Geological Note 8

Three-Dimensional Surficial Geology of the Milan Quadrangle, Erie and Huron Counties, Ohio

by
Richard R. Pavey

STATE OF OHIO
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY
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Front cover: Shown here is one of the scattered, discontinuous lenses of massive glacial till (gray material in middle of photo) completely encased in finely laminated, glaciolacustrine silt and clay deposits (top and bottom of photo). Such lenses are interpreted as clasts of till that melted from the base of floating, remnant glacial ice and are found only where the waters of high-level proglacial ancestors of modern Lake Erie were at their deepest. The example shown here is from the northern part of the Milan Quadrangle, which is underlain by a deep, central buried valley.

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ABBREVIATIONS USED IN THIS GEOLOGICAL NOTE

foot (feet)	ft
gallons per minute	gpm
mean sea level	MSL
years before present	ybp

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ABSTRACT

The Central Great Lakes Geologic Mapping Coalition (now the Great Lakes Geologic Mapping Coalition or GLGMC) was formed in the late 1990s between the USGS and a network of state geological surveys which border the Great Lakes. The GLGMC was tasked with creating innovative three-dimensional (3-D) mapping, models, and other means for displaying the complex near-surface geology common to these states. These 3-D products, along with associated databases could be used to assist decision-makers on projects including geologic hazards, groundwater, mineral industries, and land usage. The Milan 7.5-minute quadrangle (Erie and Huron Counties) in north-central Ohio was chosen as one of the pilot projects for this program. The Milan quadrangle is transitional in origin and includes glacio-lacustrine, shoreline, alluvial, and glacial processes making for extremely complex series of depositional environments. A number of data sources including water well log data, engineering boring logs, NRCS soil surveys, theses, and prior reports were used to compile a series of maps using ESRI ARC-GIS tools. Each identified geologic unit or zone was identified and displayed as a discrete body. The origin, composition, and geomorphology of each body are thoroughly discussed herein. The entire sequence of overlapping units is represented as a geologic map and cross-section at scale of 1:24,000. The geologic map is accompanied by both a bedrock topography and drift thickness maps. A thick, elongated body of sand in the center of the mapping area was identified as a potentially important economic resource. A number of derivative maps were produced that include aquifer potential, aggregate potential, aquifer recharge, landfill suitability, and suitability for excavation and construction.

INTRODUCTION

In the late 1990s, a partnership known as the Central Great Lakes Geologic Mapping Coalition was formed between the U.S. Geological Survey and the state geological surveys of Ohio, Indiana, Illinois, and Michigan. With the recent addition of the remaining lake states (Minnesota, New York, Pennsylvania, and Wisconsin), the partnership now is known as the Great Lakes Geologic Mapping Coalition (GLGMC). The land region surrounding the Great Lakes contains some of the nation's most heavily populated and heavily farmed areas. These population and agricultural locales are, for the most part, developed on top of glacial deposits of complex nature and variability and varying thicknesses. Understanding these geological underpinnings is vital to successful current and future efforts of sustainable development of communities and watersheds and, ultimately, to the long-term health of the Great Lakes. The mission of the GLGMC is to produce detailed, three-dimensional (3-D) geologic maps and information in digital format, along with related digital databases, that are required to support informed decision-making involving groundwater, mineral-resource availability and distribution, geologic hazards, and environmental management (Berg and others, 1999; CGLGMC, 1999).

With a small amount of start-up funding, pilot mapping projects were undertaken in each of the original four states. In Ohio, the Milan quadrangle (Erie and Huron Counties) was selected as the pilot project (fig. 1) because of (1) its proximity to Lake Erie, which is about one mile to the north; (2) its complex glacial geology, including an important buried valley aquifer; (3) its mixture of suburban development and agricultural use; and (4) the availability of a significant amount of data for the area. The Ohio Department of Natural Resources (ODNR), Division of Geological Survey (Ohio Geological Survey) conducted the 3-D mapping of the near-surface geology of the Milan quadrangle. Results of this detailed mapping allow for better decision making within the area by providing the necessary data and maps for society's interaction with the near-surface environment. Sustainable development of the area's ground-water resources can now be enhanced by the mapping of the depth and thickness of the aquifer system. Also, waste disposal and waste utilization siting can be aided by the characterization and mapping of unconsolidated materials that can act to block waste migration. This is important to the design and siting of landfills, sewage systems, and agricultural livestock manure or silage pits. This report also will be of benefit in

FIGURE 1. Location of the Milan, Ohio 7.5-minute quadrangle.

planning for economic development of sand-and-gravel and sandstone resources.

METHODOLOGY

A primary objective of the Ohio pilot project was to acquire the technology and knowledge to develop efficient methodologies for production of 3-D geologic frameworks. For this work, various geographic information systems (GIS) tools (within ESRI ArcGIS) were used to construct the bounding surfaces of each geologic unit and to produce grids that allowed depiction of the 3-D framework of surficial and bedrock geologic units; this methodology has been described elsewhere (Pavey, 2006; Pavey and others, 2008; Pavey, unpub. data, 2009).

Data sources used for this effort included outcrop descriptions, oil-and-gas well logs, recent seismic-refraction surveys, and one core description, all on file at the ODNR Division of Geological Survey. Also used were Natural Resources Conservation Service (NRCS) soils maps, Ohio Department of Transportation boring logs for bridge foundations, Ohio Environmental Protection Agency and Bureau of Underground Storage Tank Regulations site investigation boring logs, ODNR Division of Water logs for water wells, and project drilling logs from engineering firms (fig. 2). Water well logs are the most common records and are distributed throughout the study area. They penetrate to greater depths; however, their reliability is variable. Engineering logs tend to be more limited geographically; shallower; and clustered around roads, bridges, and large projects, such as landfills and major construction sites. The data on these records also tend to be more reliable. All data was carefully reviewed to assist in constructing digital GIS files that contain the location of each log and a record of each interval in a log, which includes elevation and thickness data, field description, and lab analysis data. Each interval was then analyzed and assigned a lithologic interpretation based on the characteristics of the materials reported in the logs. Different logs and datasets were compared against each other to derive the most reliable result. Well log and boring records made it particularly challenging for the geologist to differentiate fine-grained materials, such as clay, silt, and till. The geologist's past experience and knowledge in interpreting these lithologies from various records was of great importance. Past extensive field mapping in the Milan area also was critical in helping to make these determinations. The resultant 3-D model can be quickly manipulated to produce a range of derivative products to address the wide variety of water-management, land-use, environmental, and resource issues that are crucial to local, state, and federal agencies, private industry, and the general public.

PREVIOUS WORK

Leverett (1902) produced the first comprehensive glacial map of Ohio. Leverett and Taylor (1915) detailed the glacial history of the Great Lakes. Campbell (1955) conducted the first county-scale mapping of the glacial geology of Erie and Huron Counties. Forsyth (1959) produced a map and history of the proglacial lake beaches of Ohio, using the work of F. J.Carney (Ohio Geological Survey, unpub. data[1]), and a history of western Lake Erie in 1973. Hough (1966) presented a comprehensive history of the proglacial lake levels for the entire Great Lakes. Soils mapping was done for Erie County by Redmond and others (1971), which was in turn revised by Robbins and others (2002). Wildermuth and others (1955) produced the Huron County soils map, later revised by Ernst and others (1994). White (1982) studied the glacial geology of northeastern Ohio, with mapping extending to the Erie County border. Field data for Erie County (R. R. Pavey, Ohio Geological Survey, unpub. data[1]) and Huron County (S. M. Totten, Ohio Geological Survey, unpub. data[1]) was collected during extensive field work in the 1980s. The bedrock geology of the region has been reported on by Pepper and others (1954), Hoover (1960), and Slucher and others (2006). Herdendorf (1966) mapped the bedrock geology of the Vermilion West and Berlin Heights 7.5-minute quadrangles, which adjoin Milan to the northeast and east, respectively.

[1]Data on file at the Ohio Department of Natural Resources, Division of Geological Survey.

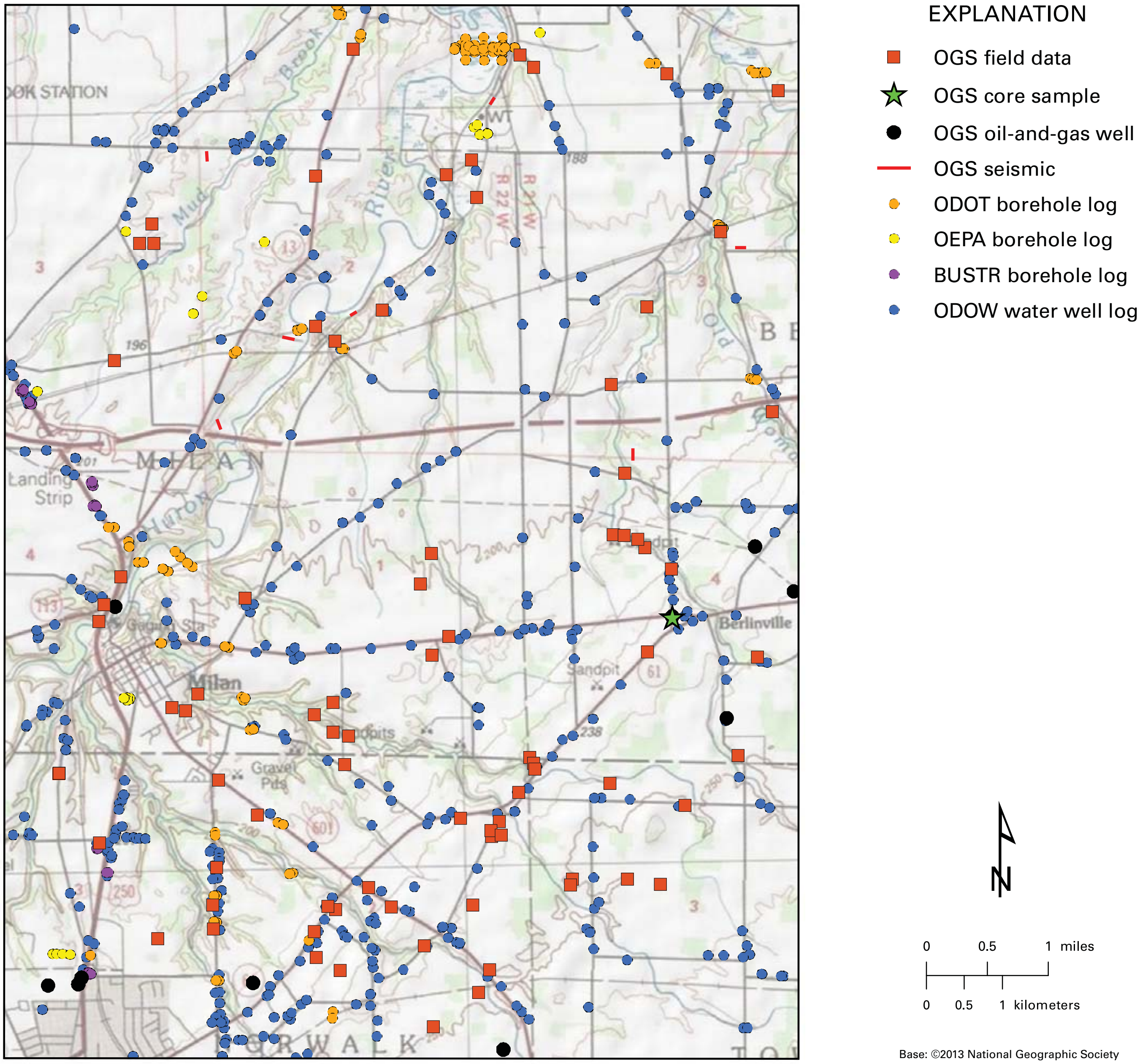


FIGURE 2. Subsurface data sources in the Milan quadrangle. OGS = Ohio Geological Survey; ODOT = Ohio Department of Transportation; OEPA = Ohio Environmental Protection Agency; BUSTR = Bureau of Underground Storage Tank Regulations.

