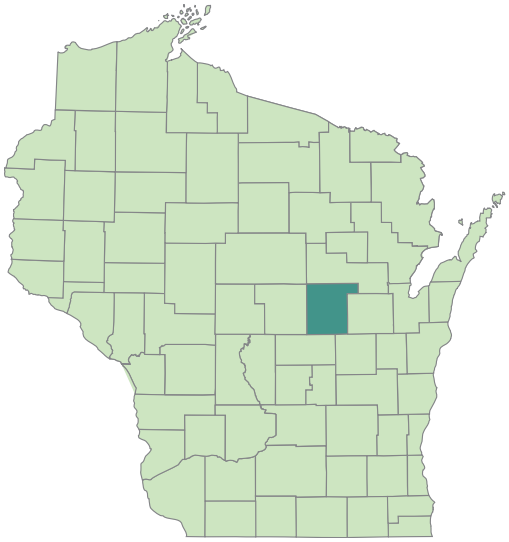

WAUPACA COUNTY

Quaternary Geology of Waupaca County, Wisconsin

MAP 509–SUPPLEMENT • 2023

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Introduction

The Quaternary geologic map of Waupaca County shows the distribution of surficial materials, revealing a diverse glacial, eolian and lacustrine landscape. The map supersedes Mode and others (2015), and this supplemental report provides a brief summary of field and laboratory observations collected during map compilation. The map units are defined by lithology, stratigraphic position, landform association, and are classified into two age groups: (1) the last part of the Wisconsin Glaciation, ca. 30,000 to 11,700 yr B.P., during the Pleistocene, and (2) the Holocene Epoch, 11,700 yr B.P. to present. The glacial sediment present in Waupaca County comprises two formations, the Holy Hill and the Kewaunee (Syverson and others, 2011a). Syverson and others (2011b) provide a review of the glacial sequence in Wisconsin and place these formations in the broader context of Quaternary history.

Bedrock topography influences glacial processes and the resulting distribution of glacial deposits and landforms. Bedrock beneath the surficial materials crops out in a few places in Waupaca County, mostly too small to show on the map. Cactus Rock, located 3.2 km south of New London, is the single outcrop of Precambrian granite sufficiently large to appear on the map. The southeastern corner of the county is underlain by dolomite of the Ordovician Prairie du Chien Group, which rests on Cambrian sandstone that rests on Precambrian crystalline rock (mainly granite). The Prairie du Chien dolomite is exposed in an escarpment at the eastern margin of the county. Cambrian sandstone occurs beneath surficial materials across the southernmost one-fifth of the county and as several isolated outliers to the north. Quaternary sediment was deposited directly on Precambrian crystalline rock in most of Waupaca County. The bedrock surface rises from the southeast toward the northwestern corner of the county. Quaternary sediment is up to 80 m thick and is thickest in a buried bedrock valley trending north-south in the southeastern part of the county (Berkstresser, 1964).

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Methods

Field mapping for this study started in 2002 and ended in 2008. Mapping was based on study of soil maps (Otter, 1984), aerial photographs, and USGS 7.5-minute topographic maps. All roads in the county were driven to find any available exposures of Quaternary sediment. Rotosonic drilling and hollow-stem augering was used to explore the subsurface, and samples were described at the WGNHS core facility. Down-hole measurements of gamma radiation were collected following Keys (1988). A hand-operated bucket auger was used to assess materials to 1.5 m depth.

