Pleistocene Geology of Portage County, Wisconsin

Lee Clayton

UWEX University of Wisconsin—Extension
Wisconsin Geological and Natural History Survey

1986
Information Circular 56

Pleistocene Geology of Portage County, Wisconsin

Lee Clayton

A description of the geologic materials underlying the surface soil and overlying the Precambrian and Cambrian rock in one of Wisconsin's central counties.

Wisconsin Geological and Natural History Survey
Information Circular 56

1986

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

Plates (Inside back pocket)

Figures

Pleistocene Geology of Portage County, Wisconsin

Lee Clayton

ABSTRACT

Portage County, in central Wisconsin, is underlain by Precambrian igneous and metamorphic rock, Cambrian sandstone, and a variety of Pleistocene materials. The eastern and southwestern part of the county is underlain by 0 to more than 70 m of till, stream sediment, and lake sediment deposited during the Arnott and Wisconsin Glaciations during the late Pleistocene; this material is included in the Keene and Mapleview Members of the Horicon Formation. In the northwestern part of the county, the Precambrian is overlain by a few metres of hillslope deposits derived from residuum, which formed at least partly during the Pleistocene.

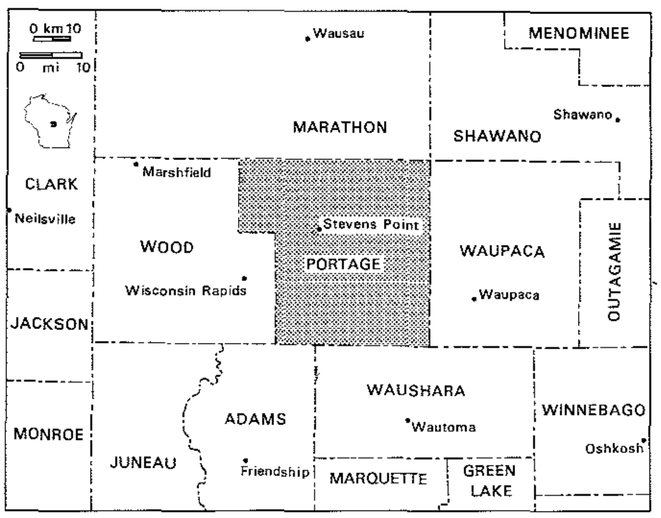

Figure 1 Location of Portage County in central Wisconsin.

INTRODUCTION

This report is a description of the Pleistocene geology of Portage County, which covers an area of 2,100 square kilometres in central Wisconsin (fig. 1). Emphasis is placed on the material below a depth of about 1 m—that is, beneath the surface soil, which has been described in detail by Otter and Fiala (1978).

Portage County is underlain by a variety of igneous and metamorphic rock formed during the Precambrian. In some areas Precambrian rock is covered by Cambrian sandstone. The surface of the Precambrian and Cambrian rock is generally rolling, with a relief of at least 120 m in Portage County.

Throughout the hilly eastern part of Portage County, the Precambrian or Cambrian rock is overlain by several tens of metres of Pleistocene till or stream-deposited sand (fig. 2); in the flat southwestern and north-central part of the county, by a few tens of metres of Pleistocene sand; and in the rolling northwestern part of the county, by no more than a few metres of material derived from the underlying rock. The present land surface ranges in elevation from about 400 m northeast of Almond to 280 m along the southeast edge of the county.

Portage County may have been glaciated several times during the Pleistocene Epoch, but abundant evidence is available for only two glaciations—the Arnott and the Wisconsin. During the Arnott Glaciation, the ice sheet moved out of the Green Bay lowland to within a few kilometres of Stevens Point, depositing the till of the Keene Member of the Horicon Formation. During the last part of the Wisconsin Glaciation, the ice sheet again moved into eastern Portage County, depositing the till and melt-water sediment of the Mapleview Member of the Horicon Formation.

This report is based on several weeks of field work during the summer of 1982 and 22 test holes that were augered from depths of 2 to 37 m (averaging 15 m) during 1983. Samples were analyzed in the Pleistocene laboratory of the Department of Geology and Geophysics of the University of Wisconsin at Madison. Contacts on plate 1 were drawn using 1:20,000 air-photo stereopairs taken in 1968 for the U.S. Department of Agriculture and 1:24,000 topographic maps (with 5-ft or 10-ft contour intervals) made by the U.S. Geological Survey. Additional lithologic information was derived from 1:20,000 soil maps (Otter and Fiala, 1978) and from unpublished township reports and logs of water wells in the files of the Wisconsin Geological and Natural History Survey.

I acknowledge the numerous helpful suggestions made by John W. Attig (Wisconsin Geological and Natural History Survey), who reviewed the manuscript of this report. Peter P. David (Département de géologie, Université de Montréal) provided interpretations of the sand dunes in Portage County.

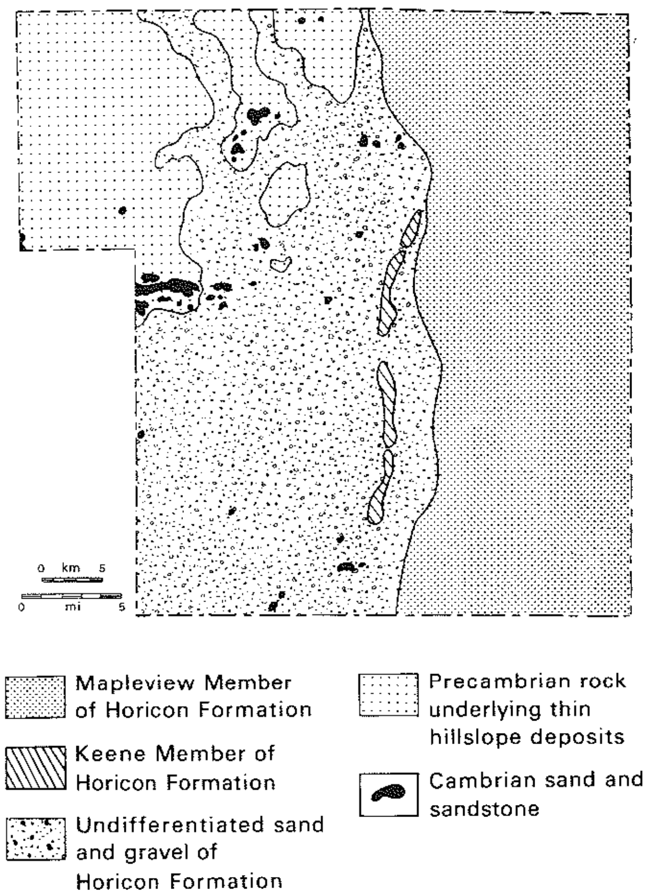

Figure 2 Distribution of stratigraphic units in Portage County.

PRECAMBRIAN MATERIAL

Precambrian rock occurs at or near the land surface in northwestern Portage County (plates 1 and 2), beneath several tens of metres of Pleistocene deposits in the northeastern part of the county, and beneath Cambrian sandstone and Pleistocene deposits in the southern part of the county. Rock in the northwest includes Late Archean gneiss, Early Proterozoic intrusive rock, and Early Proterozoic metavolcanic rock. Granitic rock of the Middle Proterozoic Wolf River Batholith occurs in the northeastern part of the county (Mudrey and others, 1982; Weidman, 1907). Outcrops wider than about 0.1 km are shown on plate 1 by map unit **PC,** but numerous smaller unmarked outcrops occur in map unit **h.**

CAMBRIAN MATERIAL

Late Cambrian sand or sandstone crops out in several places in the western part of Portage County (map unit **C,** plates 1 and 2). The most prominent outcrops are steep-sided hills, such as Lone Rock and Mosquito Bluff in southern Portage County and the unnamed hills several kilometres southwest of Stevens Point. About 45 m of Cambrian stratigraphic section occurs in Mosquito Bluff and a similar length of section occurs below the base of the bluff. About 30 m of Cambrian section is exposed southwest of Stevens Point. The Cambrian section consists largely of marine sandstone and sand, but clay, silt, and sand resulting from the weathering of the underlying Precambrian rock occur beneath the sandstone in some areas, and some conglomerate occurs at the base of the sequence (Holt, 1965, p. 23-24; Weidman, 1907, p. 389-390, 401-403).

OLDER HILLSLOPE DEPOSITS

A layer of hillslope sediment, consisting of sandy, silty, and clayey material, covers much of northwestern Portage County and adjacent parts of Wood and Marathon Counties. This material is older than the postglacial hillslope sediment (see section "Younger deposits--Hillslope sediment"). It is partly equivalent to the Wausau Member of the Marathon Formation of Mickelson and others (1984, p. A2-1). The Wausau material has been interpreted to be till, but in Portage County it consists largely of mass-movement deposits derived from a variety of materials, most of which were in turn derived from local weathered rock debris. This material was first described in detail by Weidman (1907, p. 552-563).

Description

The older hillslope deposits occur on Precambrian rock in the northwestern quarter of Portage County (map unit **h**, plates 1 and 2). On the basis of soil descriptions (Otter and Fiala, 1978), about 150 water-well driller's logs, several outcrops, and six power-auger holes, I judge the hillslope deposits to be typically about 3.5 m thick, with two-thirds of the measurements between 2 and 6 m. Maximum thickness is perhaps around 15 m. The hillslope sediment is either too thin to map or is not present on Cambrian sand and sandstone (map unit **C**, plates 1 and 2).

In Portage County, the older hillslope sediment is typically overlain by about 0.5 m of wind-blown silt; where I have observed the contact, it is fairly sharp. According to driller's logs, it is commonly underlain by several metres of "rotten," "decomposed," "soft," or "cracked" Precambrian rock. Where I have seen the base of this material in outcrop, the contact is sharp.

According to soil-substratum descriptions (Otter and Fiala, 1978) and nine grain-size analyses (fig. 3), a wide range of material is included in this unit. Where it overlies Precambrian rock, the material generally ranges from 3 to 35 percent clay-sized particles (smaller than 0.002 mm), 15 to 70 percent silt-sized particles (0.002 to 0.06 mm), 15 to 65 percent sand-sized particles (0.06 to 2 mm), and 0 to 35 percent gravel-sized particles (larger than 2 mm), depending on the nature of the underlying rock. A thin layer of much sandier material occurs on Cambrian rock.

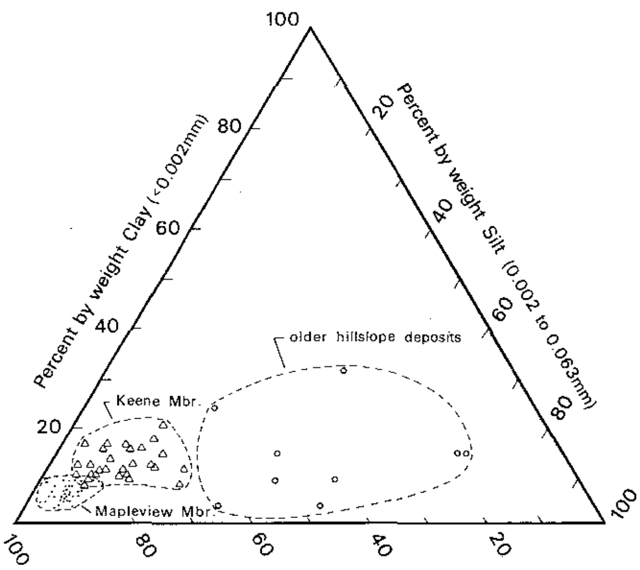

Figure 3 Grain-size analysis of the finer-than-gravel fraction of the older hillslope deposits (circles) and the till of the Mapleview (dots) and Keene (triangles) Members of the Horicon Formation in Portage County.

The gravel fraction contains two separate suites of rock types. One consists of angular pebbles, cobbles, and boulders of the underlying Precambrian rock. The other consists of rounded pebbles and cobbles of highly resistant rock types such as vein quartz, quartzite, chert, and jasper, which are commonly polished and etched by eolian sand blasting. They resemble Cretaceous or Cenozoic stream pebbles and cobbles in the Windrow Formation in southwestern Wisconsin (Thwaites and Twenhofel, 1921). This second suite is far less common than the first in areas where the underlying rock is Precambrian. However, where the underlying rock is Cambrian, any pebbles or cobbles present consist primarily of this second suite.