REGIONAL GEOLOGIC SETTING AND HISTORY

The Paleozoic bedrock of the study area is near the northwestern edge of the Appalachian Basin and dips gently southeastward (Pepper and others, 1954). The bedrock surface has been deeply scoured by multiple glaciations. The scouring left a relatively smooth bedrock surface, with a deep NNE–SSW-trending valley in the middle of the map area, which was subsequently filled by glacial deposits. Post-glacial erosion has cut through the glacial deposits in many valleys, exposing the bedrock as shown in the bedrock topography map (fig. 3). To produce this bedrock topography map, all data points that recorded the depth to the top of the bedrock surface were used, along with soils units that contain shallow or exposed bedrock. These data were analyzed to construct a contour map of the bedrock elevation. By subtracting the bedrock elevation from the digital surface elevation model, a drift thickness map was produced (fig. 4). The drift thickness map shows that the thickness of Pleistocene deposits ranges from zero, where the bedrock is exposed, to as much as 178 feet (ft) along

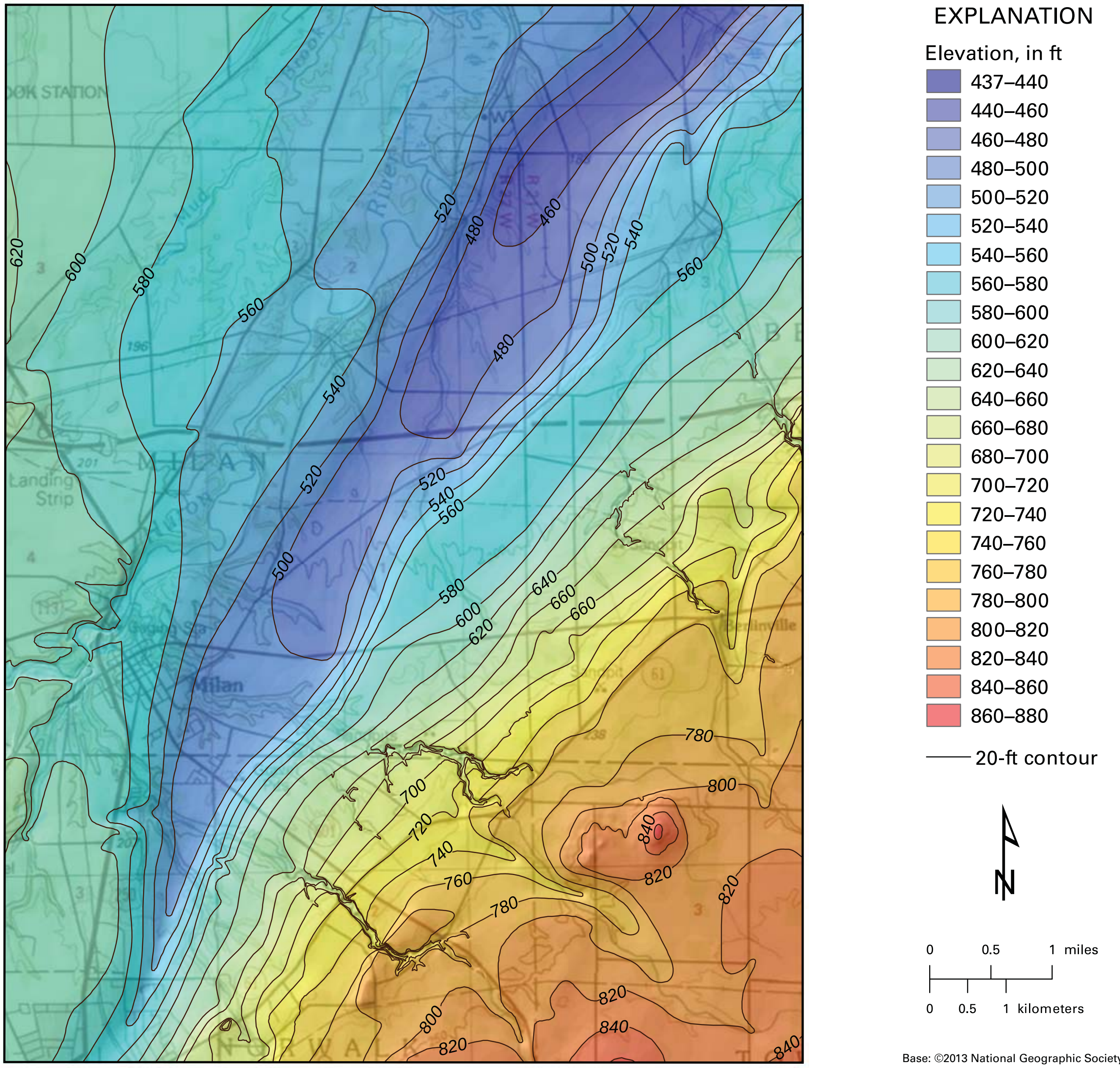


FIGURE 3. Bedrock topography of the Milan quadrangle. This map shows the elevation of the top of the bedrock surface, which over most of the mapped area also is the bottom of the glacial deposits.

portions of the northeast–southwest-oriented buried valley. Bedrock topography and drift thickness information has a wide range of uses, such as determining the amount of overburden atop bedrock resources, length of casing needed by well drillers, and excavation depth required to reach a solid bedrock foundation.

During the Ice Age of the Pleistocene Epoch (1.6 million–10,000 years before present [ybp]), Ohio was overridden by advances of mile-thick glacial ice many times. However, the erosive action of each successive ice advance removed most of the deposits of previous glaciations, leaving only remnants preserved in low-lying settings protected from scour. In the Milan quadrangle, the oldest deposits are of presumed Illinoian-age (180,000–125,000 ybp) in the lowest, most protected part of the buried valley in the center of the quadrangle. Multiple advances of Wisconsinan-age (24,000–14,000 ybp) ice covered the area with a locally thick blanket of till (a heterogeneous mix of clay, silt, sand, gravel, and boulders deposited directly by the ice sheet).

As the last Wisconsinan glacier retreated to the northeast into deeper sections of the Lake Erie basin, the

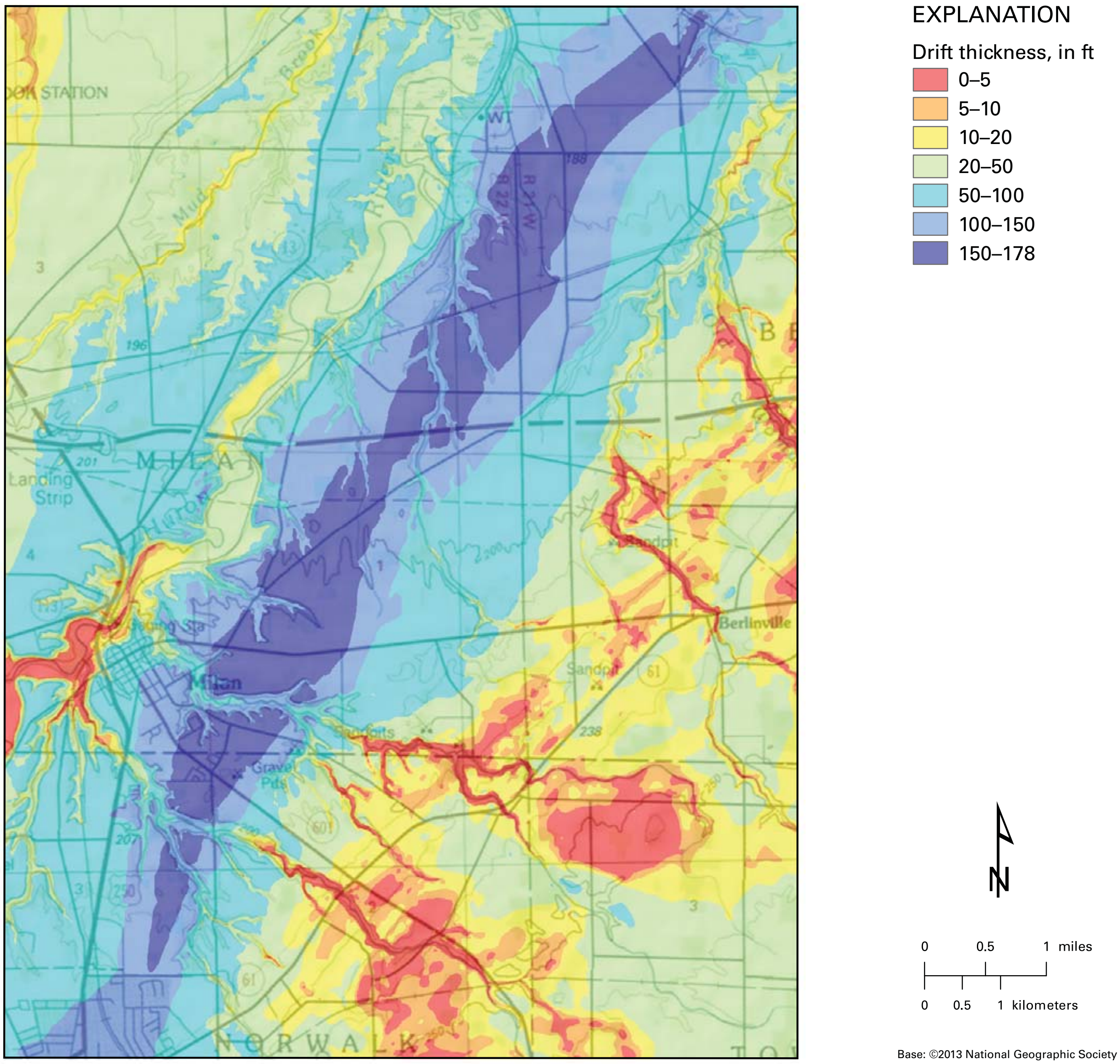


FIGURE 4. Drift thickness of the Milan quadrangle. This map shows the thickness of sediments from the top of the bedrock surface to the existing ground surface. The thickest deposits (dark blue) clearly define the long northeast–southwest valley that has been largely filled with glacial deposits and includes the best ground-water aquifer in the mapped area. Where the drift thickness is near zero (red areas), the bedrock is very thinly covered or exposed at the surface.

drainage outlet for the Great Lakes at Niagara Falls was still buried under ice, and a meltwater lake filled the Erie basin to a level almost 230 ft above modern Lake Erie. As ice continued to recede northward, a series of successively lower elevation lake outlets were uncovered, and lake levels dropped (table 1, fig. 5). Most of the Milan quadrangle was inundated by these lakes, resulting in wave erosion of till and bedrock. The eroded sediment was sorted by wave action, and a suite of lakebed (lacustrine) deposits were laid down, including gravelly shoreline beaches, sandy shallow-water deposits, and deep-water silt and clay. These units and their origins will be discussed in detail in following sections.

When the outlet at Niagara Falls was finally ice-free, meltwater had a path to the Atlantic Ocean. However, the great weight of the recent ice had depressed Earth's crust below Niagara to an elevation well below modern levels (a phenomenon known as *isostatic depression*), and the Erie

TABLE 1. ***Chronological sequence of Wisconsinan proglacial lakes in the Erie basin, from oldest to youngest*[1]**

Lake stage	Apparent water elevation (feet above MSL[2])	Outlet
Maumee I	800	Wabash River
Maumee II	760	Grand River, Imlay channel
Maumee III	780	Wabash River
Arkona	695–710	Grand River, via Lake Saginaw
Whittlesey	738	Grand River, Ubly channel
Warren I	690	Grand River
Warren II	682	Grand River
Wayne	660	Mohawk [Grand River?]
Warren III	670–685	Grand River
Lundy	615–640	Lake Michigan
Early Lake Erie	420 (approx.)	Niagara
Modern Lake Erie	571	Niagara

[1]After Leverett and Taylor (1915), Hough (1958), and Forsyth (1973). Figure 5 shows the extents and outlets of some of the major stages.
[2]Mean sea level.

basin drained to a level much below the level of modern Lake Erie. Streams in the quadrangle near the modern lakeshore eroded their valleys to levels well below modern elevations. The valleys then filled with thick Holocene-age (10,000 ybp–Present) alluvial and organic estuary sediments as the lake levels rose in response to bedrock slowly rising at the outlet.

Figure 6 shows the resultant distribution of geologic deposits that are at the surface of the Milan quadrangle; figure 7 shows a cross section of all the geologic units.

GEOLOGIC UNITS

The following section presents information about each geologic unit in stratigraphic order, from the deepest (or oldest) to the shallowest (or youngest) units, in the Milan quadrangle. A series of 3-D views of the area also are presented in this same sequence to illustrate how the geology is "stacked" and to better show the vertical and lateral variability across the mapped area.

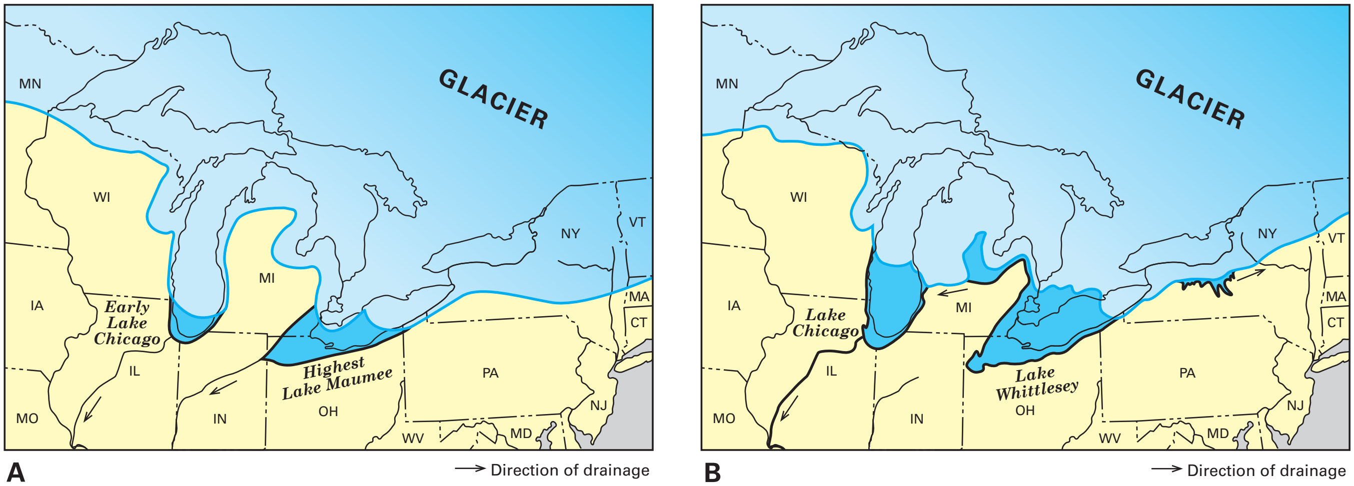
Paleozoic Bedrock Geology

Ohio and Bedford Shales

The lowest mapped-bedrock unit in the map area is the Devonian-age Ohio Shale, which underlies the entire map area (Hough, 1958) and forms the majority of the bedrock surface. Ohio Shale is mostly hard, fissile, siliceous, and carbon rich; pyrite and carbonate concretions are common in the lower portion. In outcrop, it weathers to dark-brown, platy fragments. (Hoover, 1960; Slucher and others, 2006). However, it is resistant enough to erosion to form vertical cliffs in many stream and river valleys. Although the organic-rich Ohio Shale has been investigated as a source of oil and gas, none is currently produced in the Milan quadrangle (Hoover, 1960; Boswell, 1996).