Glacial sediment

The oldest Quaternary sediment at the surface in Waupaca County was deposited by the Green Bay Lobe of the Laurentide Ice Sheet (fig. 1). The lobe advanced westward from the Michigan basin and reached a maximum extent in Portage County, located just to the west of Waupaca County (Clayton, 1986). Glacial sediment, primarily till, was deposited while the lobe advanced across the county, stood at its maximum position, and retreated to the east. Till of the Horicon Member of the Holy Hill Formation was deposited during the advance and retreat of the Green Bay Lobe and is estimated to have an age of 20,000 to 15,500 yr B.P. (Attig and others, 2011; Syverson, and others, 2011a and b ; Mode and others, 2021). Horicon Member till is brown to reddish brown, gravelly, and sandy. The average sand, silt, and clay percentages of 15 samples analyzed are 84%, 9%, and 7%, respectively. It forms rolling topography including moraines (unit **gh** on the map); several short, discontinuous moraine segments are located in western Waupaca County. Other map units consisting of till of the Horicon Member are streamlined topography (**ghs**) in areas of drumlins and collapsed topography (**ghc**) where till was deposited over buried ice. Rolling topography also includes areas where till is draped over the underlying rolling bedrock surface. Map unit **ghw** denotes areas where till has a thin, discontinuous veneer of windblown sediment. The age of the Horicon Member is estimated to be 20,000 to 15,500 yr B.P. (Attig and others, 2011; Syverson, and others, 2011a and b ; Mode and others, 2021).

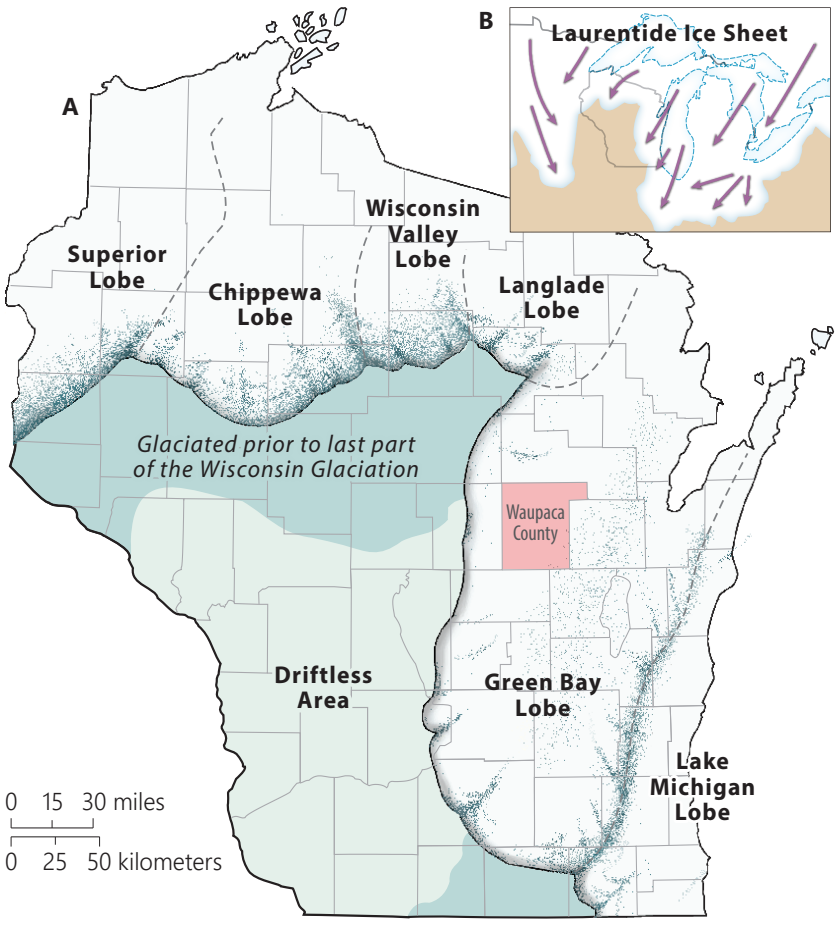

Figure 1. Location of Waupaca County in Wisconsin in relation to the lobes of the Laurentide Ice Sheet (LIS). Panel A, during the last part of the Wisconsin Glaciation, Waupaca County area (light red) was entirely covered by ice. Panel B, location of Wisconsin to the LIS across the Great Lakes region of the United States and Canada during the most recent glaciation.

Political boundaries from Wisconsin Department of Natural Resources, 2011. Wisconsin Transverse Mercator projection, 1991. Adjustment to the North American Datum of 1983 (NAD 83/91); EPSG 3071.

