Chapter 10

Coastal Geology

Geology is a science of the earth and its inhabitants spanning from the earth's origin to the present day. Lake Erie in its present form is less than 4,000 years old. The history of the lake and its precursors has taken place in the last 14,000 years. This time is within what geologists term the "Recent." The time of the ice age prior to the Recent is referred to as the "Pleistocene."

This history is remarkably complex involving numerous lake-level stages. Some of the stages may have been as much as 230 feet higher than modern Lake Erie. These higher lake stages have had a profound influence on the landscape, agriculture, transportation and economy of northern Ohio, especially northwestern Ohio.

Fertile clays deposited on the lake bottom during high-water stages and the wetland areas that remained when lake levels dropped, form one of the richest agricultural regions of the state. The beaches that formed along the shores of these higher lake stages are preserved as ridges elevated above the nearly flat former lakebeds. These beach ridges, at a specific elevation for each lake stage, outline the layout and extent of each stage, and provided dry passage through swampy terrain for Indian and pioneer trails. Later, roads and highways followed the ridge trails.

Lake Erie owes its existence to the presence of a basin or lowland formed long before the Pleistocene Ice Age began about 2 million years ago. This lowland was the valley of an east-flowing river, that geologists call the "Erigan."

The first of the major glacial advances obliterated this drainage system, deepening and enlarging the basin. Succeeding glaciations further deepened and enlarged it.

Lake Erie, the southernmost of the Great Lakes, is also the shallowest because the ice was relatively thin and lacked significant erosive power when it reached so far south.

The Lake Erie Basin is underlain by Silurian and Devonian carbonate rocks (limestone and dolomite) on the west and by Devonian shales on the east. The carbonate rocks are generally more resistant to erosion than the shales; thus the Western Basin is comparatively shallow, averaging less than 25 feet in depth. Glacial ice was able to scoop out to a greater extent the less resistant shales underlying the Central and Eastern basins. The deepest point in Lake Erie is 210 feet in the Eastern Basin.

The Lake Stages

The initial phases of lake formation in the Erie Basin began as soon as the ice had retreated north of the drainage divide and exposed lowland in which water could accumulate. The complex series of lakes that occupied this expanding basin, apparently in rapid succession during a few thousand years, owed their existence to several factors. These factors include the configuration of the glacial ice to the north and the ice dams it created. Other factors include low spots that filled with water until drainage divides were breached to form drainage outlets, the depression of the land surface by the weight of the glacial ice, and the subsequent slow rise (crustal rebound) after the ice retreated.

Lake Maumee was the earliest lake to form in the Erie Basin, about 14,000 years ago, and is divided into three substages. The initial stage, known as Highest Maumee or Maumee I, formed beaches at an elevation of about 800 feet above sea level. As Maumee I waters rose, they eventually found an outlet through a low point in the Fort Wayne Moraine in Indiana and made their way along the Wabash River to the Mississippi drainage basin.

As the ice receded northward, Lake Maumee expanded its surface area, but the lake level dropped to an elevation of 760 feet when a new and lower drainage outlet was exposed. This outlet was in central Michigan and allowed the waters of this lake stage, known as Lowest Maumee or Maumee II, to be discharged through the Grand River in Michigan to Lake Michigan and then to the Mississippi River.

The ice advanced again, closing part of the Grand River drainage outlet and raising the lake level to about 780 feet. The phase of Lake Maumee, known as Middle Maumee or Maumee III, was too low to discharge through the Fort Wayne outlet, but found an intermediate outlet in Michigan known as the Imlay Channel. This westward-flowing drainageway eventually connected with the Grand River.

Continued northward retreat of the ice and downcutting of the westward-flowing outlet through the Grand River lowered the water level to the Lake Arkona stages at successive elevations of 710, 700 and 695 feet. Modern evidence suggests that the lowering of lake level may have been influenced by changes in climate and precipitation. Each Arkona stage is marked by indistinct beaches that are poorly developed, presumably because lake level was constantly being lowered and because of erosion by the later and higher Lake Whitely. The lowest stage of Lake Arkona has been dated at about 13,600 years ago.

There is evidence that an additional low-water stage, known as Lake Ypsilanti, may have existed in the Erie Basin for a brief period about 13,000 years ago prior to the establishment of the next major lake stage, Lake Whittlesey.

A major pulsation of the Wisconsinan glacier known as the Port Huron readvance closed part of the Grand River drainage outlet and raised lake level to an elevation of about 738 feet about 13,000 years ago. The new lake stage was named Lake Whittlesey in honor of Charles Whittlesey, a geologist and topographer with the first Geological Survey of Ohio in 1837-1838. The outlet for Lake Whittlesey was a westward-flowing channel, known as the Ubly Channel that connected with the Grand River in central Michigan.

The beach ridges that mark the former shore of Lake Whittlesey are some of the most prominent and well preserved in Ohio. They are particularly well developed in northeastern Ohio because, according to Dr. Jane L. Forsyth in Division of Geological Survey Information Circular No. 25, Beach ridges of northern Ohio, the fetch for the prevailing westerly winds was greater and larger beaches were produced. The size of the beaches in northeast Ohio may also be due to the large volume of sand and gravel eroded from sandstone hills and sandy fills found here.

Lake Whittlesey came to an end when the glacier made a significant retreat. Lake level dropped dramatically, even below that of modern Lake Erie. It has been suggested that Lake Whittlesey was finally emptied through a drainage outlet (St. David Gorge) in the Niagara Gorge area. This outlet was, at the end of Lake Whittlesey time, much lower than today because it was still greatly depressed from the weight of recently retreated glacial ice.

A re-advance of the ice raised lake level to about 685 feet. This new lake, known as Highest Lake Warren (Warren I), was later lowered to about 670 feet (Lowest Lake Warren or Warren III). Weakly developed and discontinuous beach ridges at an elevation of about 675 feet define an intermediate Warren (Middle or II) lake level. Some investigators have concluded that a lake at an elevation of 660 feet immediately preceded Lowest Lake Warren. This lake, called Lake Wayne, is thought to have drained eastward through the Mohawk River Valley in New York. Geologic dating suggests that Lake Warren and Lake Wayne existed between 13,000 and 12,000 years ago.

After many pulsations through a relatively brief period of time, perhaps only 2,000 years or so, the Wisconsinan glacier made its final retreat and Lake Erie came closer to its final present shape. The last stage of precursor lakes in the Erie Basin is known as Lake Lundy. This lake is thought to have had its drainage outlet through the Mohawk River Valley in New York, but a western

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outlet in Michigan may have been used. Wherever the outlet may have been, it was evidently being continuously lowered by erosion, as beaches representing possibly three substages of Lake Lundy have been recognized.

After final retreat of the ice, the land surface began to rise, or rebound, as it was released from the great weight of the glacier, but the rebound was relatively slow. When the drainage outlet through the Niagara Gorge was finally free of glacial ice it was about 150 feet lower than it is today.

The implications of the opening of the Niagara outlet are dramatic. Water level in the Erie Basin was lowered by about 150 feet; this lowering may have occurred suddenly when the ice-dammed water finally broke through the confining edge of the glacier, creating a flood that quickly drained the Erie Basin.

The Erie Basin is so shallow that the 150-foot drop in water level would have completely drained the Western Basin and left water only in the deeper Eastern Basin and perhaps a small lake confined by a moraine in the Central Basin. It is likely that the Niagara Gorge and several other gorges in the area were cut by these cascading flood waters.

The moderately slow rise of the land in the area of the Niagara outlet created a consequent rise in the water level in the Erie Basin. By about 3,500 to 4,000 years ago, the lake level was perhaps only about 30 feet below that of the modern lake. A rapid 10- to 20-foot rise in lake level occurred about 2,600 years ago when the upper Great Lakes again began to drain through the Erie Basin. Following this rapid rise there has been a continued slow rise of the water level that has brought Lake Erie to its current mean level of 571.3 feet IGLD85.

Deciphering Lake History

The sandy beach deposits rising above the nearly flat lake plains, especially in the region called the Great Black Swamp in northwestern Ohio, captured the attention of Indian and European explorers and settlers because the ridges provided dry passage through the swamps produced on the former lake beds. The Indian trails along the beach ridges were succeeded by primitive roads and later by paved highways such as U.S. Route 30 west of Delphos and U.S. Route 20 west of Norwalk and east of Cleveland.

Whether or not early travelers realized that the sandy avenues were evidence of higher levels of lake waters is not recorded. However, it was not long after the settlement of Ohio that scientists and naturalists began to speculate on the origin of these unusual ridges. One of the earliest observers was Charles Whittlesey. In the Second Annual Report (1838) of the Ohio Survey, Whittlesey called these features "Lake Ridges" and observed that Lake Erie must have once stood more than a hundred feet higher than its present elevation.

Lake Geology Today

While Lake Erie was the last of the Great Lakes to be discovered by Europeans (by French explorer Louis Joliet in 1669), the lake holds a prominent role in the region.

Lake Erie and its coastal region are a major source of many minerals. One of the largest sandstone quarries in the world is located in Amherst (Lorain County). Salt mines in Cuyahoga and Lake counties extend under Lake Erie and are an important source of revenue in the state's economy. On average, companies in these two cities load more than 1.5 million tons of salt annually, according to the Lake Carriers' Association. Sand, gypsum, and limestone used for construction purposes are also found in abundance. Oil and natural gas are also located throughout the region.

To help provide insight as to where some of these natural products we use today came from and how they were formed, the Geology section of the Atlas divides information into various maps including:

Relief of Coastal Ohio – This map depicts the surface topography of northern Ohio.

Bedrock Geology – This map shows the distribution of bedrock based on its age.

Glacial Geology – This map shows the type and distribution of materials that were deposited on top of the bedrock during and after the glacial retreat.

Drift Thickness – This map depicts the thickness of materials overlying bedrock.

Karst Features – This map depicts probable karst areas in northern Ohio. Karst features can be geologic hazards and include sinkholes, caves and underground drainage. This section includes a feature on Seneca Caverns and gypsum.

Oil and Gas Fields – This map shows the location of producing oil and gas fields in northern Ohio.

Earthquakes – This map depicts the location and magnitude of earthquakes in northern Ohio.

