An Ice Age **Legacy**

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Introduction

Among the most striking geographic features of North America are the Great Lakes. Any map of the Midwestern region of the United States prominently displays their shape. For example, the distinctive mitten shape of Michigan with the thumb is a product of the Ice Age, created during a time called the Quaternary Period. Cycles of glaciation, coinciding with cycles of cool and warm periods, occurred a number of times during the Quaternary Period, roughly the last 2 million years. Just as the Great Lakes are a legacy of the Ice Age, so are most of the natural lakes within the Great Lakes states (Figure 1). Nearly all the lakes of the Great Lakes states have an evolutionary relationship to the history of glaciation. Most of the natural lakes are located within the limit of continental glaciation and have a natural history seated in the Ice Age. The geometry and physical characteristics of lakes, and, in many cases, the ecosystems that have established plant and wildlife communities within and around them, are related to geologic processes that occurred when glaciers occupied the landscape or because of landscape evolution in response to glaciation.

The Landscape Before and After the Ice Age

Rewinding the geologic time clock to preglacial times would present a very different view of the Great Lakes region: The Great Lakes would not have existed. The landscape of eastern Wisconsin, the Lower Peninsula of Michigan, most of Illinois and Indiana, and most of northern, western, and northwestern Ohio would have looked much like Kentucky, Tennessee, and southwest Wisconsin. These areas are underlain by nearly flat-lying beds of Paleozoic age – sandstone, siltstone, shale, limestone, and dolomite – that, through time, have eroded into a dendritic drainage pattern (Figure 2). In this well-developed drainage pattern on bedrock, there would have been no or very few lakes. In northern Minnesota and part of the Upper Peninsula of Michigan, Precambrian bedrock – hard igneous and metamorphic rocks – may have formed rugged hills and even small mountain ranges. River systems forming the upper reaches of the ancestral Saint Lawrence River probably existed in the areas now occupied by the Great Lakes. The Great Lakes occupy areas where rock was more easily eroded, and their present-day shapes are related directly to the regional bedrock geology of adjacent states and Canada.

Glaciation changed the preglacial landscape and its drainage pattern in two profound ways: (1) the underlying bedrock of much of the area of the Great Lakes states was eroded to varying degrees, and (2) the eroded debris was transported and deposited by the glaciers and meltwater streams and then redistributed across the landscape in hills, plains, river valleys, and glacial lake bottoms. In the most simplistic view, glaciers eroded rock, ground it up, and moved it south. The erosion processes and the creation of a completely new landscape had the effect of creating a new hydrologic system. Unlike the organized drainage patterns in unglaciated regions, the drainage patterns in glacial landscapes are typically chaotic because not enough time has elapsed since the last glaciers melted away for erosion to undo the disruption of the preglacial landscape by glacial deposits. The processes of glacial erosion and sediment deposition created enclosed depressions, wide valleys that now have small, narrow streams, and vast lowlands that house wetlands. Within this landscape are many different types of lakes.

Lake Types

Glacial processes resulted in the creation of tens of thousands of lakes in the Great Lakes area. Most of these lakes can be classified into categories that reflect their origin and, in many cases, their shape and size. In many ways, the types of lakes influence how we interact with them as we exploit their recreational, natural resource, or industrial value. Types of natural lakes include **bedrock erosion, kettle or ice-block depression, enclosed depression, landform-controlled, raised-beach,** and **karst lakes**. In the parts of the Great Lakes area that remained unglaciated, such as the Driftless Area of southwest Wisconsin (Figure 1), or in glacial terrain remnants from the earliest part of the Ice Age, such as southern Illinois, artificial impoundments, such as **farm ponds** and **reservoirs**, are abundant. Areas that have been developed by humans have **borrow pits** (for sand and gravel extraction) and **detention basins** or ponds, many of which are a significant component of the suburban landscape. Finally, the glacial landscape includes remnants of **ancient glacial lakes**, ones that no longer exist, and there is abundant geologic evidence that **ancestors** to the modern Great Lakes once existed.

Ancient and Ancestral Lakes

Lakes that no longer exist occupied parts of the landscape during the Ice Age. Some of these lakes were ancestors to modern lakes, which are now remnants of once larger lakes (Figure 3). These former lakes owe their existence to their direct

