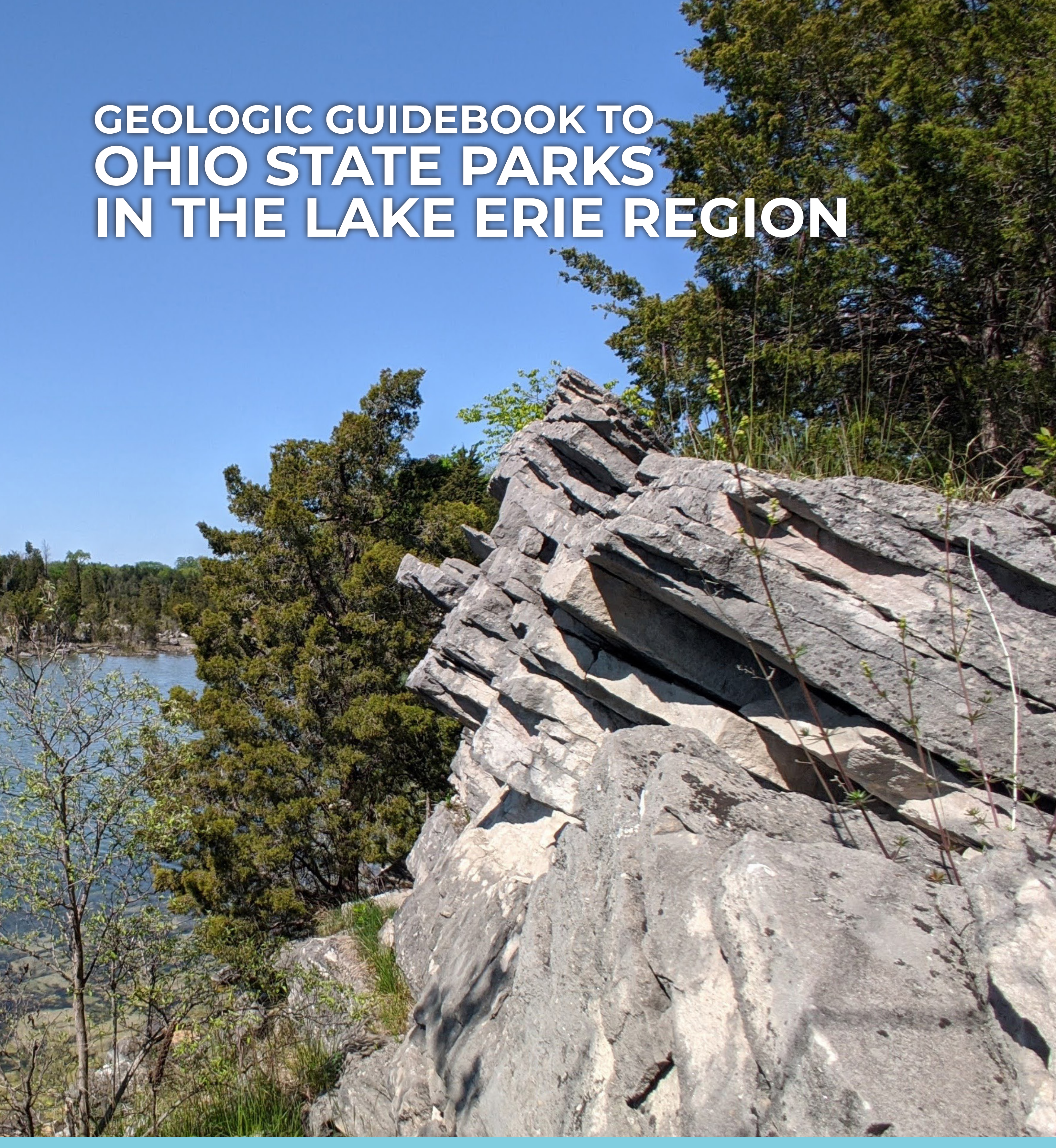
GEOLOGIC GUIDEBOOK TO
OHIO STATE PARKS IN THE LAKE ERIE REGION



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Guidebook 24

GEOLOGIC GUIDEBOOK TO OHIO STATE PARKS IN THE LAKE ERIE REGION

by
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STATE OF OHIO
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY
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Columbus 2024