Above the Ohio Shale, the discontinuous Devonian-age Bedford Shale is found in parts of the map area. The Bedford is a soft, dark-gray to reddish-brown shale containing thin beds of siltstone. This unit weathers to a soft, sticky red mud in outcrop. Much of this unit was eroded away before or during deposition of the overlying Berea Sandstone (Pepper and others, 1954). Insufficient information exists in the map area to differentiate the Bedford as a separate unit; therefore it is included with the Ohio Shale. Bedford Shale was formerly a source of clay for brick and tile, but superior clays and modern plastics have replaced its use (Hoover, 1960); no shale pits are located in the Milan quadrangle.

The combined Ohio-Bedford Shale unit varies from 70 ft thick at the northwest corner of the study area to over 300 ft thick in the southeast corner, under the Berea Sandstone (figs. 7 and 8). The shales are poor ground-water producers. Some very low-yielding wells (<3 gallons per minute [gpm]) have been installed where no other producing unit can be found (Walker, 1986; Hartzell, 1986); however, these wells may encounter water quality problems, such as gas and high sulfur content. The very low permeability of the shales provides a confining base unit for ground-water modeling efforts. Because of their low permeabilities, septic systems should not be installed within the shale. Fortunately, most areas where the shale is exposed or very shallow are along valley walls where the slope is too steep for septic system construction. Although the shale is removable with a ripper-equipped bulldozer in excavations, it has good bearing strength for foundations.



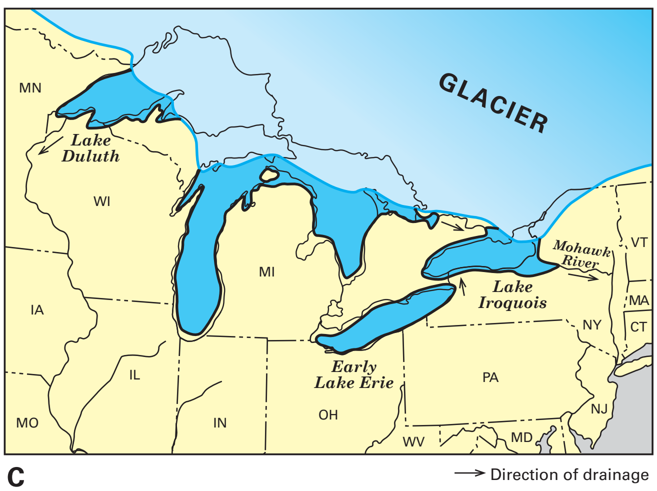


FIGURE 5. Major lake stages and outlets of the Great Lakes. Modified from Hough (1958).

A. Highest Lake Maumee (Maumee I) stage in the Erie basin. Drainage was westward across Indiana into the Wabash River system.

B. Lake Whittlesey stage in the Erie basin. Drainage was westward across central Michigan.

C. Early Lake Erie stage, when lake level was lower than modern Lake Erie. Drainage was eastward into Lake Iroquois (a predecessor of Lake Ontario) and then into the Mohawk River in New York.

Berea Sandstone

The uppermost bedrock unit within the Milan quadrangle is the Devonian-age Berea Sandstone, which overlies the Ohio and Bedford Shales, where present. Due to pre- and early-glacial erosion, the Berea is found only in the southeastern portion of the map area (fig. 9). The Berea is shades of brown; very fine grained to silty; mostly in planar to lenticular beds, with local shale interbeds; ripple-marked beds are common and locally, there are micaceous partings between beds. Scour channels that were incised prior to or during Berea deposition are present in this area, commonly eroding completely through the Bedford Shale and into the Ohio Shale. Berea deposits in these channels are much thicker than the surrounding nonchannel deposits. Although Pepper and others (1954) did not observe soft-sediment deformation in the Berea channel sands, a point on Old Woman Creek about 1,200 ft east of the Milan quadrangle exhibits a remarkable example of deformation of both Ohio Shale and Berea Sandstone. Across a distance of a few hundred feet, flat-lying beds of both units increase in dip, until a near-vertical contact crossing the streambed is reached, showing that the great weight of the accumulating Berea sands sank into the muds of the Ohio Shale, before both units became lithified.

The Berea Sandstone is historically one of Ohio's most important dimension stone sources and has been quarried for well over a century. The most productive quarries were in the thick channel sand deposits, where quarry depths were up to 200 ft thick or more (Pepper and others, 1954). Although no quarries have been developed in this quadrangle, currently there is one active Berea dimension stone quarry in the adjacent Berlin Heights quadrangle (Wolfe, 2013).

Channel sands of at least 120 ft in thickness are present in the Milan quadrangle. Much of the thick sandstone is covered by relatively thin glacial deposits and may represent a potential quarryable resource. The sandstone also has been used locally as aggregate. Currently there are no active Berea aggregate operations in the Milan quadrangle.

To the southeast, oil-and-gas production from the Berea is significant, but the unit is too shallow in the Milan

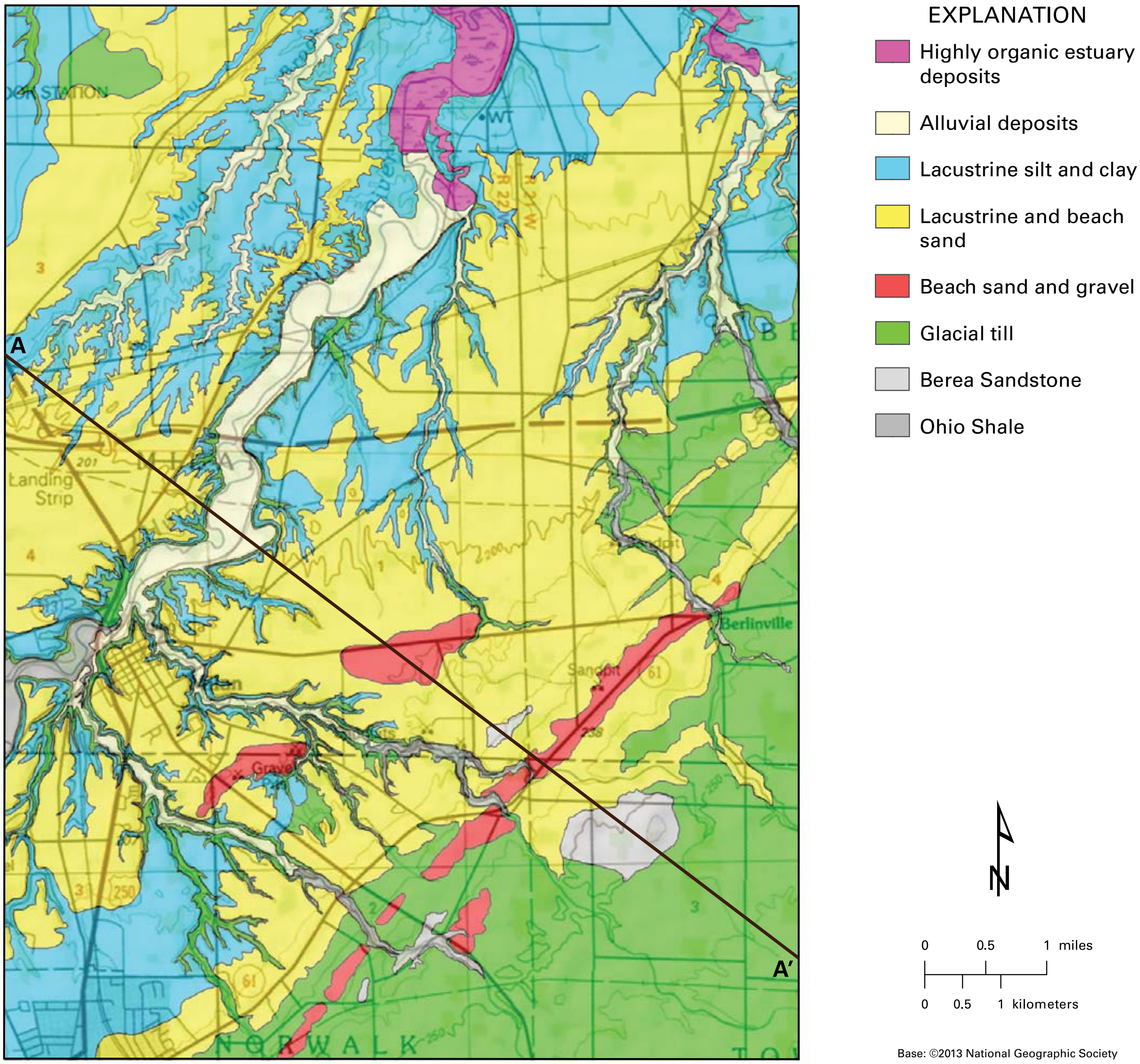


FIGURE 6. Surficial geology of the Milan quadrangle. Line A–A′ indicates the location of the cross section shown in Figure 7.

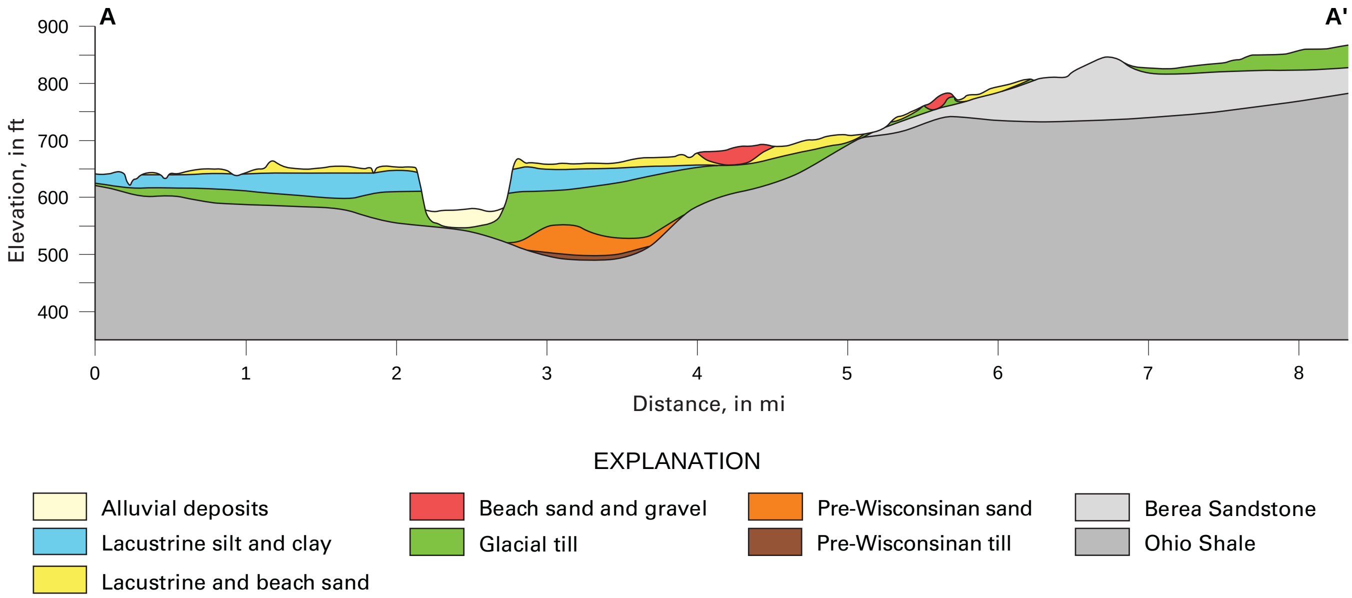


FIGURE 7. Typical cross section showing all of the geologic units in the Milan quadrangle. Cross section location shown in Figure 6.