The older hillslope sediment in Portage County is typically brown, yellowish brown, or olive brown (7.5YR, 10YR, or 2.5Y 5/3 or 4 on the Munsell scale), although it varies greatly over short distances. Convoluted color or grain-size layering is commonly present.

Interpretation

Map unit **h** consists of material that has been interpreted by Weidman (1907, p. 552-554) and Otter and Fiala (1978) to be residuum, the debris weathered from the underlying rock without subsequent reworking or transport. It seems likely, however, that much of this material consists of a variety of materials (most of which were derived from local residuum) that have undergone subsequent mass movement.

I have interpreted the original source of most of the material to have been local residuum because it contains fragments similar to the underlying rock. For example, in areas of Cambrian sandstone, surface pebbles and cobbles consist of fragments of local sandstone, not of nearby Precambrian rock. The most conspicuous exception to this generalization is the rounded quartzose pebbles and cobbles similar to those found in the Windrow Formation. No occurrences of the Windrow are known in the area, but most of these quartzose pebbles and cobbles were probably derived from former nearby occurrences of the Windrow or similar younger units. Some were also derived from the basal Cambrian conglomerate (Weidman, 1907, p. 560-563). This material is thin or absent on Cambrian sand because it contains few easily weathered minerals and therefore produced little residuum.

Although this material was derived from residuum, I do not interpret it as residuum now because of evidence of sorting and transport. Most outcrops of the material show color or grain-size segregations that I interpret to be remnants of bedding. In the few places I have observed the base of the unit, it is sharp, not gradational as would be expected if it were residuum. The mixture of rounded quartzose pebbles with fragments of the underlying Cambrian or Precambrian rock indicates that at least some transport took place. The transporting processes probably included a variety of hillslope processes, such as creep and slope wash. Where Cambrian rock occurs upslope from Precambrian rock, material derived largely from the Cambrian sandstone occurs for tens or hundreds of metres out onto the Precambrian rock. In addition, stream sediment, dune sand, and loess were probably present. Since they were deposited, all these materials have undergone a subsequent cycle of mixing; everywhere that I have observed bedding, it is convoluted, probably because of soil flowage during periods of tundra climate during glaciation. Whatever the process, it apparently has been inactive since the last part of the last glaciation because the contact with the overlying blanket of wind-blown silt deposited then has not been convoluted.

According to Thwaites (1943, p. 119-120), Hole (1943), Stewart (1973), Mode (1976, p. 42-49), and LaBerge and Myers (1983, fig. 59), areas just to the west and north of Portage County have been glaciated. Northwestern Portage County is also likely to have been glaciated, and map unit **h** is likely to contain some till or material derived from till. However, I have observed no till, and the great bulk of the unit is not till.

The age of this material is uncertain, but it is likely that it is a wide range of ages. It is older than the overlying late Wisconsin wind-blown silt. It underwent solifluction during the Wisconsin or earlier glaciations. The original residuum from which most of this material was derived formed during the Pleistocene or earlier during the Cenozoic, and map unit **h** also includes some residuum formed before the deposition of the Cambrian sandstone.

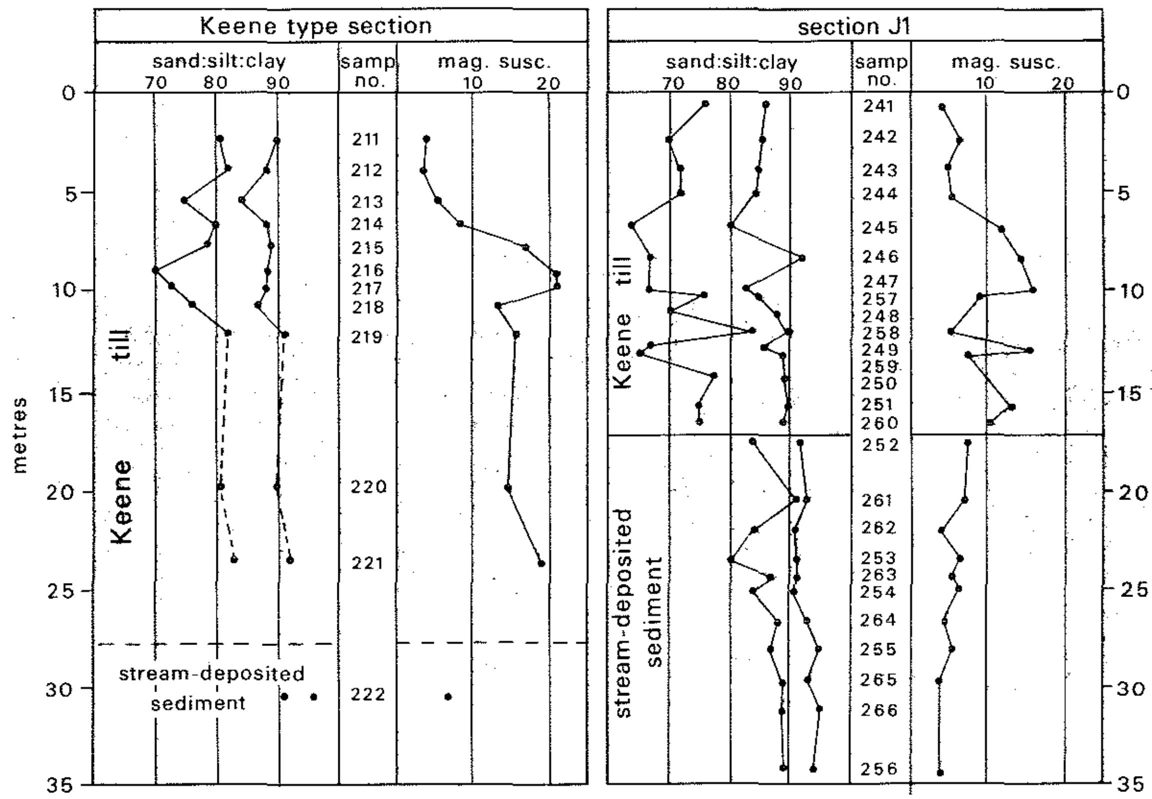

Figure 4 Description of the Keene Member. Type section is an auger hole along the road on south side of SE1/4 lot 23, sec. 30, T. 22 N., R. 9 E. (equivalent to SE1/4SW1/4SW1/4E1/2 sec. 30, T. 22 N., R. 9 E). Section J1 is an auger hole in NE1/4 lot 5, sec. 19, T. 23 N., R. 9 E. (NE1/4NE1/4NE1/4W1/2 sec. 19, T. 23 N., R. 9 E.); samples provided by D.J. Masterpole: Percentage of sand (0.063 to 2 mm), silt (0.002 to 0.063 mm), and clay (smaller than 0.002 mm) in the finer-than-gravel fractions. (Magnetic susceptibility expressed in arbitrary units of the Pleistocene laboratory of the Department of Geology and Geophysics of University of Wisconsin at Madison.)

HORICON FORMATION

The Horicon Formation was named by Mickelson and others (1984) to include brown or reddish brown, sandy, calcareous sediment of eastern Wisconsin. It consists of till, stream sediment, and associated material deposited beneath or around the margin of the Green Bay Lobe of the Laurentide Ice Sheet. In Portage County, the formation contains two named members, the Keene and Mapleview Members, plus sand not here included in any named member.

Till of Keene Member

The Keene Member is here named to include the noncalcareous and slightly calcareous till of the Arnott moraine west of the western-most occurrence of the more highly calcareous till of the Mapleview Member (fig. 2). The unit is named after the community of Keene in sec. 30, T. 22 N., R. 9 E. The type section is an auger hole southeast of Keene (fig. 4).

Description

The Keene Member occurs in a north-south ridge in central Portage County (map unit **gk**, plate 1). It presumably also occurs below the Mapleview Member in the eastern part of the county, but it has not been identified. On the basis of the type-section auger hole (fig. 4), several holes augered by Masterpole (1983), and several water-well logs in Survey files, the Keene Member is typically 10 to 30 m thick. It has not been seen in contact with the till of the Mapleview Member, but the contact with overlying sand units of the Horicon Formation is sharp. Because of poor recovery of samples from the auger holes mentioned above, the lower contact is poorly known, but the Keene Member apparently rests on sand of the Horicon Formation in most places.

The till of the Keene Member is most typically brown or reddish brown (5 or 7.5YR 4/4 on the Munsell scale) and is unbedded. It consists of about 2 to 20 percent gravel-sized material (larger than 2 mm). The smaller-than-gravel fraction (fig. 3) consists of about 65 to 85 percent sand-sized material (0.06 to 2 mm), 5 to 25 percent silt-sized material (0.002 to 0.06 mm), and 8 to 17 percent clay-sized material (smaller than 0.002 mm). The preponderant grain size is medium sand (0.25 to 0.50 mm); the smaller-than-gravel fraction consists of about 25 to 35 percent medium sand.

Pink granitic rock derived from the Wolf River Batholith in northeastern Portage County and counties to the northeast (fig. 5) is a conspicuous constituent of the coarser fractions of the Keene Member. Boulders as large as 2 m are common on the surface and consist primarily of Wolf River granitic rock on the southern part of the Arnott moraine and black igneous rock on the northern part of the moraine. The ratio of dark rock to light igneous and metamorphic rock is typically 0.1 to 0.3 in the gravel fraction (larger than 2 mm) and 0.1 to 0.2 in the very-coarse-sand fraction (1 to 2 mm) at the type section (fig. 4). Rounded quartz grains derived from the Cambrian formations (fig. 5) are most abundant in the fine-, medium-, and coarse-sand fractions; they constitute about 5 to 15 percent of the very coarse sand at the type section.

The relative magnetic susceptibility, which is a measure of the magnetic material present (primarily magnetite), is between 3 and 6 within 6 m of the surface, but is between 8 and 21 at a depth of 6 to about 20 or 25 m (fig. 4; Masterpole, 1983). (Magnetic susceptibility is here expressed in the arbitrary units of the Pleistocene laboratory of the Department of Geology and Geophysics of the University of Wisconsin at Madison.)

The sand and gravel fractions also contain a few percent chert that was derived from Ordovician formations to the northeast (fig. 5), but carbonates are absent from all observed surface exposures and from most of the type section. A few grains of calcite or dolomite were observed in the fine-sand fraction between a depth of 7 and 13 m in the type section. The sand and gravel fractions consist of several percent dolomite below a depth of about 10 m in an auger hole in lot 5, sec. 19, T. 23 N., R. 9 E. (fig. 4).

The Keene Member is distinguished from the Mapleview Member of the Horicon Formation by the

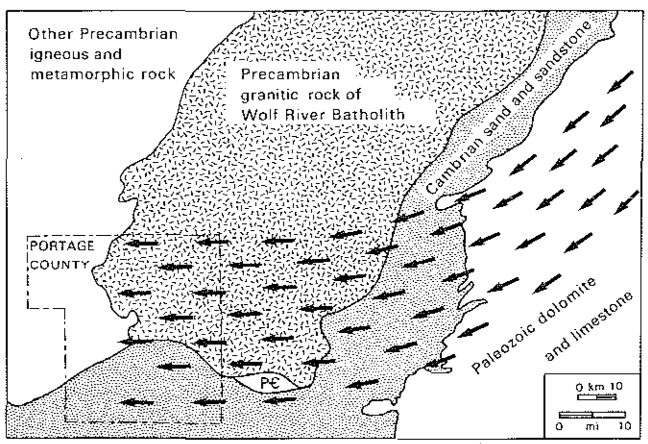

Figure 5 Source of till in Portage County. Arrows show probable direction of glacial movement. Pre-Pleistocene rock from Mudrey and others (1982).

absence of near-surface carbonates. In addition, it is generally finer grained (fig. 2), looks more weathered, and has greater magnetic susceptibility at depth.