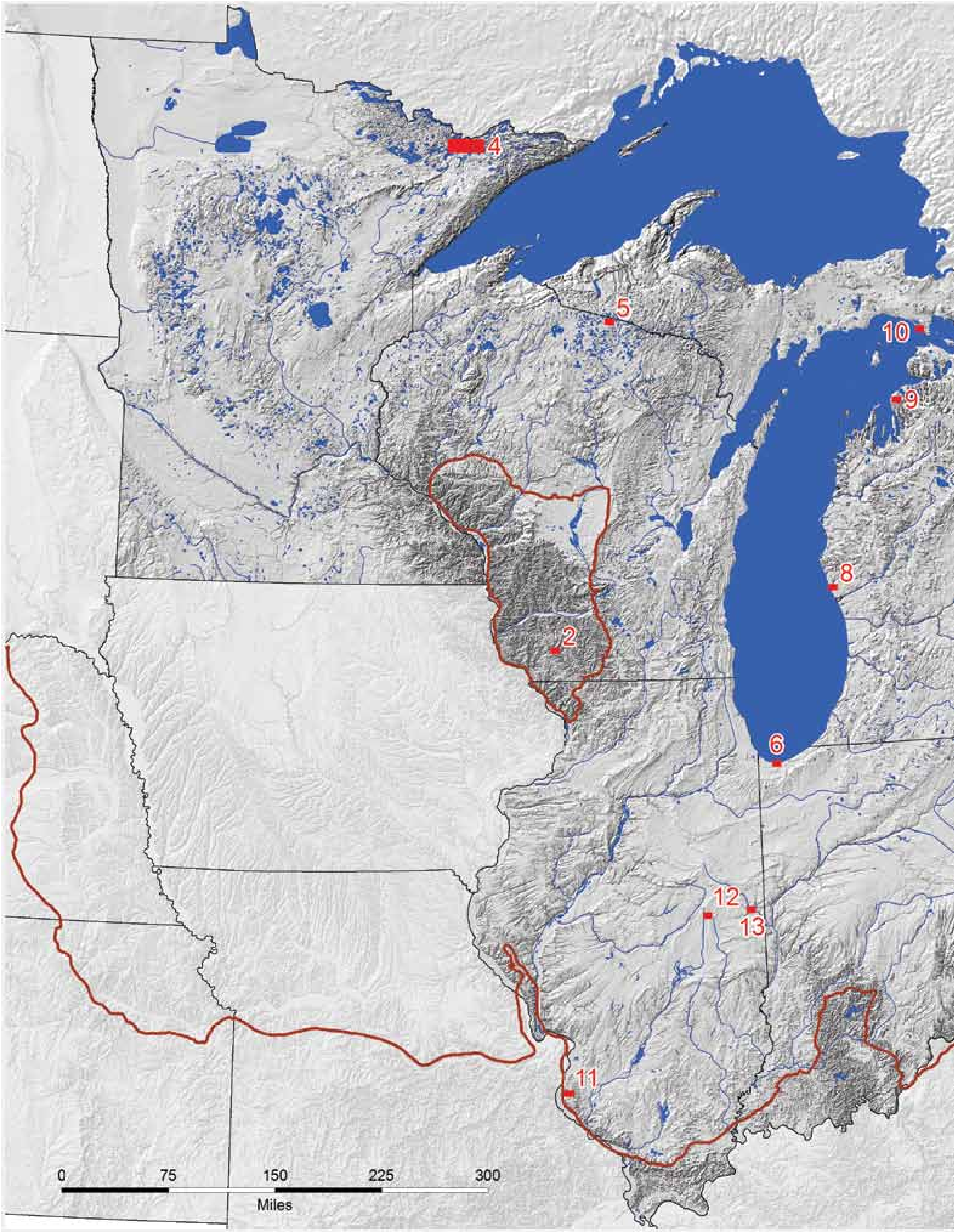

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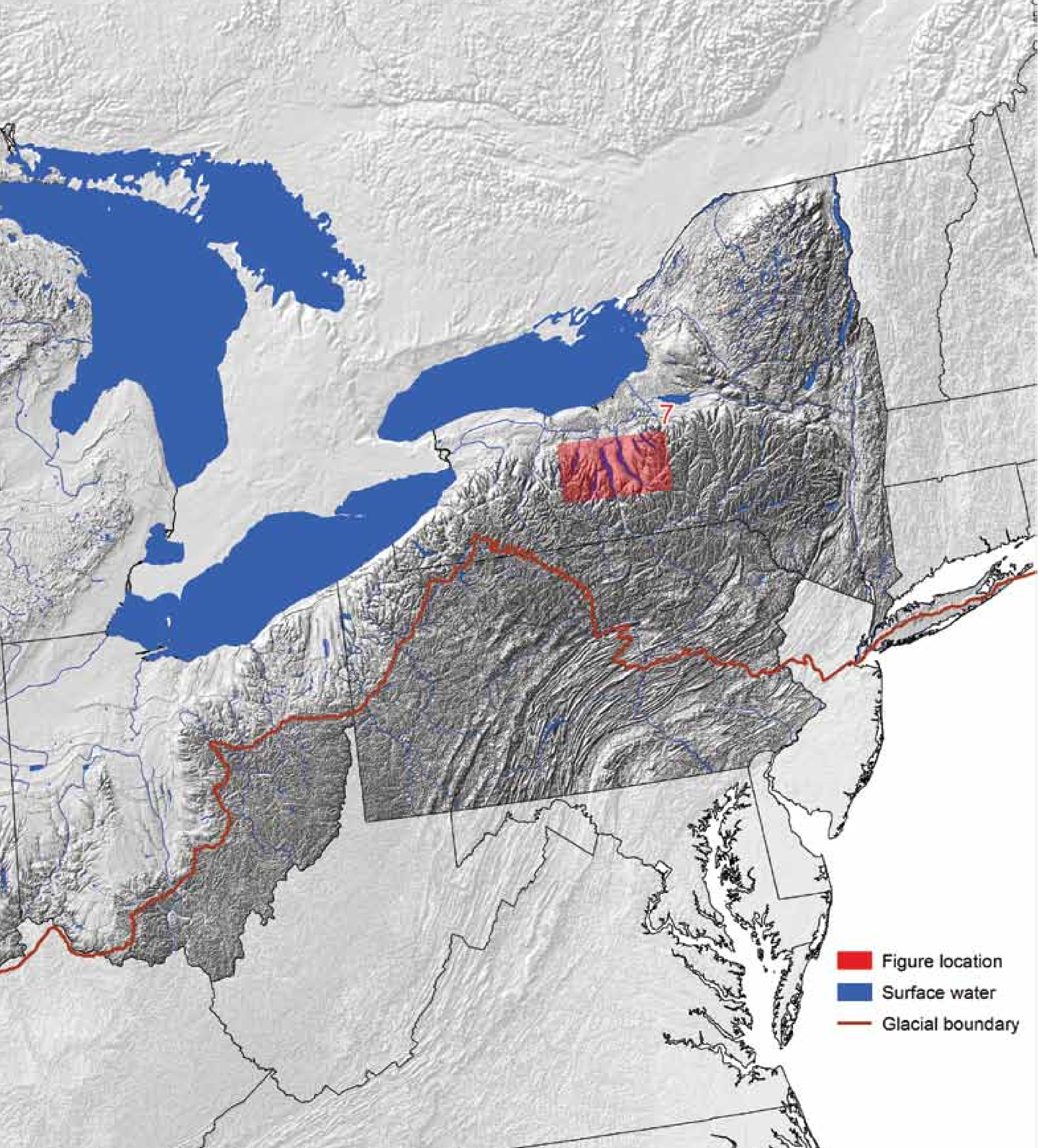
Figure 1. Shaded relief image map of the Midwestern region of the United States, emphasizing lakes and streams (shown in blue) in the Great Lakes states. The extent of continental glaciation is shown by red lines; note the Driftless Area, or unglaciated area, of southwest Wisconsin. Parts of southeastern-most Minnesota and northeastern-most Iowa have a highly dissected topography and appear unglaciated. Red numbers with adjacent red shaded boxes refer to subsequent figure numbers and geographic areas, respectively.



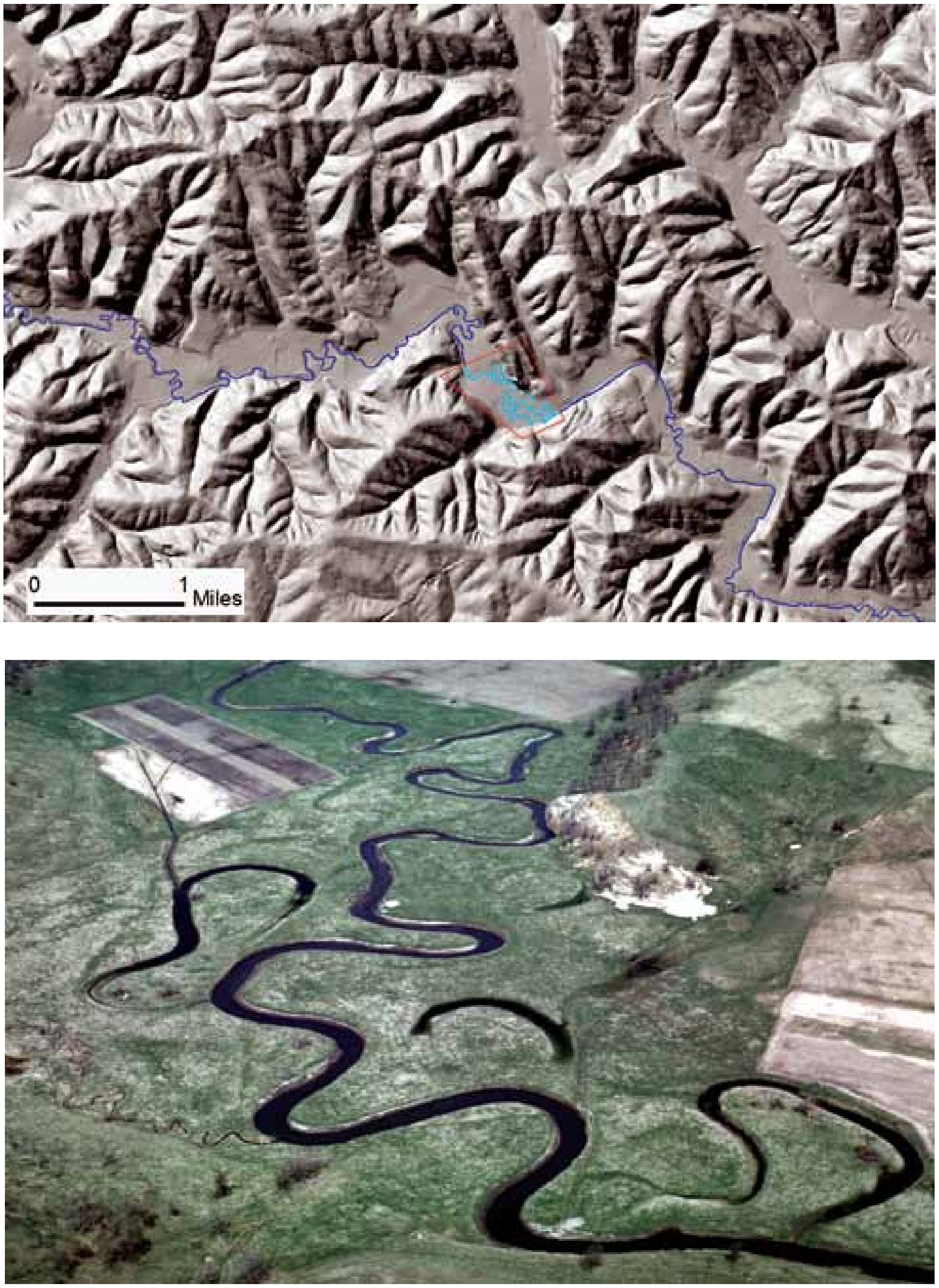


Figure 2. Dendritic drainage pattern and oxbow (meander cutoff) lakes, southwest Wisconsin. Upper panel: Shaded relief image map of a part of Lafayette County (see Figure 1 for location). The Pecatonica River is shown in blue. The light blue part of the river is the segment shown in the photograph below. Perspective of photo outlined by red line. Lower panel: Low-angle, oblique photograph of the Pecatonica River and oxbow lakes, viewpoint from the southeast viewing northwest. Photograph courtesy of Louis J. Maher Jr.