OHIO
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DEPARTMENT OF NATURAL RESOURCES

OHIO
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CONTENTS

FIGURES

FIGURES (continued)

FIGURES (continued)

FIGURES (continued)

PLATE

TABLE

ABBREVIATIONS USED IN THIS GUIDEBOOK

Units of Measure

foot or feet	ft
cubic feet	ft^3
gallons	gal
inch or inches	in
liters	L
meters	m
cubic meters	m^3
miles	mi
square miles	mi^2
kilometers	km
square kilometers	km^2
yard	yd

Other

million years ago	m.y.a.
years ago	y.a.
mean sea level	m.s.l.

PREFACE

This guidebook to the geology of the Ohio state parks in the Lake Erie region describes the geological features of state parks to tell key parts of the history of the lake's formation and Ohio's geological history. It is not a traditional geological guidebook in that it does not list stops to be visited in a particular sequence. Instead, we anticipate that users visiting one or more of the parks will find this guide useful to understand the overall geologic context of the park(s) and the surrounding region. It is expected that users of this guidebook will be drawn from a broad mix of readers, from park visitors without a geological background but with an interest in the natural sciences, to geology students and professional geologists. As such, the narrative style attempts to strike a balance that will engage geologists without alienating non-scientists. Common geologic terms are used frequently but when first introduced they appear in *italics* along with a brief explanation. When it would disrupt the flow of the text to define a term, that term appears in **bold** print, signifying that a definition can be found in the glossary at the end of the guidebook.

This guidebook is organized as follows:
- Part I discusses the general geologic background of northern Ohio and the formation of the Paleozoic rocks.
- Part II summarizes the *Quaternary* (Ice Age) history of the region and relates the regional geology specifically to the development of Lake Erie.
- Part III is a brief discussion of Lake Erie's history since modern settlement and the future of the lake.
- Part IV contains park-specific field guides to the geology of lake-adjacent state parks and nearby lands.

It is not necessary to read this entire guidebook from cover to cover or in a particular order, but those without a background in geology may find it helpful to read at least Parts II and III before moving on to the park-specific field guides. When the park-specific field guides refer to an important concept, they generally refer the reader to the section of the guidebook where that concept is introduced.

Safety was a prime concern in writing this guidebook. Please observe these guidelines when using this book in the field:

- Always adhere to federal, local, and state traffic laws.
- Wear shoes or boots with good tread and plenty of ankle support, as some sites might present wet, muddy, slippery, or uneven terrain with loose rocks and sediment.
- Never climb on outcrops.
- Wear clothing appropriate to the environment and changing weather conditions.
- All sites described in this guidebook are on public lands unless otherwise noted; do not trespass on private property. Mention in this guidebook of a site on private property is not to be taken as a suggestion to trespass. Obtain permission from private property owners before entering and comply with any rules they have for visitors.
- **Never** trespass in quarries. Whether in operation or closed and abandoned, quarries are extremely hazardous sites.
- Some Field Trip Stops are in State Nature Preserves, which may have different rules of access than the State Parks (e.g. pets prohibited). Always observe posted rules.
- Collecting of rocks, minerals, fossils, plants and endangered species in State Parks and other state lands is prohibited without a permit.

This reprint edition is dedicated to the memory of Rick Pavey, a colleague, collaborator, and friend.

GEOLOGIC GUIDEBOOK TO OHIO STATE PARKS IN THE LAKE ERIE REGION

by
D. Mark Jones

INTRODUCTION

Most of us are familiar with the concept of geologic time and the idea that Earth and most of its features—mountains, oceans, and canyons, for example—are staggeringly old. But the Great Lakes are an exception. While their origins are ancient on a human scale—no person can trace their ancestry as far back as we can trace Lake Erie— what we recognize as Lake Erie is younger than such hallmarks of humanity as art and language. Lake Erie is younger than the oldest known pottery. The oldest writing, from ancient Sumer (part of modern-day Iraq), dates to about 5,200 years ago (y.a.). At that time, what we call modern Lake Erie was about 12 meters (m) or 40 feet (ft) lower in elevation than today—its shore would be barely recognizable to anyone familiar with today's lake.

