produce plate 1.

We characterized the Pleistocene sediment in Forest County using laboratory analysis and field observations. Using 146 samples (110 collected during the summers of 1977 and 1978 and 36 collected in 1985 from Shelby-tube and split-spoon samples near the Crandon site), we determined grain-size distribution with standard sieve and hydrometer analyses. For samples collected during 1977-78, we determined the clay mineralogy of glacial till samples semiquantitatively by X-ray diffraction techniques; for 8 samples collected in 1977 and for 36 samples collected in 1985 from the Crandon site, we determined magnetic susceptibility of the fraction smaller than 2 mm.

The authors acknowledge the helpful discussions with Edward Neumann and Lance Lindwall, Soil Scientists, Nicolet National Forest, in the early stages of this project. Carleton Schroeder, Barry Hansen, and Roger Rowe of Exxon Minerals Company provided core samples and insight into Pleistocene stratigraphy near the Crandon site. Lee Clayton, John Attig, and Kenneth Bradbury, Wisconsin Geological and Natural History Survey, provided many good ideas, helpful criticism of the manuscript, and the encouragement to finish it. We also acknowledge the work of Brenda Haskins-Grahn, who aided in map compilation and production of the map (plate 1).

## PRE-PLEISTOCENE GEOLOGY

### Precambrian rock

Precambrian rock occurs in scattered, isolated exposures in Forest County and consists of Early Proterozoic granitic rock (northern and western sections); metavolcanic and metasedimentary rock, and iron formation of the Niagara Fault (extreme northwestern section); gneiss (entire central section); mafic intrusive rock (northern section); dioritic intrusive rock (west of Cavour and near Atkins Lake); biotite granite plutons (near Mole Lake, southwestern part of county); and quartzite and conglomerate near McCaslin Mountain (southeastern part of the county). The Middle Proterozoic Hager Porphyry also crops out in the southeastern part of the county. The remainder of the county is underlain by Early Proterozoic metavolcanic rock south of the Niagara

Fault (fig. 2; Greenberg and Brown, 1984). Foliations trend east-west and northeast-southwest in the western part of the county (eight measurements), northwest-southeast in the eastern part of the county (two measurements), and east-west near the Michigan border, near Newald and near Cavour (one measurement each) (Greenberg and Brown, 1984).

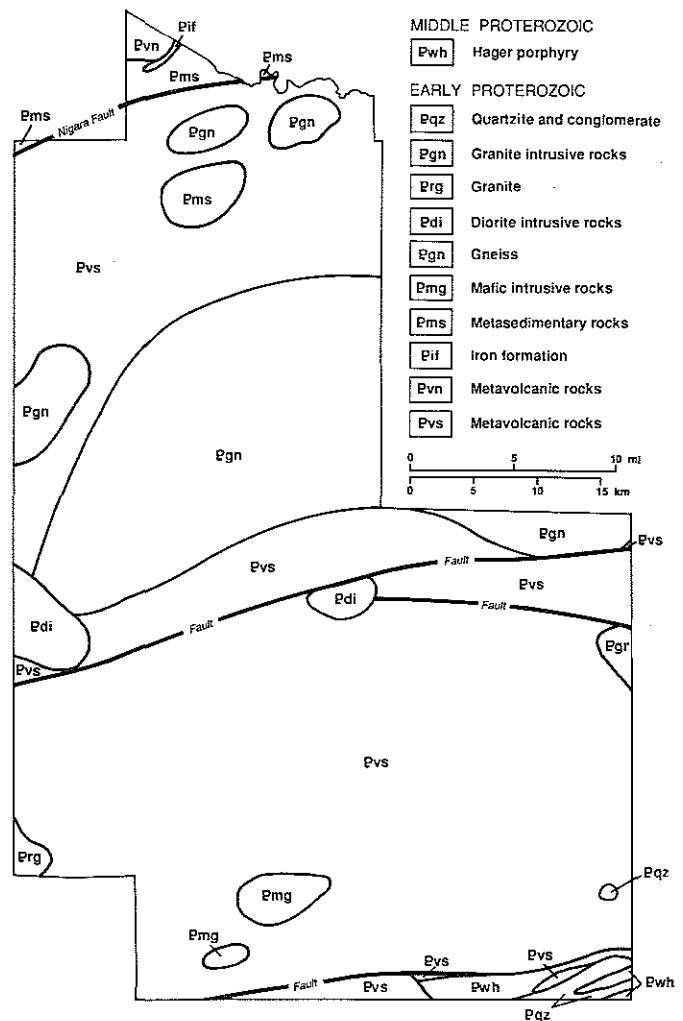


Figure 2 Map of Precambrian geology of Forest County, modified from Greenberg and Brown (1984).

### Topography of the Precambrian rock

The regional slope on the surface of the Precambrian rock is 1.3 to 1.9 m/km to the east and southeast (Oakes and Hamilton, 1973). The surface of the Precambrian bedrock in Forest County is irregular (STS Consultants,



1984). A rock upland, McCaslin Mountain, occurs at the east side of the county. Most rock outcrops, such as the Precambrian gneiss on the south shore of Pine Lake near Hiles, are located in topographic lows and are surrounded by sand and gravel deposited by meltwater streams (plate 1). A major bedrock valley, nearly 30 m deep, lies between upland areas (map unit ts on plate 1) east of Pine Lake near Hiles and west of Argonne. Scarcity of well-log data in other areas of the county prevented identification of other topographic trends on the Precambrian surface.

## PLEISTOCENE GEOLOGY

Ice of the Laurentide Ice Sheet advanced out of the Lake Superior basin into northern Wisconsin by about 26,000 years ago (Mickelson and others, 1983; Attig and others, 1985). The main body of ice separated into lobes that flowed south-southwest across the Upper Peninsula of Michigan and into Forest County. Glacial sediment of the Langlade and Green Bay Lobes was deposited during the late Wisconsin (22,000 to 12,000 years ago in this part of the state). Glacial ice flowed from the northeast to the southwest because the long axis of drumlins (low, rounded hills, which in Forest County are typically composed of sand and gravel covered by a veneer of till) is generally oriented in a southwest direction. Meltwater streams deposited sand and gravel in pitted and unpitted plains and as hummocks, eskers, and unpitted fans. Evidence from drilling in the southern part of the county and in Langlade and Marathon Counties (Mode, 1976; Stewart, 1976; Mickelson, 1986) indicates that Forest County was glaciated before the advance of the Langlade Lobe.

Pleistocene stratigraphic units recognized in Forest County include the Nashville Member of the Copper Falls Formation, deposited by the Langlade Lobe; the Mapleview Member of the Horicon Formation, deposited by the Green Bay Lobe; and the Marathon Formation (undifferentiated) and the Lincoln Formation (undifferentiated), both deposited prior to the late Wisconsin (fig. 3). Sediment from the Marathon and Lincoln Formations is present in the subsurface near the Crandon site. Sediment deposited by the Green Bay Lobe, which advanced northwestward from the Green Bay lowland, is exposed in gravel pits and found in the subsurface in the southern and eastern parts of the county.

The thickest accumulations of Pleistocene sediment (30 to 90 m) occur in the southern and southwestern parts of Forest County and in the northwestern part adjacent to Vilas County. The thickness of Pleistocene sediment in the remainder of the county ranges from 0 to 30 m (Trotta and Cotter, 1973; Mudrey and others, 1982).

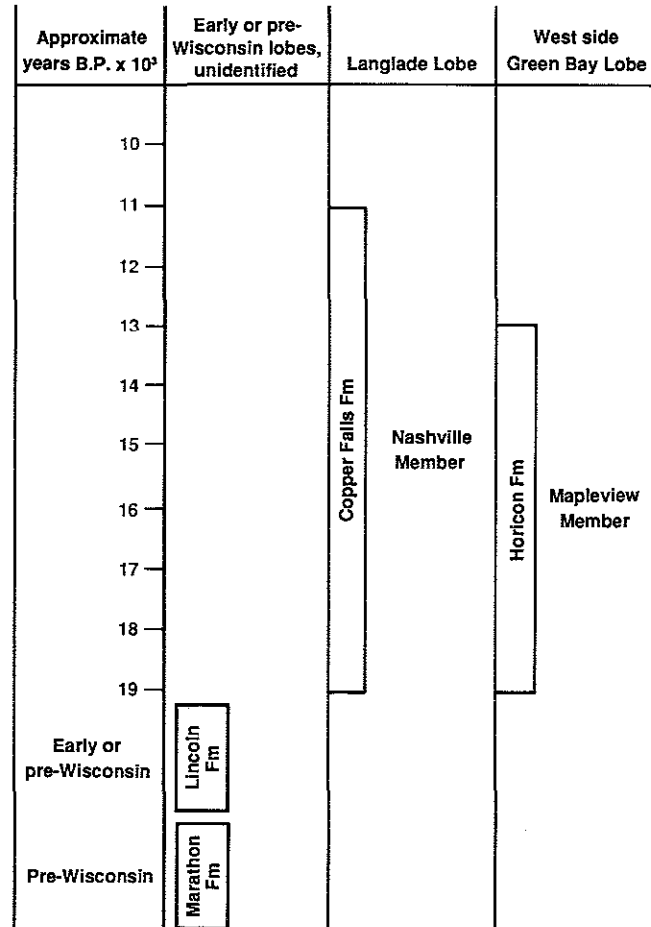


Figure 3 Stratigraphic units recognized in Forest County, modified from Attig and others (in press).

### Nashville Member of the Copper Falls Formation

The Copper Falls Formation is defined in a broad area of northern Wisconsin. This formation, deposited by the Langlade Lobe, includes sand and gravel deposited by meltwater streams, sand deposited in lakes, and till that is generally sandy and reddish brown. Copper Falls till contains a smaller proportion of sedimentary rock in comparison to deposits of the Green Bay and Lake Michigan Lobes (Mickelson and others, 1984); a higher proportion of igneous and metamorphic rock reflects a source area in the Lake Superior basin.

The Nashville Member of the Copper Falls Formation comprises the surficial Pleistocene deposits in Forest County (plate 1). This member includes the surface till and sand and gravel deposited by the Langlade Lobe and its associated meltwater. The type section is located in Nashville Township in southwestern Forest County



**Figure 4** Location of type section of the Nashville Member (till) of the Copper Falls Formation in an area of drumlins: U.S. Geological Survey Nashville Quadrangle, 7.5-minute series, topographic (T. 35 N., R. 12 E.).