For more information

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Source:

Hansen, M.C. "The History of Lake Erie" ODNR-Div. of Geological Survey. ohiodnr.com/geosurvey/lakeerie/lefact1.htm

Remnant beach from pre-Erie Lake Warren at Erie Sand Barrens State Nature Preserve, Erie County

Background photo – Glacial Grooves on Kelleys Island, Erie County

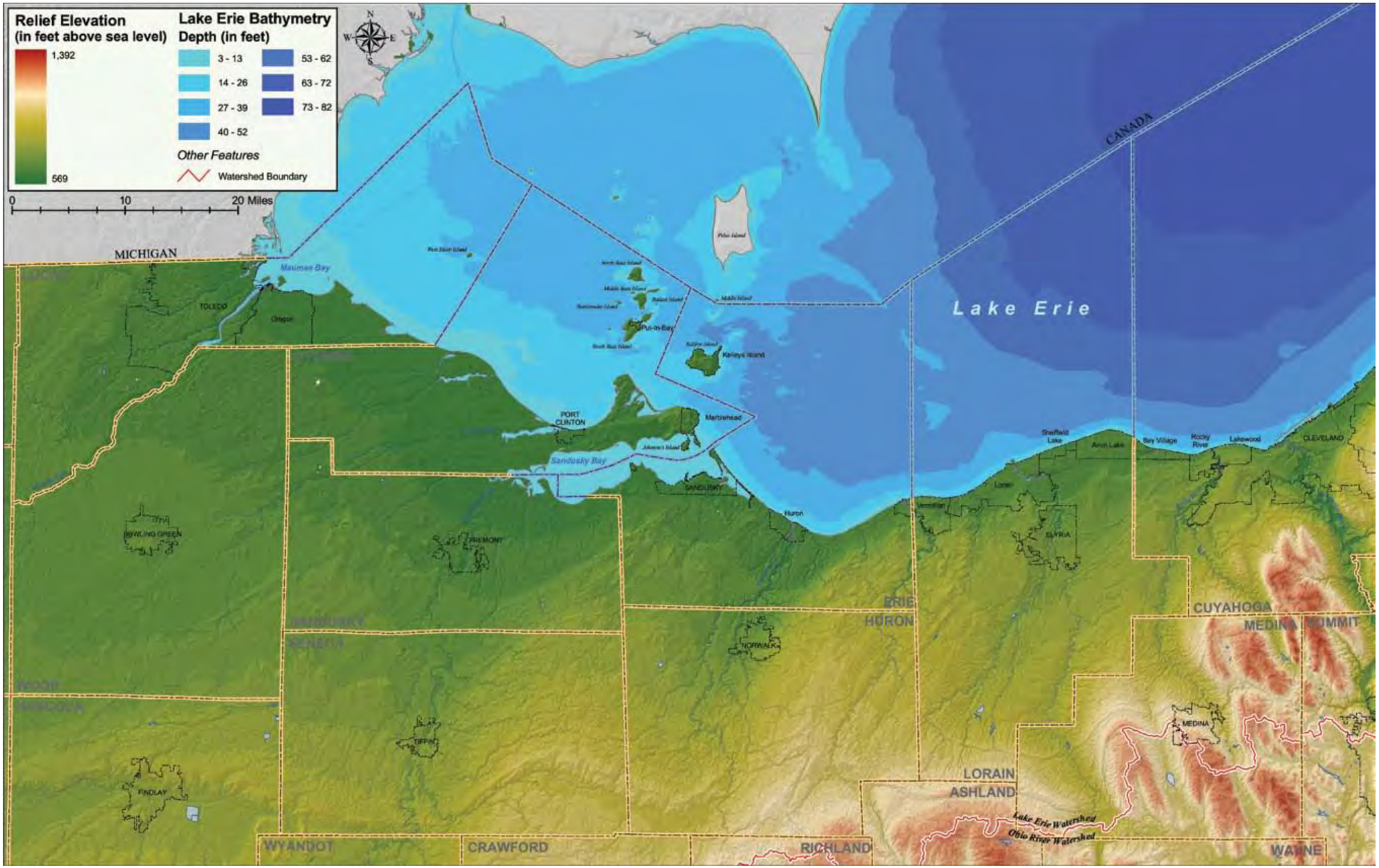
Relief Map of Ohio Coastal Region

High-relief, shale bluff, Bay Village, Cuyahoga County

Moderate-relief slope, Lorain County

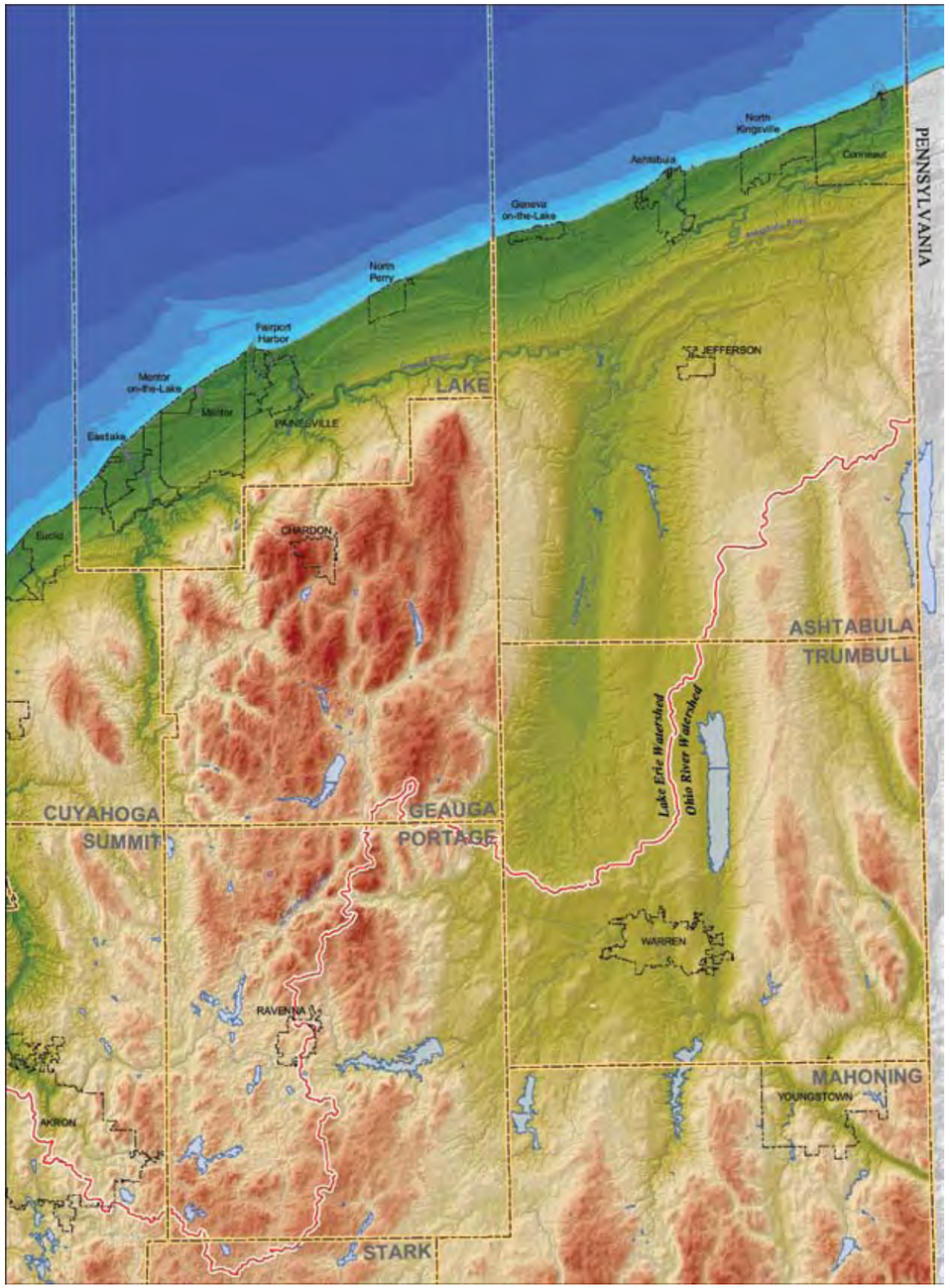
Low-relief limestone shelf, Kelleys Island, Erie County

Low-relief barrier beach, Sheldon Marsh State Nature Preserve, Erie County



Map 45 GIS data citation in Appendices

Relief Map of Ohio Coastal Region



Map 45 GIS data citation in Appendices

This map depicts the topography of northern Ohio using color to represent elevation intervals. The colorized topography has been digitally shaded from the northwest to give the appearance of a three-dimensional surface and to emphasize relief. The map is based on elevation data from the U.S. Geological Survey's National Elevation Dataset.

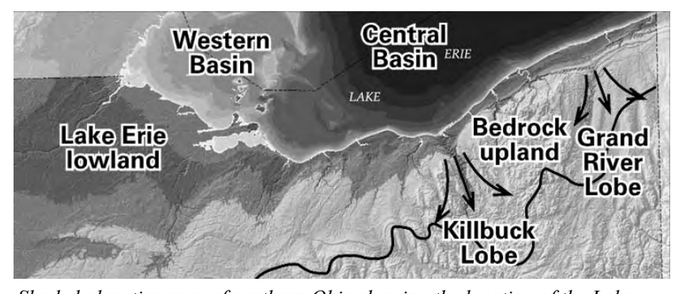
Terrain in northern Ohio can be separated into three main categories based on elevation and topographic relief. These terrain categories are:

1. The Lake Erie Lowland (represented by shades of darker green),
2. Bedrock highlands (represented by beige and reddish brown), and
3. The ridge and ground moraine area (represented by yellowish green).

The Lake Erie Lowland extends from the Lake Erie shore up to 800 feet above sea level, and is characterized by low-relief, wave-planed till overlain by silt and clay of lake origin. In northeastern Ohio, the lowland area is generally 10-miles wide and extends from Lake Erie southward to a series of northeast-oriented ridge moraines that border Mississippian- and Pennsylvanian-age bedrock highlands. In northwestern Ohio, the lowland extends as far as 50 miles from the lakeshore and defines a region of the state formerly known as the Great Black Swamp. As glacial ice retreated out of the Erie Basin some 14,000 years ago, Lake Maumee and other precursors of Lake Erie developed along the margin of the retreating ice and covered the lowland.

Lake Maumee was about 230 feet higher than modern Lake Erie and extended westward to present-day Fort Wayne, Indiana, where it drained into the Wabash River system. As the glacier margin receded or readvanced, exposing or blocking lower outlets for the proglacial lake, the level of the lake was lowered or raised. The elevation of the various lake stages is recorded by beach ridges and wave-cut cliffs that formed along the shores of the lake at its different stages, much like the barrier beaches and wave-cut cliffs of modern Lake Erie. The ancient sandy beaches are visible on the map as long, sinuous ridges standing above the surrounding flat, lake plain. The Lake Maumee beach ridges in northwestern Ohio generally correspond to the boundaries of a lobe of glacial ice called the Lake Erie Lobe.

Another category of terrain is the high-relief and high-elevation landscape (greater than 1,000 feet above sea level; beige and reddish brown on the map) of Lake, Geauga, Summit, Portage, Cuyahoga and Medina counties. These uplands consist primarily of Mississippian- and Pennsylvanian-age sandstone and shale, and were more resistant to glacial erosion and glacial advance than the limestone/dolomite and shale dominated terrain of northwestern Ohio. While glaciers did eventually override the bedrock highland, their southward progress was reduced to approximately 70 miles instead of hundreds of miles, as was the case in western Ohio.



Shaded-elevation map of northern Ohio showing the location of the Lake Erie lowlands, the bedrock uplands and the Killbuck and Grand River glacial lobes (modified from Swinford, E.M., 2002). Line represents the position of the East Continental drainage divide.

A third terrain, present between 800 and 1,000 feet above sea level (yellowish green) is located between the Lake Erie Lowland and the high-relief upland areas. It is characterized by rolling hills and low-relief till plains. Ridge moraines and ground moraine dominate the surface features and deposits in this area. In extreme northeastern Ohio, this terrain extends southward from Lake Erie about 40 miles and corresponds to the area occupied by a lobe of glacial ice called the Grand River Lobe. The Grand River Lobe is bounded on the west by uplands of the Mississippian and Pennsylvanian sandstone and shale. West of the uplands, the transitional terrain is confined to a narrow slice between the lake plain to the north and the adjacent bedrock upland to the south. In the south-central portion of the map, this narrow band widens and contains draped ridge moraines that extend westward into Indiana. Many ridge moraines in western and northeastern Ohio have a draped appearance because south-flowing ice, held back by bedrock highlands, moved more easily along major lowlands. This caused moraines to stack up on the north side or on top of the bedrock highlands, and to bulge southward into adjacent lowlands. The Killbuck Lobe was created by glacial advance south of Cleveland approximately along the axis of the Cuyahoga River southward into Summit County.

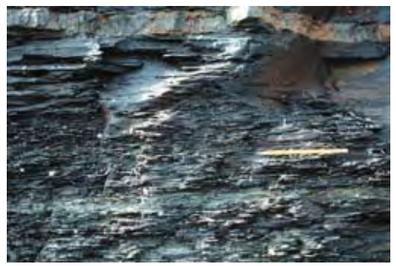
The Eastern Continental Drainage Divide extends east to west across a portion of the map. North of this divide surface water flows to Lake Erie, eventually over Niagara Falls into Lake Ontario and into the Atlantic Ocean. South of the divide, surface water flows to the Ohio River, the Mississippi River and into the Gulf of Mexico. The divide follows the crests of glacial moraines in western Ohio. In north-central and northeastern Ohio, the divide follows bedrock-controlled hills and glacial valleys containing thick glacial-lake deposits.