interaction with glaciers. The shape of some lakes was constrained by the shape of the ice margin and a pre-existing high topographic position on the landscape, such as a glacial moraine (a glacial ridge that formed along the edge of the glacier). Typically, they formed when the advancing glacier front or margin blocked water that drained an existing watershed. In addition, these **ancient and ancestral lakes** grew in size as they were fed by glacial meltwater. The ancient lake beds can form unique ecological environments. They typically occur in low places in the landscape, are flat or have low local relief, and are typically underlain by silt, clay, sand, or water-scoured glacial till (unsorted mixture of gravel, sand, silt, and clay deposited by a glacier). Because of their low relief and low landscape position, they may be occupied by wetlands.

Ice-walled lake plains are remnants of lakes that formed on top of a glacier or on a remnant piece of the glacier left on the landscape. The top of the glacier remnant would have appeared like the surface of Swiss cheese, with many circular depressions filled with water, similar to the landscape developed at the end of the Bering Glacier in Alaska today. The lakes melted downward until the lake bottom became connected with the ground surface under the glacier; the size of the lakes grew as the ice that formed their shores melted. Today, evidence of these former glacial lakes consists of flat-topped, circular-shaped hills that typically have steep surrounding hillslopes and that are composed of the sediments deposited in the vanished lakes. There are hundreds, if not thousands, of these landforms in the Great Lakes region. They can occupy any position in the glacial landscape and many are in high places, such as the tops of moraines.

Slack-water lakes formed when large volumes of meltwater loaded with glacial sediment occupied large river valleys, such as the Mississippi, Illinois, Ohio, and Wabash valleys. The aggrading sediment and high glacial flood stages dammed water in tributary valleys, causing water to back up and flood the tributary valleys. Remnants of these lakes are revealed today as high and, in places, expansive flat terraces adjacent to smaller tributary rivers and streams. Commonly, they are underlain by sand, silt, clay, or a combination thereof. In southeastern Illinois and southwestern Indiana, they also occur beyond the glacial limit (Figure 3).

Ancestral glacial lakes are those that were formed during glaciation but have a modern lake in the same or an adjacent place. The ancestral lake or lakes typically had a different shape or size from their present configuration, and some extended many miles inland of their modern extent. All the Great Lakes had ancestral counterparts. Through many advances and retreats, glacial ice filled all or parts of the Great Lakes basins, blocking the connections they have today to the Saint Lawrence River and causing them to overflow southward into the Mississippi and the Susquehanna and Hudson River systems. The sizes of the lakes were controlled by the position of ice margins,

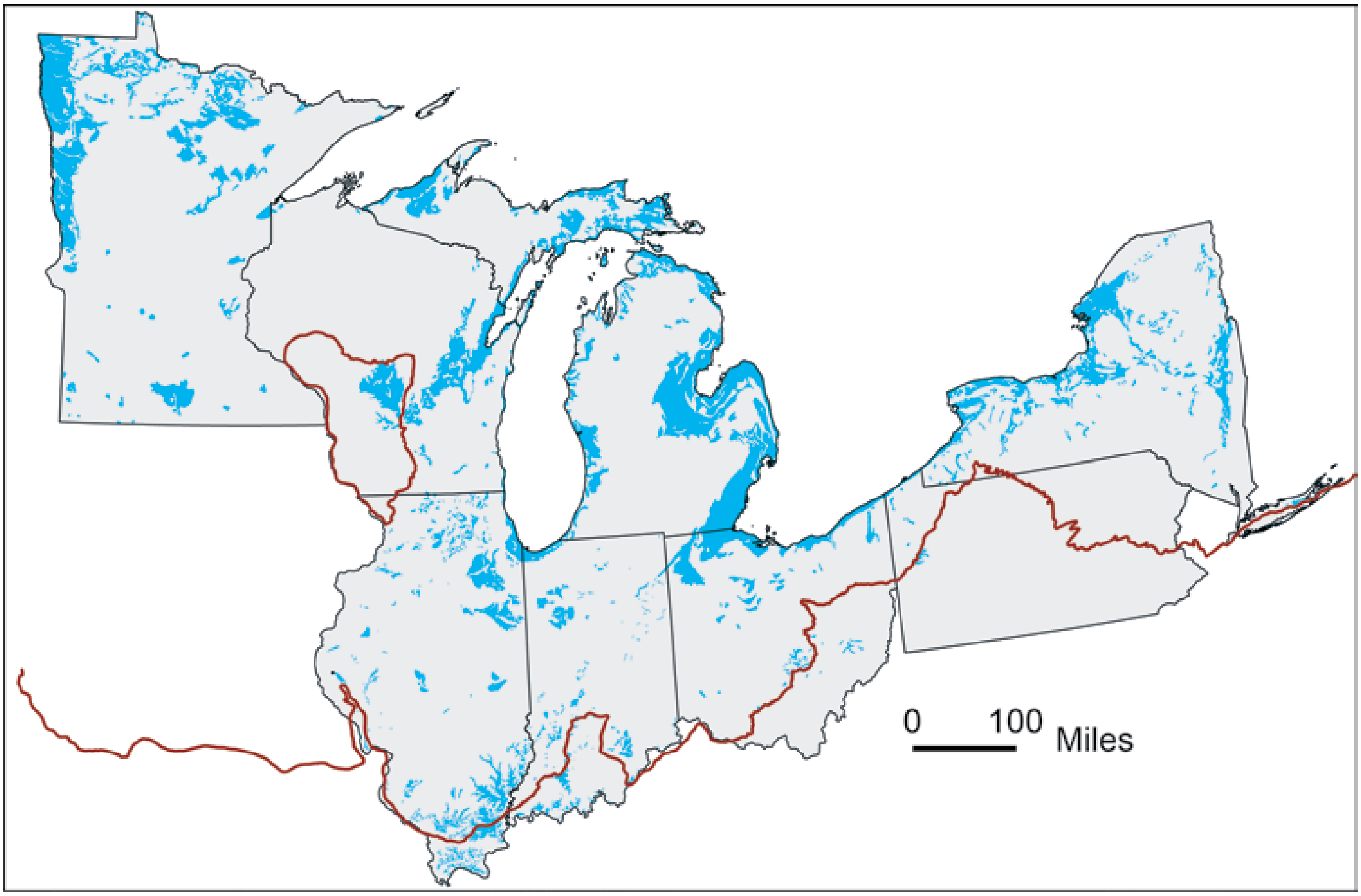


Figure 3. Distribution of sediment in former lake beds of ancient and ancestral glacial lakes. The red lines represent the limit of glaciation. The geology shown is from Fullerton et al. (2003), Gray (1989), and Lineback (1979).

the volume of meltwater filling the proglacial lake areas, and the elevation of outlets. As the ice margins melted northward, or as outlets were cut through rock or sediment, the height of lake levels changed. At times, when glacier margins fluctuated northward, the Great Lakes drained to lower levels than they are today. The altitudes of lake outlets, and therefore lake levels, were also controlled by isostatic depression as the weight of the glacial ice pressed the crust of the earth downward, then rebounded as the ice melted off the landscape.