Till of the Kirby Lake Member of the Kewaunee Formation is reddish brown and clay- and silt-rich. The average percentages of sand, silt, and clay of 54 samples from Winnebago County are 23%, 42%, and 34%, respectively (Hooyer and Mode, 2008); none were analyzed in Waupaca County. Kirby Lake Member till was deposited when the Green Bay Lobe readvanced ca. 15,500 yr B.P. (Mode and others, 2021). Till of the Kirby Lake Member is finer-textured than till of the Horicon Member because the Green Bay Lobe advanced over and incorporated into the till fine-grained sediment of glacial Lake Oshkosh. During the readvance, the ice margin terminated about midway between the eastern and western boundaries of Waupaca County, along a nearly north-south line located about 4 km east of the city of Waupaca and 3 km west of Marion. Ice recession commenced soon after, explaining why no pronounced end moraine marks the terminal position in Waupaca County. The ice margin permanently receded out of Waupaca County by ca. 14,500 yr B.P. (Mode and others, 2021). Map unit **gk** denotes low-relief areas where Kirby Lake Member till is <3 m thick and is draped over the underlying topography. Areas with streamlined topography, including drumlins and flutes, are shown as **gks**; areas of collapsed topography as **gkc**; areas with thin, discontinuous windblown sand overlying till as **gkw**; and areas with thin, discontinuous lake sediment overlying till as **gklo**. In many areas within the ice limit of the ice extent that deposited Kirby Lake Member till, Horicon Member till is present at the surface. Apparently, the Green Bay Lobe did not deposit a substantial amount of the Kirby Lake Member on these areas.

Apart from till, sediment related to glaciers presented on the map (referred to as glacial deposits, undifferentiated) include meltwater-stream sediment (stratified sand and gravel) shown as **sa**, **su** and **sc**, and lake sediment (laminated silt and clay) shown as **lo** and **low**. Sand and gravel are important as sources of aggregate and, in places where there are thick sequences below the water table, as sources of groundwater (Berkstresser, 1964). Meltwater-stream sediment is abundant in the western half of the county where it was deposited during the recession of the Green Bay Lobe beginning ca. 20,000 yr B.P.. Map unit **sa** denotes areas with stratified sediment deposited in fans or deltas. These landforms formed adjacent to and in contact with the ice margin; fans formed where a meltwater stream deposited its load, and deltas formed where meltwater streams flowed into standing bodies of water such as glacial Lake Oshkosh. Gently sloping terraces composed of meltwater-stream sediment are shown as unit **su**. They formed as floodplains and channel fills of proglacial meltwater streams. Collapsed (pitted) meltwater-stream sediment (**sc**) occurs where glacial ice was buried, creating irregular hilly areas and closed depressions in the landscape when ice melted. Eskers contain meltwater-stream sediment deposited within a tunnel in or under the ice. Several short eskers are located in western Waupaca County.

Glacial Lake Oshkosh formed in the Fox River lowland when the Green Bay Lobe was within its maximum position but still blocking drainage toward Green Bay (Thwaites, 1943; Hooyer and Mode, 2008). Lake sediment deposited by glacial Lake Oshkosh is largely restricted to the eastern half of the county, the area covered by the readvance that deposited the Kirby Lake Member. The lake sediment was deposited during recession of the Green Bay Lobe after ca. 15,500 yr B.P. and again during the readvance and retreat of the Green Bay Lobe between 13,100 and 12,500 yr B.P. (Hooyer, 2007; Hooyer and Mode, 2008). Today, lake sediment is found in Waupaca County in lowlands that occur below an elevation of 244 m. This distribution of lake sediment reflects the elevation of an outlet of glacial Lake Oshkosh located near Portage, WI. (Hooyer and Mode, 2008). Map unit **low** shows areas where thin (<2 m thick), discontinuous windblown sand rests on glacial Lake Oshkosh sediment. Lake sediment (map unit **lo**) is sandy where deposited close to shore and silty and clayey where deposited in deeper water. Thin bedding and lamination are common, and varves, which are annually deposited couplets, are present in lake sediment. For example, in rotosonic drillcore RS-7 (fig. 2, dataset 1) from southern Waupaca County, ca. 17 m of glacial Lake Oshkosh sediment, the lower 12 m of which includes 77 varve couplets, occur at the surface overlying Kirby Lake Member till. RS-7 also contains ca. 49 m of lake sediment buried by till of the Kirby Lake Member. This older lake sediment includes 1075 varve couplets. The numbers of varve couplets correspond well with the chronology of glacial and glacial lake expansions and contractions derived from radiocarbon and optically stimulated luminescence (OSL) age estimates. Graded beds deposited by subaqueous sediment-gravity flows can be mistaken for varves; however, no graded bedding was observed in sequences of glacial Lake Oshkosh sediment. Hence, these sediment couplets are likely varves. The presence of red clay throughout this older lake sediment, which is diagnostic of the Kewaunee Formation, indicates they were deposited during the readvance of the Green Bay Lobe about 15,500 yr B.P. that deposited the Kirby Lake Member. Rotosonic drillcore RS-6 (fig. 2, dataset 1) also contains glacial Lake Oshkosh sediment from this time. Two radiocarbon dates on bulk organic matter in lake sediment from RS-6 dating to about 18,000 and 21,000 yr B.P. (table 1) are likely contaminated by old carbon.