(fig. 4); reference sections are in a gravel pit west of Crandon and a gravel pit on the east side of Pine Lake near Hiles (Mickelson and others, 1984). The Nashville

Member is also recognized in northern Langlade (Mickelson, 1986), Vilas, Oneida (Attig, 1985), and Florence Counties (Clayton, 1986).

## Till

The term "till" as used in this report generally refers to subglacial till -- material deposited as a result of the melting-out or lodging of material from a debris-rich layer at the base of a glacier. In Forest County, till is typically 3 to 8 m thick, uniform areally and vertically, and compact. The long axis of pebbles is oriented upglacier and parallel to ice flow.

Supraglacial till, debris-flow sediment, and other mass-wastage deposits are present on some uplands. Supraglacial till consists of material that was let down from the ice surface and has undergone some flow or mass movement (Attig, 1984). It is much thinner (0 to 2 m) than subglacial till and is patchy in extent, has crude stratification, abundant large and somewhat more angular clasts, and a very weak fabric. We did not consider supraglacial till or debris-flow sediment to be areally extensive, mappable units for this report.

In Forest County, till of the Nashville Member is gravelly, loamy sand (U.S. Department of Agriculture classification), or silty sand. Mean grain size (93 samples) of the less-than-2-mm fraction is 77 percent sand (0.063 to 2 mm), 16 percent silt (0.002 to 0.063 mm), and 7 percent clay (smaller than 0.002 mm). Sand content is slightly greater in the northern part of the county; gravel composes 5 to 10 percent of the total sample. Color of moist till samples ranges from a reddish brown (5YR 4/4 on the Munsell chart) to yellowish red (5YR 4/6) to brown (7.5YR 4/4) to strong brown (7.5YR 4/6); the red hues are apparent in samples taken near the Michigan-Wisconsin border. Color of samples suspended in water from the Crandon site also ranges from reddish brown (5YR 4/4) to strong brown (7.5YR 4/6).

On the basis of a semiquantitative analysis technique (Stewart, 1973), typical clay-mineral abundances (17 samples) of Nashville Member till are 80 percent illite, 12 percent chlorite and kaolinite, 5 percent vermiculite, and 3 percent smectite (Simpkins, 1979). Pebble counts of the till from throughout the county average 95 percent igneous and metamorphic (primarily gneiss, granite, and quartzite) and 5 percent sedimentary (primarily red sandstone) rock. Magnetic susceptibility measurements in eight samples collected in 1978 range from  $1 \times 10^3$  to  $3 \times 10^3$  (dimensionless MKS units; approximate range of 4 to 6 in pre-1985 units of the University of Wisconsin at Madison, Department of Geology and Geophysics Quaternary Laboratory) and from  $4 \times 10^4$  to  $7 \times 10^3$  (dimensionless MKS units) in 14 samples collected in 1985 from soil borings at the Crandon site. Carbonate content in the coarse silt fraction, primarily dolomite (13 samples), is approximately 15 percent, with the greatest percentage as dolomite (table 1).

Since the initial field work was completed for this project, Attig (1985), Clayton (1986), and Mickelson (1986) have described the Pleistocene geology of adjacent Vilas, Florence, and Langlade Counties, respectively. Till of the

Nashville Member is similar in all four counties (table 2).

Till of the Nashville Member (map unit ts on plate 1) was deposited on a streamlined, subglacially molded landscape. General till thickness in drumlins is 8 m; however, one drill hole penetrated nearly 17 m of Nashville Member till in a drumlin. Exposures of the interior of drumlins in gravel pits in the southern and eastern parts of the county show thin till (1 to 8 m) overlying sediment deposited by meltwater streams (stratified sand and gravel). The cores of other drumlins in the southern part of the county also contain till and stratified sand and gravel deposited by earlier ice advances in the region. Attig (1985) identified drumlins that have a sand-and-gravel core and are capped by till and debris-flow sediments in adjacent eastern Vilas County.

Drumlins are generally clustered atop uplands and assume a variety of geometries in map view, from nearly equidimensional to long and narrow forms (figs. 4 and 5). Drumlins containing only medium to coarse sand and some gravel occur in the western part of Forest County south of Butternut Lake and west of Julia Lake (fig. 6). Drumlins trend northeast-southwest along the regional ice-flow direction, except in the area east of Crandon near East Hill (T. 35 N., R. 13 E.; plate 1), where the trend is more nearly north-south, and near McCaslin Mountain, where the trend is nearly east-west. Drumlins near East Hill attain the highest elevations in the county (Sugarbush Hill, 939 ft above mean sea level), rising 75 m above the surrounding sand and gravel (map units sup and spp). A considerable thickness of Pleistocene sediment occurs below the Nashville Member in this part of the county (Simpkins, 1979) and may account for the height of these features; bedrock does not appear to control the height of drumlins here.

### *Sand and gravel deposited by meltwater streams*

Deposits of sand and gravel of the Nashville Member are grouped into four map units (sup, spp, suf, and sh) and eskers (plate 1). All five were deposited by meltwater from glacial ice of the Langlade Lobe. They differ primarily in their surface form and in the area affected by collapse or slumping (due to melting of underlying or adjacent ice) that has occurred since the deposition of the sediment. Areas mapped as sup have little or no collapse and the original depositional surface is preserved in map view. Areas mapped as sh may have originally had gently sloping surfaces but are now hummocky and the original depositional surface is no longer identifiable. Areas of spp are intermediate between sup and sh in the amount of area affected by collapse of the original depositional surface. Unpitted fans (map unit suf) were formed by meltwater at the ice margin and are characterized by a distinctive fan shape. Eskers contain sand and gravel deposited by meltwater streams in subglacial tunnels (plate 1).

Table 1. Properties of lithostratigraphic units in Forest County. Values shown are mean values.

Formation	Member	Sediment type	Year collected	Grain-size distribution of the <2 mm fraction (mean value)				Magnetic susceptibility (dim. MKS units)		Carbonate content (%)			
				n	sand	silt	clay	n	$\bar{x}$	n	calcite	dolomite	total
Copper Falls	Nashville	till	1977-78	93	77	16	7	8	$1 \times 10^{-3}$	—	—	—	
		till	1985	14	73	21	6	14	$1 \times 10^{-3}$	13	0.9	14.0	14.9
Horicon	Mapleview	till	1977-78	16	77	16	7	8	$2 \times 10^{-3}$	—	—	—	
		till	1985	10	74	19	7	10	$9 \times 10^{-4}$	10	0.7	19.4	20.1
Lincoln	undifferentiated	till	1985	7	64	26	10	7	$2 \times 10^{-3}$	7	0.7	10.2	10.9
Marathon	undifferentiated	till	1985	3	47	40	13	3	$1 \times 10^{-3}$	3	0.4	5.4	5.8

Table 2. Properties of till of the Nashville Member in Forest and adjacent counties.

County	Reference	Grain-size distribution (sand:silt:clay)		Magnetic susceptibility	Pebble lithology (%)		Color
		subglacial	supraglacial		sedimentary	igneous/metamorphic	
Forest	this study	77:16:7	—	4.1	5	95	5 YR 4/6 7.5 YR 4/4 to 4/6
Vilas	Attig, 1985	78:15:17	79:15:6	5.2	4	96	7.5 YR 3/3 to 4/4
Florence	Clayton, 1986	(60-80):(15-30):(4-13)	—	—	5-10	90-95	7.5 YR 3/3 to 4/4
Langlade	Mickelson, 1986	77:16:7	79:16:5	7.3	2-6	94-98	5 YR 4/6



Figure 5 Part of U.S. Geological Survey Anvil Lake Quadrangle, 7.5-minute series, topographic, showing typical drumlins of the county (T. 40 N., R. 12 E.).