Bedrock Erosion Lakes

Bedrock erosion lakes occupy depressions carved into solid rock by glaciers, with the most prominent being the Great Lakes. Glacial ice flowed radially away from ice caps in Canada, and in the area of the Great Lakes, the southward-flowing ice first moved through the lowest parts of the preglacial landscape. The shapes of the Great Lakes, and of the many lakes in bedrock depressions around them, were controlled by the distribution and type of solid bedrock Thus, the advancing glaciers followed the path of least resistance – through old river valleys or lowlands where the bedrock was most easily eroded. Geologists speculate that the process of glacial advance and erosion through the Great Lakes basins occurred many times throughout the cycles of glaciation during the Ice Age. A large number of smaller bedrock erosion lakes are very common in northeastern Minnesota and Canada, where the cover of glacial debris is thin or absent and where the underlying bedrock is composed of very old and structurally complex igneous and metamorphic rocks (Figure 4). Voyageurs National Park in Minnesota, Quetico Provincial Park in Ontario, and parts of the Superior National Forest in northern Minnesota share the Boundary Waters international area, where more than 4,000 of these lakes are located in Minnesota alone!

Kettle Lakes

Kettle lakes are named after their typical shape, that of a circular kitchen kettle. Also named ice-block depressions, they are typically round with a bowl shape, are steep-sided, and can be very deep. Kettle lakes range in size and can be large or very small (e.g., fewer than 5 acres). These lakes occupy space created by blocks of ice that were buried by glacial sediment, so their shape mimics the shape of the former block of glacier ice. Blocks of ice can become detached from the glacier by a variety of processes. One way occurs when a glacial outburst of meltwater happens very quickly. Blocks of ice can be carried

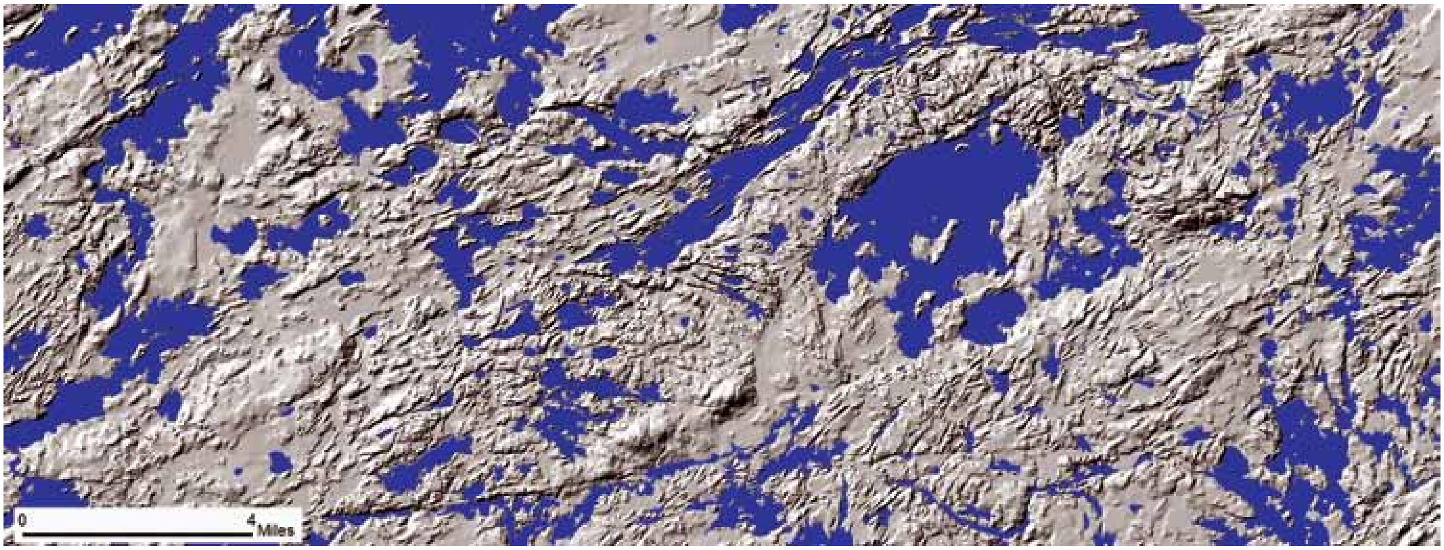


Figure 4. Shaded relief image map of a part of northeastern Minnesota adjacent to the U.S.-Canada border (see Figure 1 for location), emphasizing lakes in glacially eroded bedrock depressions. The linear pattern of the hills and low-lying areas is an expression of the varying resistance of various types of bedrock to glacial erosion.

away from the glacier margin, then buried by sand and gravel carried by the meltwater. Larger tracts of ice may detach along thrust planes in the ice or become separated from the glacier when the ice begins to flow in a different direction. In some places, the glaciers readvanced over blocks of ice and encased them in finer-grained glacial till. Kettle lakes encased in sand and gravel may be connected to the groundwater flow system, whereas kettle lakes encased in clayey glacial till may be perched and receive water primarily from rainfall and snowmelt. In addition, depending on the local hydrology, a kettle may be dry with no lake at all. Although kettle lakes occur throughout the glaciated terrain surrounding the Great Lakes, the Lower Peninsula of Michigan, and northern Wisconsin (Figure 5) have the greatest concentrations, with some counties having hundreds of these lakes. The Kettle Moraine region in eastern