Postglacial sediment

Postglacial sediment includes windblown sand, peat, and stream sediment. Deposition of this sediment began as soon as the Green Bay Lobe retreated and continued into the Holocene. Windblown sand is common in northeastern and southeastern Waupaca County (unit **w** on the map). Sand is well sorted and up to 7 m thick forming numerous dunes. Slip faces on dunes reflect formation by wind from the north to north-northwest. Sand sheets are characteristic (and dunes rare) in

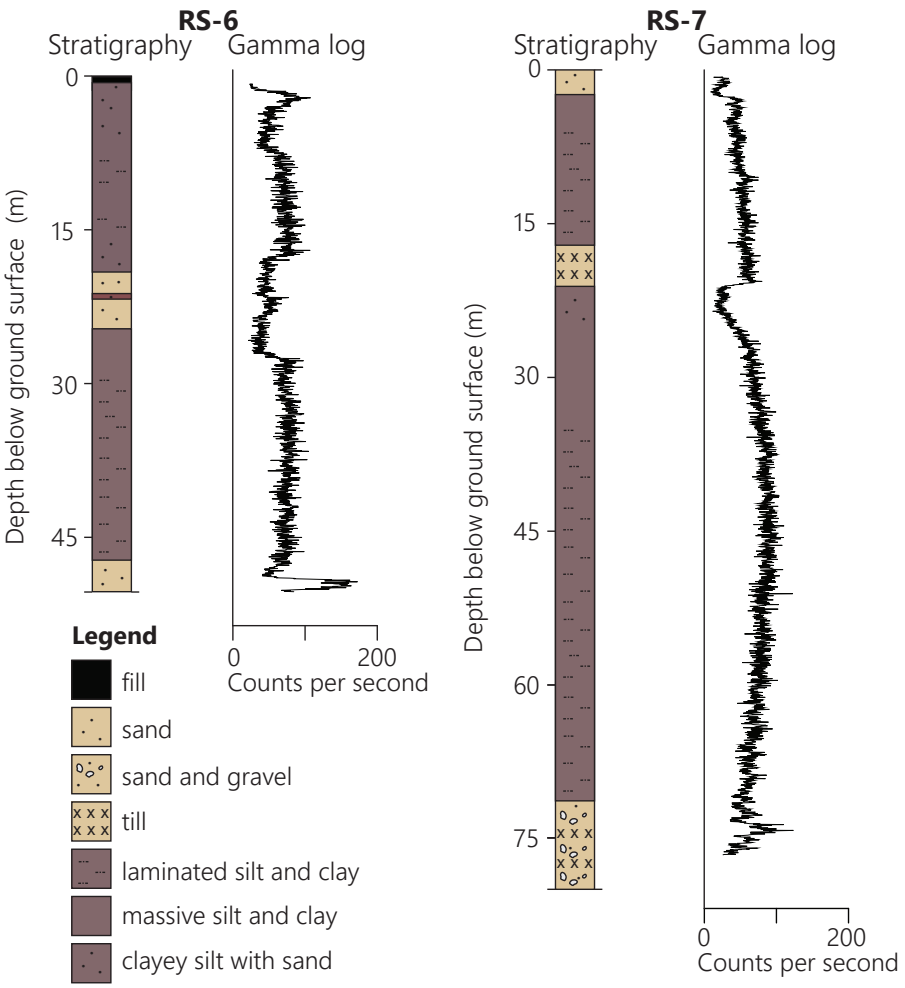

Figure 2. **Geologic logs of rotosonic drillcores RS-6 and RS-7 located in southeastern Waupaca County. Clay-rich sediment yields higher rates of gamma radiation emission in counts per second.**

Table 1. **Radiocarbon age estimates from Waupaca County.**

Sample identification	Material dated	Lab identification[a]	Depth below surface (m)	Radiocarbon age (yr B.P., ±2σ)[b]	$\delta^{13}C$ (‰, VPDB)[c]	Calibrated age (yr B.P., 2σ range)[b,d]	Median age (yr B.P.)[b,d]
RS-6	Wood	Beta-179443	5.2–5.3	8900±90	–26.3	9696–10,228	9995
RS-6	Organic sediment	Beta-179444	16.1–16.2	14,980±90	–29.5	18,128–18,359, 18,438–18,643	18,285
RS-6	Organic sediment	Beta-179445	69.6–70.2	17,940±120	–27.1	21,411–22,119	21,813

[a] Analysis completed by Beta Analytic (Miami, Fla).
[b] The abbreviation "yr B.P." indicates calendar years before present, where present is 1950 C.E.
[c] VPDB refers to isotopic standard Vienna Peedee Belemnite.
[d] Calibrated using Calib v. 8.2 (Stuiver and others, 2021) and IntCal20 (Reimer and others, 2020).