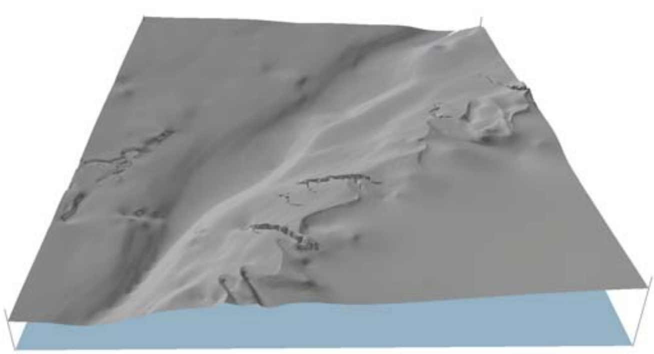


FIGURE 8. Three-dimensional view of the top surface of the Ohio Shale. This and subsequent 3-D views of the Milan quadrangle are from the south, with illumination from the northwest.

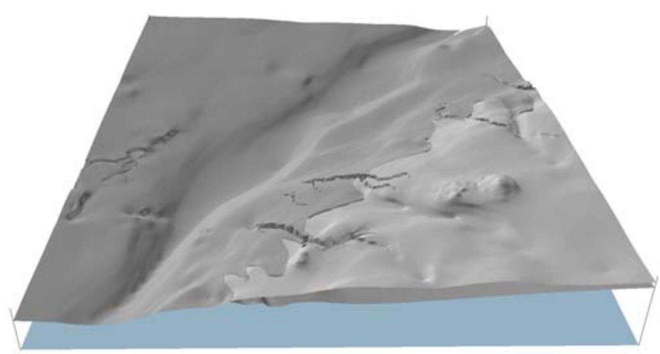


FIGURE 9. Three-dimensional view of the top surface of the Berea Sandstone (light gray) above the top of the Ohio Shale (dark gray) in the Milan quadrangle. This represents the surface of the bedrock as it was left after erosion and glacial scouring and prior to deposition of glacial and fluvial sediments, with the exception of the steep modern valleys incised into the bedrock.

quadrangle; most pore space is filled by water at this depth.

The Berea also is an important local aquifer for residential water supply (Walker, 1986; Hartzell, 1986). Where the sandstone is shallow, foundation conditions are excellent, but construction excavations require hard rock removal methods. Septic systems in the sandstone risk ground-water contaminant. Road salt has been found to be a common contaminant in shallow sandstone aquifers throughout Ohio.

Pre-Wisconsinan Deposits

In the Milan quadrangle, there are two units mapped as pre-Wisconsinan age; their deposits are restricted to the bottom of the buried valley in the center of the quadrangle and are not exposed by modern drainage. These units can be defined only by their descriptions on water well logs. However, these units probably are similar in origin and character to the probable pre-Wisconsinan deposits found in a similar buried-valley setting near the Erie-Lorain county line; these deposits are well exposed by the incision of the Vermillion River and its tributaries (R.R. Pavey, Ohio Geological Survey, unpub. data[1]).

Pre-Wisconsinan Till

Till overlying the Ohio Shale is indicated in several logs and is restricted to the deepest portion of the buried valley. Drillers generally log this unit as "hardpan" or "black sand." The lowest exposed till in the Erie-Lorain county-line buried valley is very hard ("hardpan"), has a high percentage of sand- to pebble-sized black Ohio Shale ("black sand"), and has drillers' log descriptions similar to those recorded in the base of the Milan buried valley. This till also is similar in description to till in northeast Ohio interpreted by White (1982) as pre-Wisconsinan. The pre-Wisconsinan till has a maximum thickness of 55 ft and it is too impermeable to provide a source of ground water. Within the Milan quadrangle, depth to this till varies from about 40 to 175 ft (fig. 10).

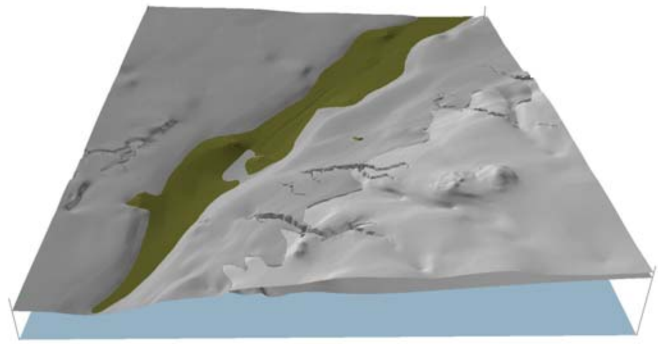


FIGURE 10. Three-dimensional view of the top surface of the pre-Wisconsinan till (brown) overlying the Ohio Shale (dark gray) in the Milan quadrangle.

Pre-Wisconsinan(?) Sand

The most important aquifer in the study area is the sand unit in the buried valley. This unit is not exposed at the surface in the study area. Depth below the surface to this unit is about 10–145 ft (fig. 11). With no exposures or samples to examine, the age and origin of this sand is uncertain. However, the geometry and borehole log descriptions suggest that the unit began with fluvial deposits in the lower elevations of the valley following the retreat of pre-Wisconsinan ice; many logs for the base of the unit contain sand and gravel. Fluvial deposition was likely followed by deltaic sand accumulation, as the valley became an embayment of a lake filling the Erie basin. The lake could have been formed by rebound of the Erie basin outlet after melting of pre-Wisconsinan ice or by blocking of a northeastern outlet by the first advancing Wisconsinan ice.

The bulk of the northern end of the deposit is described in borehole logs as sand, with some sand and gravel with ground-water yields of up to 150 gpm; the equivalent unit in the county-line buried valley is coarse- to medium-grained, cross-bedded sand. Borehole logs contain more gravel with the sand at the higher, southern end of the valley; this is interpreted as a fluvial, head-of-delta depositional environment. Ground-water production in the southern part of the unit is as high as 300 gpm for larger-diameter, properly constructed wells and has been used for irrigation of vegetable crops that thrive on the lacustrine fine sands at the surface. Well yields up to 100 gpm have been reported for similar wells in the northern portion of this sand body. This unit reaches a maximum thickness of 68 ft in the southern part of the quadrangle; the overriding Wisconsinan ice eroded the upper portion of the sand, leaving scour channels and removing an unknown thickness of the deposit.

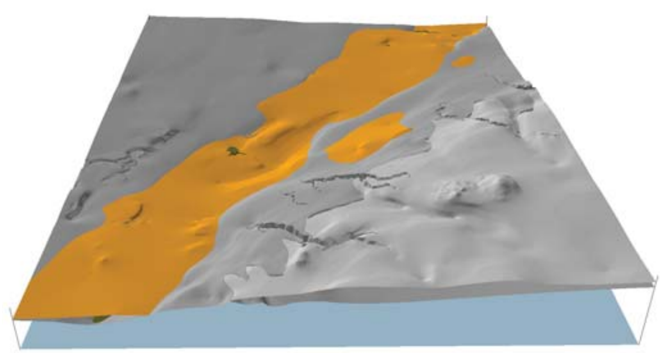


FIGURE 11. Three-dimensional view of the top surface of the pre-Wisconsinan sand (orange) overlying the Ohio Shale (dark gray) and pre-Wisconsinan till (brown) in the Milan quadrangle.

Wisconsinan Deposits

Four Wisconsinan-age geologic units are mapped in the study area. The first unit is a series of tills deposited beneath multiple advances of Wisconsinan glaciers. The other three units make up a sequence of lacustrine deposits left by proglacial lakes, including beach ridge sand and gravel, lacustrine and beach sand, and lacustrine silt and clay.

Till

Quite possibly several advances of Wisconsinan ice across the study area deposited tills, but only two distinct till lithologies can be commonly found. In this area, the first ice advance came from the north-northwest along the axis of Lake Huron and deposited a hard, silty-loam textured till. This ice had multiple minor advances and retreats in southern Ohio but probably deposited a single thick, nearly continuous layer of till in the study area. The last ice came from the east-northeast along the axis of Lake Erie and deposited a layer of softer till with higher clay content. These two distinct till units have been identified along deeper outcrops along the Vermilion River to the east and in deeper excavations in areas west of the Milan quadrangle. Insufficient information exists about the subsurface to differentiate the tills and generally, there are no deposits between them; thus they are mapped as a single unit (fig. 12), which can be as thick as 110 ft.

The tills contain a small percentage of discontinuous lenses of water-sorted material varying from sand and gravel to silt and clay; these lenses were formed by a constantly changing system of subice meltwater drainageways. Some of the coarser lenses are large enough to provide small residential water supplies. The tills generally have a high bearing strength and provide a good building foundation base. Areas of thick till may have potential as landfill sites. The low permeability of the till presents limitations for septic system performance.

Lacustrine Silt and Clay

As ice receded for the final time, the first of the proglacial lakes formed. Drainage ways became established in the Erie basin south of the lake and as these streams incised into the newly exposed, barren surface, they carried large amounts of eroded sediments to the new lake. Fine-grained sediment was carried to deep, still water in the lake and its successors and then was deposited as a thick blanket of laminated silt and clay. The lowest portion of the unit has the highest clay content, as it was deposited in the deepest water. As lake levels dropped, higher portions of the unit had more silt-rich deposition. In some areas, notably northwest of the Huron River, very fine sand partings are present between clayey silt laminations. In a few places at lower elevations near Lake Erie, lenses or clasts of clayey till have been found within the laminated silt and clay; these are interpreted as till released from sediment-laden ice floes in proglacial lakes, a process known as "ice-rafting" (Pavey, 1985).

This silt and clay unit is as much as 85 ft thick in the central part of the buried valley (fig. 13). The unit may have been thicker, but wave erosion at the various lake levels probably removed part of the total thickness. The wave erosion occurred as lake levels became subsequently lower. Silt and clay is absent above an elevation of about 705 ft above MSL; there may have been deposition of a thin blanket of fine-grained sediment during higher lake stages that subsequently was eroded away by wave action as lake levels dropped. Residential water supplies generally cannot be developed in this unit. This unit generally has a low bearing strength and presents problems for excavation and foundation construction. Areas of thick silt and clay may have potential as landfill sites, particularly when combined with underlying thick

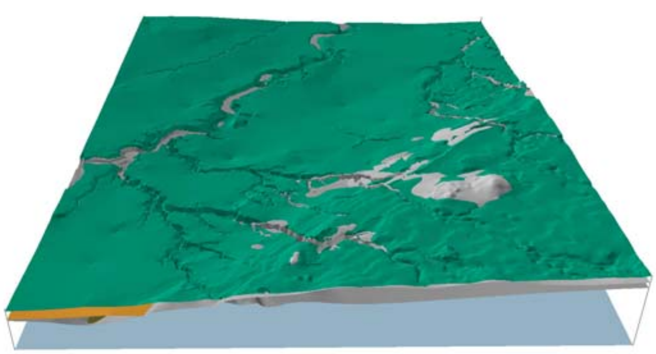


FIGURE 12. Three-dimensional view of the top surface of the Wisconsinan till (green) in the Milan quadrangle.

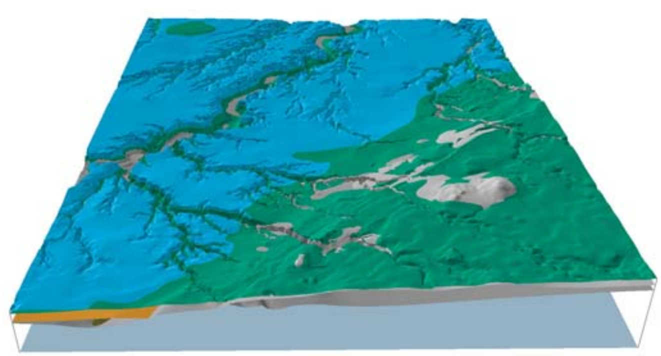


FIGURE 13. Three-dimensional view of the top surface of the Wisconsinan lacustrine silt and clay (blue) in the Milan quadrangle.

till. The low permeability of the silt and clay presents limitations for septic system performance.

Lacustrine and Beach Sand

Sand was deposited in a large portion of the study area, both as beach ridges along the various shorelines and as layers in the shallow, nearshore waters of the proglacial lakes. The source of much of the sand was the four-hundred-square-mile watershed of the newly established Huron River and its tributaries (fig. 14). These streams rapidly eroded downward in the fresh, ice-free surface and delivered large quantities of sediment to the embayment in the proglacial lake at the river mouth. Part of the reason for the rapid downcutting of the streams was their natural adjustment to the rapidly falling lake levels as the lower elevation outlets were exposed. Also, presumably the landscape lacked extensive vegetation to help keep sediments in place immediately after the retreat of the ice.

Wave erosion also supplied sand to the lake, as bluffs composed of bedrock, till, or layered lacustrine deposits were eroded along the shoreline. Sand and gravel eroded from the bluffs was distributed along the shoreline while the finer silt-and-clay component was washed out into deeper portions of the lake at that time.

Beaches are best developed at the higher lake stage levels in the study area (table 1). Many of the beaches at Maumee and Arkona levels are very gravelly; these beaches were mapped as a separate unit (see “Beach Ridge Sand and Gravel”). The Whittlesey beach, which usually is one of the most prominent in other areas, is not well developed in the Milan quadrangle and is mostly a wave-eroded bluff with a slight bench at the toe of the bluff covered with thin sand. Arkona and Warren beaches are present but are not well developed. Lower beaches are not present within the Milan quadrangle; at these stages the dominant process was deposition of a series of overlapping deltas as lake levels dropped.