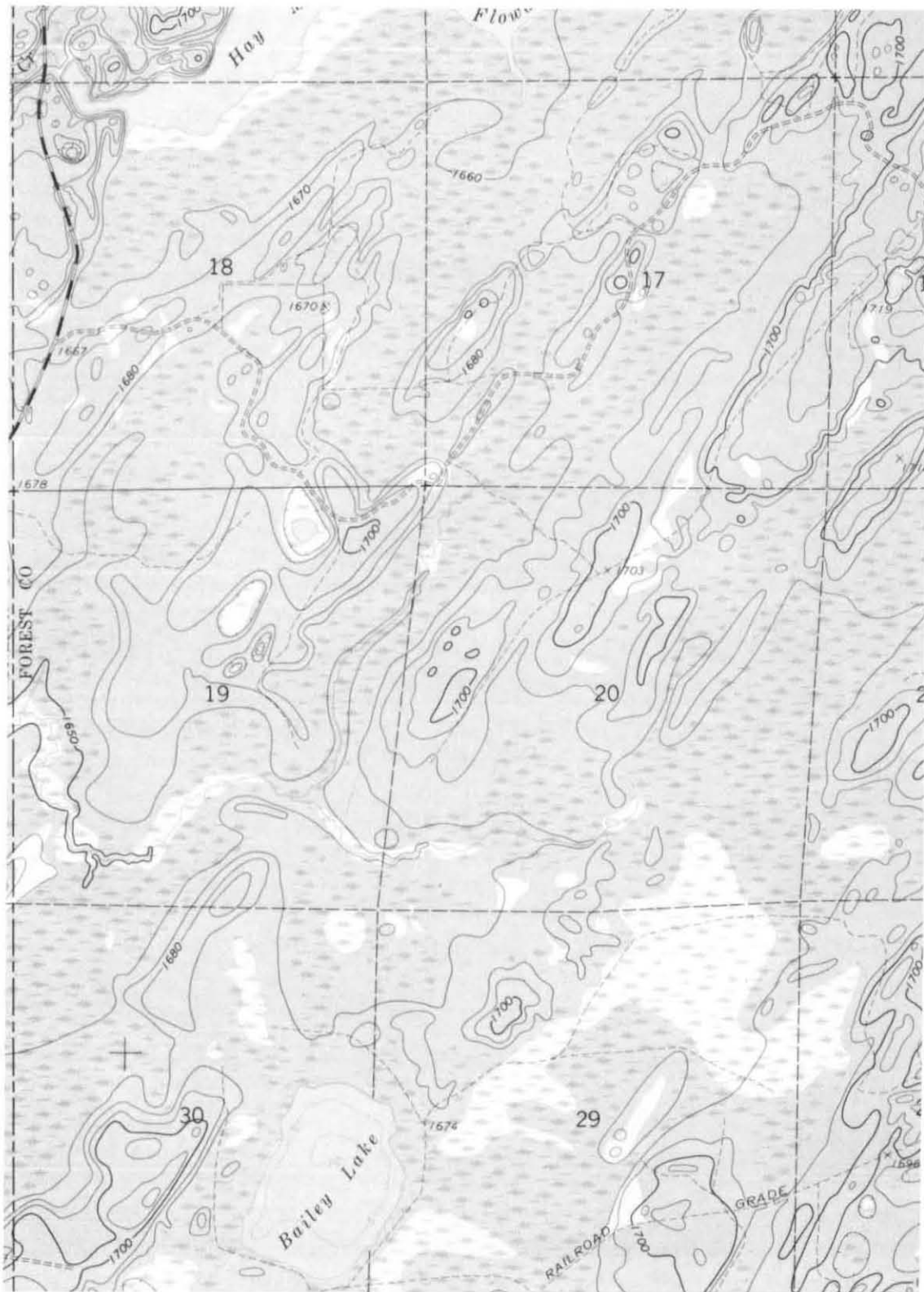
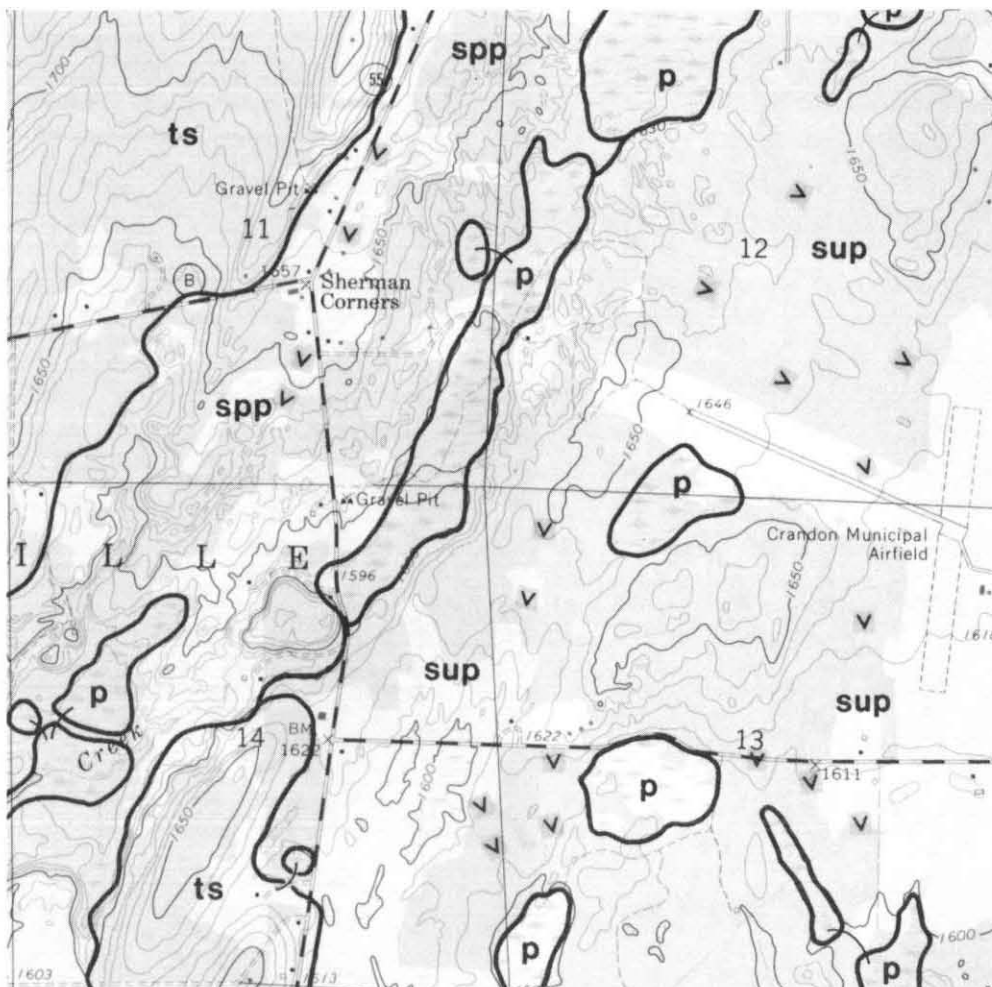


Figure 6 Part of U.S. Geological Survey Julia Lake Quadrangle, 7.5-minute series, topographic, showing drumlins composed entirely of sand and gravel (T. 39 N., R. 12 E.).



**Pitted and unpitted plains.** Sand-and-gravel map units *sup* (unpitted plain) and *spp* (pitted plain) (plate 1) occur throughout the county. The primary direction of drainage is away from the ice margin toward the southwest or south (fig. 7). Map unit *sup* is characterized by well to moderately well sorted, well stratified sand and gravel that forms gently sloping surfaces where more than 80 percent of the original depositional surface is preserved (based on maps of the U.S. Geological Survey, 7.5-minute series, topographic, scale 1:24,000). These deposits are meltwater-stream sediment deposited at some distance from the ice margin after most of the ice had melted out in the valleys; the sediment generally occupies the lowest level or surface on the landscape in Forest County. Because the water table lies at or near the surface in many areas mapped within these units, large areas of peat (map unit *p*, plate 1) may obscure the distribution of this sediment.

Map unit *spp* contains the same material as *sup*, except that pits resulting from melting ice blocks occupy between 20 and 80 percent of the surface (fig. 7). Stream sediment was deposited over and around ice blocks, and sediment collapsed and formed pits after the ice blocks melted. Collapse of the sediment probably indicates that map unit *spp* was deposited on ice blocks closer to the ice margin than map unit *sup*. There are several elevation levels of map unit *spp* surfaces throughout the county. The highest levels (30 m above the surrounding map unit *sup*) occur along the flanks of drumlins (map unit *ts*) and may have been deposited by meltwater flowing along the ice margin as ice wasted downward from the drumlin crests. The surface is only partly collapsed; the original depositional surface slope is recognizable. Proglacial and postglacial streams have acted to modify the topographic expression of these features.



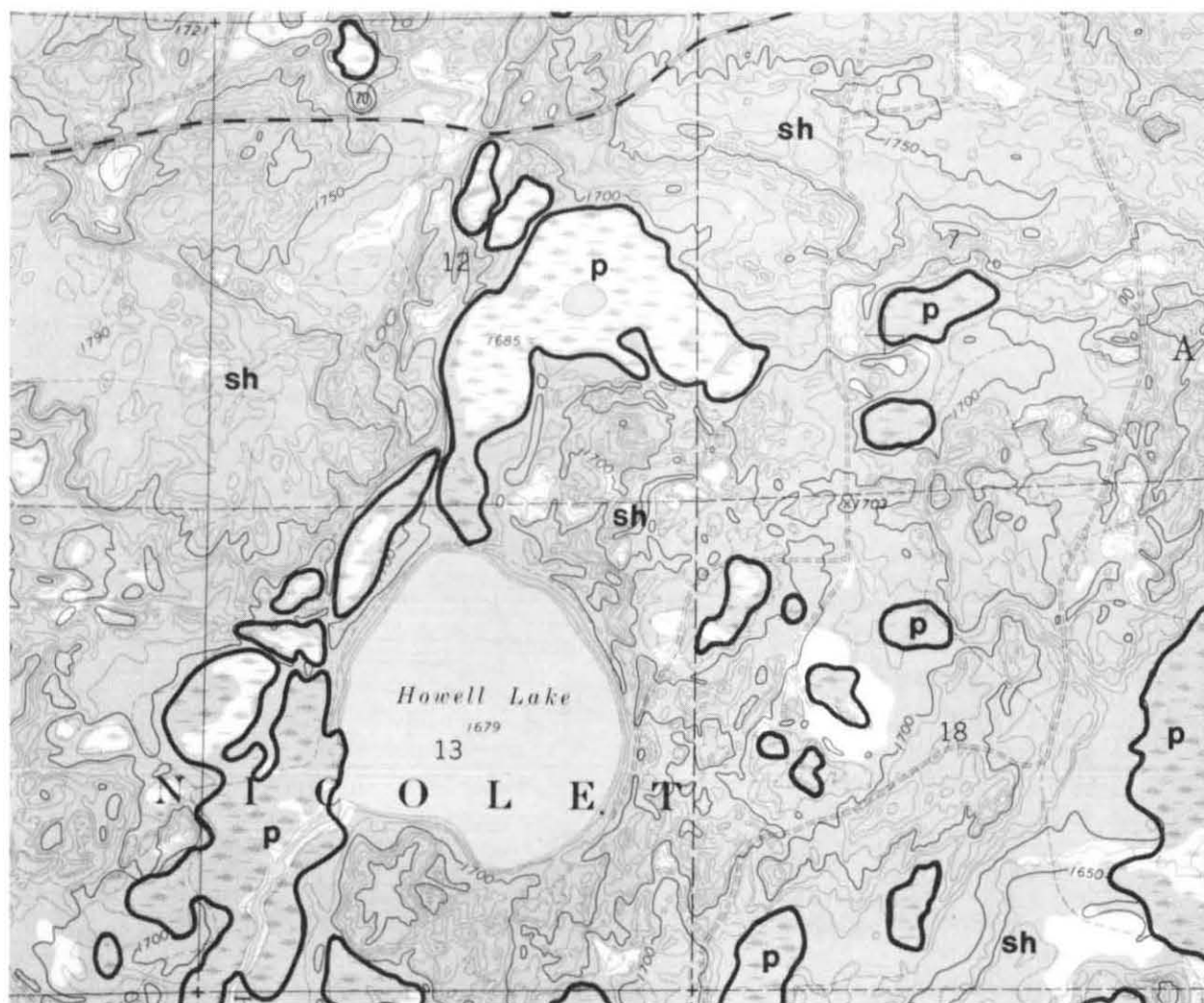
**Figure 7** Part of U.S. Geological Survey Crandon Quadrangle, 7.5-minute series, topographic, showing pitted (*spp*) and unpitted (*sup*) plains of sand and gravel deposited by meltwater streams, till (*ts*), and peat (*p*). Arrows show interpreted direction of stream drainage (T. 35 N., R. 12 E.).

**Hummocky sand and gravel.** Map unit sh identifies deposits of sand and gravel that are collapsed and contain hummocks. These deposits include poorly to moderately well sorted sand and gravel. In contrast to areas mapped as spp, the original depositional surface in areas mapped as sh is present in less than 20 percent of the area (based on maps of the U.S. Geological Survey, 7.5-minute series, topographic, scale 1:24,000). These deposits are characterized by many closely spaced depressions and perhaps some disintegration ridges, which are remnants of crevasse fills or other openings in disintegrating ice (Flint, 1971). Areas mapped as sh are also generally higher in the landscape than deposits mapped as spp and trend perpendicular and parallel to the main ice-flow direction.