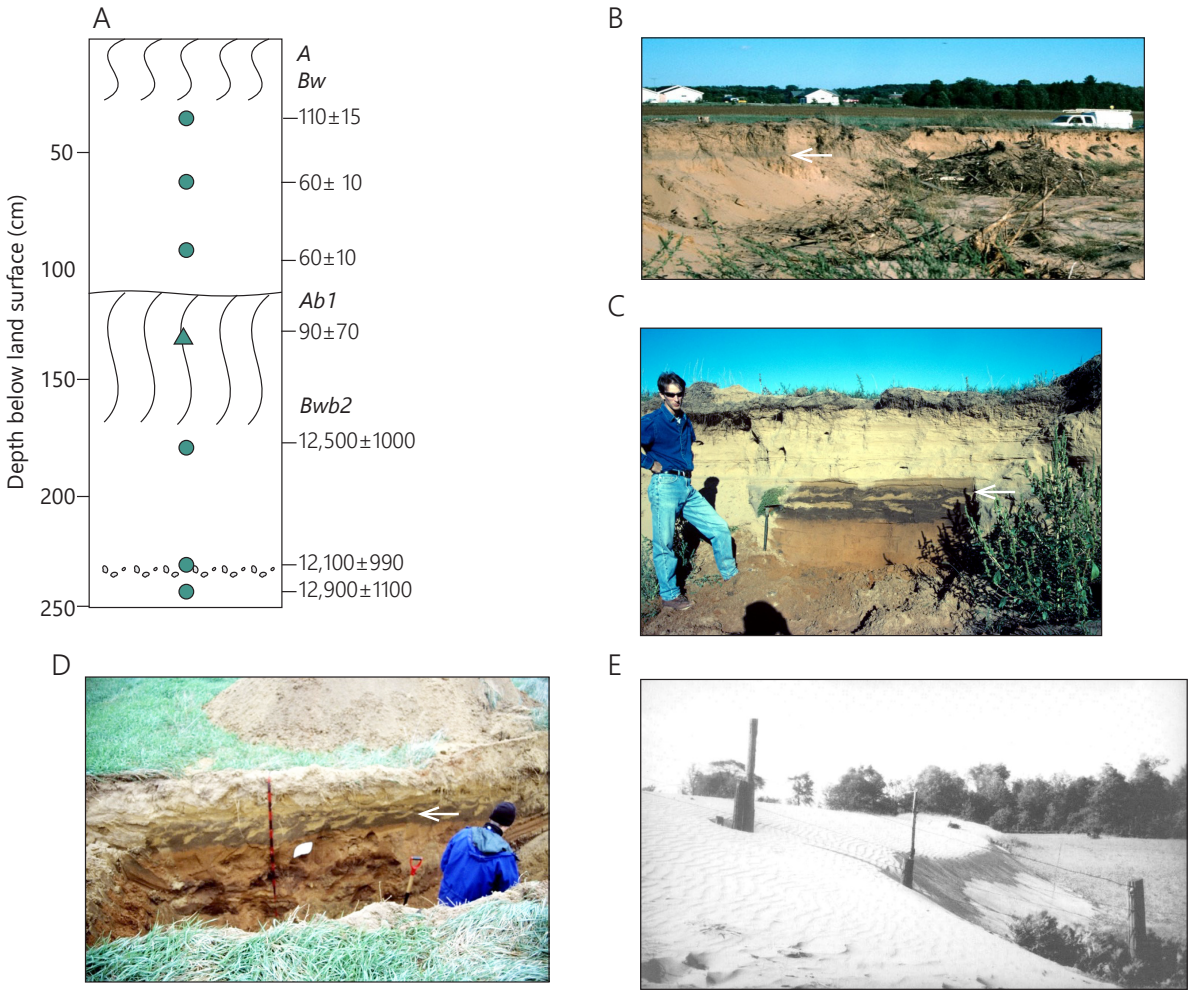

Figure 3. Evidence of 20th century activation of dunes and windblown sand deposition in southeastern Waupaca County (44.2750°N, 88.8032°W). Panel A, Lithologic log of the east wall of the sand pit showing the locations and values of Optically Stimulated Luminesence (circles) and C-14 (triangle) age estimates (modified from Forman and Hooyer, 2007). Letters correspond to soil horizons. Panel B, East wall of sand pit with buried paleosol (arrow) evident beneath unweathered sand. Panel C, Buried paleosol (arrow) with A- and B-horizons and overlying unweathered sand. Panel D, Furrows and ridges in buried A-horizon (arrow). Panel E, Reactivated sand dune in Oconto County, located at SE ¼, SE ¼, Sec. 15, T28N, R17E. Panels B-D are photographs by the authors, Panel E is a photograph by F.T. Thwaites, ca. 1930.

areas mapped as **wlo** and **wgk**. Map unit **wlo** shows windblown sand overlying glacial Lake Oshkosh sediment and wgk shows windblown sand overlying till of the Kirby Lake Member. Windblown sand is most common on the glacial Lake Oshkosh plain. Most sand was likely deposited shortly after the drainage of the lake and before the establishment of continuous vegetation cover. Optically stimulated luminescence (OSL) ages on sand below a paleosol in a sand pit (fig. 3) range from about 12,000 to 13,000 yr B.P. (Forman and Hooyer, 2007), a