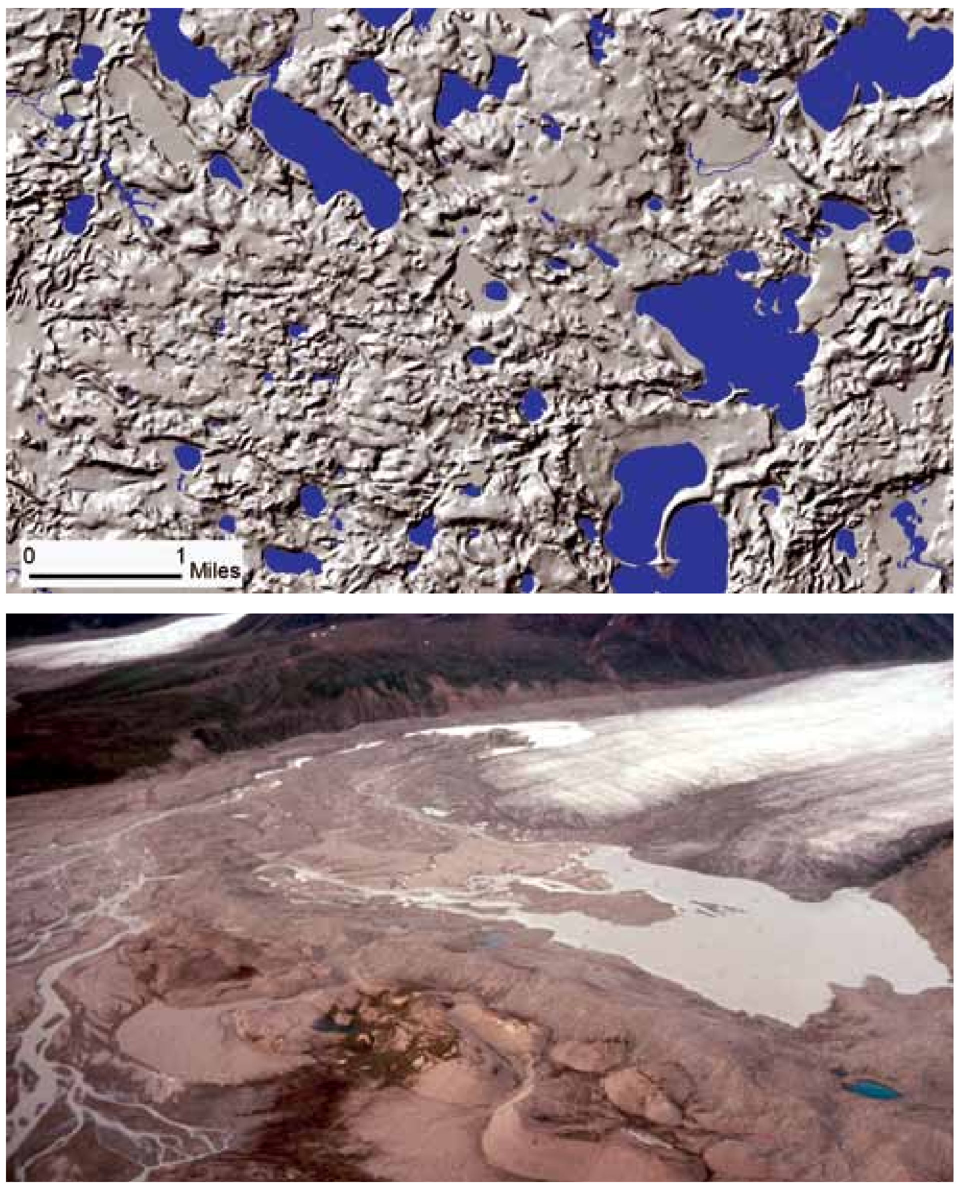


Figure 5. Example of kettle lakes. Upper panel at right: Shaded relief image map of a part of Vilas County, Wisconsin (see Figure 1 for location) with abundant ice-block depressions. Note that many depressions contain smaller lakes or no lakes at all. Lower panel: Complex ice-front environment around a retreating glacier margin on Bylot Island, Nunavut, Canada. Small kettle lakes are ice free, and a large, ice-covered lake dammed by morainic deposits rests against the front of the glacier. Location: 73°12'13"N; 79°44'37"W. Photograph courtesy of William W. Shilts.

Wisconsin, an area formed between two ice lobes, takes its name from the abundant kettles, both with and without lakes.

Enclosed Depression Lakes

Many lakes and small bodies of water are contained within shallow, enclosed depressions or basins that are not kettles. Different from kettles, the land surrounding these lakes may have gentle relief and roll. These lakes occur in landscapes formed by varying accumulations of debris that melted directly out of the glaciers, called glacial till, which can range from impermeable to slowly permeable.

Landform-Controlled Lakes

Landform-controlled lakes are dammed naturally by glacial or postglacial landforms or are created by other geomorphic processes. Some of these processes are ongoing today and may not be directly related to activity of the former glaciers. **Oxbow lakes** (Figure 2) form in the former channel of a river. When a river meander loop closes on itself, a cutoff occurs: The meander loop is abandoned, and the river segment is shortened. Oxbows can be ephemeral, filling with water seasonally or in response to weather events. The most notable oxbow lakes are those in large river valleys with low gradient rivers, such as the Mississippi River in Illinois or the Wabash River in Indiana.

The Great Lakes states host some of the most distinctive dune systems in the world. For example, dune fields can characterize large segments of the Lake Michigan shoreline (Figure 6). Migrating dunes can create enclosed basins that contain wetlands or small **dune-controlled lakes**, which, in some instances, have been described as "pans." The lakes can be very short-lived, depending on dune activity. Many of the dune fields are active today, with ongoing blowouts accompanied by dune migration. Although they continue forming as a modern geologic process, their geologic history typically relates to landscape conditions established by glaciers. Three important qualities are necessary: (1) an available sand-rich sediment source; (2) accommodation space; and, of course, (3) wind. Glacial deposits provide the sediment supply because rock fragments that have been ground to silt and sand are abundant.

Figure 6. A small lake, or "pan," surrounded by dunes within the Indiana Dunes National Lakeshore. The surrounding area has been greatly affected by urban and industrial development. Photograph courtesy of Steven E. Brown.

Less common, although distinctive, are lakes that occupy long, linear troughs sculpted into rock, older glacial deposits, or both. Instead of ice, the sculpting agent has been suggested to be subglacial meltwater. Because the subglacial water would have been under pressure, the lake bottoms do not follow a gradient. In addition, these types of lakes are typically very deep. Examples of lakes in these **meltwater-sculpted lake basins** include the Finger Lakes of New York State (Figure 7).

Sedimentation lakes form when sediment transported by flowing water or wind fills in a space where a river would flow. Common along the Michigan coast of Lake Michigan, these lakes are found at the mouths of many of the major rivers that end at Lake Michigan. Two geologic processes created these lakes. First, during low stages of the ancestral Great Lakes, rivers incised their channels downward to adjust to the lower lake level. The postglacial rise of lake levels flooded the incised river mouths, creating drowned estuaries. Second, in some cases, these drowned estuaries became closed from Lake Michigan when longshore currents and dune migration filled the connection with sand (Figure 8).

Other lakes are dammed between positive relief landforms. Opposite of kettle lakes, these lakes are not in depressions made by ice, but are in places between high landforms constructed by the glacier. For example, "drumlins" are one of the most distinctive glacial landforms in the Great Lakes area. Notable in Wisconsin, Michigan, and New York, the teardrop-shaped hills typically occur in large belts. Lakes may occupy the low places between drumlins (Figure 9).

Raised-Beach Lakes

Raised-beach lakes (Figure 10) occur in the low areas, or swales, between beach ridges that represent former shorelines of the ancestral Great Lakes and where the land has risen because of the release of the weight of glaciers (isostatic rebound).

Karst Ponds or Lakes

The term "karst" applies to landscapes that are underlain by soluble carbonate rock, limestone, or dolomite, that have distinctive landforms shaped by the dissolution of rock. Figure 11 (left panel) shows potential karst areas in the Great Lakes region. The fracture system in the rock, combined with the ability of the rock to dissolve with slightly acidic rainwater, creates a network of land