Interpretation

Otter and Fiala (1978) interpreted the material in the Keene Member north of sec. 7, T. 22 N., R. 9 E. to be residuum derived from igneous rock. However, well logs indicate that at least a few tens of metres of Pleistocene sediment–not igneous rock–is present here (Nelson, 1978). Most geologists have interpreted it to be till, and the ridge made up of Keene till has been interpreted to be an end moraine–the Arnott moraine–because of its similarity to the nearby moraines formed during the last part of the Wisconsin Glaciation (Weidman, 1907, p. 456-459; Thwaites, 1943, p. 120). As noted by Thwaites (1943, p. 120), the Arnott moraine was formed by the Green Bay Lobe, not by a glacier from the west, because it is composed primarily of material derived from the Wolf River Batholith and Cambrian units to the east.

The Arnott Glaciation has never been dated, but it occurred long before the last part of the Wisconsin Glaciation and probably before the first part as well. This interpretation is based on the degree of erosion of the Arnott moraine and the degree of weathering of the till.

The Arnott moraine is about 1 km wide and 10 to 25 m high, or roughly the same size as the Hancock Moraine, the outermost late Wisconsin moraine (fig. 6). If the two moraines originally had similar topography, the Arnott moraine has undergone enough erosion to remove all undrained depressions and small-scale hummocks, the larger of which, at least, are still preserved on the Hancock moraine (Weidman, 1907, p. 458; Thwaites, 1943, p. 120). That is, at least several metres more erosion has occurred since the Arnott moraine was formed than has occurred since the Hancock moraine was formed.

Although much of the early weathering zone has been eroded from the Arnott moraine, the remaining Keene till is still obviously more weathered than the Mapleview till (Weidman, 1907, p. 258; Thwaites, 1943, p. 120). In outcrop, Keene till is much more variably colored than Mapleview till, with differential concentrations of iron oxides along joints and across other permeability discontinuities. Bright-colored oxide stains are most common in the upper 10 m of the Keene type section. Weathered-looking feldspar grains are much more abundant in the Keene till than in the Mapleview till, especially in the upper 10 m of the Keene type section.

The leaching zone on the Keene Member is several times as thick as that on the Horicon Member. The Keene till is less permeable than Horicon till, which results in less rapid leaching. However, the Keene till may originally have had less carbonate, which results in more rapid leaching. In any case, the differences in leaching indicate that the Keene Member is much older than the Horicon Member, perhaps several times as old. That is, the Arnott Glaciation probably occurred before the Wisconsin Glaciation, and the weathering zone may have been formed, at least in part, at the same time as the Sangamon weathering zone of Illinois. The till is more highly leached at the type section than at the auger hole J1, 13 km to the north (fig. 4), probably because the till is sandier and more permeable at the type section than to the north.

The sand beneath the till of the Keene Member (fig. 4) was deposited by melt-water rivers during the Arnott Glaciation or during earlier glaciations. The sand of map unit **sa** (plate 1) west of the Arnott moraine is interpreted to have been deposited during the Arnott Glaciation because it slopes westward away from the moraine, but it might also include postglacial material resulting from the erosion of the moraine. Farther west it has been buried under the sand plain sloping westward from the late Wisconsin moraines (plate 1). However, no attempt has been made to map the sand bodies in Portage County as part of the Keene or Mapleview Members because they are lithologically difficult to distinguish; rather, they are considered an undifferentiated part of the Horicon Formation (plates 1 and 2).

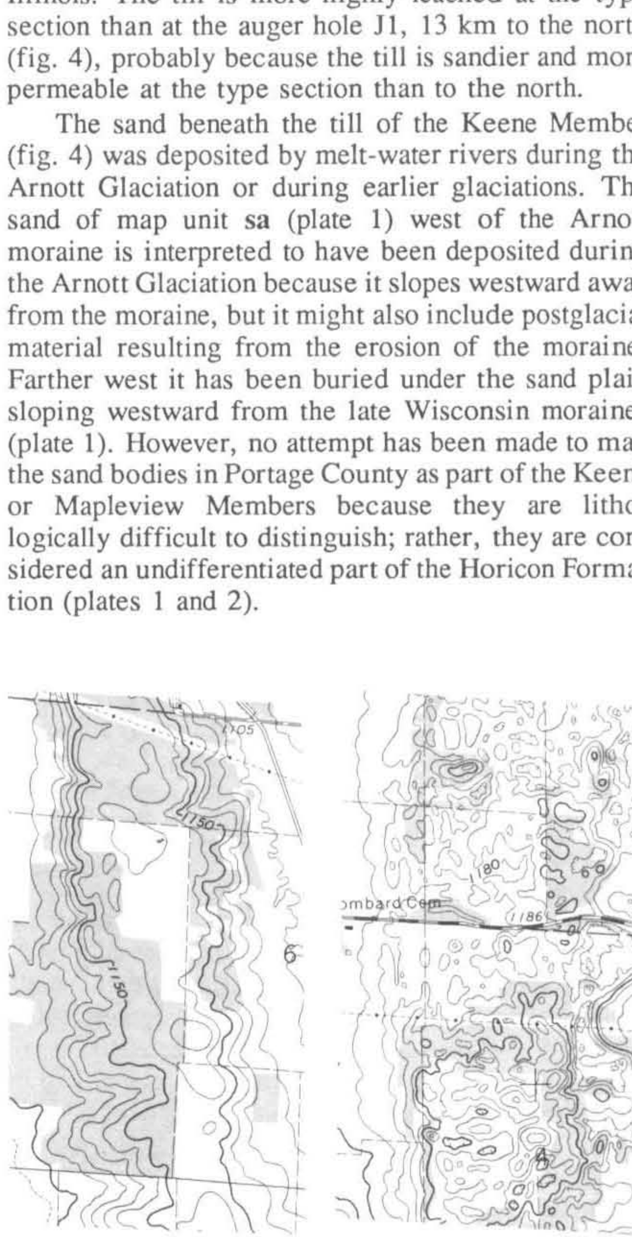

Figure 6 Comparison of topography of Arnott moraine (left) and Hancock moraine (right). From south-central part of U.S. Geological Survey Arnott Quadrangle (7.5 minute; 10-ft contour interval), at north edge of T. 22 N., R. 9 E. Areas shown are 1.0 km wide.

Till of Mapleview Member

The Mapleview Member has been named by Mickelson and others (1984) to include the calcareous sandy till and associated deposits of southeastern Langlade County, northwestern Menominee County, western Shawano County, and eastern Marathon County. It also continues northward to Florence County and beneath the Kewaunee Formation around Green Bay. Its southern extent is unclear, but it may include material as far south as Rock County.

Description

The till of the Mapleview Member occurs in the eastern half of Portage County (fig. 2; map units **gh**, **ga**, and **gd**, plate 1). It is most typically brown (7.5YR 4 or 5/4 on the Munsell scale) and unbedded. It consists of about 5 to 20 percent gravel-sized material (larger than 2 mm). The smaller-than-gravel fraction (fig. 3) consists of about 80 to 90 percent sand-sized material (0.06 to 2 mm), 5 to 10 percent silt-sized material (0.002 to 0.06 mm), and 5 to 10 percent clay-sized material (smaller than 0.002 mm). The preponderant grain size is medium sand (0.25 to 0.50 mm), which makes up about 35 to 40 percent of the smaller-than-gravel fraction (fig. 7b).

Pink granitic rock derived from the Wolf River Batholith in northeastern Portage County and counties to the northeast (fig. 5) is a conspicuous constituent of the coarser fractions of the Mapleview Member, especially in the northern part of the county. Boulders of Wolf River granitic rock as large as 2 m are common on the surface. The ratio of dark rock to light igneous and metamorphic rock in the gravel fraction (larger than 2 mm) is typically 0.2 to 0.4; in the very-coarse-sand fraction (1 to 2 mm), typically 0.1 to 0.3. Judging by the likely paths of glacial movement (fig. 5; Prest, 1969), the dark rock was derived from eastern Lake Superior or the area to the northeast of Lake Superior or from unmapped occurrences in eastern Portage County or adjacent Waupaca County. Rounded quartz grains derived from the Cambrian formations (fig. 5) are abundant in the fine-, medium-, and coarse-sand fractions; they constitute about 5 to 15 percent of the very coarse sand.

Relative magnetic susceptibility, which is a measure of the amount of magnetite present, is generally between 5 and 7 in Mapleview till in Portage County.

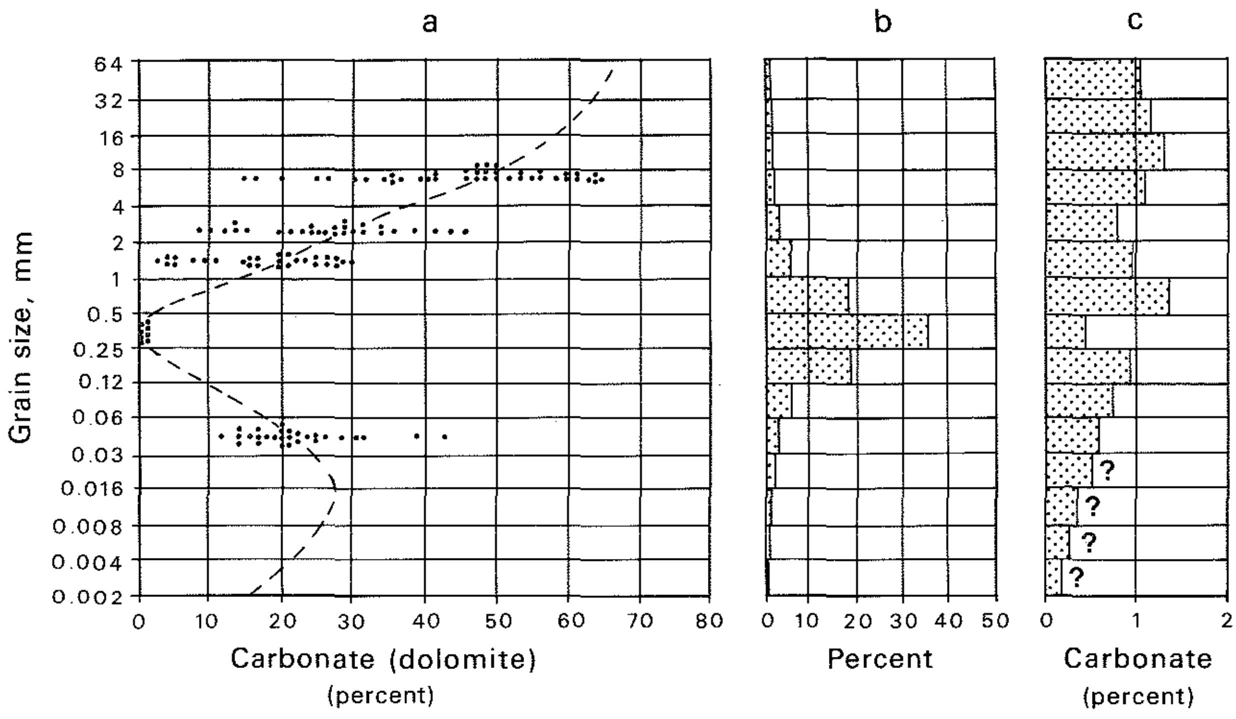

Figure 7 Carbonate in the Horicon Formation in Portage County. a: percentage of carbonate (largely dolomite) as a function of grain size. Coarser than 6 mm: pebble counts in road-materials reports on file with the Wisconsin Geological and Natural History Survey; mostly melt-water deposits; may include partly leached samples. 1 to 4 mm: till fractions counted under microscope (about 100 grains each). 0.25 to 0.5 mm: Chittick analyses of till fraction, checked by counting several hundred grains under a microscope for each sample. 0.03 to 0.06 mm: Chittick analyses of till fraction. Dashed line is approximate average value. b: average of grain-size analyses of 37 till samples; values above 2 mm and below 0.06 mm are prorated from total gravel and silt values. c: product of a and b: the part of the total carbonate (roughly 10 percent) in each grain-size fraction in typical Horicon till in Portage County.