period closely following the final drainage of glacial Lake Oshkosh (Hooyer and Mode, 2008). However, dune activity continued until 10,000 yr B.P. nearby in the Central Sand Plain approximately 50 km to the west (Rawling and others, 2008) as well as western Wisconsin (Schaetzl and others, 2018).

In southeastern Waupaca County, evidence of dune reactivation during the 20th Century was discovered. At this time, sand was deposited over a well-developed soil as indicated by several lines of evidence (fig. 3): (1) up to 70 centimeters of unweathered sand overlies the buried paleosol, which is developed in the sand of a small parabolic dune, (2) in a trench dug transverse to the exposure in the sand pit, the A-horizon of the buried soil was broken into regular blocks resembling ridges and furrows of a plowed field, (3) organic matter from the buried A-horizon was dated by radiocarbon at 83±60 yr B.P. (Forman and Hooyer, 2007), and (4) sand overlying the buried paleosol was dated by OSL as 60 to 110 yr B.P. (Forman and Hooyer, 2007). Goc (1990) documented wind-borne sand in

central Wisconsin during the Dust Bowl (fig. 3), and the sediment described here appears to have formed as a sand sheet spread across a plowed field and buried it in as much as 70 centimeters of windblown sand. Land clearance and dry climate both contributed to wind erosion of sand in Wisconsin in the 1930s (Goc, 1990).