Shaded Elevation data used to create the map to the left taken from:

Powers, D.M., Laine, J.F., Pavey, R.R., 2002 (revised 2003), Shaded elevation map of Ohio: Ohio Division of Geological Survey Map MG-1, scale 1:500,000, 1 map and 1 GIS file, modified from: National Elevation Dataset (NED), U.S. Geological Survey (USGS), EROS Data Center, 1999, 4 GIS data files.

Bedrock Geology

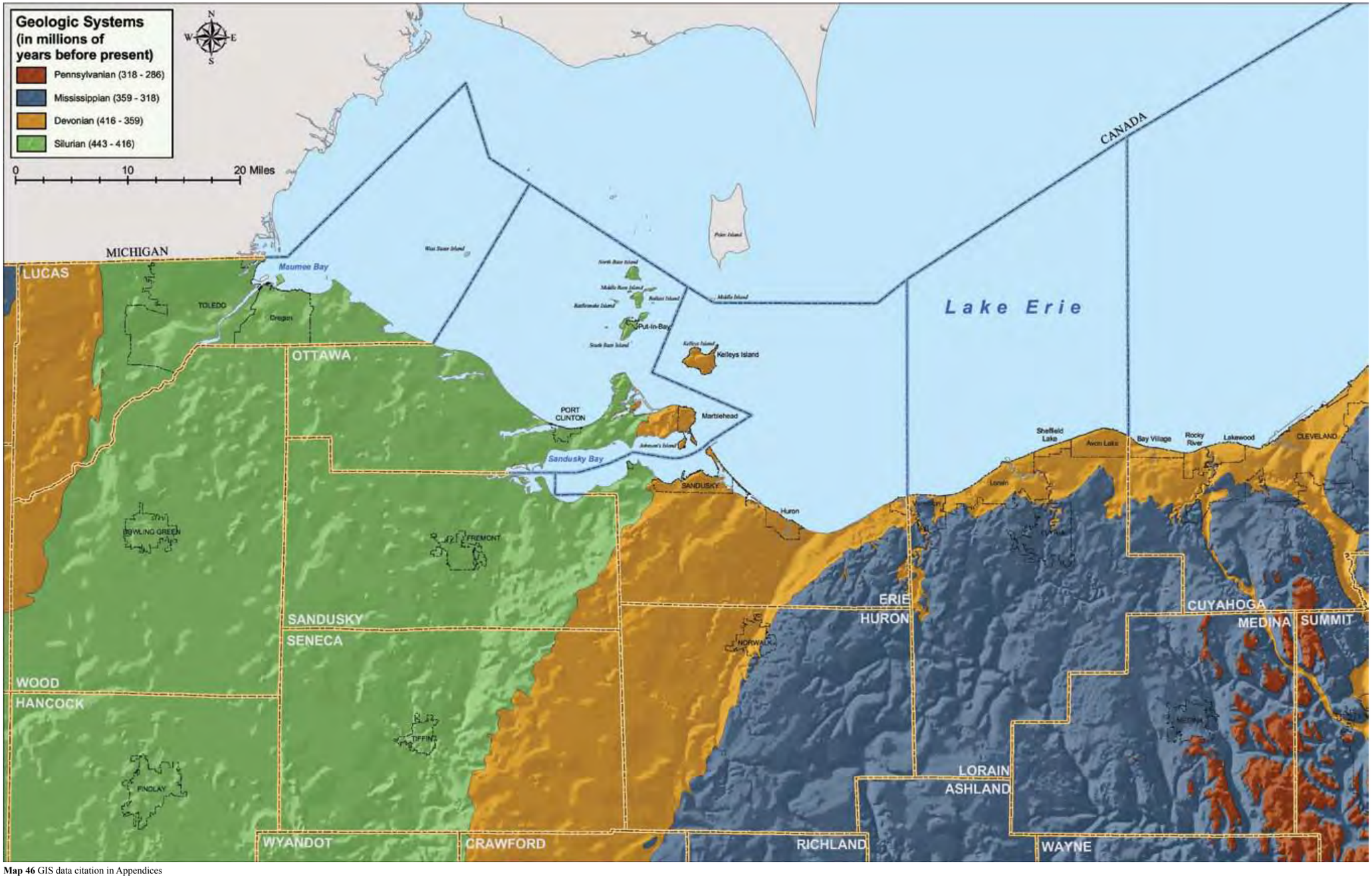
Sandstone block on beach, Erie County



Shale at Showse Park, Lorain County

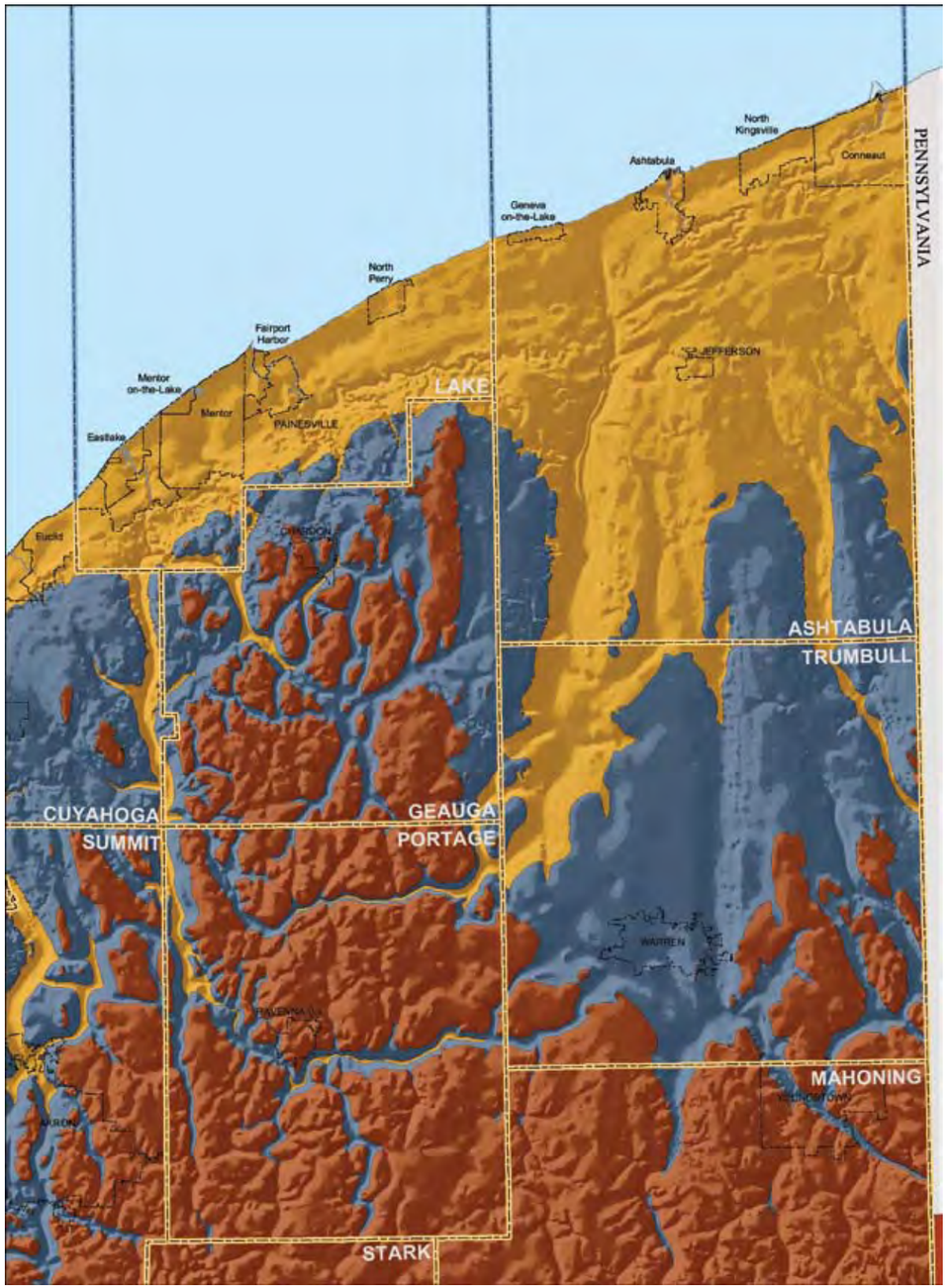
Fossiliferous limestone

Dolostone, Catawba Island Township, Ottawa County



Map 46 GIS data citation in Appendices

Bedrock Geology



Map 46 GIS data citation in Appendices

Bedrock formed millions of years ago and is the foundation of materials and topography in a region. Bedrock is found beneath the soils and may be buried beneath glacial till composed of rock fragments of various sizes that were released from glaciers as they receded. Bedrock irregularly protrudes or crops out through these materials. Bedrock outcrops may also be exposed alongside roads and creek beds.

Bedrock geology describes the basic rock formations that underlie soils and unconsolidated materials. Bedrock helps geologists understand the large-scale structures and processes of geological history. Bedrock is also a major source of groundwater which can occur in the porous and fractured layers.

Bedrock geology maps are important tools for land planners and government officials because they serve as the base for other environmental maps including: watershed characterization, ground water recharge, aquifer, radon, sinkhole potential and ecological habitat. Bedrock geology maps are helpful in the evaluation of water supply and the cleanup of contaminated ground water and allow people to identify and assess oil and gas resources. Underground construction as well as mineral resource assessment and management are also aided by bedrock maps.

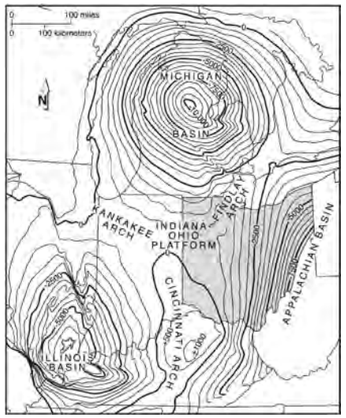
This bedrock-geology map of northern Ohio shows the age of bedrock strata (layers) at the land surface and strata that directly underlie unconsolidated Quaternary sediments (glacial, lacustrine and riverine) that have been deposited on the bedrock surface. The bedrock types (shale, siltstone, sandstone, conglomerate, limestone, dolomite, etc.) present in northern Ohio vary widely, but can be generally characterized by age and geographic location.

Bedrock units in coastal Ohio range in age from the Silurian Period (416 to 443 million years ago) to the Pennsylvanian Period (286 to 318 million years ago). These rock units are composed of sediments eroded from ancient mountain ranges located north and east of Ohio. With the passage of time and subjection to many geologic processes, these sediments were transformed into the rock units seen at or near the surface today in northern and eastern Ohio. The unconsolidated Quaternary sediments which conceal underlying bedrock in most of the coastal area are much younger than underlying bedrock strata, and were deposited within the past 2 million years – primarily by ice age glaciers.

Bedrock units, present at the surface or buried beneath glacial deposits along the Lake Erie shore, are predominantly Silurian- and Devonian- age limestone and dolomite west of Sandusky and Devonian-age shale to the east. This major rock type change also marks the west edge of the Central Basin of Lake Erie and the area of the Lake Erie Islands. Silurian-age dolomite underlies Sandusky Bay and crops out in the Catawba Island Peninsula and the Bass Islands. Kelleys Island has Devonian-age limestone exposed at the surface.

Devonian-age bedrock also crops out along a narrow, north-south oriented trend extending from Portsmouth on the Ohio River, through Columbus, to Sandusky on Lake Erie, where the trend bends northeastward toward Ashtabula. Ohio's oldest Devonian-age bedrock consists primarily of limestone that is well exposed in quarries near Sandusky and Kelleys Island. Most of the state's commercial caves are found in these rocks. Overlying this limestone is a thick sequence of younger, Devonian-age shale. Devonian-shale bedrock is well exposed in the valley walls of the Rocky River in Cuyahoga County.