Map unit sh is found in the northwest part of the county near Butternut and Franklin Lakes (fig. 8), and south and east of Lake Lucerne. Areas mapped as sh were mapped as an end moraine by Thwaites (1943) and

Hadley and Pelham (1976), although the deposits apparently contain no till of the Nashville Member. Thwaites (1943) named the hummocky ridge that passes through the town of Laona the Laona moraine. This discontinuous feature, which is composed primarily of sand with some gravel, rises 25 to 30 m above the surrounding lowlands (sand-and-gravel and peat deposits) and has a mean width of about 900 m and a length of 12 km (fig. 9). Attig and others (1985) correlated this ridge with the Stormy Lake ice-margin position in Vilas County. The origin and significance of the large areas of map unit sh that lie parallel to regional ice-flow direction in the northwestern and southwestern parts of the county are not known.

Unpitted fans (map unit suf) are characterized by smooth, fan-shaped surfaces that are perpendicular to regional ice-flow direction and that generally slope away from a steep ice-contact face present on the north-facing side.



**Figure 8** Part of U.S. Geological Survey Alvin NW Quadrangle, 7.5-minute series, topographic, showing area mapped as sand and gravel in areas of hummocky topography (sh) and peat (p) on plate 1 (T. 40 N., R. 12 and 13 E.).



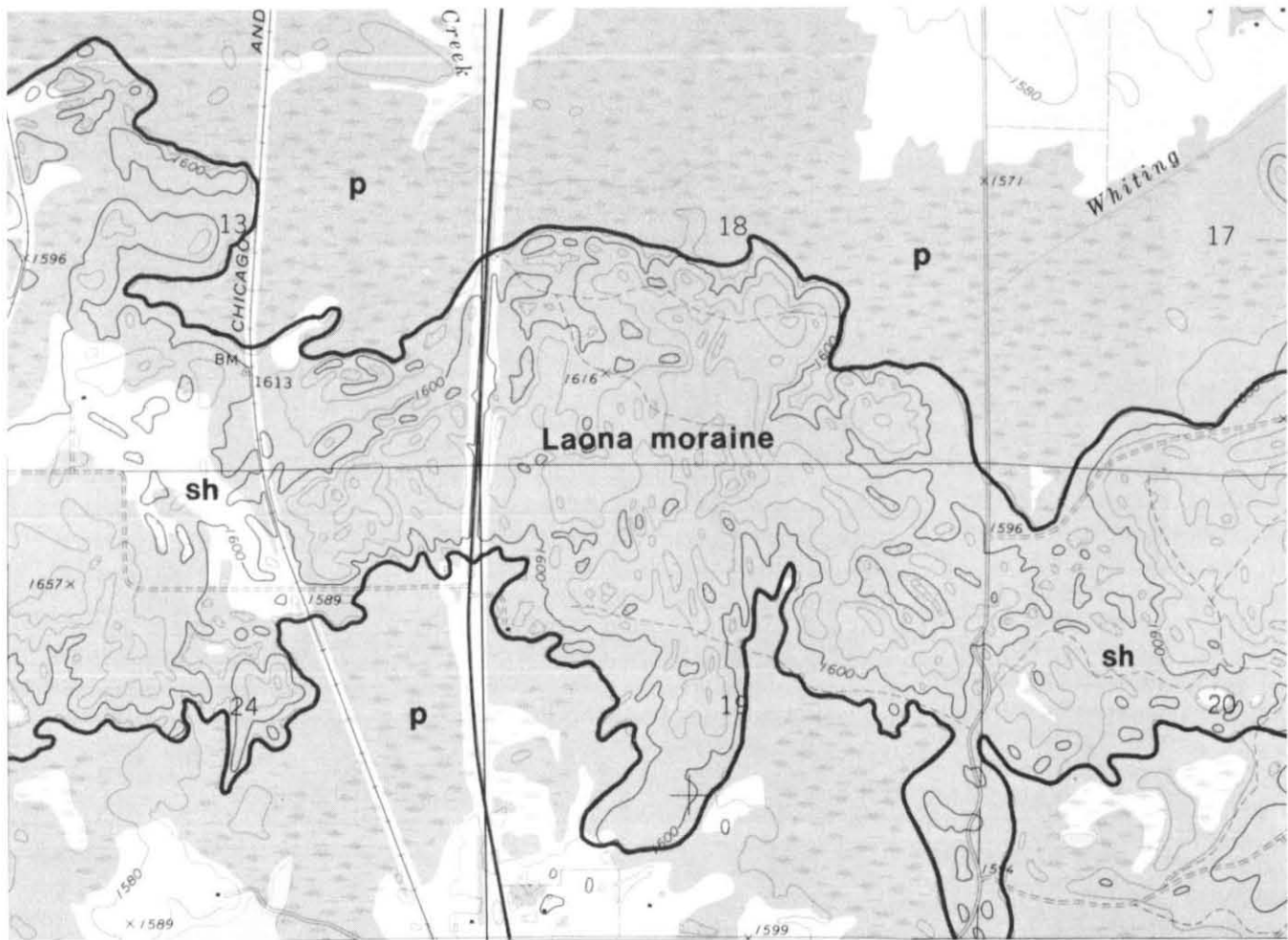


Figure 9 Part of U.S. Geological Survey Laona Quadrangle, 7.5-minute series, topographic, showing area (sh) known as the Laona moraine (T. 36 N., R. 14 and 15 E.).

Meltwater streams discharging from the ice deposited gravel at the fan margin. Grain size of the sediment diminishes away from the ice-contact face. The ice-contact slope may show evidence of slump or may be adjacent to a deposit of hummocky sand and gravel (map unit sh) (fig. 10). Only fans with distinct contacts were mapped on plate 1. Many fans that merged imperceptibly with pitted and unpitted plains were generally included within the unpitted-plain map unit (sup). Two fans in the county occupy more than 18 km<sup>2</sup> in area; most fans are commonly in the range of 3 to 5 km<sup>2</sup> in area.

Eskers are composed of sand and gravel deposited by meltwater in subglacial tunnels. After the ice constraining the sediment in the tunnel melted, linear, sinuous, steep-sided ridges were left on the landscape. In Forest County these ridges are generally less than 200 m wide, 10 to 21 m high, and 5 km long. Eskers are most common in the central and northern parts of the county (fig. 11). Many small ridges in areas with hummocks (map unit

sh) may actually be disintegration ridges. Larger esker forms occur in areas mapped as sup and spp. Only the upper portion of the esker is exposed above these map units; considerably more of the form could be present in the subsurface. Large boulders are more common in the larger eskers, suggesting that the flow velocity was considerably higher in the tunnels that formed these eskers than in the tunnels that formed the more numerous, smaller eskers containing well sorted sand. In many areas eskers merge into unpitted fans, indicating an ice-margin position.

#### *Sand in unpitted lacustrine plains*

Map unit sul consists of sediment, primarily sand with some silt and clay, that was deposited in lakes. Generally the form of these deposits is that of a featureless plain adjacent to an existing lake. In most places, map unit sul deposits are covered with peat and are obscured (fig. 12).

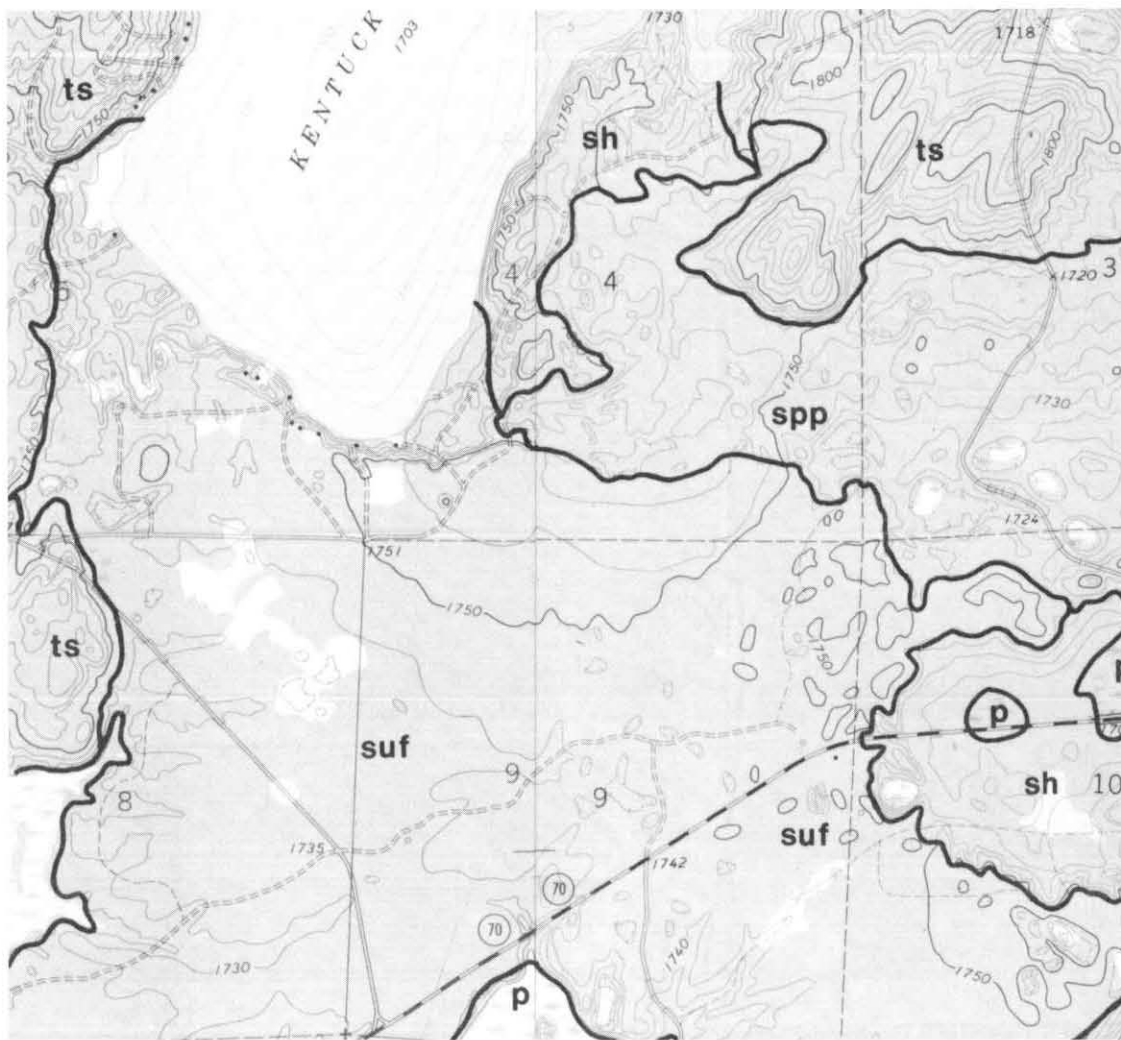


Figure 10 Parts of U.S. Geological Survey Anvil Lake and Alvin NW Quadrangles, 7.5-minute series, topographic, showing a large unpitted fan deposited by meltwater streams from the Langlade Lobe (suf), sand and gravel in areas of hummocky topography (sh), pitted plains (spp), till (ts), and peat (p) (T. 40 N. and R. 12 E.).