Peat is widespread in Waupaca County. Map unit **p** denotes extensive deposits up to 3 m thick, when it is difficult to know what underlies the peat. Map unit **po** occurs where peat overlies glacial Lake Oshkosh sediment, limited to lower than 244 m of elevation, **pg** where peat overlies till of either the Holy Hill or Kewaunee Formation, and ps where peat overlies either meltwater stream sediment or postglacial stream sediment.

Postglacial stream sediment (unit **s** on the map) is silty and sandy and was deposited in stream channels and on floodplains. It can be organic-rich, such as the thick (4.5 m), gray silty sediment recovered from the Wolf River floodplain near the top of rotosonic drillcore RS-6 (fig. 2; dataset 1). A radiocarbon age on wood near the base of that gray silty sediment is between 9660 and 10,220 yr B.P. (table 1), indicating that the entire thickness is Holocene in age.

Meltwater channels

Till ridges that are elongate in the east-west direction and are 1 to 3 km wide and 2 to 6 km long occur in western Waupaca County (fig. 4). Located on these ridges are drumlins with a similar long-axis direction as the larger till ridges. The till ridges and the drumlins are composed of till of the Horicon Member (unit **ghs** on the map; fig. 4). The ridges rise several tens of meters above adjacent lowlands composed of meltwater stream sediment (unit **su** on the map). These lowlands are broad (0.5 to 2 km wide) and generally trend east-west. Clayton (1986) described similar ridges in adjacent eastern Portage County and suggested the lowlands