Shale, siltstone and sandstone are the dominant Mississippian-age rock types in Ohio, and, like Devonian-age rocks, crop out along a trend landward of Lake Erie in northeastern Ohio. Pennsylvanian-age rocks consist primarily of sandstone with some conglomerate, shale and siltstone with some coal, and are exposed in the bedrock highlands of Geauga, Medina and Summit counties.



Generalized, regional structure contour map drawn on top of the Trenton Limestone (Wickstrom, L.H., Gray, J.D., and Stieglitz, R.D., 1992). Contour interval is 500 feet.

Regional arches (large-scale anticlines) and regional basins (large-scale synclines) control the surface distribution of the bedrock (see figure). These regional structures cause bedrock units to gently rise and fall in elevation in a predictable manner and largely control the outcrop pattern depicted on the bedrock map. The predominant structural feature controlling the distribution of bedrock in eastern Ohio is the western edge of the Appalachian Basin. The outcrop pattern of bedrock units in and around Lake Erie is controlled by the northwestern edge of the Appalachian Basin and the Findlay Arch.

Near Lake Erie, the Appalachian Basin edge swings to the northeast and causes bedrock of Devonian age to crop out parallel the lakeshore and dip to the southeast. Rocks of Devonian age parallel the Lake Erie shore from Pennsylvania to the Sandusky Bay area. Westward, the structural rise of the Findlay Arch causes older formations of Silurian age to be exposed at the surface. Farther west, the bedrock begins to dip into the southeastern portion of the Michigan Basin, thereby causing surface bedrock to become progressively younger in a northwesterly direction.

Bedrock geology data used to create the map to the left taken from:

Slucher, E.R., (principal compiler), Swinford, E.M., Larsen, and others, with GIS production and cartography by Powers, D.M., 2006, Bedrock geologic map of Ohio: Ohio Division of Geological Survey Map BG-1, version 6.0, scale 1:500,000, 1 map and GIS files.

Ohio Division of Geological Survey, 2003, Bedrock topography map of Ohio: Ohio Division of Geological Survey Map BG-3, map layout scale 500,000, 1 map and GIS files.

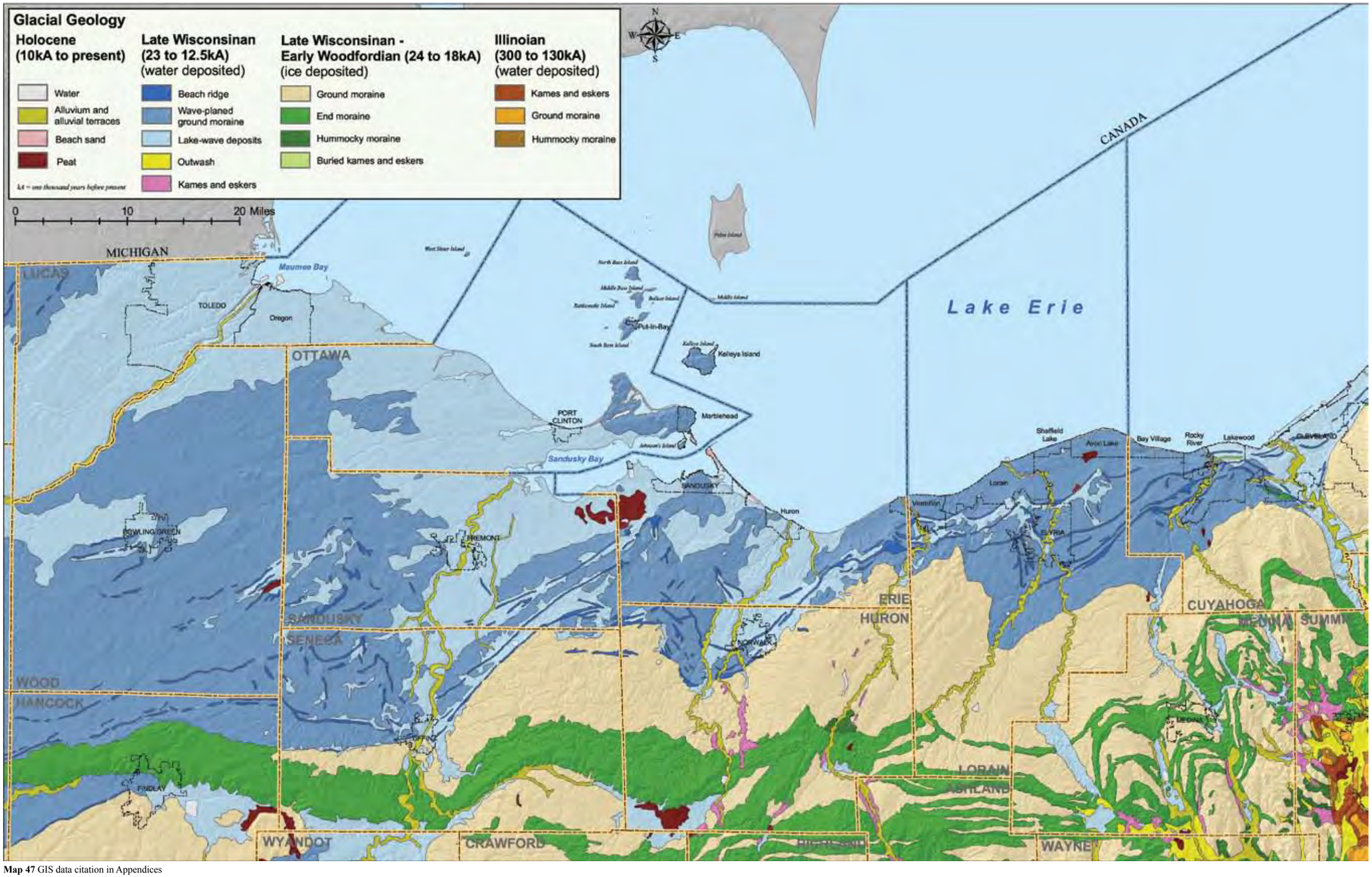
Glacial Geology

Till, Lorain County

Proglacial lake, Baffin Island, Canada
Photo by Dr. R.P. Goldthwaite

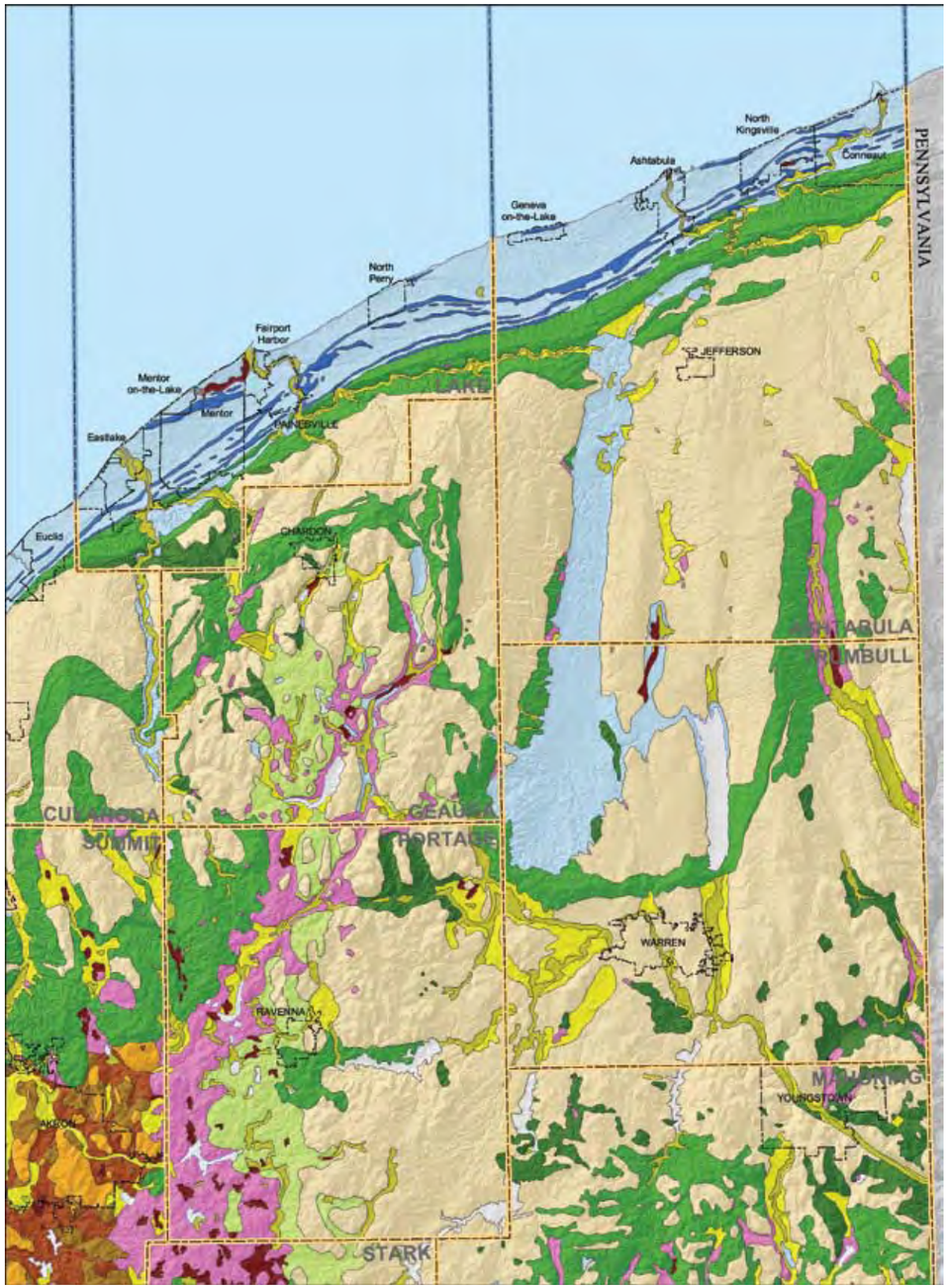
Glaciolacustrine sediment, Erie County

Glacial grooves, Kelleys Island, Erie County



Map 47 GIS data citation in Appendices

Glacial Geology



Map 47 GIS data citation in Appendices

As glaciers advanced into and retreated from northern Ohio, they left in their wake deposits consisting of clay, sand, gravel and boulders. Certain deposits are of economic importance, particularly clay, peat, sand and gravel – the later two of which are important to Ohio's construction industry and are among the state's most productive sources of ground water. Linear sand features where former Lake Erie beaches once served as trails and are now today's roadways. This glacial map interprets the origin and age of glacial features found in northern Ohio today.

Glacial Formation

At various times in the recent geologic past (within the last 1.6 million years), almost three-fourths of Ohio's surface area has been covered by vast sheets of ice up to 1 mile thick. This period of geologic history is referred to as the Pleistocene Epoch or, more commonly, the Ice Age. However, there is abundant evidence that Earth has experienced numerous other "ice ages" throughout its 4.6 billion years of existence.

Ice Age glaciers coming into Ohio formed in central Canada in response to cooling climatic conditions that allowed massive ice buildups. Because of their great thickness, these ice masses flowed under their own weight, and ultimately moved south as far as northern Kentucky. Oxygen-isotope analysis of deep-sea sediments indicates that more than a dozen glaciations occurred during the Pleistocene Epoch. Portions of Ohio were covered by the last two glaciations, known as the Wisconsinan (the most recent) and the Illinoian (older), and by an unknown number of pre-Illinoian glaciations. The Lake Erie Basin and many land areas shown on this map have been glaciated and covered by Wisconsinan-age glacial deposits that range in thickness up to several hundred feet thick, with the exception of small isolated areas of bedrock outcrops (see drift-thickness map).