The carbonate material in the Mapleview Member consists primarily of dolomite (rather than calcite) derived from the Ordovician formations to the northeast (fig. 5). Unleached Mapleview till consists of roughly one-tenth dolomite. The dolomite content of the various size fractions is shown in figure 7. Roughly half the pebble fraction and a fifth of the very-coarse-silt fraction consists of dolomite; however, only about 1 percent of the medium-sand fraction consists of dolomite because of the concentrations of Cambrian quartz grains in this fraction. Most of the carbonate in the till is in the sand and gravel fractions (fig. 7c). Somewhat more dolomite is present in the Mapleview till in southern than in northern Portage County. Mapleview till has been leached of carbonates to depths ranging from 0 to at least 7 m, depending largely on position in the landscape, with an average value of roughly 2 m.

Landforms

Mapleview till in Portage County has several different surface forms. The most conspicuous are moraines (end moraines), which are ridges of till formed at or near the margin of a glacier. They are indicated in two different ways on plate 2: the Hancock and Almond moraines are shown as map units **ga** and **gh;** the smaller Elderon moraines are shown by a line with cross bars.

The westernmost of the moraines composed of Mapleview till is the Hancock moraine (plate 1). It ranges from about 0.2 to 1.5 km wide (averaging nearly 1 km wide) and is typically between 6 and 21 m high (fig. 6). The next moraine to the east, the Almond, ranges from about 0.2 to 0.7 km wide (averaging about 0.5 km); it is typically between about 5 and 18 m high. The Elderon moraines are typically 0.1 to 0.2 km wide. As viewed from the west, they are generally only a few metres high; viewed from the east, they are generally between 3 and 15 m high.

The Hancock and Almond moraines can be traced almost continuously north to Langlade County and south to near Coloma in Waushara County. They nearly merge with each other near Polonia in north-central Portage County (plate 1), but there seems little doubt that the two moraines north of Polonia correlate with the two south of Polonia. The moraines here referred to as the Hancock and Almond were called the "Outer" and "Second" moraines by Thwaites (1943), who suggested that they correlate with the Brooklyn and Johnstown moraines of southern Wisconsin. However, it seems as likely that the Hancock correlates with the Johnstown, and the Almond correlates with the Milton moraine. (The moraines are renamed here because, in different places, the Hancock is either the first or second from the west and the Almond is the first, second, or third.)

The Elderon moraines, as a group, can be traced northward to Langlade County and southward through Waushara County (Thwaites, 1943), but individual moraines are discontinuous and difficult to correlate. Correlations are partly based on matching stream surfaces, deltas, and lake outlets formed west of each moraine.

The thickness of the till in the moraines is generally unknown, but it is probably roughly equivalent to the height of the moraines--that is, several metres to perhaps a few tens of metres thick. This is confirmed by the masking effect of the moraines: where the moraines cross pre-existing landforms, they largely bury them. In contrast, the till behind the moraines is probably considerably thinner: the topography is much more complex than in the moraines, as if pre-existing topography is not masked to the same degree as in the moraines. Till overlying sand has been seen in outcrop in several places, and some water-well logs (plate 2) can be interpreted to show thin till overlying sand. However, the till of Portage County is so sandy that it is generally difficult to distinguish it from stream sediment in the water-well logs. Nevertheless, I gained a general impression that the till of the last glacial advance is generally only a few metres thick behind the moraines.

A few drumlins are present along the east edge of the county (plate 1), but they are more abundant to the east in Waupaca County. The drumlins are several hundred metres long, a few hundred metres wide, and roughly 10 m high, with their long axis oriented east-west (plate 1). The drumlins were formed on larger till ridges that are typically 1 to 2 km wide, several kilometres long, and a few tens of metres high. These larger ridges are also oriented east-west and occur primarily east of the Almond moraine. They appear on plate 1 as elongated areas of till surrounded by stream sediment, such as the one extending eastward from the north edge of sec. 29, T. 24 N., R. 10 E. The origin of these ridges is unknown. They may be partly the result of glacial erosion and deposition, but they are more likely till remnants resulting from erosion by subglacial rivers in the intervening areas (see the later discussion of tunnel channels).

Stream sediment

The sediment of melt-water streams in the Horicon Formation occurs throughout eastern and central Portage County (map units **su, sc, so,** and **sa** on plate 1). On plates 1 and 2, the sediment has not been subdivided into separate members, but most of it is part of the Mapleview Member, as originally defined

(Mickelson and others, 1984). None of it is included in the Keene Member, as defined here, but melt-water sediment of the Arnott Glaciation has been distinguished on plate 1 (map unit **sa**) on the basis of its position in the landscape; lithologically, however, the Arnott melt-water deposits have not been distinguished from the melt-water deposits of the Mapleview Member. Similarly, material deposited by the Wisconsin River (map unit **so**, plate 1) was derived from Marathon and Langlade Counties and therefore may have some characteristics of the Copper Falls Formation of Langlade County (Mickelson, 1987), but it has here been included in the Horicon Formation because it cannot be distinguished from the Horicon on the basis of presently available lithologic information.

Most Horicon stream sediment is slightly gravelly sand (with between a trace and 10 percent of the material larger than 2 mm). A small proportion of it is gravelly sand (10 to 30 percent larger than 2 mm) or sandy gravel (30 to 70 percent larger than 2 mm). Grain size decreases downstream, away from the original source at the edge of the glacier (stream-flow direction is indicated on plate 1 by arrowheads). Stream flow was southward down the Wisconsin River, southwestward from the Hancock and Almond ice margins in the northern part of the county, and westward from the Hancock and Almond ice margins in the central and southern part of the county. After the glacier melted eastward from the drainage divide at the Almond moraine, drainage shifted southward; melt water from the Elderon ice margins flowed westward a short distance and then southward between the ice and the Almond moraine. In the western half of Portage County, Horicon stream sediment contains pebbles no more than 1 or 2 cm in diameter, but within about 5 km of the Hancock moraine, deposits with pebbles as large as 5 cm are common, and sandy gravel with cobbles and boulders between 20 and 50 cm is common near the moraines. Small and intermittently worked construction-aggregate pits occur throughout the eastern part of the county, but most of the large pits occur in the center of the county, just west of the Hancock and Almond moraines.

The mineralogy of Horicon stream sediment is similar to that of the equivalent size fractions in the Horicon till, described above. The proportion of dolomite in unleached stream sediment has a wide range of values depending on the grain size (fig. 7a). Unleached sediment consisting primarily of medium sand has only about 1 percent dolomite grains; unleached sediment consisting of large pebbles is half dolomite. Consequently, there is a wide range of leaching depths. Sandy gravel is commonly leached at a depth of 1 m or less; medium sand may be leached of dolomite to a depth of more than 10 m.

Most of the Horicon stream sediment shown on plate 1 was deposited by shallow, braided, melt-water streams with abundant bedload. The resulting sediment is typically flat bedded where it consists primarily of gravel-size material, but cross bedding is common where it consists largely of sand. Much of the Horicon stream sediment can be considered outwash because it was washed out of the glacier by supraglacial, englacial, and subglacial melt-water streams, but a large proportion of it was probably eroded from previously deposited fluvial sediment and till by subglacial melt-water streams. Till was deposited over all of eastern Portage County during each glacial advance, but it was largely removed from low areas by subglacial streams, leaving till mainly in the east-west ridges indicated by map unit **gd** on plate 1.

Most of the Horicon stream sediment shown on plate 1 was deposited west of the margin of the actively moving glacier. Where deposited on solid ground (map unit **su**, plate 1) the topography is nearly flat. Gentle depressions and rises no more than about 1 m high are remnants of the original system of braided-channel scars. In most areas, the channel pattern is obscure because it has been partly obliterated by subsequent wind erosion, by the deposition of a thin layer of wind-blown sand or silt, and by the churning action of permafrost (ice-wedge polygons, described below, can be seen from the air in a few places). In a few areas, however, the channel pattern is well preserved, as shown in figure 8.

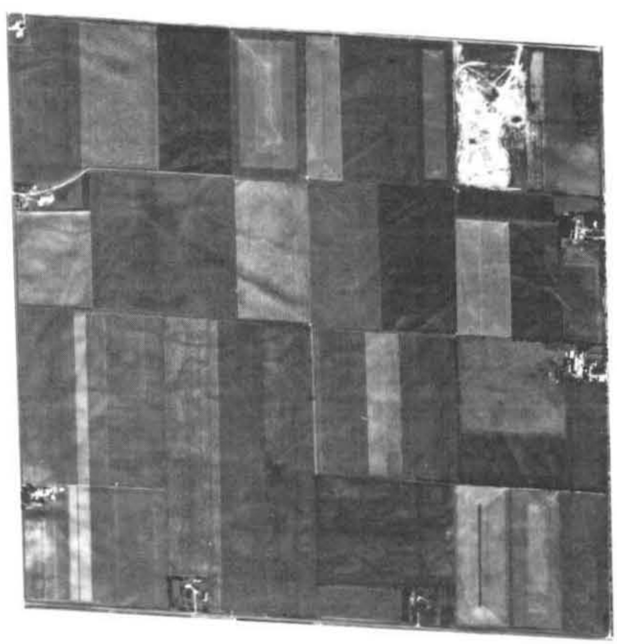

Figure 8 Braided-stream pattern in sec. 32, T. 23 N., R. 9 E., west of Hancock moraine (U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service aerial photograph BIF-2JJ-151). Area shown is 1.6 km wide. North is up.

Where deposited on buried masses of stagnant glacial ice (map unit **sc**), the topography is hilly because of the collapse of the stream sediment as the ice melted. The difference in elevation between a collapsed stream-sediment surface and the adjacent uncollapsed surface is approximately the former thickness of buried ice. Where the collapsed stream sediment is exposed in gravel pits, the bedding is generally intact except for faults that are typically spaced metres or tens of metres apart. This indicates that collapse occurred with slightly deformed flood-plain surfaces separated from each other by fault scarps. A system of fault scarps is seldom apparent today, however, because of subsequent modification of the landscape by hillslope processes, producing the rolling topography that characterizes collapsed stream sediment.

The above is a discussion of stream sediment deposited beyond the margin of the glacier. The streams flowing behind the margin (under the glacier) eroded in some areas and deposited in others. Where the streams eroded, the channel, cut into the subglacial material and roofed by glacial ice, is referred to as a tunnel channel. Where erosion continued until stream flow ceased, the tunnel channel may be preserved, but where erosion was followed by deposition, the channel may have been partly or completely filled. Where deposition rather than erosion occurred, or where deposition occurred after the tunnel channel filled, a ridge, or esker, resulted; eskers occur in eastern and northern Wisconsin, but no good examples of eskers are present in Portage County.

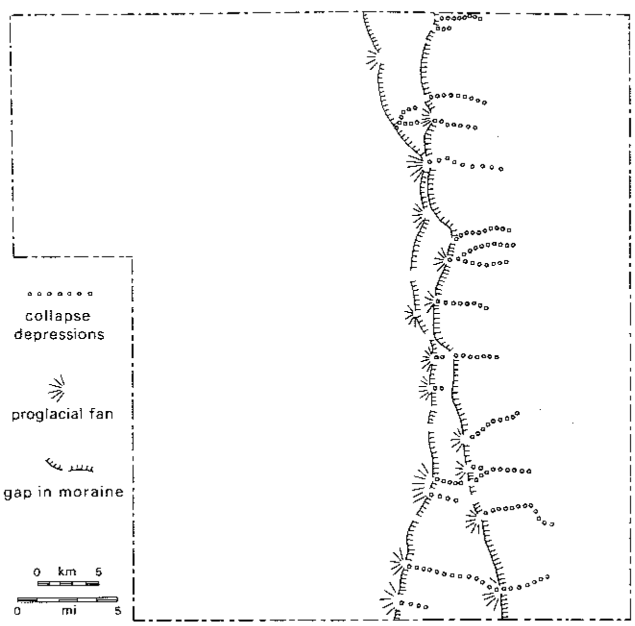

Figure 9 Evidence of tunnel channels associated with Hancock and Almond moraines.