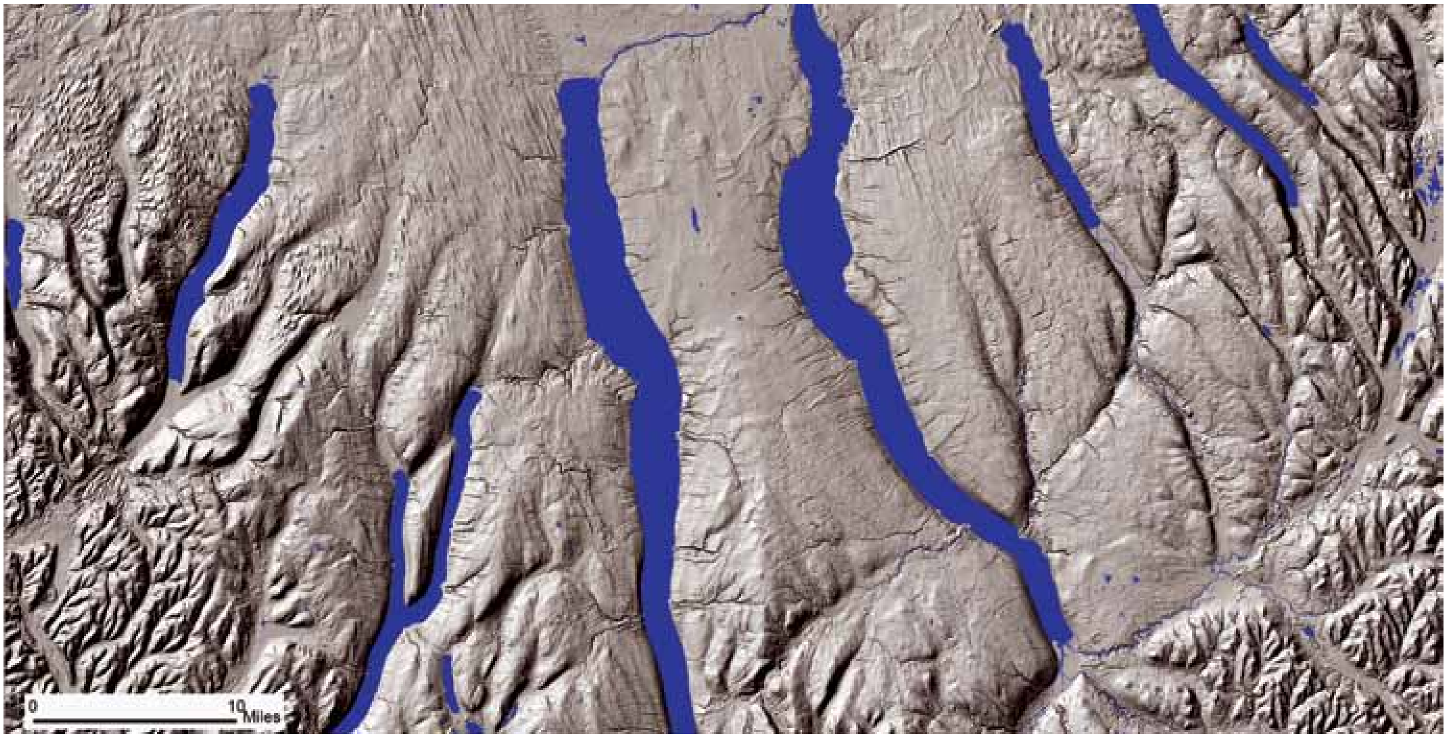


Figure 7. Shaded relief image map of a part of the Finger Lakes region of New York State. The distinctive linear troughs in which the lakes are situated may have been carved by meltwater flowing under the glacier with tremendous pressure. The fields of linear features are the famous New York drumlin fields (see Figure 1 for location).

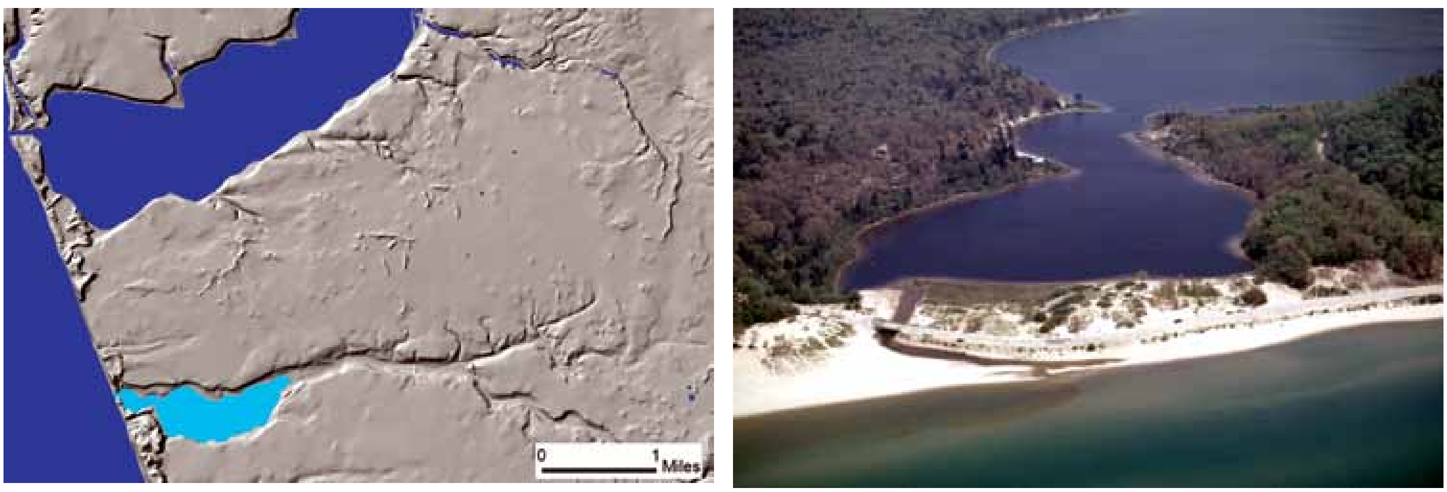


Figure 8. Lakes dammed by coastal dunes adjacent to Lake Michigan. Left panel: Shaded relief image map of a part of the Lake Michigan coast, approximately 7 miles north of Muskegon, Michigan (see Figure 1 for location). White Lake (dark blue, top) and Duck Lake (light blue, bottom) are adjacent to Lake Michigan (dark blue, left). Right panel: Low-angle oblique photograph of the Lake Michigan coast and Duck Lake. Note that sand dunes block the connection of Duck Lake to Lake Michigan. Viewpoint from slightly north of west to slightly south of east. Photograph courtesy of Louis J. Maher Jr.

surface sinkholes or circular depressions linked to underground cave systems. In areas where karst has been overridden by glaciers, the glacial deposits may create an impermeable or semi-impermeable layer within the sinkhole. A **karst pond** or **karst lake** may then form in the sinkhole (Figure 11, right panel). Some of these have been artificially modified and may more appropriately be classified as farm ponds.

Reservoirs, Farm Ponds, Detention Basins, Borrow-Pits, Quarries, & Mines

Reservoirs are large engineered structures that have been designed to control flooding, capture surface water runoff for use as a consumptive water supply, and provide water for generation of electric power. The reservoirs created for use as a water supply are typically built where groundwater resources are scarce or not available. Typically, these are in the public domain and also serve a secondary purpose for recreation. Many include public access through a state or federal park or designated recreation area.