Types of Deposits

Rock debris scoured and carried along by the glacier was deposited either directly by the ice or by meltwater flowing out of the glacier. Some sediment reaching the front edge of the ice was carried away by streams of meltwater to form outwash deposits (primarily sand and gravel; yellow areas on the map). Sand and gravel deposited by flowing meltwater on and under the surface of a glacier itself formed ice-contact features called kames and eskers (magenta areas on the map in the vicinity of Summit, Portage and Geauga counties). Kame deposits commonly appear as conical mounds, while eskers deposited in tunnels under the ice generally have a sinuous or serpentine appearance.

Glacial deposits that have been moved by water were sorted and layered. The large boulder-size pieces of rock were left behind and the smaller clay-size particles were carried far away, leaving the intermediate gravel- and sand-size material along the stream courses.

Sand and gravel are vital to Ohio's construction industry. These outwash deposits are among the state's most productive sources of ground water. Beach ridges that formed along the margin of the proglacial lakes served as trails for early pioneers and as roadways today.

Non-sorted, clay- to boulder-size material deposited directly by glacial ice, rather than by meltwater, is called till. Some till was deposited as ridges parallel to the edge of the glacier, forming "terminal" or "end" moraines (green areas on the map). These mark the position of the ice when it stopped moving for a period of time, possibly a few hundred years. When the entire ice sheet drew back because of melting, much of the ground-up rock material still held in the ice was deposited on the surface as "ground moraine" (tan areas on the map).

Many glacial lakes were formed in Ohio during the Ice Age. Lake deposits (blue areas on the map) consist primarily of fine-grained clay- and silt-size sediments. The most extensive lake deposits in Ohio occur in the former Great Black Swamp region of northwestern Ohio and in coastal regions of northeastern Ohio. These deposits, and adjacent areas of wave-planed ground moraine, are the result of sedimentation in and erosion by large lakes that occupied the Erie basin as Wisconsinan-age ice melted back into Canada. The different levels of this lake are recorded by a series of sandy beach ridges (dark blue lines) and wave-cut cliffs that formed along the shore of the lake. Other lake deposits accumulated in stream valleys whose outlets were temporarily dammed by ice or outwash. Many outwash-dammed lake deposits are present in southeastern Ohio, far beyond the glacial boundary.

The continental glaciers that moved from Canada into Ohio carried many rock types not found in Ohio. Pebbles, cobbles and boulders of these foreign rock types are called "erratics." Rock collecting in areas of glacial drift may yield granite, gneiss, trace quantities of gold and, very rarely, diamonds. Most rocks found in glacial deposits, however, are types native to Ohio.

Glacial deposits make up the entire bank or bluff along 52 percent of the lakeshore and overlie much of the rockbound shore that makes up 26 percent of the lakeshore. Glacial deposits also occur in the nearshore area along many parts of the lake. Erosion of these glacial deposits contributes sand and gravel from which Lake Erie beaches are built by waves and longshore currents.

Glacial geology data used to create the map to the left taken from:

Pavey, R.R., Goldthwait, R.P., Brockman, C.S., Hull, D.N., Swinford, E.M., and Van Horn, R.G., 1999, Quaternary geology of Ohio: Ohio Division of Geological Survey Map M-2, scale 1:500,000, 1 map and GIS files captured at 1:250,000-scale.

Drift Thickness

Bluff composed of till, glaciolacustrine sediment, till and sand, Ashtabula County

Till over shale at Showse Park, Lorain County

Variation in drift thickness at Interstate 71 excavation, Ashland County

Map 48 GIS data citation in Appendices

Drift Thickness

Map 48 GIS data citation in Appendices

The Drift Thickness Map of northern Ohio depicts the thickness and distribution of glacially derived sediments (called "drift") and post-glacial stream sediments overlying the buried bedrock surface. Drift thickness has many implications for land-use planning, construction engineering and resource management. For example, thick accumulations of glacial outwash are often good sources of ground water. Areas having thick accumulations of clayey glacial drift are generally more suitable as solid-waste disposal sites than thin-drift areas. The thickness and composition of glacial drift affects the stability of slopes eroded into those deposits; classic examples occur all along Lake Erie and in the valleys of Lake Erie tributaries.

Additionally, a shallow depth to bedrock significantly impacts the location, development, maintenance and cost of public services, such as sewers, water supply systems and roads. Construction feasibility and costs for building foundations, septic tanks and roads, are partially dependent on the depth to bedrock. Shallow bedrock may damage these man-made structures by frost heaving and deformation.

This drift thickness map was digitally produced by electronically subtracting bedrock-surface elevations from land-surface elevations to produce a map showing drift thickness. Colors portray thickness intervals of glacial and modern sediments, which can range up to several hundred feet.

Variation in drift thickness is illustrated in bluffs along Lake Erie. In Ashtabula County, where bedrock occurs just below lake level, the 65-foot-high bluff is composed entirely of glacial drift. In contrast, from Cleveland to Vermilion and in the island area, bedrock rises a few to many feet above lake level and is capped by only thin deposits of glacial drift.

Prior to the onset of continental glaciation in the Early Pleistocene, nearly two million years before present, rolling hills and deeply incised valleys dominated the Ohio landscape. Erosion and deposition by repeated advances and retreats of continental glaciers that crossed northern and western Ohio produced a low-relief land surface compared to the high-relief land surface of un-glaciated southeastern Ohio.

Drift thickness in western and northern Ohio is highly variable, a consequence of numerous geologic processes acting alone or in combination. In some areas, drift has been deposited on a relatively flat bedrock surface, and variations in drift thickness are due solely to differences in the amount of glacial sediments deposited on top of the bedrock as ground moraine, ridge moraines, eskers and kames. In other areas, drift thickens where ancient preglacial valleys were filled with glacial sediments and are now completely concealed under a land surface dominated by moraines and other glacial features. In still other areas, elevation of the modern land surface parallels elevation of the underlying buried-bedrock surface resulting in relatively uniform drift thickness.

In northeastern Ohio, narrow thick-drift areas south of Lake Erie also delineate the courses of preglacial bedrock valleys that have been partially or entirely filled by as much as 450 feet of glacial drift, primarily till and glacial-lake ("glaciolacustrine") sediments. Some of these buried valleys have been partially re-excavated by later, northward flowing rivers such as the Cuyahoga River and portions of the East Branch of Rocky River. Glaciolacustrine deposits exposed in the steep valley walls of the Cuyahoga River can be more than 250 feet thick and are notoriously landslide prone.

In northwestern Ohio, repeated scouring of the relatively soft bedrock surface by glacial ice flowing southwest from the Erie Basin smoothed the bedrock surface, destroyed most preexisting drainage systems, and deposited additional drift. Drift thickness in this ground-moraine dominated area is generally less than 50 feet and varies less than other parts of the state. The upper surface of the drift was planed or leveled off by wave action in proglacial lakes that formed along the margin of the retreating Wisconsinan-age glacier.

In western and northern Ohio, draping linear features of thick drift, called ridge moraines, formed along the temporarily stationary ice front as glacial sediment was released from the ice. These bands of thick drift define the lateral dimensions of glacial ice lobes, particularly those of the last Wisconsinan ice sheet. Many ridge moraines in western and northeastern Ohio have a draped appearance because south-flowing ice, impeded by bedrock highlands, moved more easily along major lowlands. This caused moraines to stack up on the north side or on top of the bedrock highlands, but spread down into adjacent lowlands. The numerous resistant, sandstone bedrock highlands in northeastern Ohio caused ridge moraines to be especially curved and stacked close together parallel to the Lake Erie shore, and abutted against the highlands to the south.

Drift thickness data used to create the map to the left taken from:

Powers, D.M., and Swinford, E.M., 2004, Shaded drift-thickness of Ohio: Ohio Division of Geological Survey Map SG-3, map layout scale 1:500,000, 1 map and GIS files.

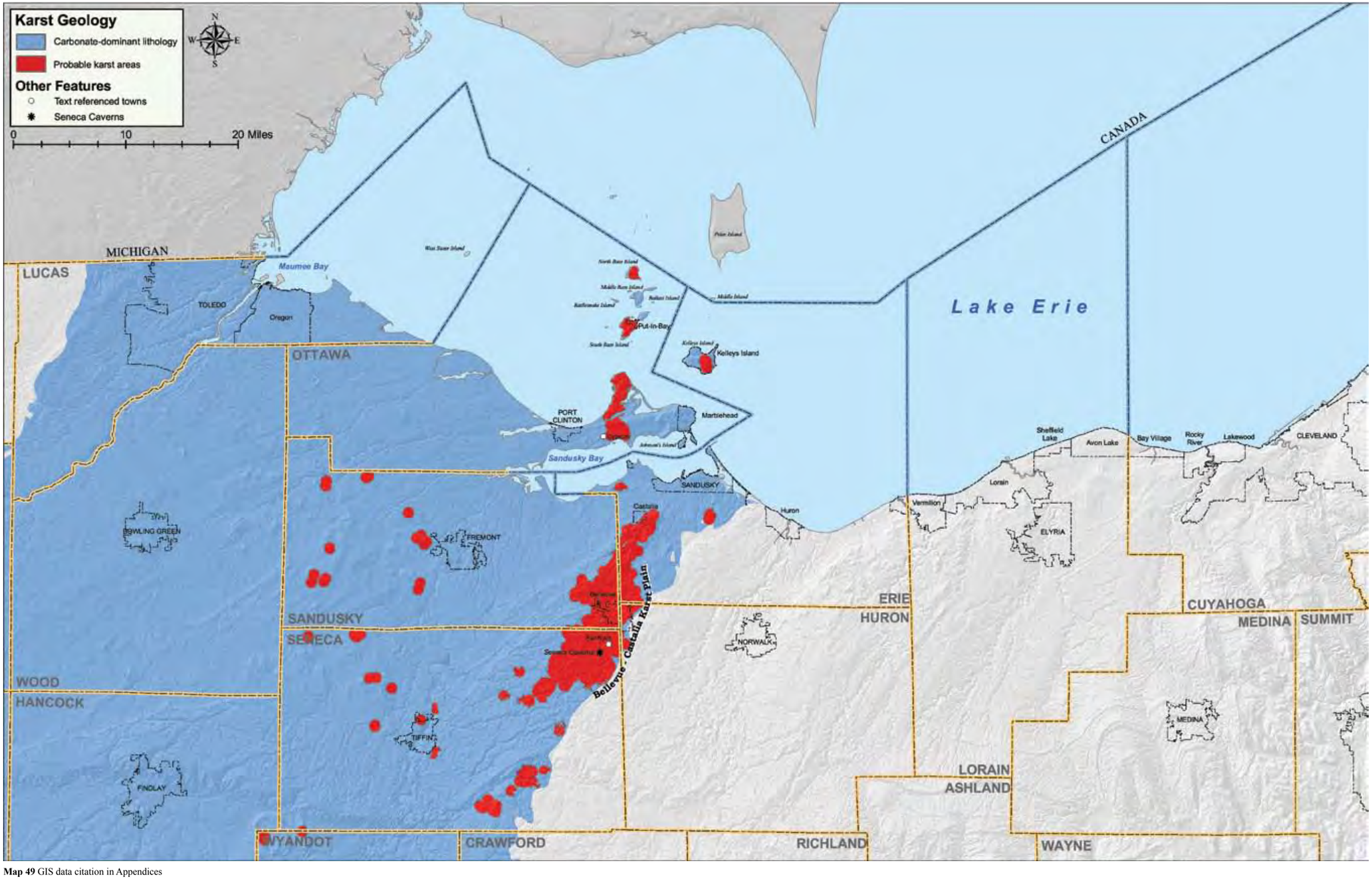
Karst Geology

Arched structure in bedrock, South Bass Island, Ottawa County

Non-natural sinkhole (filled in) along Plasterbed Road resulting from mining operation, Ottawa County

Sinkhole on Billings Road in Castalia,Erie County. Photo taken looking south from Bardwell Road

Karst topography along Billings Road, USGS tographic map, Castalia quadrangle 5' contours



Map 49 GIS data citation in Appendices

Karst Geology

Karst landforms develop on or in limestone, dolomite or gypsum where ground water has dissolved the rock and formed a subsurface drainage system. Karst regions contain aquifers that are capable of providing large supplies of water. They are also characterized by features such as sinkholes, caves and underground (or internal) drainage through solution-enlarged fractures called "joints." While karst landforms and features are striking in appearance and host some of Ohio's rarest fauna, they can also be a significant geologic hazard.