Tunnel channels discharged at the glacier margin during the time that the Hancock and Almond moraines formed–no well developed tunnel channels are associated with younger moraines (fig. 9). The routes of the tunnel channels are marked by rows of deep collapse depressions in areas of collapsed supraglacial stream sediment, and the mouth of each is marked by a large fan of proglacial stream sediment (fig. 9; map unit **su** on plate 1).

The form of the tunnel channels is not well preserved in Portage County, but judging by the size of the rows of collapse depressions and the size of the gaps cut through the Hancock and Almond moraines, they were typically about 0.5 km wide, at least 10 km long, and perhaps a few tens of metres deep. This indicates that the melt-water rivers were much larger than the typical Wisconsin esker river, more similar in size to the spillways carrying catastrophic floods from proglacial lakes (Teller and Clayton, 1983). That is, the tunnel channels probably represent the sudden discharge of subglacial water ponded behind a zone about 10 km wide where the glacier was frozen to its bed. A narrow thawed-bed zone, on the order of 1 km wide, probably existed west of the frozen-bed zone, where the moraine formed (Clayton, Mickelson, and Lundqvist, 1985). Eskers and drumlins are generally absent in the frozen-bed zone, but are common east of it, near the east edge of Portage County (fig. 10). A

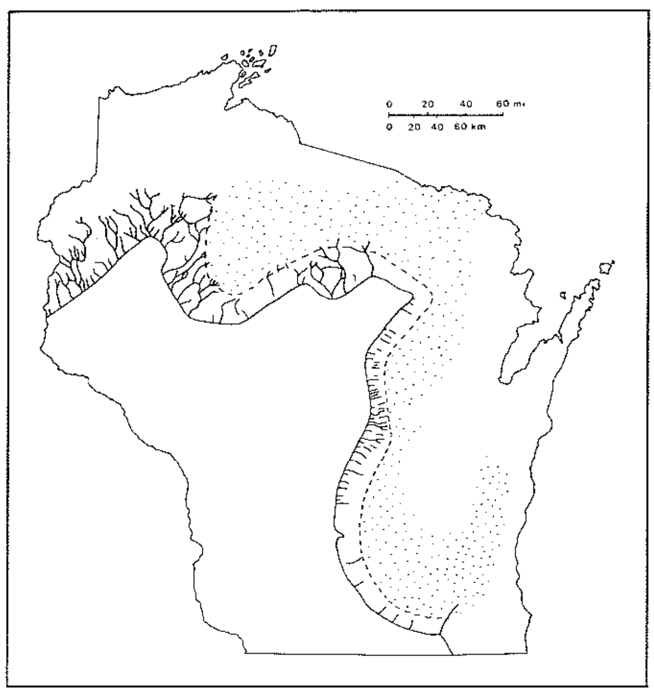

Figure 10 Tunnel channels in Wisconsin, between the outermost extent of ice during last part of Wisconsin Glaciation (solid line) and the drumlin zone (dotted area, bounded by dashed line).

similar conclusion was reached by Wright (1973) for the tunnel channels formed at about the same time in Minnesota.

Offshore sediment

The glacier that deposited the Horicon till carried mostly sand, and, as a result, little silt and clay was available to deposit in proglacial lakes. Clay is reported in some water-well logs from eastern Portage County (plate 2), but silt and clay deposited in lakes is seldom seen in outcrops. A rare example occurs in SW1/4SE1/4NW1/4 sec. 8, T. 22 N., R. 10 E., 7 km southwest of Amherst, where 4 m of laminated silt occurs in a roadcut. According to Otter and Fiala (1978), silt occurs in some of the ice-walled-lake plains near Polonia (map unit **ot,** plate 1). Most of the areas thought to have been occupied by glacier-dammed lakes, however, are underlain by sand or slightly gravelly sand (map units **od, ou,** and **oc,** plate 1). The sand is rarely well exposed; as a result, there is little lithologic basis for distinguishing stream sand from offshore sand.

In eastern Portage County, map units **ou** and **oc** are shown on plate 1 where proglacial lakes are judged to have occurred on the basis of the configuration of the ice margins shown in the maps near the end of this report. Braided channel patterns can be seen from the air in some places where stream sediment is mapped (fig. 8), but they are absent in areas thought to have been occupied by proglacial lakes.

Offshore sand probably also occurs in southwestern Portage County, in the area occupied by Lake Wisconsin (map unit **ou,** plate 1). Lake Wisconsin existed when the Green Bay Lobe moved onto the east end of the Baraboo Range, damming the Wisconsin River valley (fig. 11). The outlet was the East Fork Black River in Jackson County, at an elevation of about 296 m.

If the earth's crust had remained stable since then, no Lake Wisconsin sediment would exist above that elevation, and none would occur in Portage County. However, the weight of a glacier did depress the earth's crust, for perhaps 200 km beyond the edge of the glacier (Andrews, 1975, p. 99), causing the crust to tilt. A tilt rate of roughly 0.5 m/km to the northeast seems likely. This accommodates the Black River outlet, the outlet at the east end of the Baraboo Range, possible shore features in Adams County, and a break in slope in Adams, Waushara, and Portage Counties.

The break in slope occurs between elevations of 320 and 330 m in southwestern Portage County. Above the break in slope, the surface of the stream sediment (map unit **su,** plate 1) slopes westward at about 1.5 to 2 m/km, the slope below the break (map unit **ou**) is about 0.5 m/km to the west. East of the break in slope, the scars of braided melt-water channels can commonly be seen from the air or on topographic maps, but they are lacking to the west. The stream sediment east of the break in slope is too coarse or too poorly sorted to have been the source of much wind-blown sand, but to the west wind-blown sand is abundant (map unit **ws,** plate 1).

Lake clay is reported in water-well logs at a depth of 3 to 18 m east of New Rome in northern Adams County and southwestern Portage County (plate 2, cross section S21). This clay would be above the level of Lake Wisconsin if there had been no crustal tilting, but it would have been deposited in about 12 m of water if the crust tilted at about 0.5 m/km.

If Lake Wisconsin did extend as far northeast as the break in slope in Portage County, it is likely that map unit **ou** (plate 1) is offshore sand deposited by dense underflow currents (turbidity currents). Melt-water rivers entering Lake Wisconsin were dense because they were cold and because they contained a large amount of suspended sediment, causing the water to sink to the bottom of the lake as underflow currents. The stream deposits consist largely of fans with their apexes at the mouths of tunnel channels. Therefore, the bulk of the stream deposits and the bulk of the underflow deposits consist of sediment deposited during the sudden discharge of large amounts of

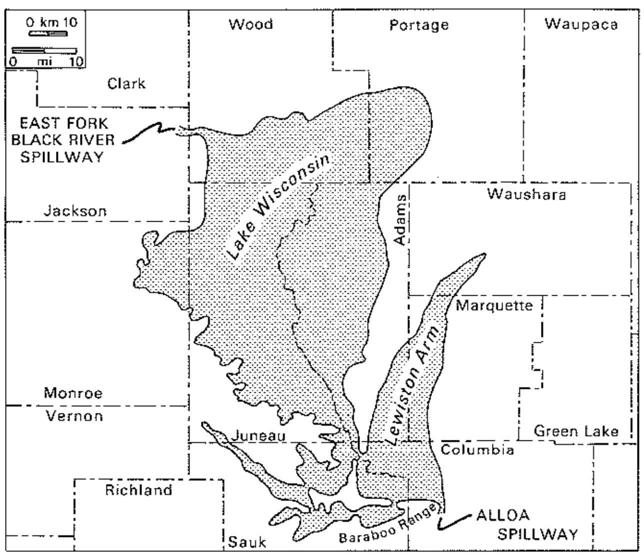

Figure 11 Approximate location of Lake Wisconsin, based on hypothetical tilt due to crustal rebound of about 0.5 m/km to northeast (N 65° E). The Lewiston Arm was contemporaneous with the later phases of the main body of Lake Wisconsin, between the time the Green Bay Lobe wasted back from the Johnstown moraine and the time the lakes drained through the Alloa spillway. It was at the same level as the rest of Lake Wisconsin; its northeastern extent is uncertain.

water from the tunnel channels. As a result, the underflow currents were capable of carrying sand as bedload many kilometres out into the lake, forming the nearly level plain below the break in slope (map unit **ou,** plate 1).

YOUNGER DEPOSITS

The great bulk of the near-surface material in Portage County was deposited as a direct result of the Wisconsin Glaciation. During the glaciation other material was being deposited beyond the immediate influence of the glacier, and after glaciation various materials were deposited in some parts of the county. These are discussed in the following sections. None of these materials have as yet been formally included in any lithostratigraphic unit.

Hillslope sediment

If the topography of the glacial deposits of Portage County is compared with the topography of material recently deposited at the edge of modern glaciers, it is obvious that the modern glacial deposits are much fresher looking than those of Portage County. That is, a considerable amount of hillslope erosion has taken place since the last glaciation. The glacial topography of Portage County is also considerably less fresh than that formed during the very last part of the Wisconsin Glaciation in northern Wisconsin, indicating that much of this erosion took place soon after the last glacial ice had melted but while permafrost was still present. Permafrost prevented the subsurface drainage of rain water and snow melt, resulting in intense slope-wash activity and causing the surface material to be water logged and therefore subject to mass movement, including shallow soil flowage and creep. At the end of the Wisconsin Glaciation, the rate of hillslope erosion greatly decreased, but some continues to the present day, especially on cultivated land.

Evidence of permafrost in Portage County is of two main types. Black (1965) reported well developed ice-wedge casts in a borrow pit in the SW1/4SE1/4 sec. 7, T. 22 N., R. 9 E. No pit exists in that location; he probably meant the overgrown pit on the east side of the Arnott moraine at the south edge of lot 14, sec. 7, T. 22 N., R. 9 E. Ice-wedge polygons show up on aerial photographs in a few places in the county (indicated with a star symbol on plate 1). They are typically 10 to 100 m in diameter, and most occur on melt-water sediment west of the Hancock moraine (fig. 12). In addition, the convoluted bedding in the Marathon Formation (discussed above) is probably the result of soil flowage in the presence of permafrost.

The older hillslope deposits in northwestern Portage County have been included in map unit **h** (plate 1), but the younger ones in eastern Portage County occupy areas that are too small to be shown on plate 1. Most of these were deposited in low points in the landscape, many of which are now covered by peat. However, parts of southeastern Portage County were entrenched by east-flowing streams as the last glacial ice was melting (map unit **sp,** plate 1), producing steep hillslopes, the bases of which are covered with material eroded from the slopes. Few exposures of this material have been seen, and its characteristics are largely unknown, but presumably it resembles the material in hillslopes from which it was derived and consists primarily of sand and is generally noncalcareous.

Early postglacial stream sediment in eastern and southwestern Portage County

The flood plains of melt-water streams in Portage County (map unit **su,** plate 1) generally slope westward away from the glacier, but in parts of southeastern Portage County slightly younger surfaces slope eastward down the regional slope into the Green Bay lowland. These flood-plain surfaces, shown as map unit **sp** on plate 1, are generally between 0.2 and 1 km wide in Portage County, but they broaden where they enter the flatter lowlands of Waupaca County. These surfaces occur 10 to 25 m below adjacent melt-water-stream deposits, indicating that at least that much erosion occurred after deglaciation. The sediment is primarily sand and is difficult to distinguish from melt-water-stream deposits, from which most of it was derived, but it contains far fewer pebbles and is less calcareous, probably because it was derived from

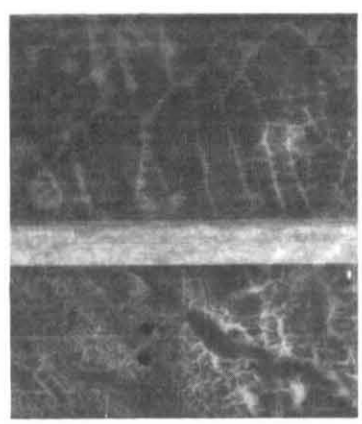

Figure 12 Ice-wedge polygons in lot 15, sec. 30, T. 21 N., R. 9 E. (equivalent to SE1/4NW1/4E1/2 sec. 30, T. 21 N., R. 9 E); U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service aerial photograph BIF-2JJ-163). Area shown is 0.33 km wide. North is up.

previously leached soil. Scanty information indicates it is commonly at least 10 or 20 m thick.