Sand in beach ridges is mostly medium to coarse grained with minor amounts of gravel. The deltaic sand is mostly fine to very fine. The area appears to be lacking dunes or other wind-blown, fine-sand landforms, which are present along these shorelines at other regions. Maximum sand thickness is about 30 ft (fig. 15). The sand is too thin and also too vulnerable to surface contamination to provide a reliable water source. This unit is suitable for septic system performance, except where slopes may allow surfacing of effluent. Several extraction pits are found in the beach ridges, but none are currently active. Bearing strength in the sand is low at shallow depths and becomes moderate at depth in thicker sections.

Historically, the sand plains were an impediment to harvest-time delivery of grain to the Lake Erie port at the mouth of the Huron River, as the loose, dry sand of unimproved roads hindered travel. Therefore, the Milan Canal was developed in 1839 to bypass the sand plain and improve commerce in the region (Frohman, 1976). The canal’s southern end is near the southern extent of the sand (fig. 16); roads to the south on “clay” (lacustrine or till) were at their best during the dry season (Frohman, 1976). The sand areas have since become an important area for the cultivation of vegetable crops and are the home for many truck farms and produce stands.

Beach Ridge Sand and Gravel

The sand-and-gravel beach ridges are much coarser than the sand ridges previously described. Most of the coarse sediment, up to cobble size, was eroded by waves directly from till and bedrock and deposited at the shoreline; some was supplied by the early Huron River into the Arkona Lake (table 1). The beach ridges associated with the Maumee III lake level (table 1) are the best developed in the study area and are mostly sand and gravel. The Maumee II lake level is relatively indistinct in this area; much of it was modified by waves of the final Maumee level. Of note is the presence of Maumee I beach and shoreline features. Previous workers (Hough, 1958; Forsyth, 1973) interpreted this lake stage as being found only outside the Defiance Moraine, as ice stood at this moraine. However, field studies by the Ohio Geological Survey in the 1980s show that Maumee I shoreline features are common inside the moraine; thus this lake formed after ice retreated from the moraine. In the Milan quadrangle, there are discontinuous beach ridges and lacustrine sand at the Maumee I level of 800–805 ft.

Several sand-and-gravel pits for aggregate use have been excavated in this unit. Currently, no pits are in operation in the area. With a maximum thickness of about 20 ft and being at or near the surface, the sand and gravel is not a reliable ground-water source (fig. 17); but historically, dug wells and well points in this unit provided seasonal water for gardens and nurseries. The high permeability and generally sloping nature of this unit could lead to surfacing of septic system effluent. This unit has a moderate bearing strength.

Holocene Deposits

Alluvium

Alluvium, or floodplain sediment, is found along major streams and their tributaries throughout the map area (fig. 18) and is formed as material eroded along stream banks is transported downstream, primarily during flood events. The composition of alluvium varies with the source of the eroded deposits, from very coarse near bedrock to very fine near silt and clay deposits.

When the Wisconsinan ice retreated north of the Niagara outlet and drainage was established eastward to the St. Lawrence River, the bedrock at Niagara was still isostatically depressed and the Erie basin drained to a level

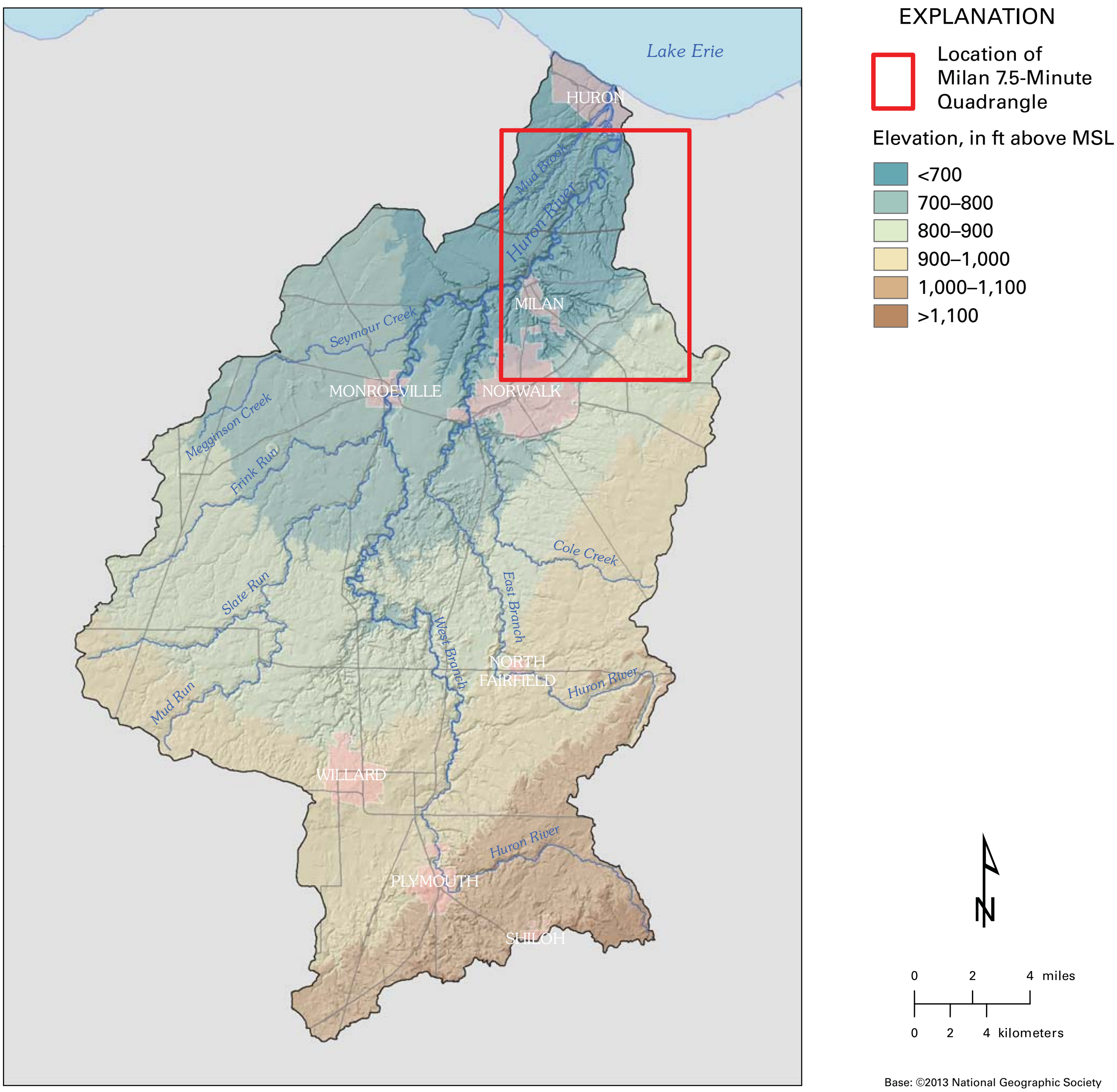


FIGURE 14. Extent of the Huron River watershed in Ohio.

at least 150 ft below the present Lake Erie. In addition, drainage from the upper Great Lakes was eastward across Ontario to the St. Lawrence, instead of into the Erie basin. Forsyth (1973) referred to this lake stand as Early Lake Erie. Drainage ways near the lakeshore incised their valleys well below modern lake level to establish a new gradient to the lake.

As the outlet rebounded, the lake gradually rose to the modern Lake Erie level. This rise was accompanied by a buildup of alluvium in the major incised valleys of the study area as the streams established a new, lower gradient to the rising base level of the lake. In the Milan quadrangle, the Huron River valley alluvial sediments reflect these changes and can be found up to 40 ft thick.

The noncompacted alluvium has a very low bearing strength; bridge foundations must penetrate to a lower, more competent unit. Other permanent construction on alluvium is not recommended, since it is frequently

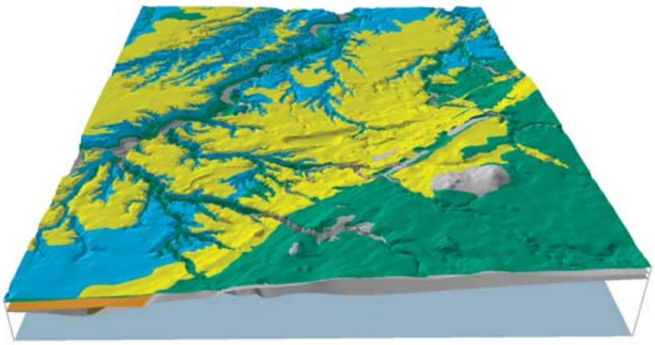


FIGURE 15. Three-dimensional view of the top surface of the Wisconsinan lacustrine and beach sand (yellow) in the Milan quadrangle.

flooded. Preferred uses of alluvium include in parks and recreation facilities; in wildlife preserves; and when trees are planted to create an effective buffer zone or riparian corridor to protect a stream from runoff, which may carry sediments or pollutants that can harm water quality.

Organic-Rich Estuary Deposits

As modern Lake Erie rose, the lower reaches of the Huron River and Old Woman Creek valleys became ponded estuaries at the level of the lake. These level, slack-water areas contained abundant wetland vegetation, which produced up to 37 ft of organic deposits (fig. 19). These organic sediments are interlayered with alluvium brought in by frequent floods. The loose, saturated organic layers have no bearing strength; bridge foundations must penetrate to a lower, more competent unit. Other permanent construction on this unit is not recommended since it is always flooded. These estuary deposits are primarily protected wetlands; the Old Woman Creek deposit is part of a National Estuarine Research Reserve. Also, the northern terminus of the Milan Canal is located near the southern edge of the estuary deposit, where the Huron River is at the level of Lake Erie.

CONCLUSIONS

The elevation surfaces that bound each geologic unit, along with the unit thicknesses, allow the user to produce a wide variety of products in the GIS setting that address societal concerns involving natural resources, geologic hazards, and environmental issues. Only a few examples are described here; many others can be produced.

Uses for the 3-D Geologic Model

The ground-water resource map (fig. 20) adds detail to the mapping of Walker (1986) and Hartzell (1986). Construction of this map assumes that a minimum of 25 ft of casing is required to protect the resource from surface contamination, and a minimum of 10 ft of screened aquifer interval below the casing generally is needed for adequate production. The buried pre-Wisconsinan sand aquifer (fig. 21) is this area's most important ground-water source (Hartzell, 1986; Walker, 1986). Knowledge of the depth to this unit and its thickness will aid in sustainable development of this resource. Thickness is defined by subtracting the unit's base elevation data from the unit top elevation data; depth is found by subtracting the top from the land surface elevation data (fig. 21).

Landfill siting (fig. 22) requires a sufficient thickness of low-permeability material for isolation of waste from surface and ground water. In addition to landfills, this map also has applicability as a reconnaissance tool to aid locating suitable areas for other forms of solid waste treatment and disposal, including sewage treatment plants, the spreading of septage and/or sewage, and agricultural livestock manure or silage pits. In the Milan quadrangle, the suitable low-permeability materials are Wisconsinan till and lacustrine silt and clay. A minimum thickness of 30 ft of these deposits was used for the suitability map (fig. 22). In addition, unsuitable high-permeability overburden must be minimized for economic siting of landfills. For this map, areas of more than 20 ft of sand/sand and gravel were excluded from consideration. Finally, a vertical separation distance of 20 ft of low-permeability cover is required between the landfill base and any aquifer.

Limitations on construction and excavation exist in the area (fig. 23); a key element was selecting all bedrock shallower than ten feet. It is important to note that other factors external to geology, such as the presence of streams and lakes, proximity to population centers, and location of water wells, are not factored into mapping these limitations.