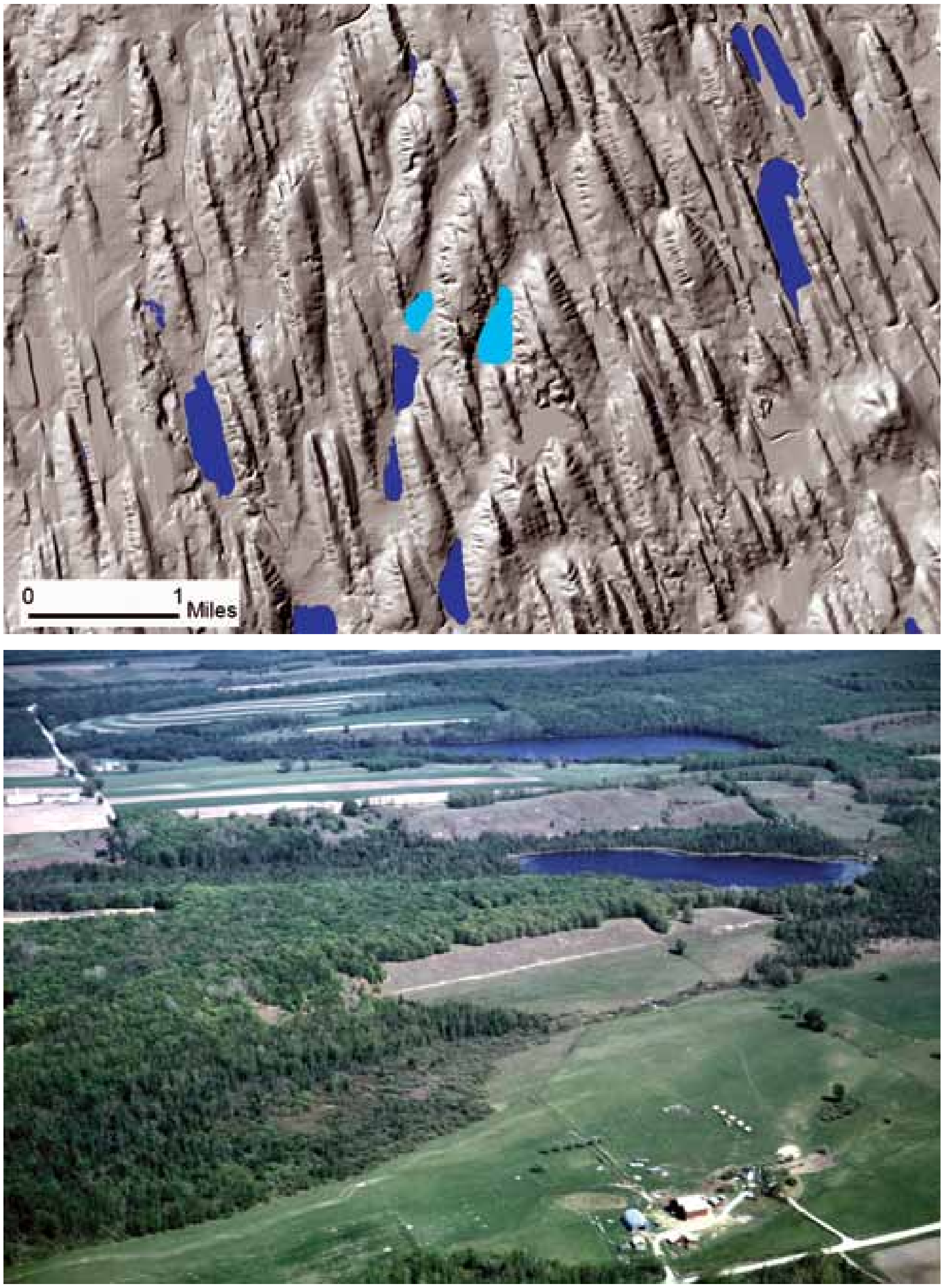


Figure 9. Lakes located in low places between drumlins. Upper panel: Shaded relief image map of a part of Charlevoix and Antrim Counties, Michigan, east of U.S. Route 31 and north of County Highway C-48 (see Figure 1 for location). The teardrop-shaped hills are glacial drumlins and trend north-northwest to south-southeast. The lakes shaded in light blue are Cunningham Lake (left) and Skinner Lake (right). Lower panel: Low-angle oblique photograph of drumlins and Cunningham (closer) and Skinner (farther) Lakes in depressions between drumlins. Viewpoint is from northwest to southeast. Photograph courtesy of Louis J. Maher,Jr.

Farm ponds are typically very small ponds or lakes that have been created to hold water for livestock or small-scale irrigation. They may or may not be connected to groundwater flow and typically rely on surface water runoff to sustain their level. In glaciated areas, they may be constructed in a pre-existing enclosed depression in glacial till. In unglaciated areas or areas covered only by the oldest glacial deposits where there is more incision of the landscape, they may have been created by dams across gullies. These also rely on surface water runoff for replenishment. Some are located near a natural spring or seep and are fed by both surface water runoff and groundwater. **Detention basins** are constructed for storm water runoff in urban areas (Figure 12). Increasingly, these have become havens for unwanted wildlife, such as large populations of Canada geese. **Borrow-pit lakes** are minor elements of the landscape and are typically very small. Created from the excavation of material for construction fill, these are common along the interstate highways.

Quarry or gravel pit lakes and surface **coal mine lakes** (Figure 13) are prominent in excavations for the extraction of sand and gravel aggregate or coal. After the resource is extracted, they are often remediated to form major recreation areas and support ecosystems that formerly did not exist in that location. The locations of gravel pit lakes are directly related to regions where sand and gravel, deposited by glacial meltwater rivers, were thick enough to mine. Lakes in quarries are generally, though not always, near urban areas, and coal mine lakes are found in areas where geologic processes have brought coal seams very close to the land surface. More than 100 surface coal mine lakes in western Indiana, where there are few natural lakes, are now managed for public use by the Indiana Department of Natural Resources.

Lakes – Shaping Midwestern History and Culture

Lakes are a significant part of the geography of the Great Lakes region: The cultural characteristics of the region are linked to the physiography of the glacial landscape and the lakes within that landscape. The exploration and settlement history of the Great Lakes region is tied to the unique characteristics of the Midwestern glacial landscape. The Great Lakes themselves provided the earliest transportation route from the Atlantic Ocean to the continental interior. Exploration of the Great Lakes coastal areas and later discoveries of connections to major rivers and water bodies, such as the Mississippi River and the Gulf of Mexico, opened trading routes and access to midcontinent natural resources long before western population expansion. The discovery of natural resources, such as copper and iron ore, and opportunities for wealth facilitated early occupation by Europeans. As major strategic, trading, and transportation centers such

Figure 10. Raised beach lakes between beach ridges near the north shore of Lake Michigan about 10 miles northwest of St. Ignace, Michigan. The ridges and lakes have risen because of glacial isostatic rebound. Viewpoint is from west to east. U.S. Route 2 parallels the shoreline, adjacent to Pointe aux Chenes Bay (see Figure 1 for location). Photograph courtesy of Louis J. Maher Jr.

as Chicago and Detroit grew, so did the importance of the Great Lakes for commerce and industrial development. During the Industrial Revolution, steel mills and related factories were built in protected coastal harbors, and in some areas, such as the vast steel mill complex in northwestern Indiana, harbors were built to connect the Great Lakes shipping industry to the land-based railroad network. The lakes and their tributaries have provided efficient transportation of the raw materials that fed the industrial complexes that grew on the shores of the lakes of the Midwest. The prairie soils of the southern Great Lakes states, rich with minerals from rocks pulverized by glaciers and nutrients derived from the extensive prairie vegetation, attracted farmers, who developed a thriving agricultural industry. They traded food for timber from the forests of the northern Great Lakes states via the Great Lakes shipping industry.

The growth of mining, manufacturing, and agriculture brought hundreds of thousands of people to the Midwest during the 19th and early 20th centuries. By the middle of the 20th century, inland lakes became increasingly important for their recreational and wildlife value. The "lake country" states of Minnesota, Michigan, Indiana, and Wisconsin became popular summer recreation areas. By the 1950s and 1960s, accessible inland lakes, particularly those close to cities, were populated by shoreline cottages. In the early and middle parts of the 20th century, many of the state and national park and recreation areas in the Midwest were established around both natural and human-constructed lakes, facilitated by a growing recognition of their significant natural heritage. Today, many lakes provide places for fishing and hunting, and states depend on the tourism value of lakes for their economies. On many lakes that are near major population centers, such as Minneapolis, Milwaukee, Chicago, and Detroit, lake communities have year-round residents. To some extent, all the lakes in the Great Lakes region face ongoing challenges related to intense human use, including pollution, nutrient loading, and degradation or displacement of natural flora and fauna, particularly by invasive plant and animal species.