This material (map unit **sp**) was deposited when the water table was somewhat higher than at present; no streams occur today in the westernmost 2 to 7 km of these valleys. The presence of rare ice-block depressions indicates that at least part of it was deposited just after deglaciation, before the last ice melted (fig. 13). The presence of silt in the west end of the valley (SE1/4NE1/4 sec. 18, T. 21 N., R. 10 E.) suggests that the valley was blocked for a time by a readvance of the ice, perhaps westward to the mouth of the valley in sec. 15, T. 21 N., R. 10 E.

Similar deposits occur in southwestern Portage County (map unit **sp**, plate 1). There the terrace surface is generally no more than a few metres above present-day flood plains or below the melt-water-stream plain.

Nonglacial stream sediment in northwestern Portage County

The melt-water-stream surface west of the Hancock and Almond moraines (map unit **su**, plate 1) can be traced to a point 3 km northwest of Stevens Point, where it is at the same level as a terrace of the Wisconsin River (map unit **so**, plate 1). For this reason, and because both surfaces have a cover of windblown silt and have inconspicuous channel scars, the terrace is interpreted to consist of melt-water deposits rather than postglacial deposits. About 3 m below that terrace is another terrace, here referred to as the Love terrace (named for Love Creek in sec. 26, T. 23 N., R. 7 E., southwest of Stevens Point); it is shown as map unit **sl** on plate 1. Love terrace has little or no windblown silt and has conspicuous channel scars, and for that reason it is considered to be significantly younger than the Hancock-Almond terrace. It is 6 to 10 m above the modern flood plain and slightly above the highest floods before dams were constructed on the Wisconsin River, and it is therefore significantly older than the modern flood plain. The Love terrace may have been formed when the glacier had melted back to northern Wisconsin, perhaps to the Winegar moraine, but it may have been formed later by nonglacial water. It appears to be a cut terrace, with no more than a few metres of sediment deposited on older stream deposits or on Precambrian rock. Love sediment resembles the sediment of Hancock-Almond terrace (map unit **su**, plate 1) but is somewhat coarser, consisting of sandy gravel or gravelly sand in most places.

A similar terrace occurs along the Plover River northeast of Stevens Point (map unit **sp**, plate 1). It is a few metres below the Hancock-Almond stream surface (map unit **su**, plate 1) and a few metres above the modern flood plain, and it presumably is underlain mainly by sand. The meander scars on this surface are slightly larger than those of the modern flood plain, indicating a slightly more moist climate than at present; but they are small enough to indicate that the river did not contain large amounts of glacial melt water when the terrace formed.

The streams north and west of the Wisconsin River, such as the Little Eau Pleine River and Mill Creek, are bordered by scattered terrace remnants a few metres above the present flood plains (map unit **sn**, plate 1). They are graded to the level of the upper and lower terrace of the Wisconsin River (map units **so**

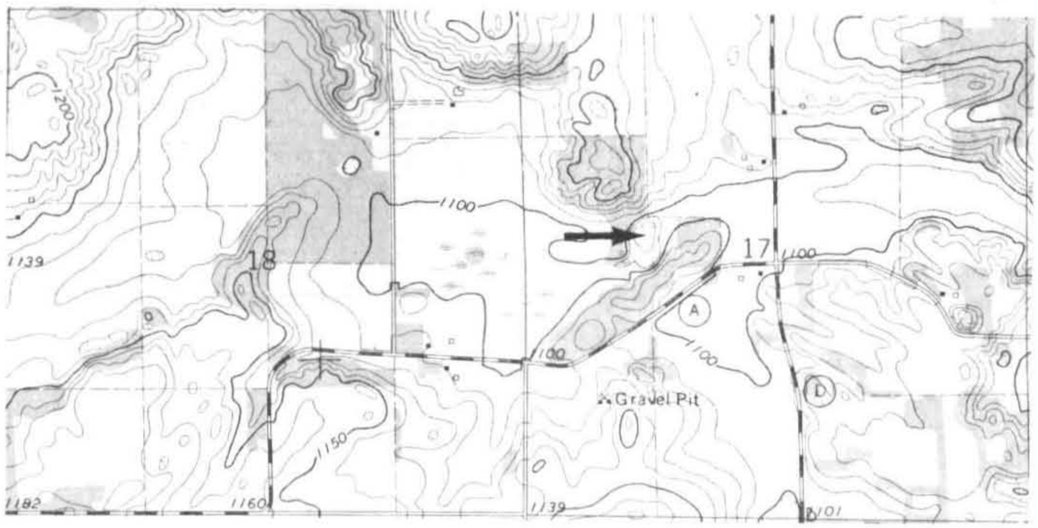

Figure 13 Ice-block depression (arrow) in east-sloping early-postglacial stream deposits. From middle of U.S. Geological Survey Blaine Quadrangle (7.5 minute; 10-ft contour interval). Area shown is 3.3 km wide (east-west). Sec. 17 and 18, T. 21 N., R. 10 E.

or **sl**, plate 1) and were therefore formed during the last glaciation or somewhat later. No glacier was present in their headwaters at that time, and the terraces are therefore composed of slightly gravelly sand and gravelly sand eroded from their drainage basins by non-melt-water rivers.

Modern stream sediment

The flood plains of present-day rivers are underlain by the sediment of map unit **sm** on plate 1. Little information is available about the character of this material, but it probably resembles the older stream deposits and probably consists largely of gravelly sand and sandy gravel. It is generally noncalcareous.

Wind-blown sediment

Wind-blown silt (loess) is not shown on plate 1, but a thin blanket of it covers most of Portage County, with the exception of steeper slopes and flood plains, where it has been eroded away. It is roughly 0.5 m thick and generally contains a considerable admixture of sand and pebbles from the underlying material. Most of it was probably deposited near the end of the last glaciation because the intense erosion resulting from the presence of permafrost during glaciations is likely to have removed most earlier surface deposits. Wind-blown sand is indicated by map units **wm** and **ws** on plate 1. It occurs largely in southwestern Portage County, overlying offshore or stream sand of map unit **ou**, but scattered patches are also present in the northwestern part of the county. Its thickness is highly variable, averaging roughly 1 m in many areas. Maximum thickness is several metres. Bedding is generally obscure, but Holt (1965, p. 31) noted eastward-dipping cross bedding.

Some sand dunes are as high as 6 m (sec. 20, T. 22 N., R. 8 E.). Most are 1 to 2 m high and are parabolic or oval in outline (fig. 14). The long axes of the oval dunes are oriented about N. 68° W. and are about 0.2 km long, and the short axes are about 0.1 km long. The parabolic ridges tend to be concave to the south-southeast, indicating they were formed by wind from that direction.

Blowouts are active today in a few places, but the dunes are generally covered by vegetation. The exact age of the dunes is unknown. If the material of map unit **ou** (plate 1) were deposited in Lake Wisconsin, the dunes formed after the lake drained, which was after the glacier melted back from the younger Elderon moraines. Dunes are absent on Love terrace (map unit **sl**, plate 1), indicating that Love sediment is too coarse or poorly sorted to yield dune sand or that the Love terrace formed after the sand dunes. The dunes also formed, at least partly, before the peat of map unit **p** (plate 1) was deposited. For example, the Philippine Islands, which are dunes in Dewey Marsh, 10 km north of Stevens Point (sec. 20 and 21, T. 25 N., R. 8 E.), formed when the water table was lower than at present and the adjacent melt-water-stream surface was dry enough to yield wind-blown sand. The dunes probably formed in early postglacial time (perhaps around 12,000 to 14,000 years ago) or more likely during dry middle Holocene time (6,000 to 7,000 years ago).

Organic sediment

Muck and peat are indicated by map unit **p** on plate 1. Muck and peat are shown on plate 1 where they are more than about 0.5 m thick. Many small or thin deposits have not been indicated on the map. An average or maximum thickness is unknown, but it is more than 2 m thick in many areas. The water table is well below the surface, and therefore peat, as well as lakes and rivers, are lacking in a zone on either side of the drainage divide (Almond moraine) in the central and south-central part of the county.

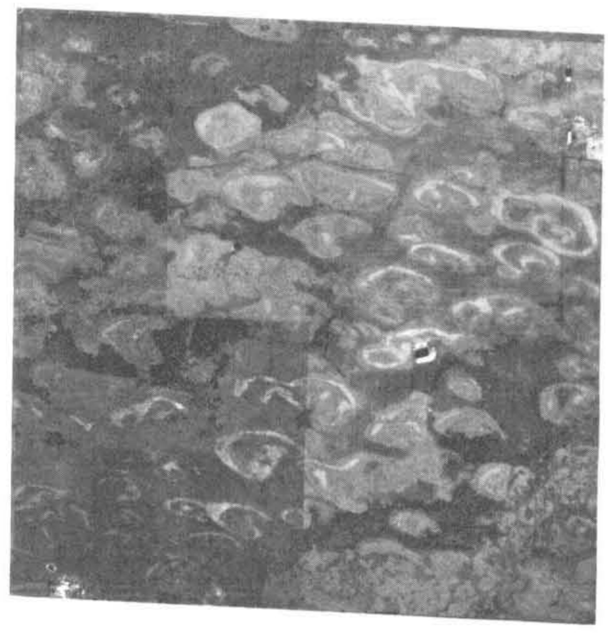

Figure 14 Oval sand dunes in sec. 12, T. 21 N., R. 7 E. (U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service aerial photograph BIF-3JJ-9). Area shown is 1.6 km wide. North is up.

SUMMARY OF GEOLOGIC EVENTS

The Precambrian rock of Portage County was formed between about 3,000,000,000 and 1,500,000,000 years ago. Little evidence remains for events during the next 1,000,000,000 years, but toward the end of that time the land had been eroded down to a gently rolling landscape covered with several metres of clay, silt, and sand formed by the weathering of the surface rock. In northwestern Portage County, that landscape has been exhumed more recently by the removal of the overlying late Cambrian sand; during the early Cambrian, as now, Rock Hill (7 km southwest of Junction City) was a prominent knob rising above the rolling plain.

About 530,000,000 years ago (in late Cambrian time) the sea rose, covering the region with shore sand, remnants of which occur in parts of Portage County (map unit **C**, plate 1). Other marine sediment was deposited after Cambrian time, perhaps as late as 150,000,000 years ago, but was later eroded away.

Since then the area has been above sea level, with land generally sloping to the south. South-flowing rivers deposited sand and gravel in valley bottoms during the Cretaceous and Cenozoic, remnants of which include the quartzose pebbles and cobbles in the older hillslope deposits of map unit **h** (plate 1). Weathering and slope processes during the late Cenozoic produced the bulk of the material in map unit **h** (fig. 15).

Finally, in latest Cenozoic time the region was glaciated several times, beginning sometime after about 3,000,000 years ago. Late Pliocene and early Pleistocene glaciers probably reached nearby counties to the north and east, and they may have reached Portage County. However, little evidence exists for glaciation in the county until late Pleistocene time, during the Arnott Glaciation, when the moraine west of Arnott was formed and the till of the Keene Member was deposited (figs. 15 and 16). The Arnott Glaciation was followed by a period of weathering and erosion.