### Mapleview Member of the Horicon Formation Till

The Mapleview Member of the Horicon Formation is recognized on the west side of the Green Bay Lobe in eastern Langlade and Marathon Counties. Mapleview till is a cobbly, pebbly, silty sand and is distinguished from till of the Nashville Member of the Copper Falls Formation primarily by the more abundant dolomite pebbles in the Mapleview Member (Mickelson and others, 1974).

The following are results of analysis of Mapleview till in Langlade County: composition of pebbles (18 samples) averages 33 percent igneous rock, 40 percent metamorphic rock, and 26 percent sedimentary rock; mean grain size of the less-than-2-mm fraction (48 samples) is 77 percent sand (0.063 to 2 mm), 19 percent silt (0.002 to 0.063 mm), and 4 percent clay (smaller than 0.002 mm)

(Mickelson and others, 1984); mean clay-mineral abundances (48 samples) are 69 percent illite, 13 percent kaolinite plus chlorite, and 14 percent smectite (Stewart, 1973); mean magnetic susceptibility for 48 samples is 6.3 (pre-1985 units of the University of Wisconsin at Madison, Department of Geology and Geophysics Quaternary Laboratory; Mickelson, 1986). In Langlade County north of the township of Bryant, the Mapleview Member is overlain by the Nashville Member.

The Mapleview Member is also exposed below the Nashville Member in gravel pits and is present in the subsurface in southern and eastern Forest County. A calcareous till thought to be the Mapleview Member is present in a gravel pit (reference section 2 of the Nashville Member) on the eastern shore of Pine Lake in a northeast-southwest trending drumlin near Hiles, Wisconsin (fig. 13). Approximately 6 m of the Nashville Member till and 7.5 m of sand are exposed in the northeast

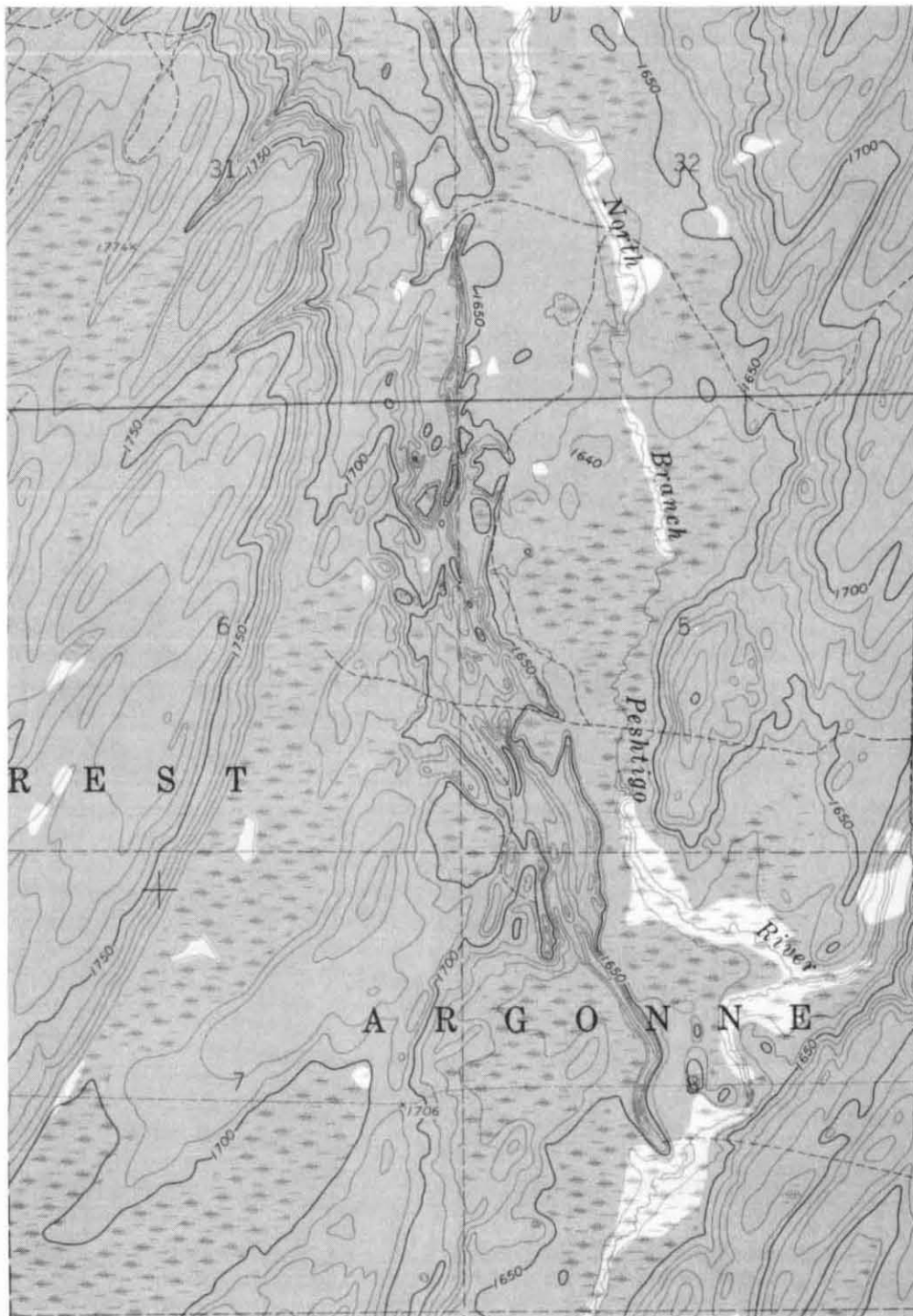


Figure 11 Part of U.S. Geological Survey Argonne Quadrangle, 7.5-minute series, topographic, showing a large esker (T. 37 and 38 N., R. 13 E.).

side of the gravel pit; these deposits presumably overlie the lower Mapleview till unit, which is only present on the south side of the gravel pit. About 3.6 m of this unit is exposed at the surface; drilling next to the outcrop face revealed another 11.5 m of till below the surface.

Laboratory analyses of this till indicate that it is indistinguishable from the Nashville till on the basis of grain-

size distribution, color, clay mineralogy, or magnetic susceptibility (table 1). In this exposure, mean grain-size distribution of the less-than-2-mm fraction (12 samples) is 77 percent sand (0.063 to 2 mm), 16 percent silt (0.002 to 0.063 mm), and 7 percent clay (smaller than 0.002 mm). Color ranges from yellowish red (5YR 4/6) to strong brown (7.5YR 4/6). Mean abundances of clay minerals

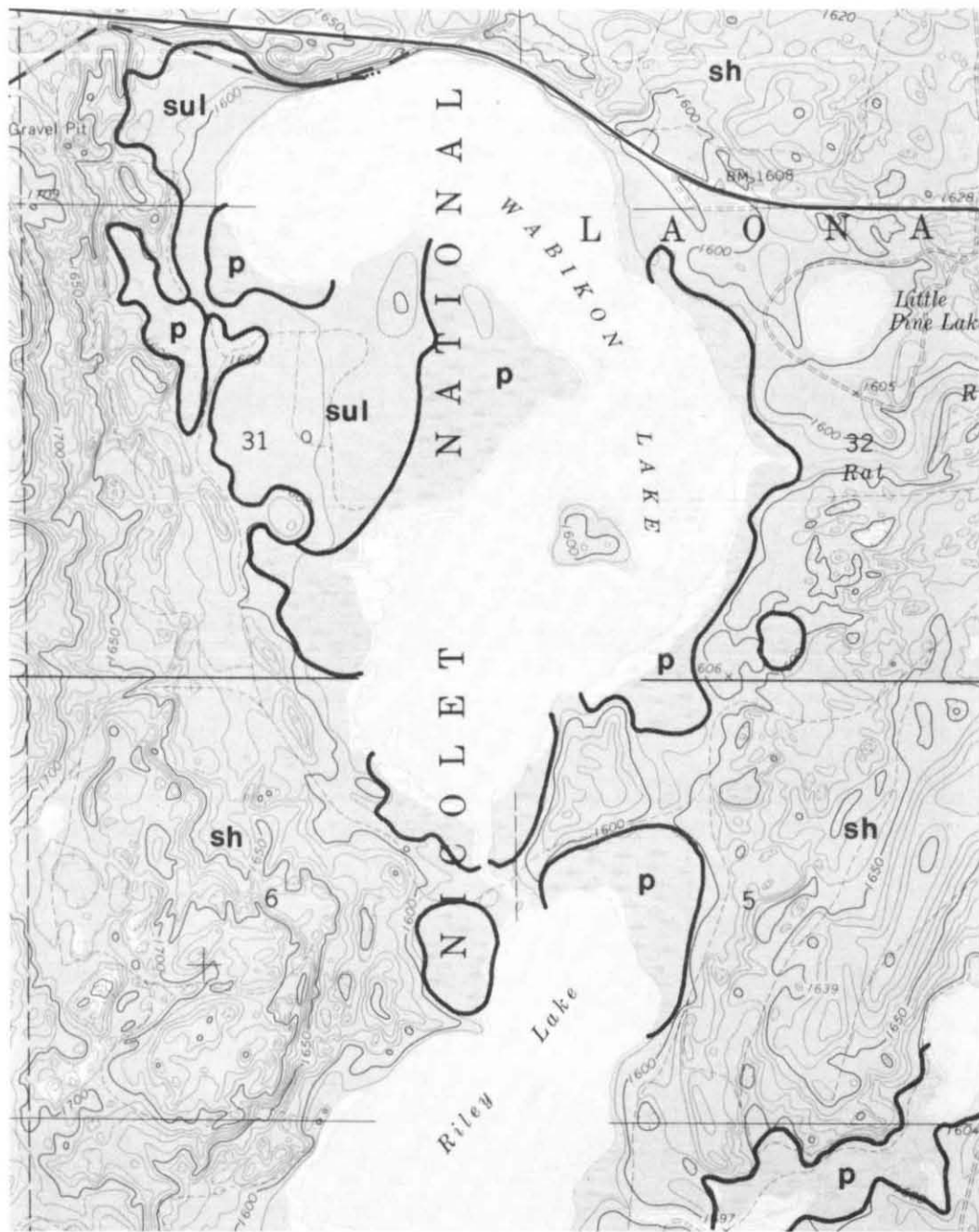


Figure 12 Part of U.S. Geological Survey Lake Lucerne Quadrangle, 7.5-minute series, topographic, showing area mapped as sand in unpitted lacustrine plains (sul) and sand and gravel in areas of hummocky topography (sh) west of Waubikon Lake (T. 36 N., R. 14 E.). Peat obscures most of the extent of lacustrine sand around the lake.

determined for 12 samples by using the method of Stewart (1973) are 79 percent illite, 8 percent kaolinite and chlorite, 7 percent smectite, and 5 percent vermiculite. On the basis of these analyses alone, this till could be an older Nashville Member till, perhaps deposited in association with the initial advance of the Langlade Lobe to the Parrish ice-margin position. The upper till at this site could represent the sediment deposited during the later advance to the Summit Lake ice-margin position.