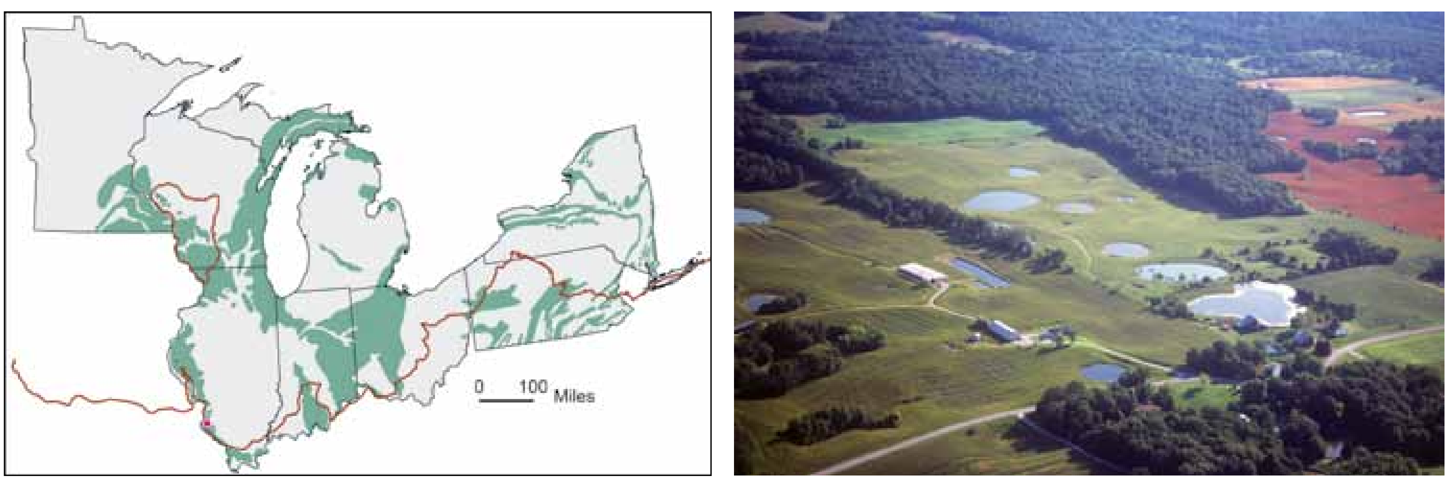


Figure 11. Area of potential karst and karst lakes. Left panel: Distribution of carbonate rocks susceptible to karst in the Great Lakes states (geology from Tobin and Weary 2004). Location of the photograph is shown as the pink box. Right panel: Low-angle oblique photograph of karst ponds about 5 miles west of Waterloo, Illinois (see Figure 1 for location). A veneer of glacial sediment covers the landscape and the sinkholes in the karst landscape. Viewpoint is from southwest to northeast. Photograph by Joel Dexter. ©2012 University of Illinois Board of Trustees; used courtesy of the Illinois State Geological Survey.

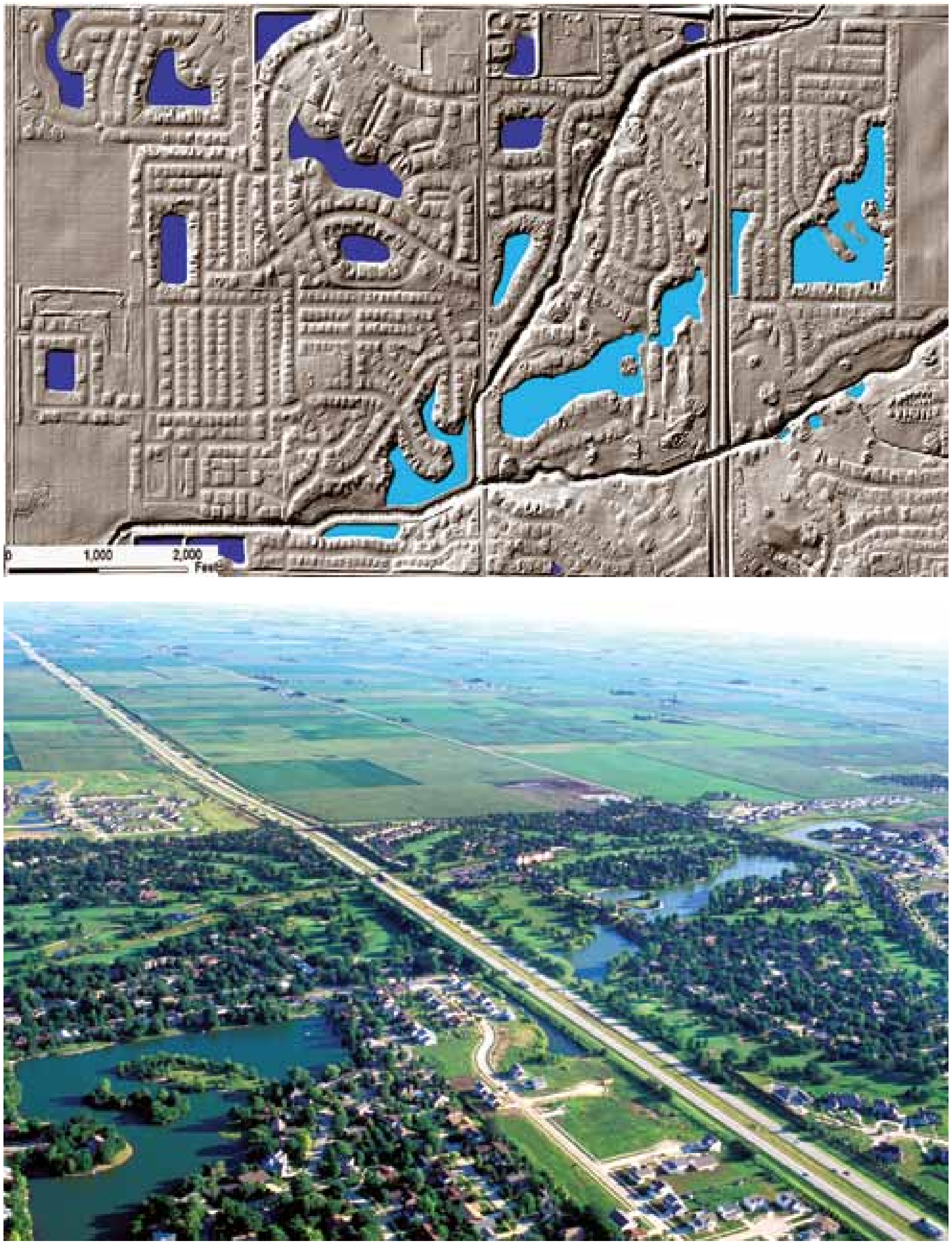


Figure 12. Human-made urban lakes are built to capture storm water runoff and add aesthetic value for home owners. Upper panel: Shaded relief image map of a part of the City of Champaign, Illinois. Lower panel: Low-angle oblique photo of southwest Champaign, Illinois. Suburban development straddles Interstate 57. Viewpoint is from northeast to southwest. Photograph by Joel Dexter. ©2012 University of Illinois Board of Trustees; used courtesy of the Illinois State Geological Survey.

The origin and location of lakes in the Great Lakes region are intricately tied to their Ice Age legacy. Indeed, our interaction with the lakes and their landscapes has been profoundly shaped by this legacy. Understanding the complexities of lake formation can only lead to better stewardship of our lake environments, and to leaving an additional legacy for future generations.

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Figure 13. Lakes created during coal surface mining dot the coal mining regions of Illinois and Indiana. Upper panel: Low-angle oblique photograph of coal mine lakes near Danville, Illinois. Viewpoint is from northwest to southeast. Photograph courtesy of Illinois Department of Natural Resources, Abandoned Mine Lands Division. Lower panel: *USDA-Farm Service Agency National Agriculture Imagery Program (NAIP) aerial photograph of the Danville, Illinois area acquired on August 25, 2011. Interstate 74 crosses the lower left part of the photo. Perspective of photo above outlined by red line.*

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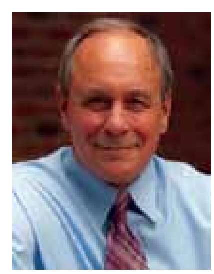

Dr. William Shilts, executive director of the Prairie Research Institute at the University of Illinois since 2008, is a native of Hudson, Ohio, and a graduate of DePauw, Miami of Ohio, and Syracuse Universities. Before moving to Illinois in 1995 to become chief of the Illinois State Geological Survey, one of five State Scientific Surveys in the Prairie Research Institute, William was a research scientist at the Geological Survey of Canada, where he specialized in glacial geology, environmental/exploration geochemistry, and the impact of seismic events on lakes. He can be contacted at shilts@illinois.edu.