Evidence for the early part of the Wisconsin Glaciation may exist elsewhere in the Midwest, but not in central Wisconsin--unless the Arnott Glaciation occurred then rather than earlier as suggested here. During the last part of the Wisconsin Glaciation, less than 25,000 years ago, the Green Bay Lobe moved westward into Portage County and stabilized during the Hancock Phase at the moraine east of Arnott (figs. 15 and 17). Lake Wisconsin came into existence sometime before or early in the Hancock Phase when the glacier dammed the Wisconsin valley at the Baraboo Range (fig. 11). Sudden outbursts of subglacial water cut tunnel channels under the glacier and through the moraine, depositing sand westward beyond the mouths of the tunnels. The glacier then melted back from the Hancock moraine an unknown distance and readvanced during the Almond Phase and stabilized at the moraine east of Almond (fig. 18). Tunnel channels again formed, as during the Hancock Phase. The east

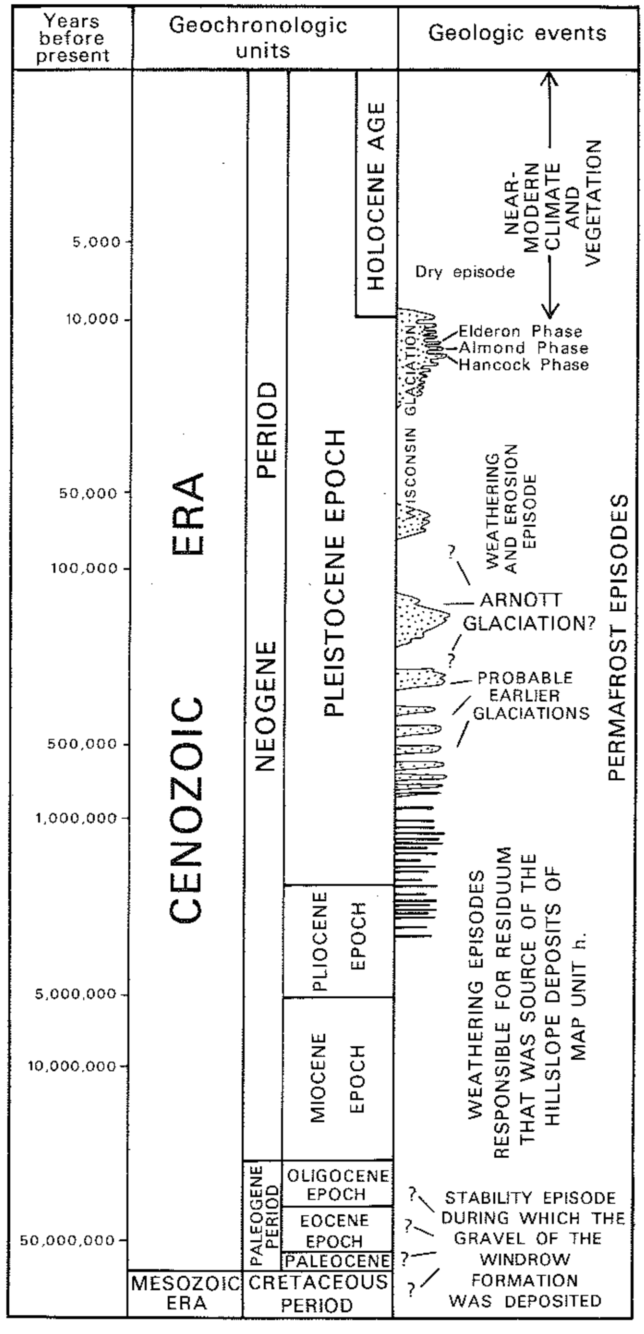

Figure 15 Chronology of events in Portage County. Logarithmic time scale. Dotted areas (thinning downward to horizontal lines) represent glaciations; the horizontal axis is distance, with Lake Superior at the left edge of the events column and Portage County at the right edge of the dotted area.

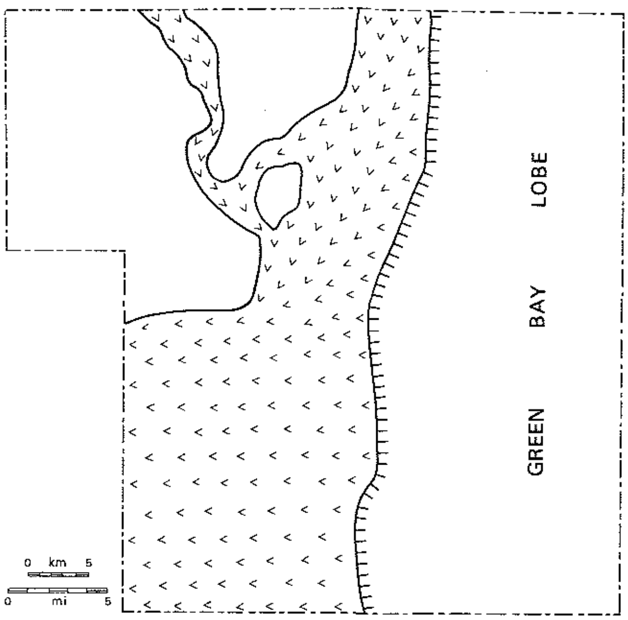

Figure 16 Portage County during maximum extent of Arnott Glaciation. Extent (or existence) of Lake Wisconsin at this time is uncertain. The Keene Member of the Horicon Formation was deposited at this time (map unit **gk**, plate 1). Arrowheads indicate direction of melt-water flow. Blank areas west of glacier are dry land above the flood plain.

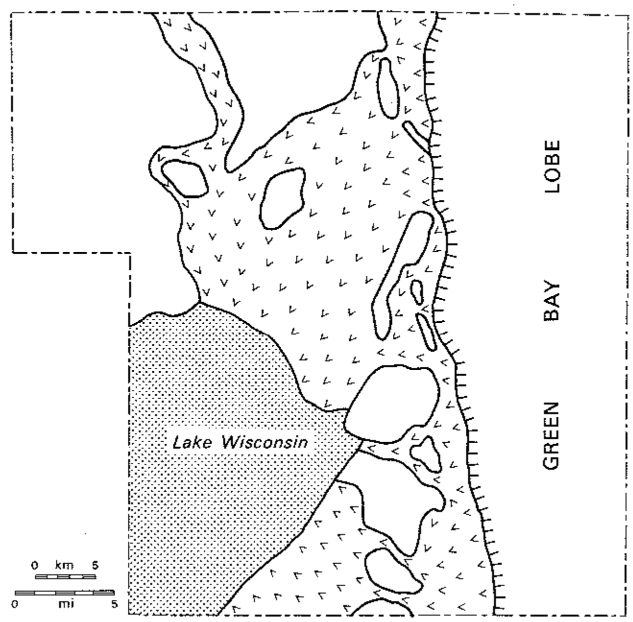

Figure 18 Portage County during Almond Phase of Wisconsin Glaciation. Part of the Mapleview Member of the Horicon Formation was deposited at this time.

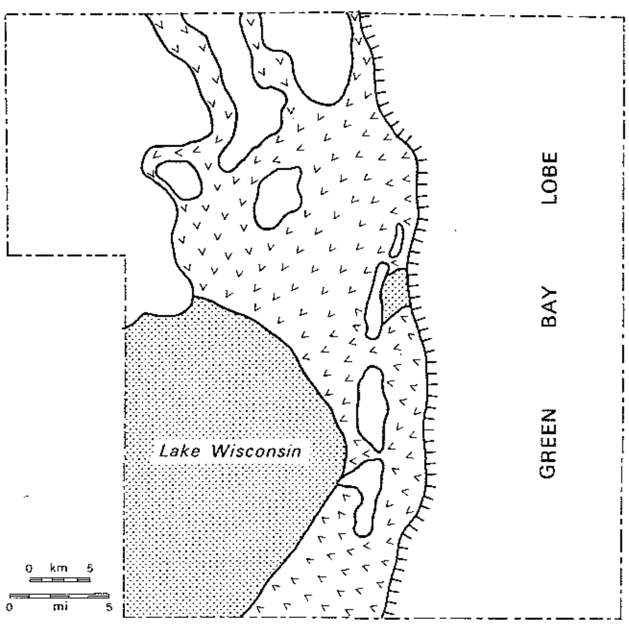

Figure 17 Portage County during Hancock Phase of Wisconsin Glaciation. Part of the Mapleview Member of the Horicon Formation was deposited at this time. Dotted pattern indicates lake water.

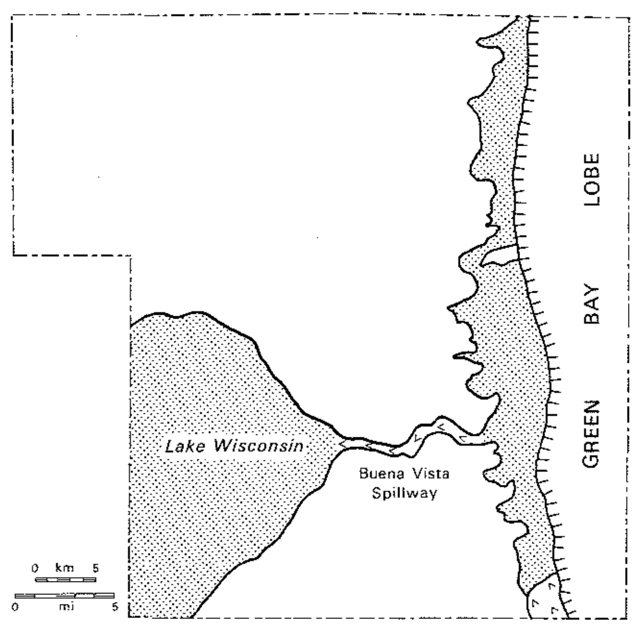

Figure 19 Portage County during Elderon subphase 1 of Wisconsin Glaciation. Part of the Mapleview Member of the Horicon Formation was deposited at this time.

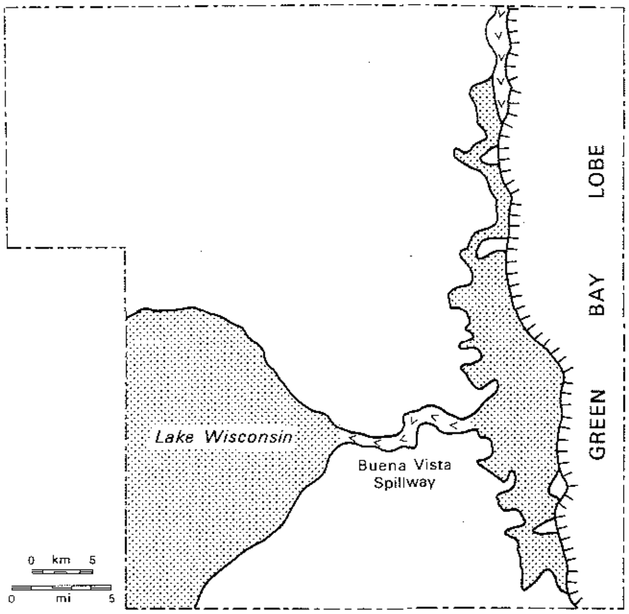

Figure 20 Portage County during Elderon subphase 2 of Wisconsin Glaciation. Part of the Mapleview Member of the Horicon Formation was deposited at this time.

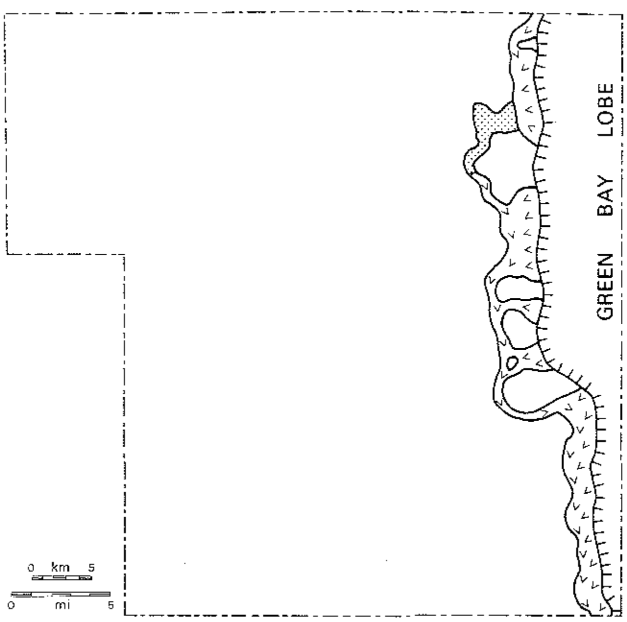

Figure 21 Portage County during Elderon subphase 3 of Wisconsin Glaciation. Part of the Mapleview Member of the Horicon Formation was deposited at this time.