Potential aggregate resources in the Milan quadrangle (fig. 24) are the sand, sand-and-gravel, and Berea Sandstone units. A minimum of ten feet of resources, with less than ten feet of overburden, was considered an economically viable resource area. The sand resource and the sand-and-gravel resource are contiguous and gradational between the units, with no intervening unit; thus the thicknesses of both units were added together. The total area was then limited to the area greater than ten feet to display the potential resource area. The outline of the more economically desirable sand-and-gravel unit was added to the map to highlight the areas of best potential. Sandstone thickness also was constrained to the resource area greater than ten feet. The amount of nonaggregate overburden overlying the sandstone was determined by using the elevation surface representing all units underlying the sand unit and then subtracting the elevation of the top of the sandstone; those areas with greater than ten feet of overburden were then excluded from the resource area. An outline of the sandstone resource area also was added to

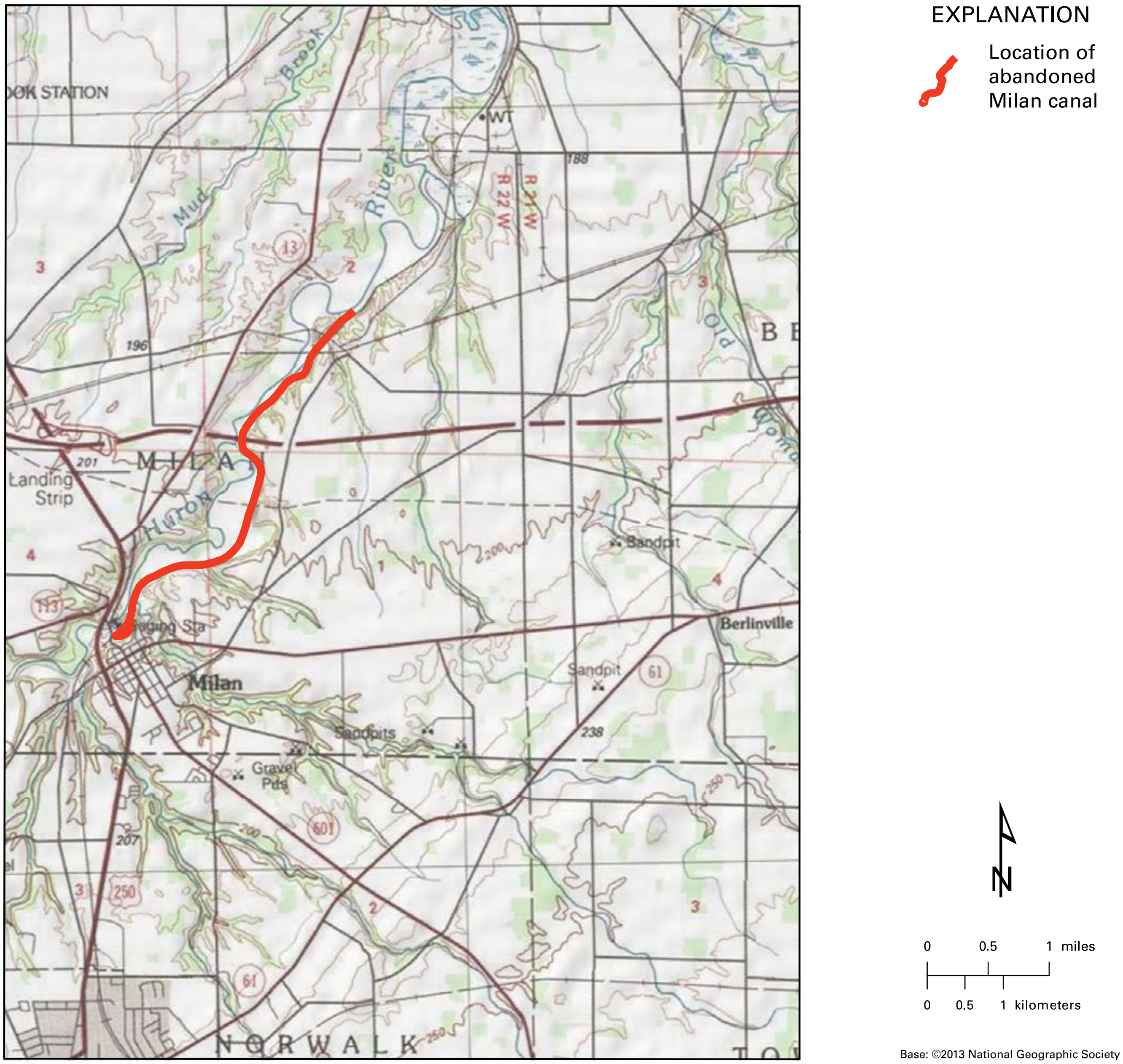


FIGURE 16. Location of the abandoned Milan Canal in the Milan 7.5-minute quadrangle.

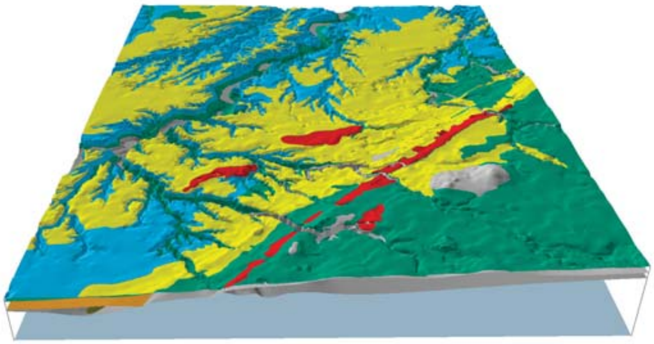


FIGURE 17. Three-dimensional view of the top surface of the Wisconsinan beach ridge sand and gravel (red) in the Milan quadrangle.

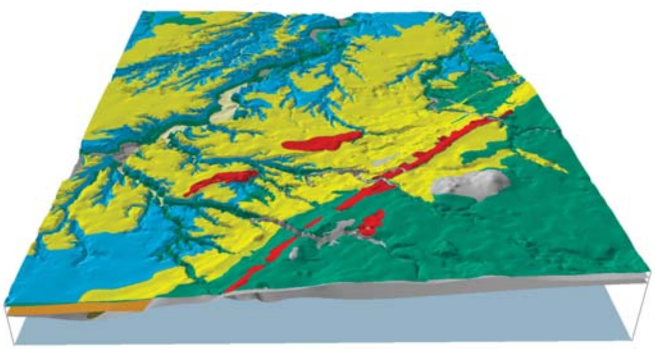


FIGURE 18. Three-dimensional view of the top surface of the Holocene alluvium (light yellow) in the Milan quadrangle.

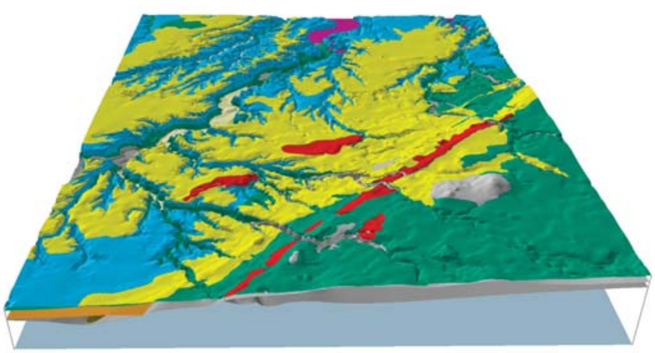


FIGURE 19. Three-dimensional view of the top surface of the Holocene estuary deposits (purple) in the Milan quadrangle. This map completes the sequence of the map "stack." This map alone (in a 2-D top down view) shows how prior surficial mapping was done—only showing the materials present at the surface. The 3-D stack sequence mapping now allows access to the location and qualities of all near-surface materials.

show where it is available within ten feet below the sand/sand-and-gravel resource areas.

The Berea Sandstone also is one of Ohio's most important dimension stone sources, and it has been quarried for well over a century. To determine the dimension stone resources in the Milan quadrangle, the area of sandstone greater than 50 ft thick was selected. This area was further limited by removing areas where the overburden is greater than 20 ft thick. Contours show the total extent and thickness of the Berea Sandstone in the area (fig. 25).

The completed 3-D geologic model also has been used to produce a complex 3-D ground-water flow model (Pavey and others, 2008). Such modeling has many environmental protection applications, such as determining recharge and discharge areas, pathways for flow of potential contamination at any given site, and sensitivity to potential pollution in the mapping area. Examples of flow model results include the unsaturated thickness (fig. 26), which shows the depth to the unconfined water table, and the relative recharge zones in the area (fig. 27).

The mapping and information reported here can be utilized by area residents and planners to best utilize and protect local resources. It is hoped that this geologic model and report is used as an educational tool for all to (1) visualize the complexities of an area's geology in a way that cannot be duplicated with two-dimensional maps and (2) understand the opportunities and limitations of the geology beneath any given location.

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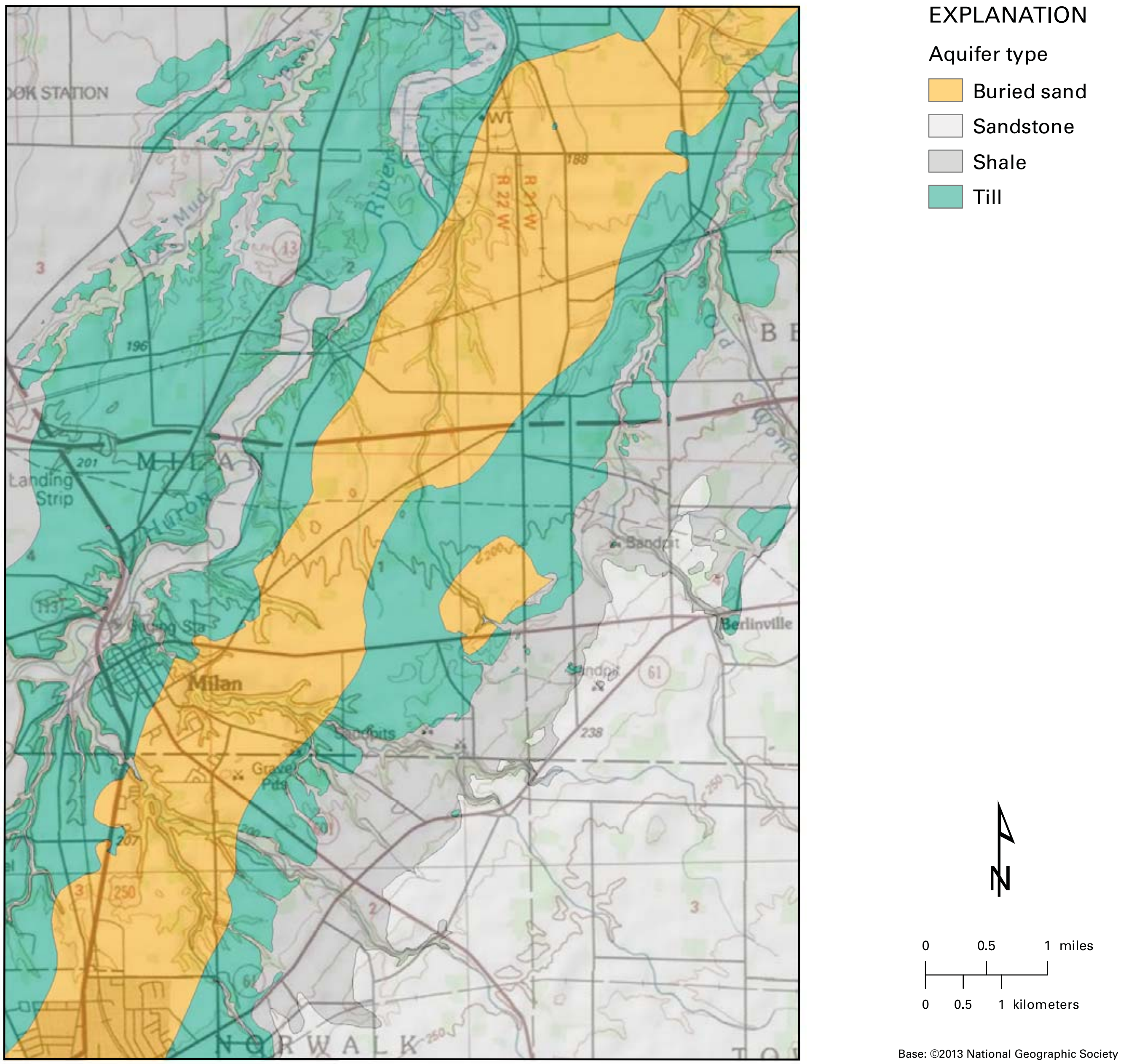

FIGURE 20. Ground-water resources of the Milan quadrangle. Construction of this map assumes that a minimum of 25 ft of casing is required to protect from surface contamination, and a minimum of 10 ft of screened aquifer interval below casing is generally needed for adequate production.