Relative abundances of clay minerals and grain-size distribution in this till suggest it is not part of the older Marathon and Lincoln Formations (Stewart, 1973; Stewart and Mickelson, 1976; Mickelson and others, 1984). These formations have consistently higher relative abundances of smectite and vermiculite than late Wisconsin tills, suggesting a longer period of weathering. For example, the Merrill Member of the Lincoln Formation typically has relative abundances of 53 percent illite, 9



percent kaolinite plus chlorite, 22 percent vermiculite, and 16 percent smectite (Stewart, 1973; Mode, 1976; Mickelson and others, 1984). Grain-size analyses show these older till units contain more silt: the Merrill Member has a mean of 68 percent sand, 28 percent silt, and 10 percent clay (Mickelson and others, 1984).

Sedimentary rock lithologies are more prominent visually in the till at the Hiles gravel pit, although actual pebble counts show only slightly more sedimentary clasts (13%) than the Nashville Member (5%) and fewer than in the Mapleview Member at its type section location. Significant lithologies include numerous cobbles of sandy dolomite, a typical lithology in outcrops of the Cambrian Franconia and Jordan Formations to the east (M.E. Ostrom, Wisconsin Geological and Natural History Survey, verbal communication, 1978). Vuggy dolomite cobbles are also present in the till. Magnetic susceptibility of the Mapleview Member here ranges from  $1 \times 10^{-3}$  to  $8 \times 10^{-3}$ , with a mean of  $2 \times 10^{-3}$  (8 samples; dimensionless MKS units). These values are similar to those for the Nashville Member.

Till fabric analysis (measurement of the plunge of the long axis of elongate pebbles) provides the most conclusive evidence for an easterly source area for this till. Measurements in this exposure showed a strong preferred orientation of S. 50° E. to S. 60° E.; this suggests

that the ice that deposited this unit was flowing N. 50° W. to N. 60° W. at this location (fig. 13).

Till presumably of the Mapleview Member is also exposed in other gravel pits in Forest County and in core from the Crandon site. Two calcareous till units (presumably Mapleview Member) are exposed in a gravel pit southwest of Wabeno, Wisconsin (center NW1/4 NW1/4 sec. 18, T. 34N., R. 15E.; fig. 13). The till units are exposed at the base of the north wall of the pit and lie beneath a sequence of sand and gravel of the Mapleview Member. Another calcareous, sandy till is present beneath the Nashville Member in drumlins just east of Duck Lake and about 1.6 km east of the Crandon site in STS boreholes EX-11, EX-12, and EX-13 (fig. 14). (STS Consultants and Golder and Associates drilled test holes in Forest County as part of mining feasibility studies: STS Consultants, 1984; Golder and Associates, 1982.) Maximum thicknesses here are 30 m; in borehole EX-11 there may be two calcareous sandy till units. The clay mineralogy of these units is primarily illite with only small amounts of smectite or vermiculite, a characteristic of late Wisconsin till units. Magnetic susceptibility of this sediment ranges from  $5 \times 10^{-4}$  to  $1 \times 10^{-3}$  with a mean of  $9 \times 10^{-4}$  (dimensionless MKS units; 10 samples). Total carbonate content is about 20 percent, slightly higher than that for till samples designated as the Nashville Member (table 1).

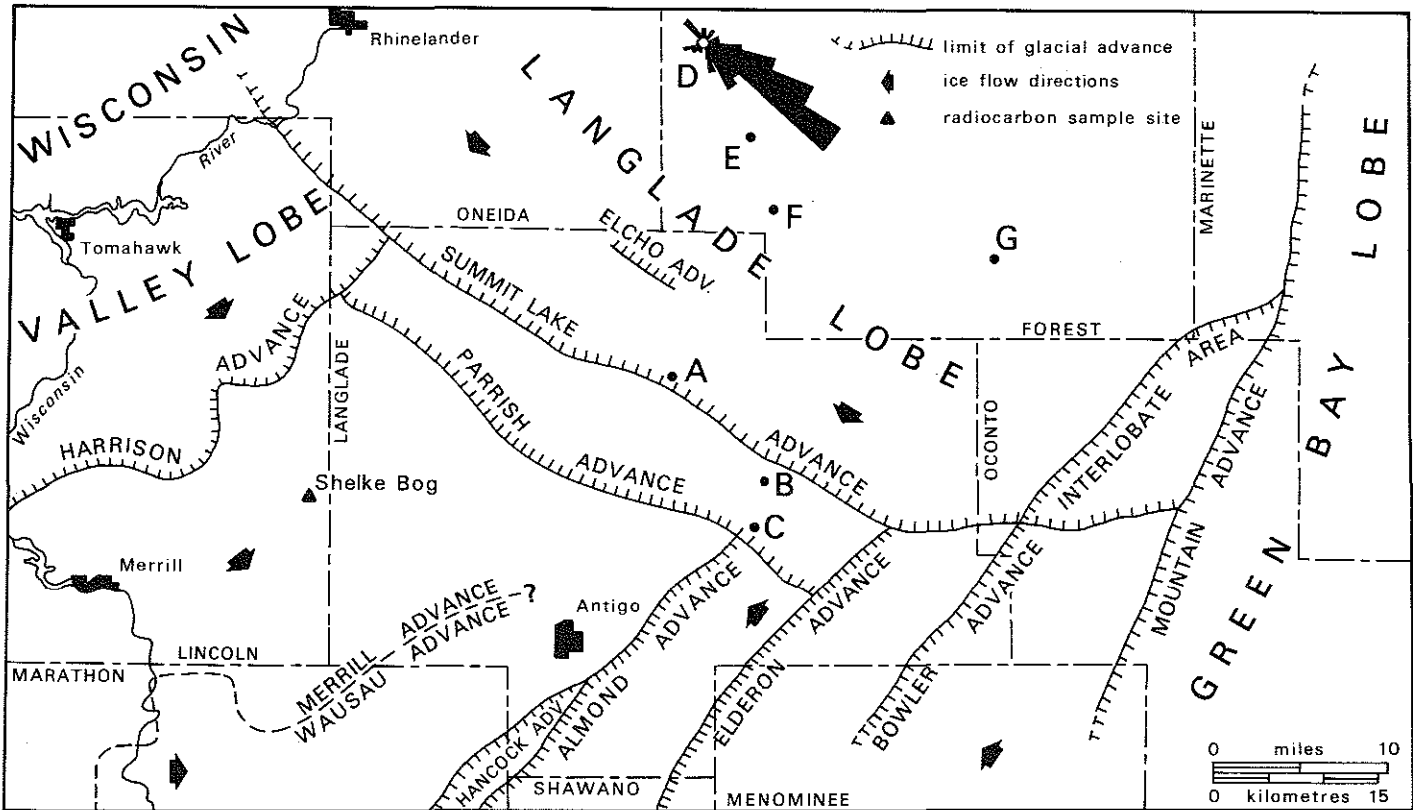


Figure 13 Map of north-central Wisconsin showing ice-margin positions and areas covered by various advances (modified from Mickelson, 1986). Point A is location of buried Merrill till; points B and C are locations of Mapleview till under Nashville till; point D is Hiles gravel pit (direction of ice flow for Mapleview Member till is shown by pebble fabric diagram constructed from orientation of pebbles with long axis of at least 2:1); point E is Crandon gravel pit; point F is Crandon site; and point G is Wabeno gravel pit.

### *Sand and gravel deposited by meltwater streams*

Sand and gravel of the Mapleview Member generally occurs stratigraphically between till of the Nashville Member and till of the Mapleview Member and may also directly underlie sand and gravel of the Nashville Member. In general, sediment of the different members can be distinguished by the more abundant dolomite cobbles present in the Mapleview Member (Mickelson and others, 1984). The best surface exposure of the Mapleview Member sand and gravel in Forest County occurs at reference section 2 of the Nashville Member (Crandon gravel pit, fig. 13). At this site, 11 m of coarse dolomitic gravel and boulders of the Mapleview Member is overlain by 1.5 to 6.1 m of till of the Nashville Member. Drilling indicated another 23 m of fine to medium, well sorted sand with lenses of silt over 7.5 m of brown (7.5YR 4/3) to reddish brown (5YR 4/3) silt and clay; the same sequence is also present east of Crandon in STS boreholes EX-2 and EX-3 (fig. 14). This sequence of silt and clay (lake sediment) at the base grading upward to sand and gravel deposited by meltwater streams probably records the advance of the Green Bay Lobe from initial ponding of streams against the ice margin to gradual coarsening of sediment upward through the section as the ice margin advanced into the area. The large size of boulders (up to 2-m long axis) at the Crandon gravel pit suggests that the ice from the Green Bay Lobe advanced at least to this point; however, no Mapleview till has been found overlying the sand and gravel at the pit.