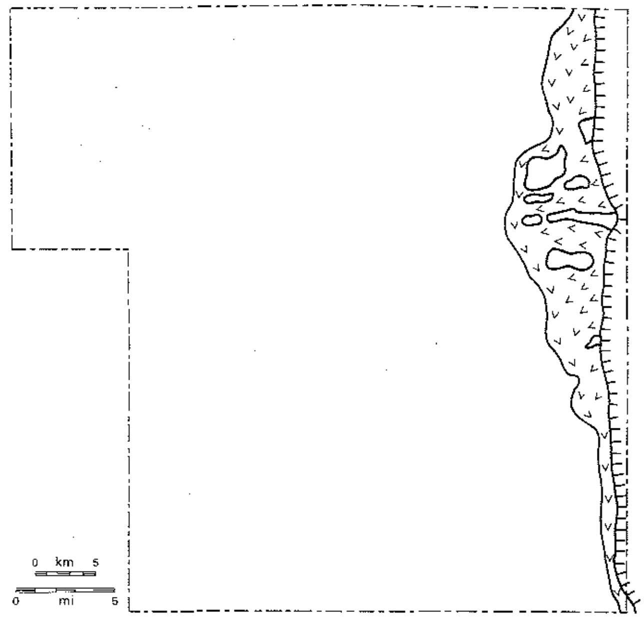

Figure 22 Portage County during Elderon subphase 5 of Wisconsin Glaciation. Part of the Mapleview Member of the Horicon Formation was deposited at this time.

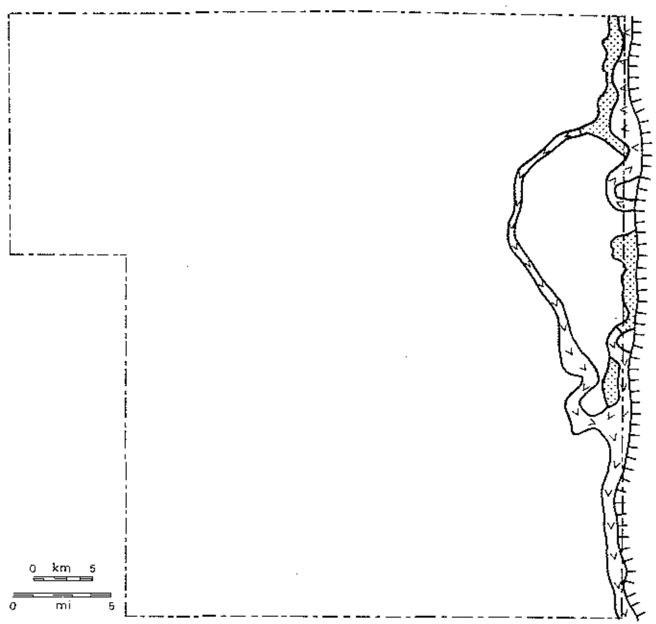

Figure 23 Portage County during Elderon subphase 6 of Wisconsin Glaciation. Part of the Mapleview Member of the Horicon Formation was deposited at this time.

shore of Lake Wisconsin was now farther west as a result of rebound of the earth's crust as some of the weight of the glacier was removed between the Hancock and Almond Phases and as a result of deposition of sand along the east shore.

During the last part of the Almond Phase, the glacier margin retreated eastward from the Almond moraine and then either paused or readvanced a short distance several times during the Elderon Phase (figs. 15, 19, 20, 21, 22, and 23). During the first two Elderon subphases, water was dammed between the glacier and the high area capped by the Almond moraine (figs. 19 and 20). Lake water spilled westward across the low point of the moraine and entrenched the Almond proglacial plain; this spillway is now occupied by the headwaters of Buena Vista Creek. After the second Elderon subphase, melt water flowed southward along the ice margin into the Lewistown Arm of Lake Wisconsin (fig. 11) if the ice still covered the east end of the Baraboo Range (fig. 21); during the last subphases (figs. 22 and 23) it flowed directly into the Wisconsin River near Portage. The Elderon Phase probably occurred around 13,000 or 14,000 years ago.

Tundra conditions with permafrost existed until the Almond Phase and probably also through the Elderon Phase. Hillslope erosion was rapid during that time, and sand dunes were active in the western part of the county. After melt-water flow ceased, rivers such as the Wisconsin, Plover, and Tomorrow entrenched their valleys several metres, and east-flowing streams in southeastern Portage County downcut a few tens of metres. A postglacial forest became established at least by 12,000 years ago. Since then the landscape has become more stable, except perhaps for increased wind erosion during a drier period 6,000 to 7,000 years ago and increased soil erosion in cultivated areas during the past century.

(In the preceding discussion the term "phase" has been used as a geologic-event term, not as a diachronic term. A geologic-event term is interpretive, defined in terms of reconstructed events; a diachronic term is descriptive, defined in terms of type sections.)

CONSTRUCTION MATERIAL

Sand and gravel

About 300 sand and gravel pits were noted in Portage County, and many more probably escaped notice (plate 1). Most consist of small inactive or intermittently worked pits. More than one-third occur in flat deposits of melt-water streams (map unit **su**, plate 1), and nearly another third occur in hilly deposits of melt-water streams (map unit **sc**). The remaining third are in a variety of materials, including the material of Love terrace along the Wisconsin River (map unit **sl**) and in the undifferentiated melt-water-stream sediment and offshore sediment in eastern Portage County (map units **ou** and **oc**). At least two dozen occur in areas shown as till on plate 1 (map units **gh, ga, gd,** and **gk**); these are in deposits of melt-water streams too small to be mapped separately from the surrounding till and in deposits of melt-water streams overlain by thin till, and a few are in gravelly phases of the till. A few pits are also in nonglacial stream deposits (map units **sm, sp, sl,** and **sn**), wind-blown sand (map units **wm** and **ws**), and Cambrian sand (map unit **C**).

The great bulk of construction aggregate, however, comes from a few large pits (east and southeast of Stevens Point) that are in deposits of melt-water streams no more than 2 km west of the Hancock or Almond moraines (map units **su** and **sc**). In this area the sand and gravel is tens of metres thick, and the water table generally is at a depth of 10 to 20 m. Judging from the few road materials investigation field books available for the area (unpublished; on file with the Wisconsin Geological and Natural History Survey), much of the material being mined consists of about half aggregate coarser than 6 mm. In general, it is coarser and better graded (more poorly sorted) eastward toward the moraine, and boulders are abundant in gravel located within a few hundred metres of the west edge of the moraine. The largest pits are located near Stevens Point to reduce haulage distance; similar deposits of gravel can probably be found in similar settings to the north and south, but in northern Portage County the water table is within a few metres of the surface. However, the gravel varies widely in grain size, and profitable deposits must be located by test drilling. Similar but smaller deposits also occur along the west sides of the Elderon moraines (plate 1).

The horizontal hydrologic conductivity of the saturated sand of southwestern Portage County (map units **ou** and **su**, plate 1; map unit **s**, plate 2) is around 0.5 to 1 x 10^{-3} m/s (Ken Bradbury, Wisconsin Geological and Natural History Survey, personal communication). This value is derived from pump tests of a large number of irrigation wells with long screens.

Crushed stone

Several small inactive quarries used for crushed stone occur in northwestern Portage County in areas where Precambrian igneous and metamorphic rock is near the surface (map units **PC** and **h**, plate 1). Some of these sites have been described in road materials investigation reports (unpublished; on file with Wisconsin Geological and Natural History Survey).

Building stone

Several inactive building-stone quarries occur in areas of Cambrian sandstone (map unit **C**, plate 1). Some old buildings were made of locally quarried sandstone, as were the foundations of many of the buildings in western Portage County (Buckley, 1898, p. 239-241).

Clay

Little clay exists in Portage County. Brick factories near Stevens Point once used clay from a weathering zone on the Precambrian rock (Buckley, 1901, p. 226-227; Ries, 1906, p. 123-126). Presumably this was the Cenozoic weathering zone (the Marathon Formation, map unit **h**, plate 1), but clay also occurs in the weathering zone beneath the Cambrian sandstone in some parts of Portage County (Weidman, 1907, p. 388-390). Clay for the liner of the county dump near Custer was mined from the Marathon Formation west of Stevens Point (NE1/4SE1/4 sec. 31, T. 24 N., R. 7 E.). However, most of the Marathon Formation contains less than about 35 percent clay-sized material (fig. 3).

Till

The grain-size distribution of the Mapleview till (map units **gh, ga,** and **gd,** plate 1) in Portage County is remarkably uniform (fig. 3), and for that reason it seems likely that its engineering characteristics are also uniform. According to the Unified System of Classification, most of the Mapleview till is SM (silty sand); according to the AASHTO system, it is A-2 material, probably mostly A-2-4 (Otter and Fiala, 1978). The Keene till (map unit **gk,** plate 1) is somewhat more variable and less sandy (fig. 3).

REFERENCES

Andrews, J. T., 1975, Glacial systems: North Scituate, Massachusetts, Duxbury Press, 191 p.

Black, R. F., 1965, Ice-wedge casts of Wisconsin: Wisconsin Academy of Science, Arts, and Letters Transactions, v. 54, p. 187-222.

Buckley, E. R., 1898, On the building and ornamental stones of Wisconsin: Wisconsin Geological and Natural History Survey Bulletin 4, 544 p.

Buckley, E. R., 1901, The clays and clay industries of Wisconsin: Wisconsin Geological and Natural History Survey Bulletin 7, 304 p.

Clayton, Lee, Mickelson, D. M., and Lundqvist, Jan, 1985, Deposition of the late Wisconsin Johnstown moraine, south-central Wisconsin: Geological Society of America abstracts with programs, v. 17, p. 283.

Hole, F. D., 1943, Correlation of the glacial Border drifts of north central Wisconsin: University of Wisconsin [Madison], Ph.D. thesis, 137 p.

Holt, C. L. R., Jr., 1965, Geology and water resources of Portage County, Wisconsin: U.S. Geological Survey Water-Supply Paper 1796, 77 p.

LaBerge, G. L., and Myers, P. E., 1983, Precambrian geology of Marathon County, Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 45, 88 p.

Masterpole, D. J., 1983, Site characteristics of a histic deposit in sandy outwash: University of Wisconsin, Madison, M.S. thesis, 121 p.

Mickelson, D. M., 1987, Glacial and related deposits of Langlade County: Wisconsin Geological and Natural History Survey Information Circular 52, 30 p.

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, 15 p.

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

Nelson, J. F., 1978, Characterization of soils and parent material of the Arnott moraine in Portage County, Wisconsin: University of Wisconsin, Stevens Point, M.S. thesis, 96 p.

Otter, A. J., and Fiala, W. D., 1978, Soil survey of Portage County, Wisconsin: U. S. Soil Conservation Service, 99 p.

Prest, V. K., 1969, Retreat of Wisconsin and recent ice in North America: Geological Survey of Canada Map 1257A.

Ries, Heinrich, 1906, The clays of Wisconsin and their uses: Wisconsin Geological and Natural History Survey Bulletin 15, 259 p.

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

Teller, J. T., and Clayton, Lee, 1983, Glacial Lake Agassiz: Geological Association of Canada Special Paper 26, 451 p.

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

Thwaites, F. T., and Twenhofel, W. H., 1921, Windrow formation; an upland gravel formation of the Driftless and adjacent areas of the upper Mississippi Valley: Geological Society of America Bulletin, v. 32, p. 293-314.

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

Wright, H. E., Jr., 1973, Tunnel valleys, glacial surges, and subglacial hydrology of the Superior Lobe, Minnesota: Geological Society of America Memoir 136, p. 251-276.