Sudden collapse of an underground cavern or opening of a sinkhole can cause surface subsidence that can severely damage or destroy any overlying structure such as a building, bridge or highway. Improperly backfilled sinkholes are prone to both gradual and sudden settling, and similarly threaten overlying structures. Agricultural, industrial and ice-control chemicals, sewage and animal wastes entering sinkholes as surface drainage are conducted directly and quickly into the ground water system, thereby posing a severe threat to potable water supplies. Because of such risks, many of the nation's state geological surveys and the U.S. Geological Survey are actively mapping and characterizing the nation's karst regions.

To produce this map, karst features identified in the field or on aerial photos, topographic maps and soil-survey reports were plotted on 7.5-minute topographic quadrangle maps. Arcs with a radius of one-half mile were drawn around known and probable karst features to initially designate preliminary karst areas. Areas within arc borders that are not underlain by karst-forming bedrock and that are underlain by 20 feet or more of clayey glacial drift or impermeable bedrock were then subtracted from preliminary karst areas to yield the probable karst areas depicted on this map.

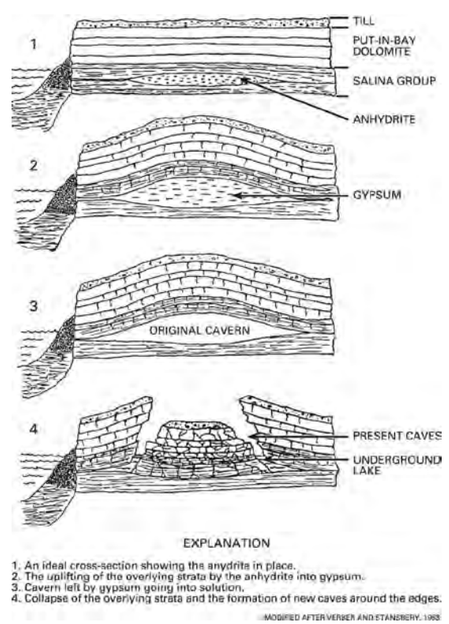
Most karst areas in Ohio are developed in soluble limestone and dolomite bedrock where glacial overburden (glacial-drift materials overlying bedrock) is thin or absent. Upland areas where Columbus Limestone, Delaware Limestone, Salina Group dolomite, Tymochtee Dolomite, Greenfield Dolomite and Lockport Dolomite lie at or just below the land surface are highly susceptible to karst formation.

The Bellevue-Castalia Karst Plain occupies portions of northeastern Seneca County, northwestern Huron County, southeastern Sandusky County and western Erie County. Adjacent karst terrain in portions of Ottawa County, including the Marblehead Peninsula, Catawba Island and the Bass Islands, is related in geologic origin to the Bellevue-Castalia Karst Plain. The area is underlain by up to 175 feet of Devonian carbonate bedrock (Delaware Limestone and Columbus Limestone) overlying Silurian dolomite, anhydrite and gypsum of the Bass Islands dolomite and Salina Group.

The Bellevue-Castalia Karst Plain is believed to contain more sinkholes than any of Ohio's other karst regions. Huge, irregularly shaped, closed depressions up to 270 acres in size and commonly enclosing smaller, circular-closed depressions 5 to 80 feet in diameter, pockmark the land between the village of Flat Rock in northeastern Seneca County and Castalia in western Erie County. Surface drainage on the plain is very limited, and many of the streams disappear into sinkholes often called "swallow holes."

Karst in the Bellevue-Castalia and Lake Erie islands region is due to collapse of overlying carbonate rocks into voids created by the dissolution and removal of underlying gypsum beds. According to Verber and Stansbery (Ohio Journal of Science, 1953), ground water is introduced into Salina Group anhydrite ($CaSO_4$) through pores and fractures in the overlying carbonates. The anhydrite chemically reacts with the water to form gypsum ($CaSO_4 \cdot 2H_2O$), undergoing a 33 to 62 percent increase in volume in the process. This swelling lifts overlying strata, thereby opening fractures and creating massive passageways for transmission of greater volumes of ground water through the Salina Group strata. Gypsum, being readily soluble in water, is dissolved, creating voids. Overlying carbonate rocks then collapse or break down, leaving surface depressions similar to those resulting from roof failure of an underground mine.

The map of probable karst areas in Ohio is available from the ODNR Division of Geological Survey as a full-color, 1:500,000-scale paper map and as a digital map and dataset on Compact Disc-ROM. A page-sized map is available in hard-copy format from the Division or can be downloaded at www.ohiodnr.com/geosurvey/.



Formation of sinkholes, caves and collapse features in the Bellevue-Castalia and Lake Erie region (Modified after Verber and Stansbery, 1953).

Seneca Caverns

Karst processes are responsible for many unusual surfical and underground geologic phenomena. Seneca Caverns, located in Seneca County just south of Bellevue and within the Bellevue-Castalia Karst Plain, is a prime example of karst geology. Known as "The Earth Crack," it is one of Ohio's largest underground cave systems. The designated Ohio Registered Natural Landmark is also believed to be the only fracture cave open for public tours in the United States.

The limestone-rich caverns are comprised of an unknown number of levels— the top seven of which are open for public tours tunneling 110 feet below the surface. Each level consists of at least one irregularly shaped "room" and a system of linking passageways. The largest room is 250 feet long. Flowing through the deepest reaches of the caverns is a crystal clear, underground stream known as the Ole Mist'ry River. This river is believed to be part of an expansive aquifer network which supplies water to much of the surrounding area. Although the river's source is yet to be determined, studies have concluded that the river flows as far north as the Castalia area in Erie County.

Seneca Caverns was discovered in 1872 and opened to the public in 1933 (with admission). Along the one-hour tour, visitors are guided through all seven levels and are able to observe several fossils and cave formations. Seneca Caverns also provide visitors with the only available views of the subterranean Ole Mist'ry River.

For more information:
Seneca Caverns
15248 East Thompson Road (Township Road 178)
Bellevue, Ohio 44811
Tel: 419-483-6711

Source:
Seneca Caverns: www.senecacavernsohio.com
Lake Erie Coastal Ohio: www.coastalohio.com
Sandusky County Convention and Visitors Bureau: www.sandskycounty.org/seneca.htm

Gypsum

The karst region found in Ottawa County is home to at least one gypsum manufacturing company located in a small town named "Gypsum" just east Port Clinton.

Gypsum is a mineral found in sedimentary rock formations in a crystalline form known as calcium sulfate. One hundred pounds of gypsum rock contains approximately 21 pounds (10 quarts) of chemically combined water. Gypsum rock is mined or quarried and then crushed. The crushed rock is then ground into a fine powder and heated to about 350 degrees Fahrenheit, driving off three-fourths of the chemically combined water in a process called calcining. The calcined gypsum (or hemihydrate) is then used as the base for gypsum plaster, gypsum board and other gypsum products.

To produce gypsum board, the calcined gypsum is mixed with water and additives to form a slurry that is fed between continuous layers of paper on a board machine. As the board moves down a conveyer line, the calcium sulfate recrystallizes or rehydrates, reverting to its original rock state. The paper becomes chemically and mechanically bonded to the core. The board is then cut to length and conveyed through dryers to remove any free moisture.

Gypsum board is often called drywall, wallboard, or plasterboard and differs from products such as plywood, hardboard and fiberboard, because of its noncombustible core.

Source:
Gypsum Association
810 First St., NE, #510
Washington DC, 20002
Tel: 202-289-5440
Fax: 202-289-3707
E-mail: info@gypsum.org

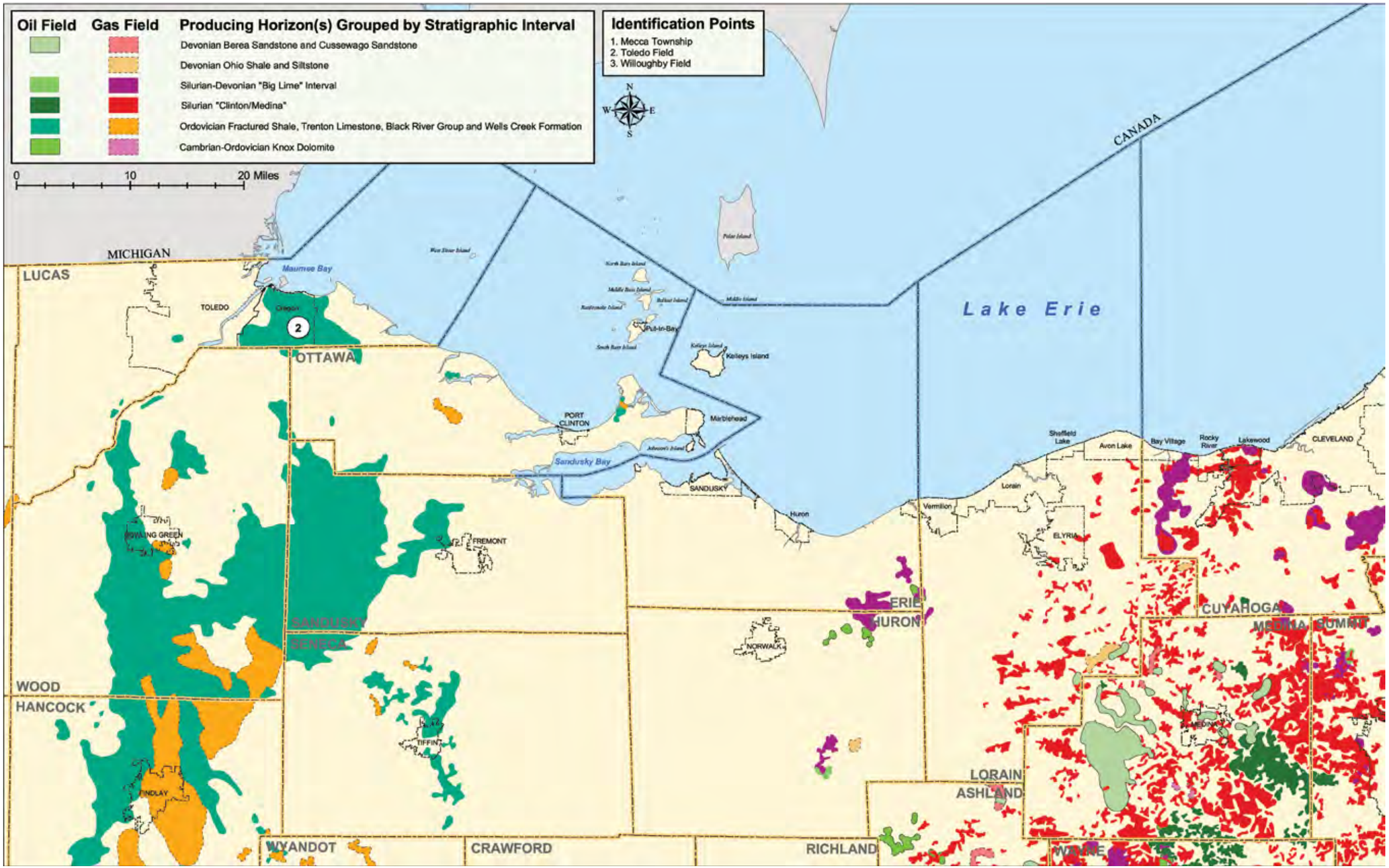
Karst data used to create the map to the left taken from:
Pavey, R.R., Hull, D.N., Brockman, C.S., Schumacher, G.A., Stith, D.A., Swinford, E.M., Sole, T.L., Vorbau, K.E., Kallini, K.D., Evans, E.E., Slucher, E.R., and Van Horn, R.G., 1999 (revised 2002), Known and probable karst in Ohio: Ohio Division of Geological Survey Map EG-1, scale 1:500,000, 1 map and GIS files.