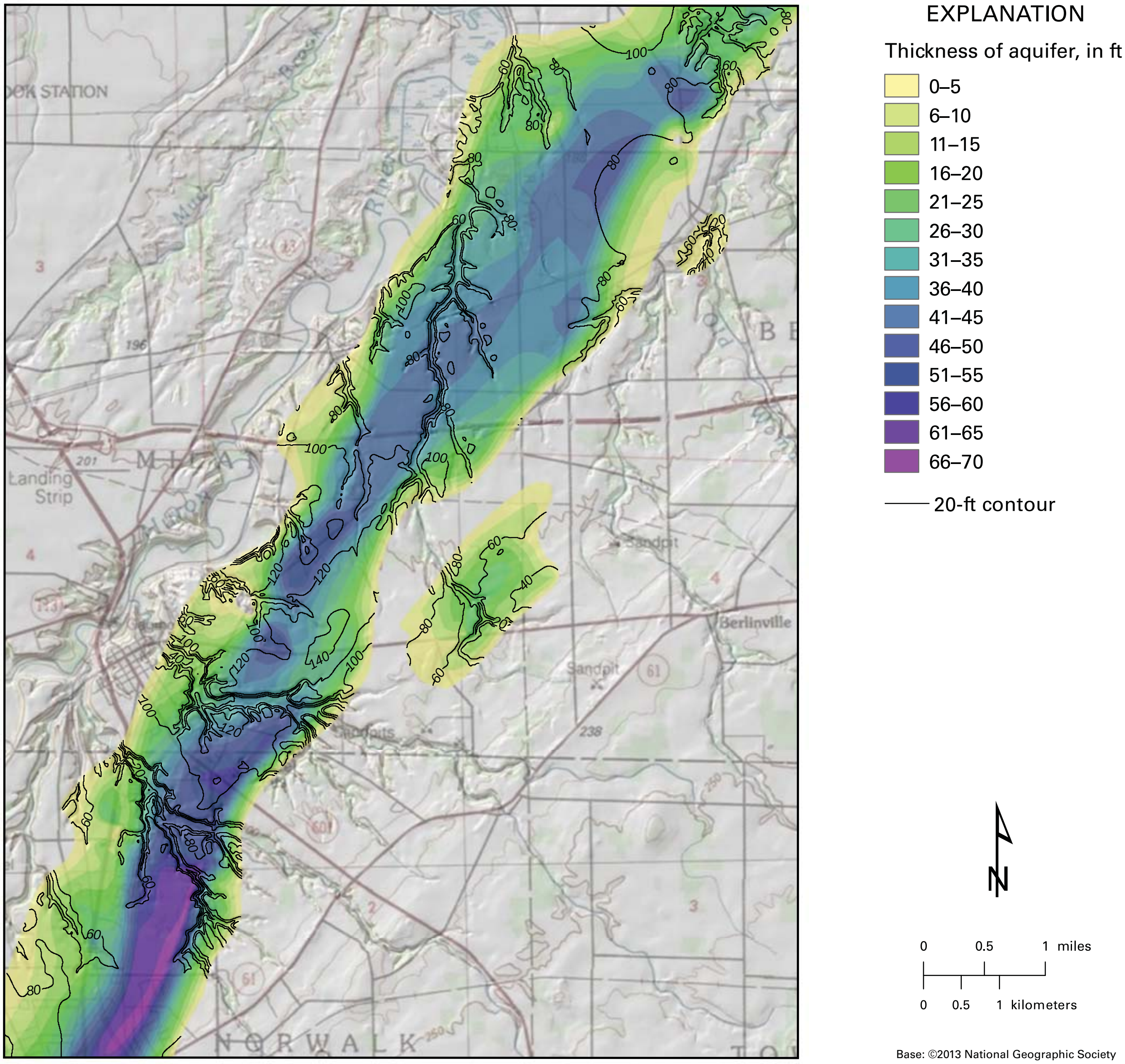

FIGURE 21. The thickness of the Milan quadrangle primary aquifer (pre-Wisconsinan sand) is shown in color; contours indicate the depth to this unit.

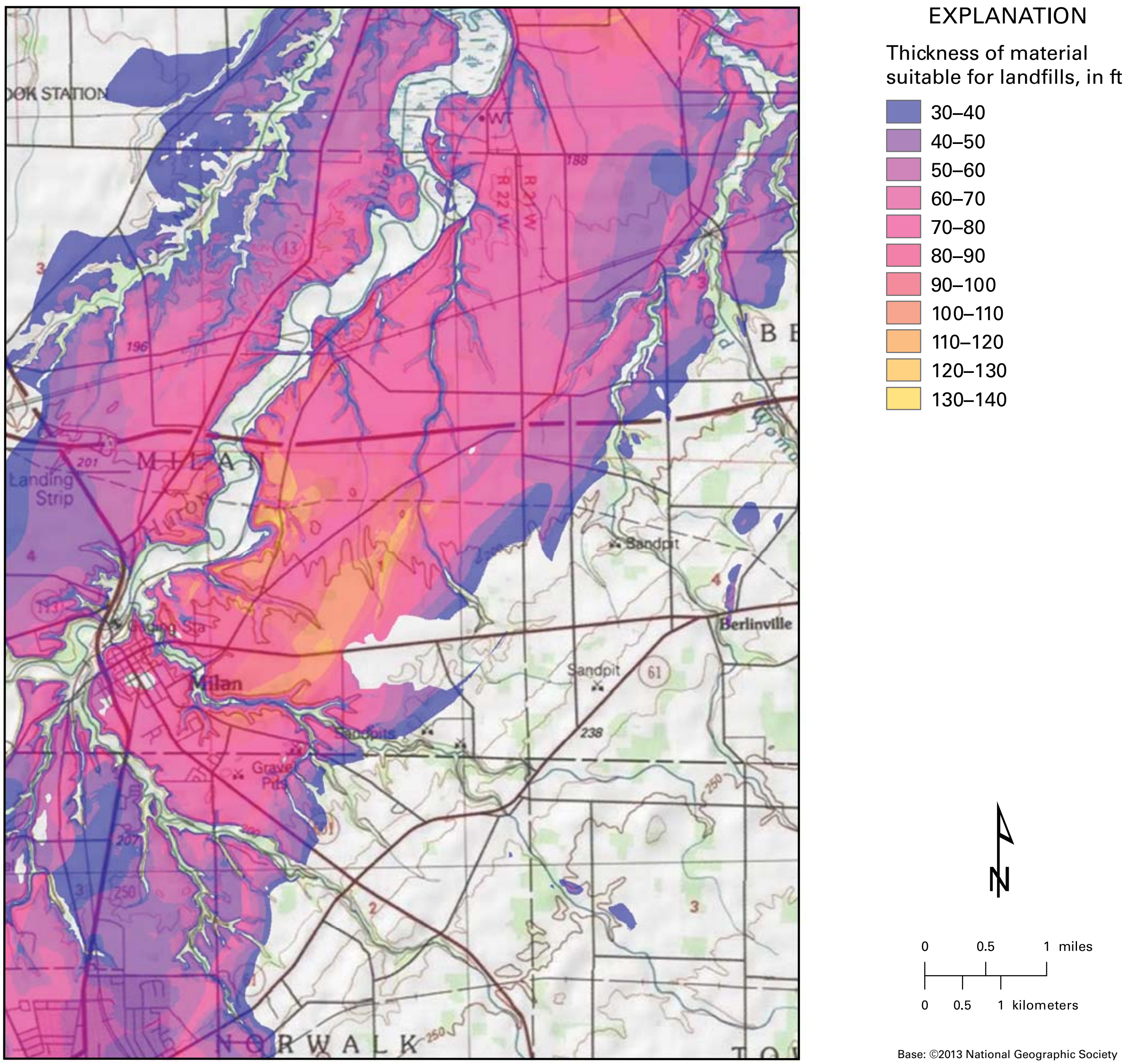

FIGURE 22. Areas suitable for landfills in the Milan quadrangle. Suitablility requirements are a minimum of 30 ft of low-permeability material, with a minimum 20 ft of separation from aquifers, and a maximum high permeability cover of 20 ft.

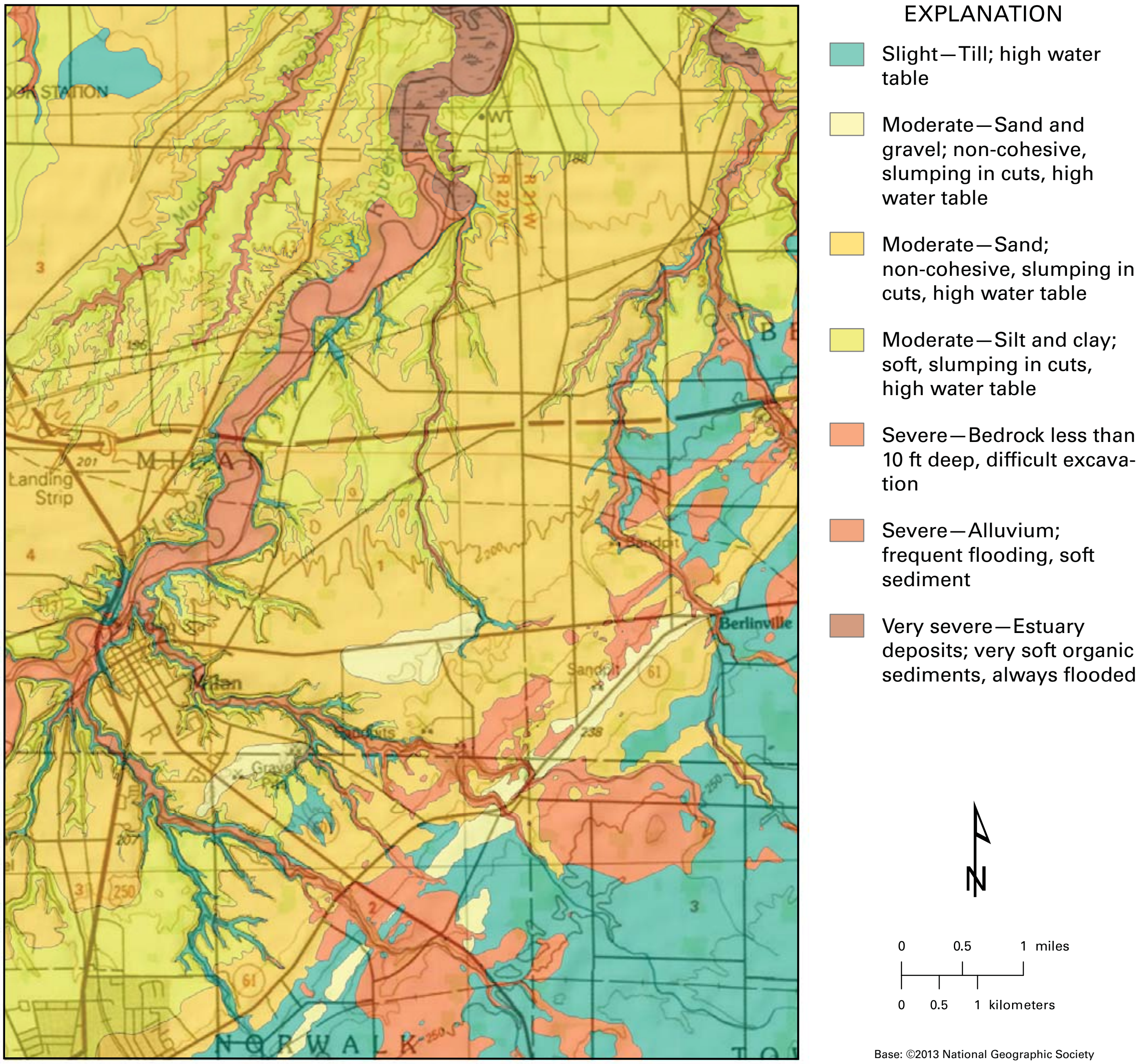

FIGURE 23. Limitations on construction and excavation in the Milan quadrangle.

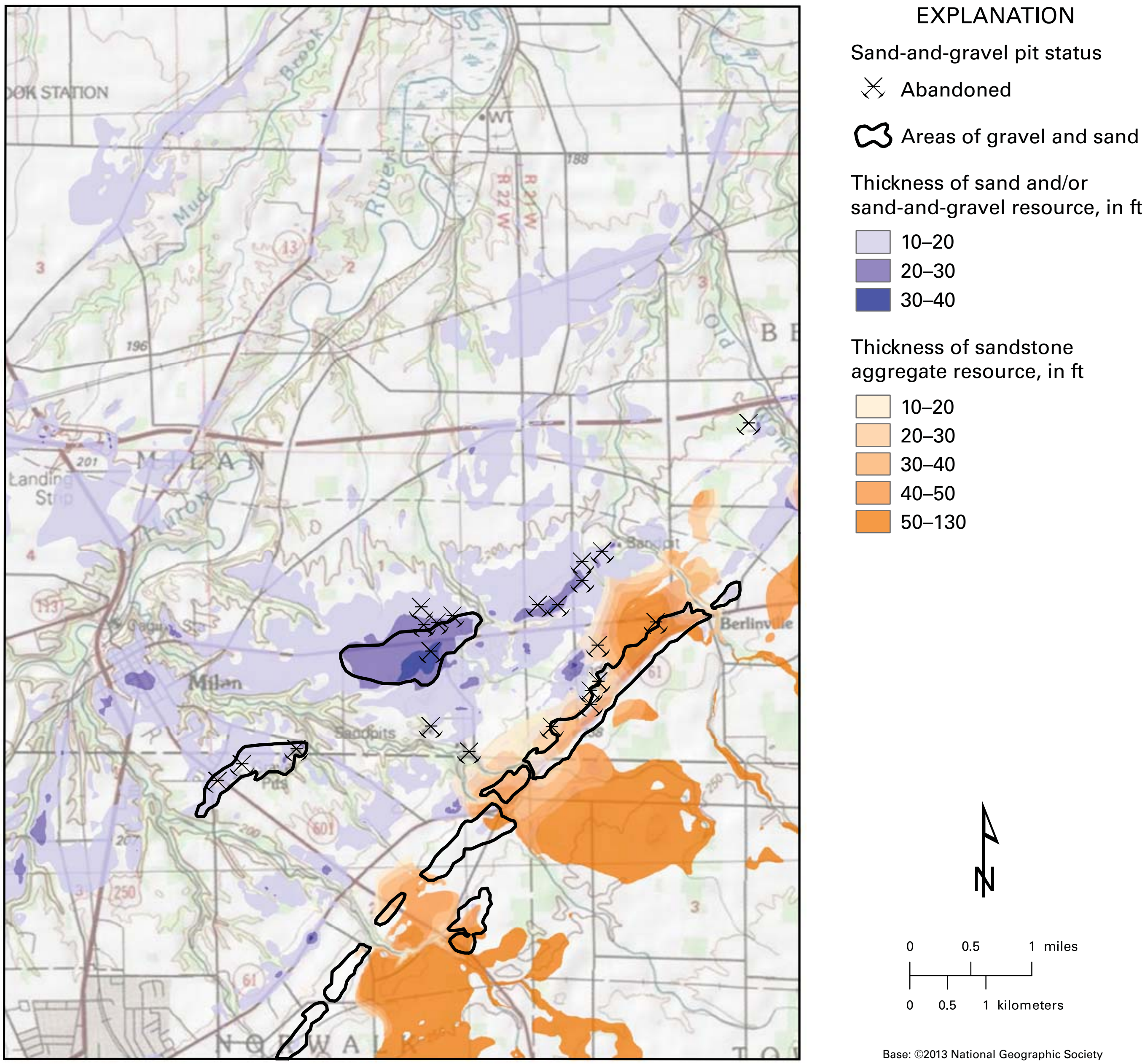

FIGURE 24. Aggregate resources in the Milan quadrangle.