### **Lithostratigraphic units older than late Wisconsin**

Analysis of core taken near the Crandon site suggests the presence of two or more units deposited before the late Wisconsin (table 1; fig. 14). A yellowish red (5YR 4/6), noncalcareous to calcareous, sandy till (57 to 62% sand in the less-than-2-mm fraction) is present below till(s) of the Nashville Member in STS borehole EX-2 and Golder boreholes G40-H16 and G40-M15, and also below till of the Mapleview Member in boreholes G40-H16 and EX-13 (table 1). These sediments may represent the up-ice equivalent of the Lincoln Formation. Relative abundances of clay minerals in these sediments (specifically, the presence of mixed-layer clays) suggest that the sediment underwent some weathering after deposition. X-ray diffractograms from sample EX-13-5 are similar to those described for the Merrill Member in Marathon County (Stewart, 1973; Mode, 1976). The source of carbonate in these units is not known, but it may be derived from incorporation of underlying units; however, the total carbonate is less than that of the late

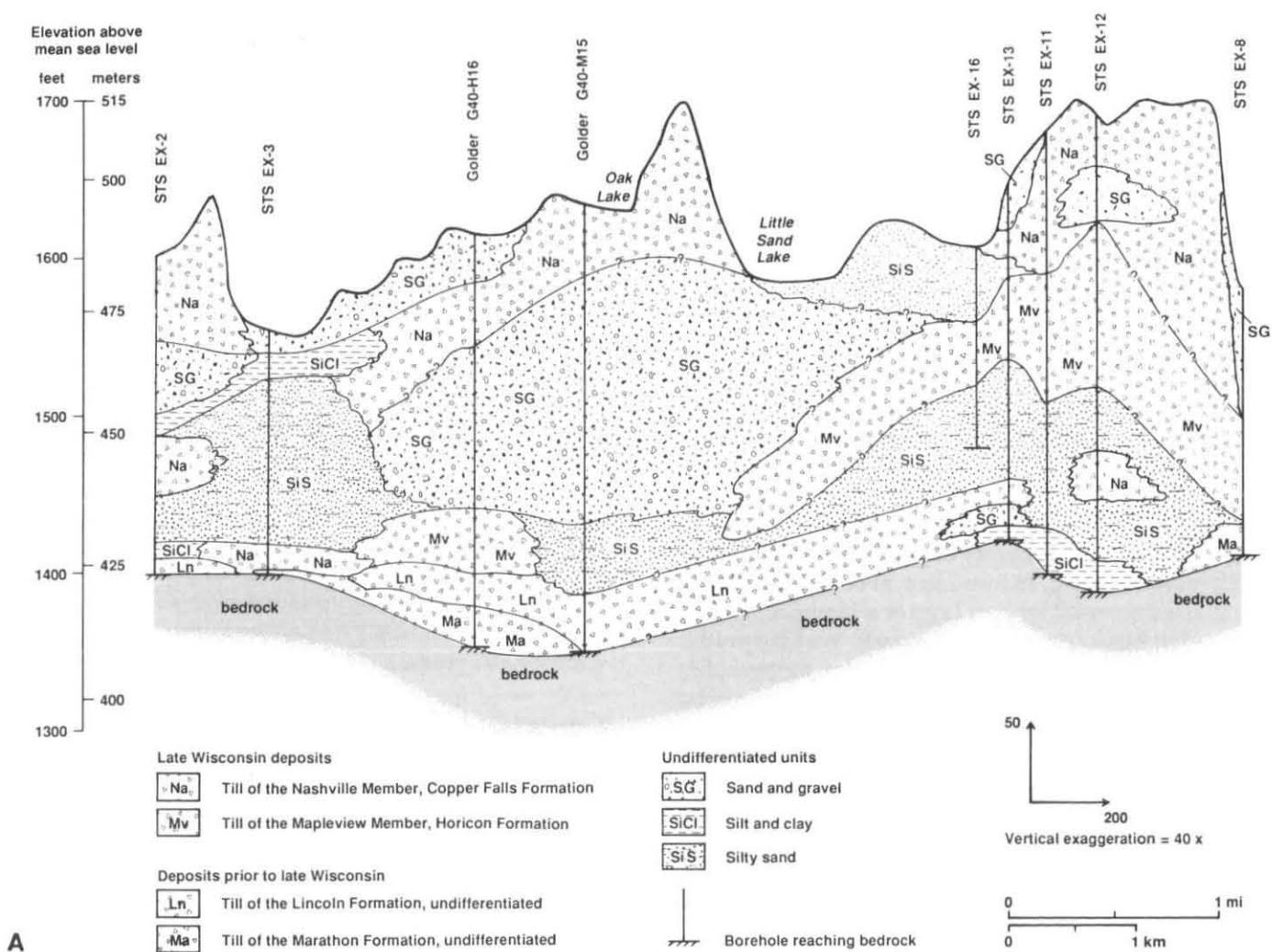
Wisconsin units. Depth of leaching cannot be strictly compared to the type sections of the Lincoln Formation near Merrill because the material near the Crandon site was glaciated and covered with Pleistocene sediment from glaciation during the late Wisconsin.

A calcareous, dark brown to brown (7.5YR 3/4 to 7.5YR 5/4) till unit underlies the Lincoln Formation in Golder boreholes G40-H16 and underlies till of the Mapleview Member in STS borehole EX-8 (fig. 14). The magnetic susceptibility of this unit is similar to the till units above it (table 1), and it has a clay mineralogy similar to that described for the Wausau and Edgar Members of the Marathon Formation (Mode, 1976). These units are the oldest units known in the region; the long period of weathering they have undergone resulted in greater relative abundances of smectite and vermiculite than found in younger units. Sand percentages range from 41 to 49 percent. On the basis of these limited data, we believe that these till units are part of the Marathon Formation, which Mickelson and others (1984) interpreted to be pre-Wisconsin.

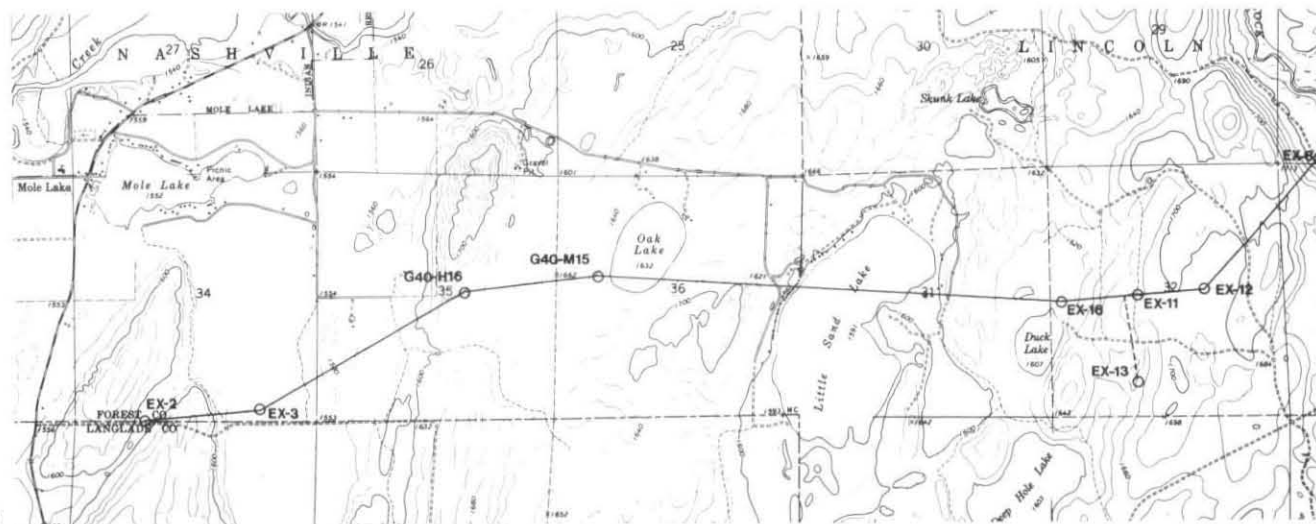
### **Use of Pleistocene sediment**

Pleistocene sediment in Forest County is a source of construction aggregate and contains the major source of private water supply. Present gravel pit operations are typically found in the areas mapped as eskers, spp, sup, suf, and sh (plate 1). Areas mapped as ts (plate 1) may also be a source of coarse aggregate because many drumlins in the southern and eastern parts of the county have cores of sand and gravel of the Mapleview Member. Most of these deposits vary widely in thickness and sorting depending on the distance from the ice margin during deposition. Gravel pits, such as those west of Crandon (reference section 2 of the Nashville Member), are underlain with fine sand that may be usable for road-foundation fill but not for coarse aggregate. Gravel pits near and east of Crandon may have a higher percentage of gravel for coarse aggregate.

Extensive deposits of sand and gravel in the subsurface provide private and municipal water supplies to the residents of Forest County and industrial water to the lumber industry. The thickness of sand and gravel in major valleys is typically 10 to 30 m; in other areas, it may be only a few metres thick. Groundwater flows from upland recharge areas to discharge areas in the stream valleys. The water table in the valleys is generally less than 4 m deep (STS Consultants, 1984). In the upland areas (generally shown as map unit ts on plate 1), depth to producing sand-and-gravel aquifers may range from 30 to 50 m (STS Consultants, 1984).



A



B

Figure 14 A) Geologic cross section across the Crandon site constructed from unpublished data from Golder and Associates (1982) and STS Consultants (1984); data for samples used to construct the cross section are also in Simpkins and others (1987). B) West to east line of section shown on part of U.S. Geological Survey Mole Lake Quadrangle, 7.5 minute series, topographic. Crandon site is immediately north of Little Sand Lake.

## POST-PLEISTOCENE GEOLOGY

### Wind-blown sediment

Wind-blown sediment consisting of fine sand and silt is present throughout the county. Thickness is generally less than 0.6 m, but can approach 1 m on uplands. Much of this sediment has been transported downslope through creep and slopewash processes and can now be recognized as slopewash or mass-movement sediment. The thickest deposit of loess in the county (nearly 2 m) is exposed in a gravel pit along the present channel and flood plain of the Wolf River (SE1/4 NE1/4 NE1/4 sec. 31, T. 36 N., R. 12 E.); however, some of this thickness may consist of alluvial silt. Wind-blown sediment is not separately distinguished on plate 1.

### Organic sediment

Map unit p consists primarily of grass-sedge, moss, and woody peat. It occurs in low areas, at or near the water table in areas occupied by open bogs or swamps containing white cedar, black spruce, and tamarack. We interpreted the distribution of peat in plate 1 from topographic maps. Peat is typically a few metres thick, but may be less than 1 m thick in many areas. It is underlain by meltwater sand and gravel and lacustrine sand, although a layer of clay, silt, or marl may be present between the peat and the stream or lake sediment. Peat in Forest County probably formed during the late Holocene.

### Sediment deposited by modern streams

Modern streams have deposited sediment in their channels and on their flood plains since deglaciation. This sediment was not distinguished separately on plate 1.