Oil and Gas Fields

Oil pump

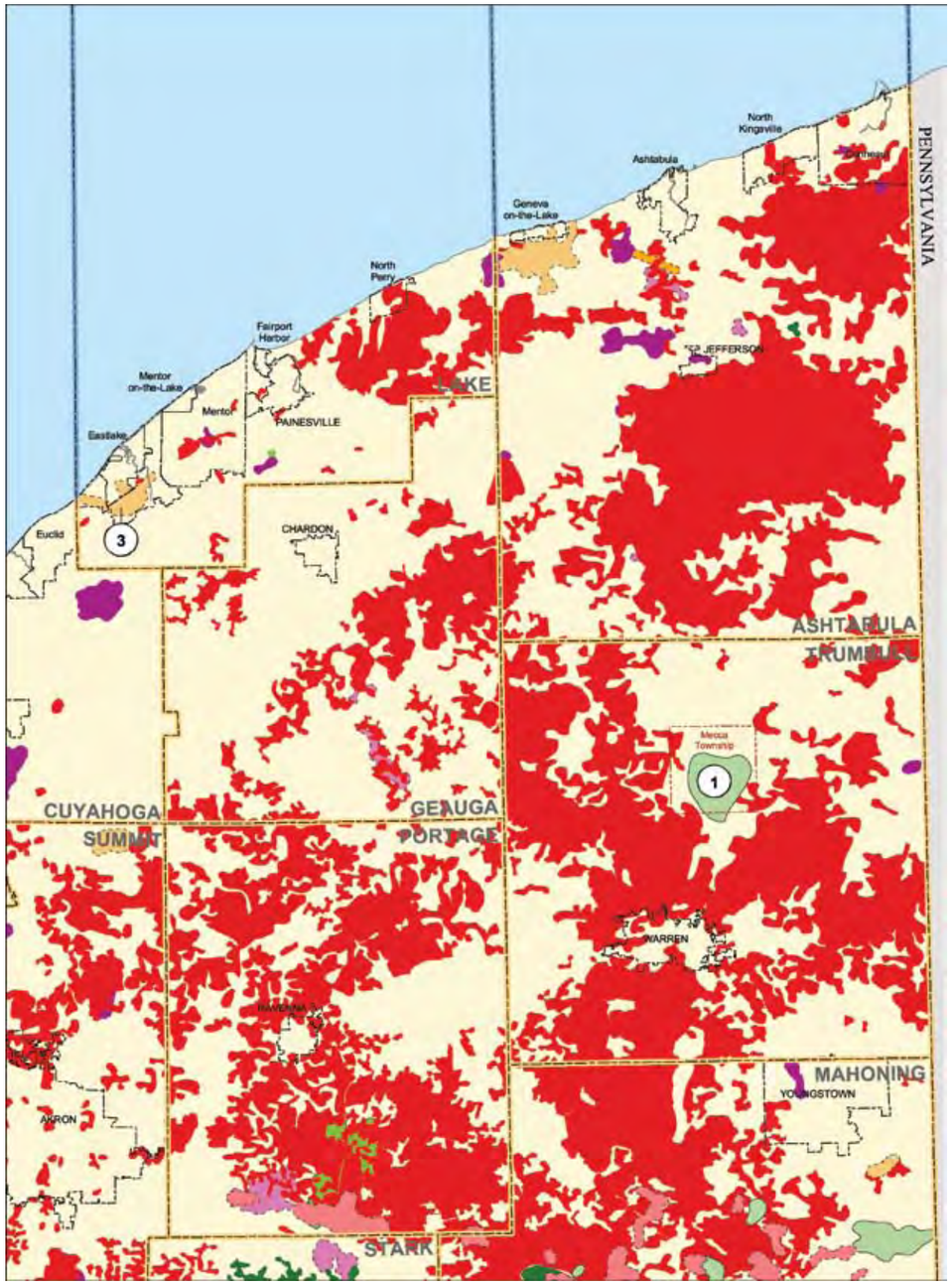
Cygnet oil field, circa 1890, Wood County

Cable-tool drill rig



Map 50 GIS data citation in Appendices

Oil and Gas Fields



Map 50 GIS data citation in Appendices

Ohio's rich history of oil and gas production began in 1859 when the first commercial well for petroleum production was drilled in Mecca Township (Trumbull County, #1 on map). This was just a few months after petroleum entrepreneur Colonel Edwin Drake completed his first well near Titusville, Pennsylvania, to which most historians trace the start of the oil industry.

Much of the drilling in northern Ohio took place from the late 1800s through the 1950s— prior to large-scale development of lakefront communities. For example, drilling in the Toledo Field (#2 on map) just south of Maumee Bay began in 1887. Drilling in Cuyahoga County began about 1912 and continued through the 1930s and Lake County's Willoughby Field (#3 on map) was discovered in 1957. Recently, there has been a significant amount of drilling activity in Ashtabula County and eastern Lake County targeted at deeper gas-producing horizons including the "Clinton" sandstone, Trenton-Black River limestone and the Rose Run sandstone.

On land, commercial quantities of oil and gas have been found in 67 of Ohio's 88 counties. The majority of current production is in the eastern third of the state. Cumulatively, Ohio has produced more than 1 billion barrels of oil and 9 trillion cubic feet of natural gas since 1860. More than 220,000 productive oil and gas wells have been drilled in Ohio, more than 60,000 of which are in operation. Most producing wells in the state are referred to as "stripper" wells – meaning they produce less than 10 barrels of oil (or 56,000 cubic feet of natural gas) per day.

Oil and gas have been produced from more than 30 individual geologic formations (primarily limestone, dolomite, shale and sandstone) ranging in age from Late Cambrian (488 million years before present) through Late Pennsylvanian (299 million years before present), and at depths ranging from 50 to 9,100 feet.

The commercial discovery of oil and gas in northwestern Ohio in 1884 initiated a 20-year oil and gas boom in which production was from the Trenton limestone in the Lima-Indiana oil and gas fields. The Ohio portion of this trend, extending across Lucas, Wood, Hancock, Allen and Van Wert counties, produced more than 380 million barrels of oil and approximately 2 trillion cubic feet of gas. More than 23 million barrels of oil were produced in 1896 alone, helping Ohio lead the nation in oil production from 1895 to 1903.

Oil and natural gas are generally believed to have formed through geochemical alteration of decayed organic remains (mostly plant life and marine organisms) that have been deeply buried and subjected to high temperatures and pressures. Once formed, these hydrocarbons commonly migrate with other formation fluids (i.e., brine or salt water) through fractures and voids in bedrock until trapped or until escaping to the surface as a natural seep. It is the trapped hydrocarbons stored in a reservoir that energy companies seek and produce.

Being lighter than water, hydrocarbons float on top of formation fluids and occasionally accumulate in structural traps such as the higher portions of deeply buried domal or anticlinal structures and the upper margins of sealed fault systems. In other instances, hydrocarbons occasionally accumulate in stratigraphic traps where rock layers laterally transition from a porous and permeable state to a nonporous impermeable state. Most of Ohio's oil-and-gas resources are produced from stratigraphic traps, although a significant amount is also produced from structural traps.

A good example of a structural trap occurs in northwest Ohio where the large oil fields of Wood County follow the trend of the Bowling Green Fault System. Within this fault system, the earth's crustal forces fractured and displaced the Ordovician-age (444 to 488 million years before present) Trenton limestone. This allowed hydrocarbons to migrate along fractures and accumulate where displaced and overlying impermeable rocks prevented further migration.

An example of a large stratigraphic trap system can be seen in northeast Ohio where a series of "Clinton" sandstone fields extend from Ashtabula County to Medina County. These fields represent an area where the reservoir rock, the Silurian-age (416 to 444 million years before present) "Clinton"/ Medina sandstones transition from relatively porous sandstone in the east-southeast to a nonporous dolomite and shale in the west-northwest. Hydrocarbons migrating upward and westward out of the Appalachian Basin have accumulated along this trend and are an exploration target.

While Ohio oil and gas production has never again reached the levels attained in 1896, petroleum producers have worked continuously since then to steadily identify and develop oil-and-gas resources across the state.

For more information/ source:

ODNR Division of Geological Survey

U.S. Army Corps of Engineers Chicago District- Known and Potential Environmental Effects of Oil and Gas Drilling Activity in the Great Lakes

Oil and gas fields data used to create the map to the left taken from:

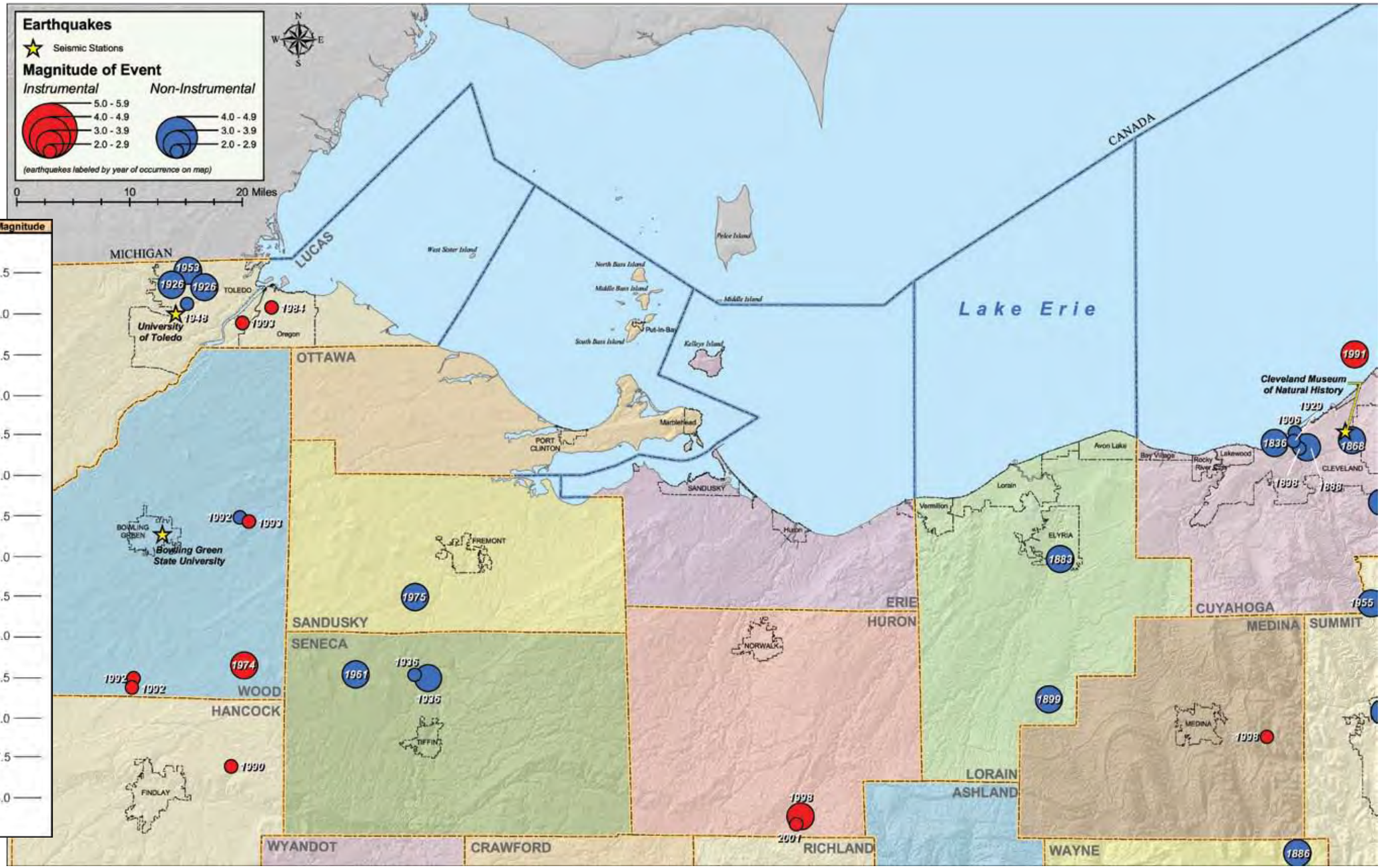
Riley, R.A., Baranoski, M.T., and Wickstrom, L.H., 2004, Oil and gas fields map of Ohio: Ohio Division of Geological Survey Map PG-1, scale 1:500,000, 1 map and GIS files.