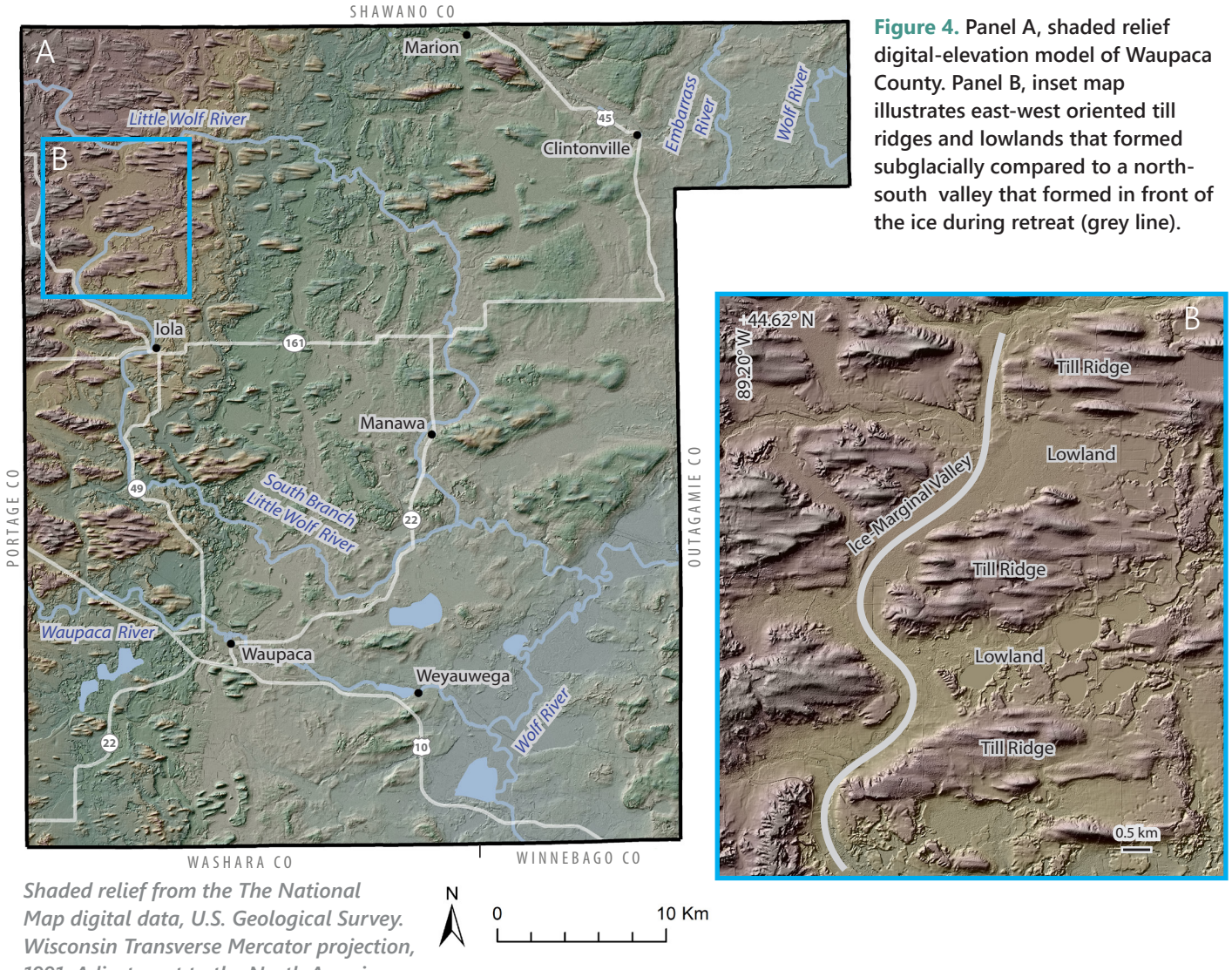

Figure 4. Panel A, shaded relief digital-elevation model of Waupaca County. Panel B, inset map illustrates east-west oriented till ridges and lowlands that formed subglacially compared to a north-south valley that formed in front of the ice during retreat (grey line).

Shaded relief from the The National Map digital data, U.S. Geological Survey. Wisconsin Transverse Mercator projection, 1991. Adjustment to the North American Datum of 1983 (NAD 83/91); EPSG 3071.

could have been formed by subglacial meltwater-stream erosion. This process would have been similar to the formation of tunnel channels that occur farther west in Portage County. However, the morphology of these lowlands is very different from that of the tunnel channels to the west in Portage and Waushara counties that are longer, more continuous, and narrower (Attig and others, 1989; Zoet and others, 2019).

Johnson (1999) described similar ridges in northwestern Wisconsin, which were referred to locally as Spooner hills and expanded upon Clayton's (1986) explanation by adding glacial erosion by substrate freezing onto the base of the glacier. The lowlands in Waupaca County that are aligned east-west would have carried subglacial meltwater between the ridges westward toward the ice margin in Portage County, driven by the westward slope of the ice surface. This is consistent with the hydraulic gradient modeled by Zoet and others (2019). Cutting across the east-west grain of this topography are north-south oriented channels that formed along the ice margin as it retreated eastward (fig. 4). Meltwater draining westward off the Green Bay Lobe was diverted southward to glacial Lake Oshkosh by the southeastward bedrock slope and the north-south trending ice margin. Ice-marginal channels are often much narrower (<0.5 km) than the lowlands between the hills in Waupaca County (fig. 4) and are incised below the level of the terraces (map unit **su**) in those broader lowlands. Meltwater-stream sediment (map units **su** and **sc**) floors both the broad, east-west lowlands and th ice-marginal channels; this sediment was deposited as ice receded from the area.

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Supplemental material

The following materials are available for download at https://doi.org/10.54915/bger3320:

Map: Geologic map
A map (.pdf format) of the Quaternary geology of Waupaca County

Dataset 1: Geologic log data
One spreadsheet (.xlsx) of site and lithological data from 10 logs.

Dataset 2: GIS data for map
A geodatabase (.gdb) including unit contacts and metadata.

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