## PLEISTOCENE AND HOLOCENE GEOLOGIC HISTORY

In Forest County, sediment from glaciations earlier than the last part of the Wisconsin is recognized only in the subsurface near the Crandon site, and little is known about its total extent. The late Wisconsin covers the time period between about 22,000 and 12,000 years ago in this part of Wisconsin. These dates are not based on information from Forest County, but from correlation to other dated sites in northern Wisconsin. Attig and others (1985) summarized the late Wisconsin chronology of glacial phases in northern Wisconsin. We will place glacial events in Forest County within that framework and use similar terminology.

The term "phase" is used by Attig and others (1985) to "describe the period of time during which the glacial margin advanced to or paused during wastage, at an ice-margin position, and the time of wastage from that

position." Phases may represent a pause in an ice margin that is wasting back or a considerable advance of the margin.

### Pre- or early Wisconsin Glaciation

Sediment deposited by pre- and early Wisconsin glacial events has been described by Stewart (1973), Mode (1976), and Mickelson and others (1984) in the areas beyond the late Wisconsin ice-margin positions; this sediment is present in Forest County. Formal stratigraphic units in this area of Wisconsin include the Wausau and Edgar Members of the Marathon Formation and the Bakerville and Merrill Members of the Lincoln Formation (Mickelson and others, 1984). Sediment of the Marathon Formation has a source area in the Winnepeg lowlands; sediment of the Lincoln Formation has a source area in the Lake Superior basin (Mickelson and others, 1984; Attig and others, in press; Attig and Muldoon, in press). On the basis of organic silt and clay overlying the Merrill Member at Schelke Bog (Stewart and Mickelson, 1976; Mickelson and others, 1984), all these units are older than  $40,800 \pm 200$  years.

### Late Wisconsin phases

Forest County was covered by advances of the Green Bay and Langlade Lobes during the late Wisconsin. Events in Forest County can be inferred from documented relationships farther to the south in Langlade County. Mickelson and others (1974) and Mickelson (1986) concluded that the Green Bay Lobe advanced to the Hancock ice-margin position in Langlade County, retreated, readvanced to the Almond ("Second") ice-margin position and then retreated before the Langlade Lobe advanced to its maximum extent at the Parrish ice-margin position. The Green Bay Lobe was probably the first to advance into Forest County in the late Wisconsin, although in STS borehole EX-12, a reddish brown, non-calcareous, sandy till underlies sediment that we have identified as till of the Mapleview Member. This deposit may represent an early Green Bay Lobe advance that has been deeply leached, an earlier advance of the Langlade Lobe, or perhaps an advance of the Wisconsin Valley Lobe to this point. The Green Bay Lobe spread northwest and laterally from its central axis in the Green Bay lowland, and up the regional bedrock slope (Thwaites, 1943). Evidence for this advance into the county includes the presence of calcareous, sandy loam till that shows preferred ice-flow direction to the northwest in a gravel pit near Hiles in western Forest County, in two gravel pits near Wabeno in eastern Forest County, and in boreholes east of the Crandon site (15 to 30 m thick) (figs. 13 and 14). Presence of sediment at the Hiles gravel pit probably marks the westward extent of the Green Bay Lobe into Forest County.



The Langlade Lobe advanced across Forest County to the Parrish ice-margin position, cross-cutting the Hancock moraine in Langlade County and burying sediment of the Green Bay Lobe within Forest County. Mickelson (1986) suggested that only a short interval separated the advances of the Green Bay Lobe and Langlade Lobe in Langlade County; this was probably the case in Forest County as well. Stagnant ice left by wastage of the Green Bay Lobe may still have been present when the Langlade Lobe advanced over it and its associated meltwater-deposited sand and gravel; collapse of this sediment may explain some of the large areas mapped as sh on plate 1. (Note orientation of map unit sh in southern Forest County in relation to later Green Bay Lobe ice-margin positions in fig. 13.)

Following the advance of the Langlade Lobe to the Parrish ice-margin position, the ice margin melted back and stabilized or possibly readvanced across Forest County. The next northward ice-margin position is the Summit Lake in Langlade County (fig. 13). Mickelson (1986) concluded that this represents a readvance of the Langlade Lobe. Whether the ice totally withdrew from Forest County to the north and then readvanced to the Summit Lake ice-margin position is not known. However, the presence of two yellowish red, noncalcareous, sandy tills separated by sand and gravel and fine sand in STS borehole EX-2 near the Crandon site suggests that it was a major readvance (fig. 14). Both tills are underlain by similar sequences of fine sand and sand and gravel, suggesting that northward or eastward drainage was blocked and lakes formed in similar fashion during each advance of the ice margin. Attig (1984, 1985) and Attig and others (1985) tentatively correlated the Flambeau ice-margin position in adjacent Vilas County with the Summit Lake ice-margin position in Langlade County. The next northward ice-margin position is the Bittersweet in Vilas County; the Bittersweet correlates with the Elcho ice-margin position in Langlade County.

The Langlade Lobe retreated from the Bittersweet ice-margin position and stabilized at the Stormy Lake ice-margin position in Vilas County. This ice-margin position has been correlated to the Laona moraine (Attig, 1985; Attig and others, 1985). No till has been found in the Laona moraine; hence, it is mapped as sh on plate 1. However, there is little doubt that it represents an ice-margin position. Two unpitted fans also occur along this same ice-margin position to the west (plate 1).

One unnamed ice-margin position is recognized in northern Forest County near Alvin (Attig and others, 1985; plate 1); this position may correlate to the early Mountain phase in adjacent western Florence County as described by Clayton (1986). No significant late Wisconsin ice-margin positions are known north of this location in Forest County.

### *Development of landforms*

The glacial landforms in Forest County are the results of southwestward advance and subsequent northeastward retreat of the Langlade Lobe between about 22,000 and 12,000 years ago. When the Langlade Lobe stabilized at the Parrish, Summit Lake, and Elcho ice-margin positions, all of Forest County was covered by ice in the zone of "streamlining and till lodgement" described by Sugden and John (1976). Drumlins within the county contain sand and gravel of the Nashville and Mapleview Members, which suggests that drumlins were formed in pre-existing material on the landscape. Till was deposited when the ice lobe advanced across the county or when the ice retreated (Whittecar and Mickelson, 1979). Drumlins in the northwestern part of the county contain little if any till on their surfaces (fig. 6), suggesting relatively debris-free ice at this location. Conversely, irregular shapes of drumlins northeast of Argonne may be the result of deposition of supraglacial debris on their surfaces. In either case, drumlin formation occurred within a "zone of erosion" rather than the "zone of deposition." Nelson and Mickelson (1974) constructed an equilibrium ice-sheet profile of the Langlade Lobe at the Parrish ice-margin position that would place drumlin formation in Forest County under wet-based ice about 1,000 m thick.

Sand and gravel deposited by meltwater streams make up most of the sediment in Forest County. This sediment was deposited by meltwater streams as unpitted and pitted plains, hummocks, unpitted fans, and eskers. Features such as eskers and unpitted fans have previously been associated with stagnant ice in regions of hilly topography, such as that found in New England or recently deglaciated areas in Glacier Bay, Alaska (Flint, 1971; Goldthwait and Mickelson, 1982). To account for some of these features in the much lower relief in Forest County, Simpkins (1979) and McCartney and others (1979) originally proposed a abnormally flat ice-surface profile where segments of ice were separated from the main ice margin and down-wasted separately in the lowlands between drumlins. Recent work by Attig (1985) and Attig and others (1985), however, suggests a more continuous ice margin at the Stormy Lake phase (correlative with the ice-margin position at the Laona moraine) that encompasses many of the ice-margin features in Forest County. The retreat of the Langlade Lobe in Forest County is an example of retreat of relatively debris-free ice influenced by the hilly topography of the region, with stagnation of the ice occurring in wide zones near the margin. Many large areas of ice were probably left behind from previous ice advances and after the Langlade Lobe ice margin had wasted back to the north; this resulted in the large areas of pitted and hummocky topography in the county.

## Holocene landscape evolution

Features produced by the Langlade Lobe in Forest County have been modified only slightly in the last 10,000 years. Soils have developed on most of the landscape, and peat and mineral material have continued to accumulate in lowland areas. Lakes occupying pits or kettles in sand-and-gravel sediment will gradually be filled by silt and peat. Over time the drainage system will become more integrated and erosion will reduce the landscape relief and modify most of the glacial topography.

## SUMMARY

At least four distinct Pleistocene lithostratigraphic units overlie Precambrian igneous and metamorphic rock in Forest County. The oldest units are found only in the subsurface and are included in the Marathon and Lincoln Formations. Till of the Marathon Formation is calcareous (6% total carbonate in the coarse silt fraction), dark brown to brown, and has magnetic susceptibility similar to late Wisconsin till units, a higher apparent abundance of expandable clay minerals, and 20 percent less sand (0.063 to 2 mm) than the Lincoln Formation. Till of the Lincoln Formation is noncalcareous to calcareous (11% total carbonate in the coarse silt fraction), yellowish red, and has a higher apparent abundance of expandable clay minerals and 10 to 20 percent less sand (0.063 to 2 mm) than tills of the younger Copper Falls (Nashville Member) and Horicon Formations (Mapleview Member). In contrast, glacial till of the Nashville and Mapleview Members is sandy (at least 70 percent sand, 0.063 to 2 mm fraction), reddish brown to yellowish red, relatively unweathered, has the highest total carbonate content, and has illite as its predominant clay mineral. Till of the Mapleview Member generally has more dolomite clasts and its matrix is more calcareous (20% total carbonate in the coarse silt fraction) than till of the Nashville Member (15% total carbonate). Sand and gravel deposited by meltwater streams and sand deposited in former lakes are associated with all four of these units.

These four lithostratigraphic units record glacial activity in the region from pre-Wisconsin through late Wisconsin time. The earliest recorded event (possibly pre-Wisconsin) was an ice advance from the north or northwest that deposited sediment of the Marathon Formation. After ice retreat, sediment of the Lincoln Formation was deposited during the early part of the Wisconsin by ice flowing from the north. During the late Wisconsin, ice from the Green Bay Lobe advanced from the southeast to the western part of Forest County and deposited sediment of the Mapleview Member of the Horicon Formation. The final recorded event was the

southwestward advance of ice of the Langlade Lobe. Ice and accompanying meltwater from advance and retreat produced the major landforms in the county, such as drumlins, pitted and unpitted plains, hummocks, eskers, unpitted fans, and lacustrine plains. These landforms contain the glacial till and sand and gravel that make up the surface material in the county. Since deglaciation, soils have developed on the landscape and peat and mineral matter have accumulated in lowland areas.

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