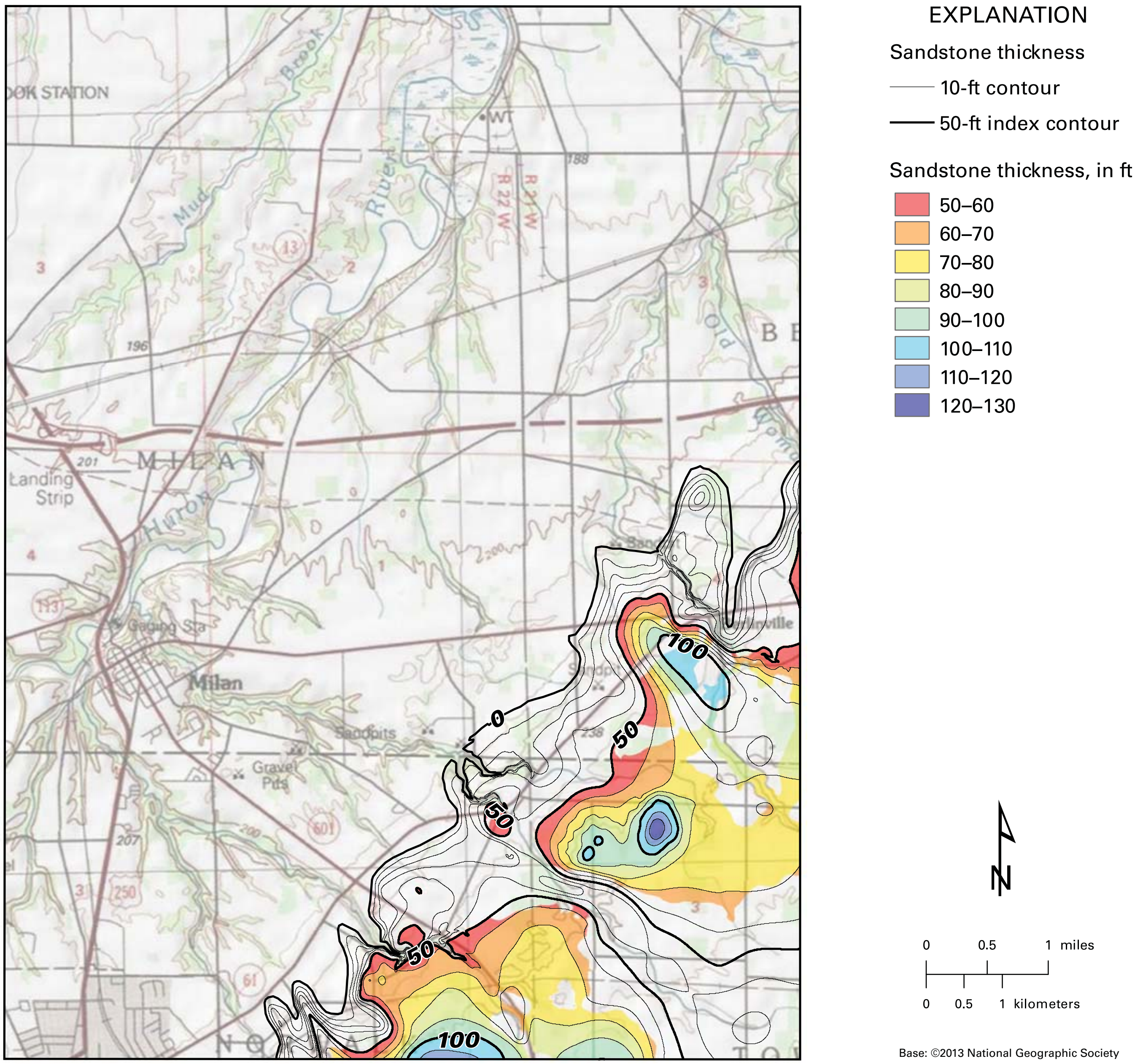

FIGURE 25. Map showing potential dimension stone resources in the Milan quadrangle. Black contours indicate the thickness of the Berea Sandstone. Color fill indicates thickness of resources that are at least 50 ft thick and have less than 20 ft of overburden.

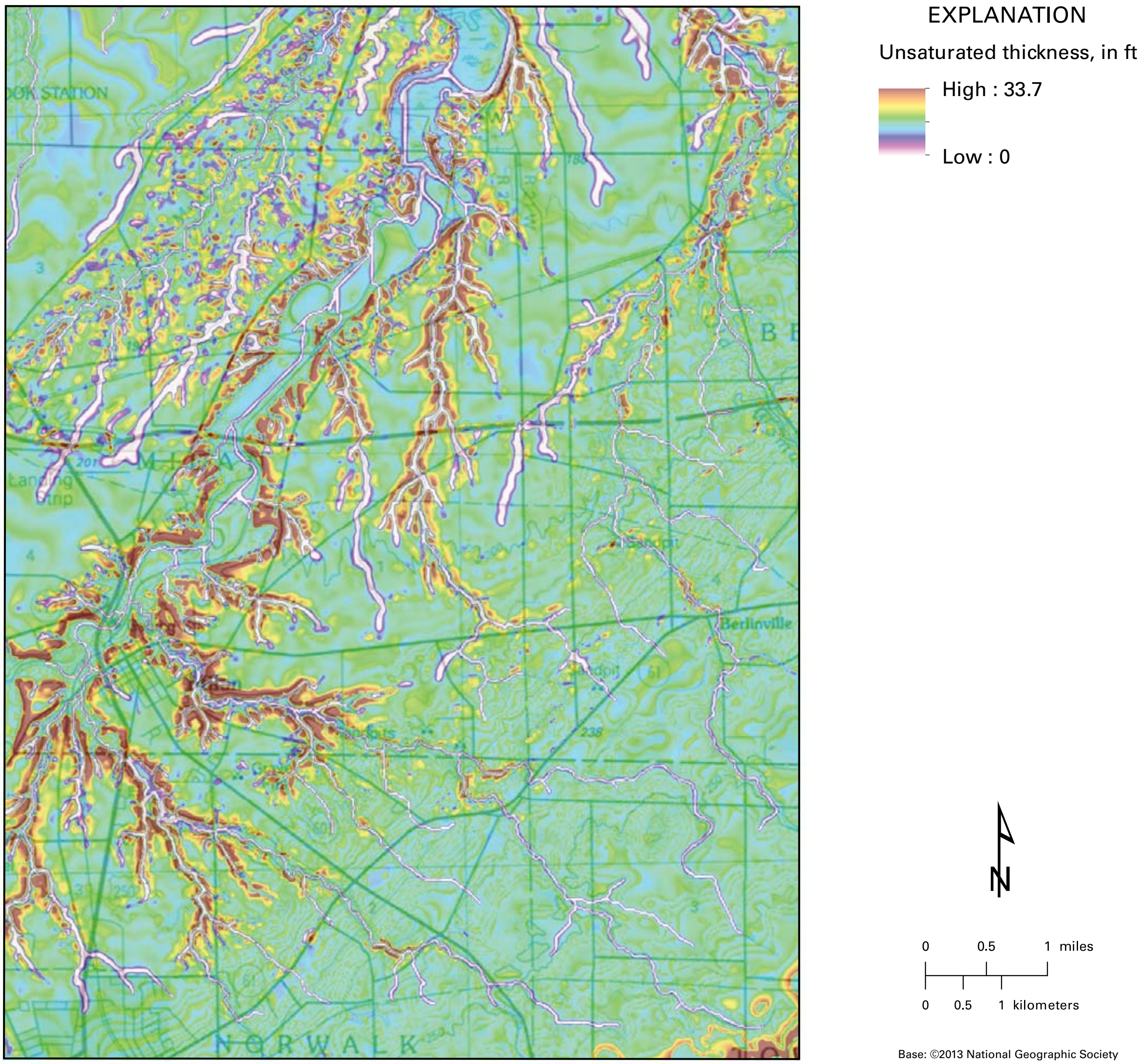

FIGURE 26. Unsaturated thickness of surficial units in the Milan quadrangle. This indicates the model estimate of depth to the unconfined water table.

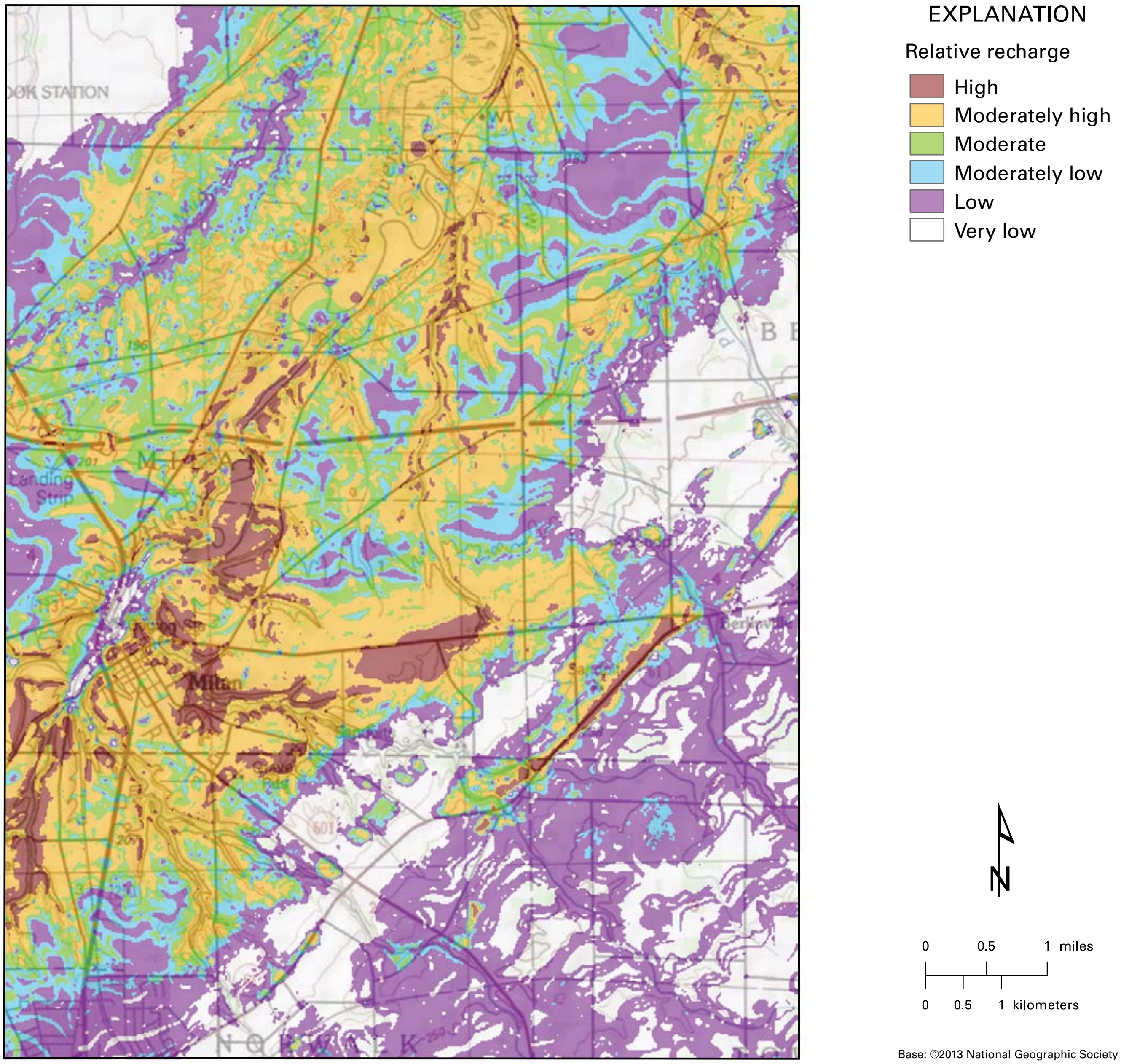

FIGURE 27. Relative ground-water recharge areas of the Milan quadrangle.

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