Earthquakes

Earthquake Epicenter data used to create the map to the right taken from:
Hansen, M.C., 2002 (revised 2003), Earthquake epicenters in Ohio and adjacent areas: Ohio Division of Geological Survey Map EG-2, scale 1:500,000, 1 map and GIS files.

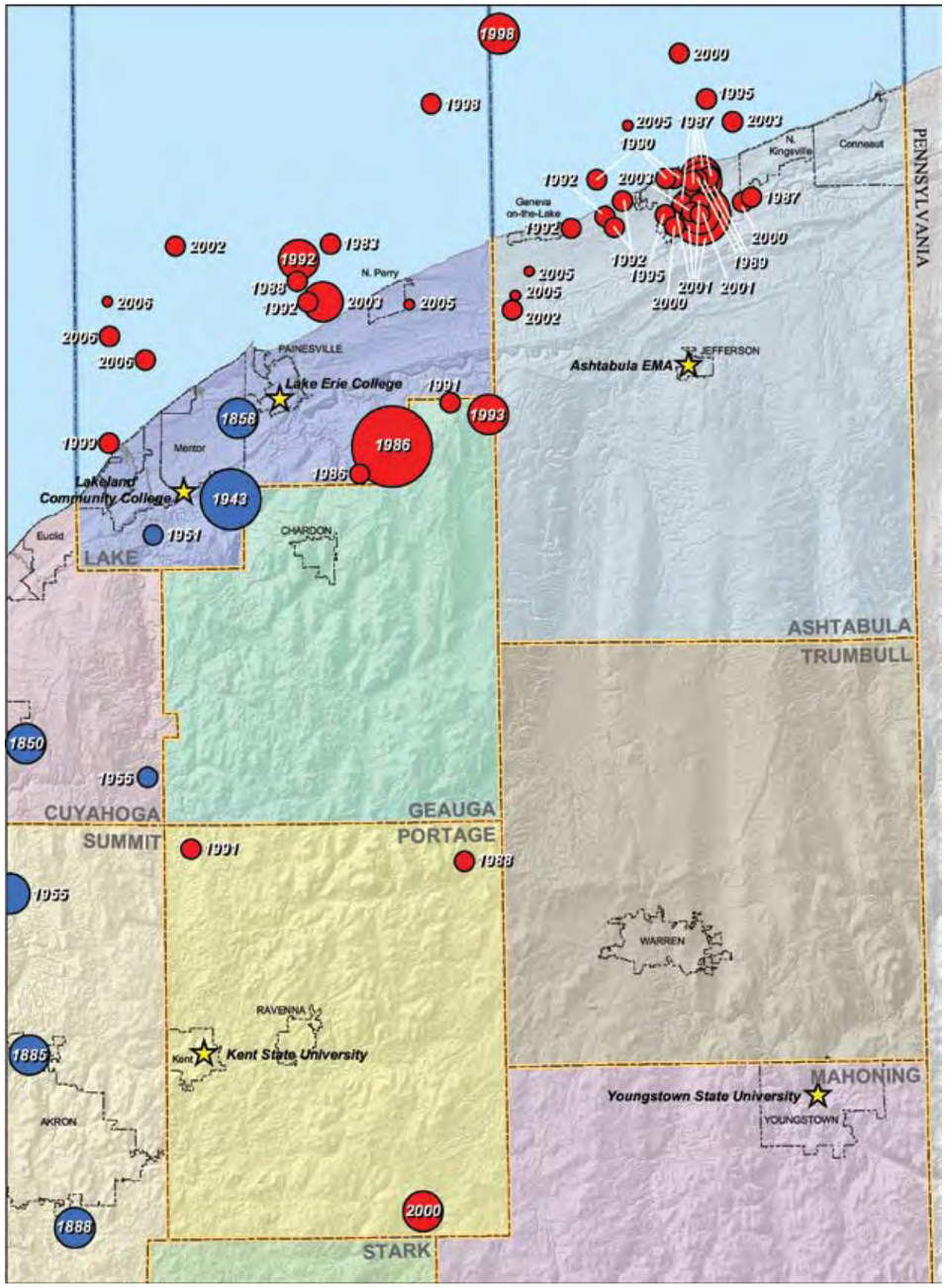
Modified Mercalli Intensity Scale		Richter Magnitude
I	Detected only by sensitive instruments	1.5
II	Felt by few persons at rest, especially on upper floors; delicately suspended objects may swing	2.0
III	Felt noticeably indoors, but not always recognized as earthquake; standing autos rock slightly, vibrations like passing truck	2.5
IV	Felt indoors by many, outdoors by few, at night some awaken; dishes, windows, doors disturbed: standing autos rock noticeably	3.0
V	Felt by most people; some breakage of dishes, windows and plaster; disturbance of tall objects	3.5
VI	Felt by all, many frightened and run outdoors; falling plaster and chimneys, damage small	4.0
VII	Everybody runs outdoors; damage to buildings varies depending on quality of construction; noticed by drivers of autos	4.5
VIII	Panel walls thrown out of frames; walls, monuments, chimneys fall; sand and mud ejected; drivers of autos disturbed	5.0
IX	Buildings shifted off foundations, cracked, thrown out of plumb; ground cracked; underground pipes broken	5.5
X	Most masonry and frame structures destroyed; ground cracked, rails bent, landslides	6.0
XI	Few structures remain standing; bridges destroyed, fissures in ground, pipes broken, landslides, rails bent	6.5
XII	Damage total; waves seen on ground surface, lines of sight and level distorted, objects thrown up into air	7.0
		7.5
		8.0

Modified Mercalli Intensity Scale and Richter Magnitude equivalent



Map 51 GIS data citation in Appendices

Earthquakes



Map 51 GIS data citation in Appendices

Earthquakes are sudden motions in the earth as rock masses slide past each other in response to accumulated crustal stress. Ohio experiences earthquakes because about a billion years ago, the land that would become Ohio was at the intersection of two great crustal plates that collided. The resulting fractured rock, or faults, now lie buried deep beneath the state. As the earth's plates continue to slowly move, pressure builds along these ancient faults, causing them to "slip" and generate earthquakes.

Although no active earthquake faults are exposed, evidence of past faulting can be seen along Ohio's coast. Many small non-earthquake related faults exposed in shale cliffs from Vermilion to Cleveland show displacements of several feet. Movement of rock along the faults weakens the rock, making it more easily eroded. Waves erosion of the weakened rock creates erosional embayments which typically trap sand to create beaches along an otherwise beachless shore. If the beach is wide enough, it dissipates wave action and slows further erosion of the fault-weakened bedrock.

The map shows earthquake epicenters (instrumental magnitudes of 2.0 or greater) located in northern Ohio. For display purposes, some events are not plotted precisely, especially in areas of multiple events. Non-instrumental earthquake locations and magnitudes were calculated from historical accounts (i.e., newspapers, scientific publications, reports). Locations and magnitudes for these quakes may be very imprecise because of the scarcity of original reports for some earthquakes.

From 1992 until the establishment of the Ohio Seismic Network (OhioSeis) in 1999, Ohio lacked instate capability to locate earthquakes. During this period, some small events were detected and instrumentally located by out-of-state networks. However, some instrumental locations are imprecise because of seismic-station distance and distribution that prevent the best possible triangulation.

Today, OhioSeis consists of 24 volunteer-operated seismograph stations located at Ohio colleges, universities, high schools and local government institutions. Seven of the network stations are located in the Lake Erie watershed— Toledo, Bowling Green, Cleveland, Kirtland, Painesville, Jefferson and Kent— to allow reliable pinpointing of earthquake epicenters in this seismically active region.

The network is coordinated by the ODNR Division of Geological Survey and is partially funded by the Federal Emergency Management Agency through the Ohio Emergency Management Agency and by the U.S. Geological Survey through the Central United States Earthquake Consortium. Data is collected by network scientists to gain insight into the location of deep faults beneath the surface and to better understand the geologic history of Ohio.

Seismic Risk

Seismic risk is based on proximity to earthquake epicenters, bedrock geology and frequency of earthquakes. Seismic waves travel long distances, and the relatively brittle and flat-lying sedimentary rocks of the Lake Erie Region (see Bedrock Map) carry waves from even moderate-size earthquakes throughout thousands of square miles. If an earthquake similar in magnitude to those of California were to occur in the eastern United States, damaging ground motion could occur in an area about 10-times larger than for a comparable earthquake in California. Ground motion from seismic waves tends to be magnified by unconsolidated sediments such as thick deposits of clay or sand and gravel. Such deposits are extensive in Ohio (see Drift Thickness Map). Buildings constructed on bedrock tend to experience much less ground motion, and therefore less damage.

Earthquakes in Ohio are generally infrequent, and the time between large earthquakes is typically very long, on the order of hundreds or even thousands of years. Given that the historic record for earthquakes is only about 200 years– an instant, geologically speaking– it is nearly impossible to predict either the frequency or magnitude of earthquakes for a particular site. However, the brief historic record of Ohio earthquakes suggests that active seismic zones in western Ohio could generate an earthquake with a magnitude of between 6.5 and 7.0, and the northeastern seismic zone could generate an earthquake with a magnitude of between 6.0 and 6.5. However, at this time, there is no evidence that Ohio has experienced such large earthquakes in the last 10,000 years. Historically, earthquakes in northern Ohio have been Richter magnitude 3.9 or less.

A quake of moderate strength (Richter magnitude 5.0) occurred on Jan. 31, 1986, and was one of the strongest seismic events in Ohio in modern times. The epicenter of this widely felt event was in southern Lake County just north of the Geauga County line.

The Ashtabula area was not known to be seismically active until July 13, 1987, when many residents of the City of Ashtabula felt a 3.8-magnitude earthquake. This earthquake was the first in a series of more than 70 earthquakes with epicenters in the northeastern Ohio coastal area occurring since 1987.

Of the 13 earthquakes occurring in 2000 and 2001, 11 had epicenters in Ashtabula County. Many of those were in the vicinity of a deep Class-I injection well that was periodically used from 1986 to 1994 to pump waste fluids into a deep Cambrian-age sandstone. A 4.5-magnitude earthquake in this area on Jan. 25, 2001, resulted in the Ashtabula County Emergency Management Agency receiving 50 damage reports including the rupture of two residential gas lines.

Of the 30 earthquakes that occurred from Jan. 1, 2002, to July 25, 2006, 19 (63 percent) were in Lake County. Most of those were offshore beneath Lake Erie. During this same time frame, seven earthquakes have occurred in Ashtabula County. A complete database of Ohio and border-region earthquakes is available online at Ohiodnr.com/OhioSeis.

Source:

ODNR Division of Geological Survey, M.C. Hanson, Earthquakes in Ohio, Educational Leaflet No.9, Revised 1999

Seeber, Leonardo, and Armbruster, J. G., 1991, The NCEER-91 earthquake catalog: Improved intensity based magnitudes and recurrence relations for U. S. earthquakes east of New Madrid, National Center for Earthquake Engineering Research, Technical Report NCEER-91-0021, 92 p