Growing up in Cleveland, the author frequently heard about the role of glaciers in sculpting northern Ohio's landscape. The narrative that ice carved out the basin of Lake Erie and the other Great Lakes and then melted, leaving a system of interconnected lakes, is part of the region's local geographic lore, a story that seemingly every resident is at least somewhat familiar with. But, while not wrong, this account is grossly oversimplified. The full story is much more complicated and more fascinating.

PART I: GENERAL GEOLOGIC FRAMEWORK AND PALEOZOIC HISTORY

Geologic framework is an all-encompassing term that refers to the broad geologic background of a region, including bedrock, structure, and tectonics. A discussion of Lake Erie's geologic framework necessarily includes northern Ohio and also applies to parts of the surrounding states and Ontario, Canada. However, this discussion generally concentrates on the geology of northern Ohio and Lake Erie.

Although Lake Erie is a geologically young feature, it owes its origins and shape in part to the rocks beneath it, which predate the lake by hundreds of millions of years. Discussion of the geology starts with the rocks of the Silurian Period, the oldest rocks exposed at the surface in the Lake Erie region. Much older rocks exist in the region, but they are buried and are not exposed at the surface.

The Silurian Period dates from about 444 million to about 419 million years ago[1] (m.y.a.; fig. 1). During Silurian time, the future North America was still under construction in the form of the **protocontinent** Laurentia (fig. 2). Most of the rock that makes up Ohio's surface had not yet formed, and a warm, tropical sea covered the area that would become Ohio and the lower Great Lakes (fig. 3). The equator was only about 20 degrees to the north (Coogan, 1996), about the distance that Cuba is from the equator today, and the sea (fig. 4) supported life that included trilobites; algae; corals; *gastropods* (mollusks related to modern-day snails); primitive fishes; and hard-shelled, clam-like bivalve organisms known as *brachiopods*.

The remains of much of these life forms ended up on the bottom of the sea, preserved in various ways. Hard-shelled fauna, such as trilobites, gastropods, and brachiopods, leave behind *body fossils*—casts of their shells. Zooplankton and phytoplankton—microscopic organisms that swim freely in the water—accumulate by the billions as a mucky sediment of tiny calcium carbonate shells that settle on the seafloor as a constant rain. Some algae live as colonies and accumulate as *bioherms* (mounds) or mats that become mineralized and preserved as rocky masses. Corals may be preserved as solitary specimens (horn corals) or as extensive colonial reefs. All these examples are found in the Silurian rocks of Ohio.

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[1] Beginning and ending boundaries of geologic time subdivisions vary slightly according to the specific source cited; this guidebook relies on the International Chronostratigraphic Chart (Cohen and others, 2013).

ERA	PERIOD	EPOCH	OLDEST AGE (years before present)	LAKE ERIE-REGION ROCKS OR DEPOSITS DISCUSSED IN THIS GUIDEBOOK
CENOZOIC	QUATERNARY	Holocene	11.7 thousand	Lake clays, organic deposits, alluvium
		Pleistocene	2.6 million	Glacial tills and outwash, lake clays
	NEOGENE	Pliocene	5.3 million	Alluvium in buried valleys (?)
		Miocene	23 million	NA**
PALEOZOIC	PERMIAN	ND*	299 million	NA
	PENNSYLVANIAN	ND	323 million	NA
	MISSISSIPPIAN	ND	359 million	Primarily shales and sandstones
	DEVONIAN	Upper Middle Lower	419 million	Ohio Shale Delaware Limestone Columbus Limestone
	SILURIAN	ND	444 million	Limestones / dolomites

*ND: Not discussed in this guidebook and omitted for clarity.
**Not applicable; no rocks of this age deposited in Lake Erie region.

FIGURE 1. Geologic time scale (Cohen and others, 2013) and listing of major rock units and deposits discussed in this guidebook. Wavy lines are unconformities; broader wavy line represents a gap of about 229 million years between end of Permian and start of Neogene. Simplified for clarity, this is by no means a complete bedrock column for Ohio or the Lake Erie region

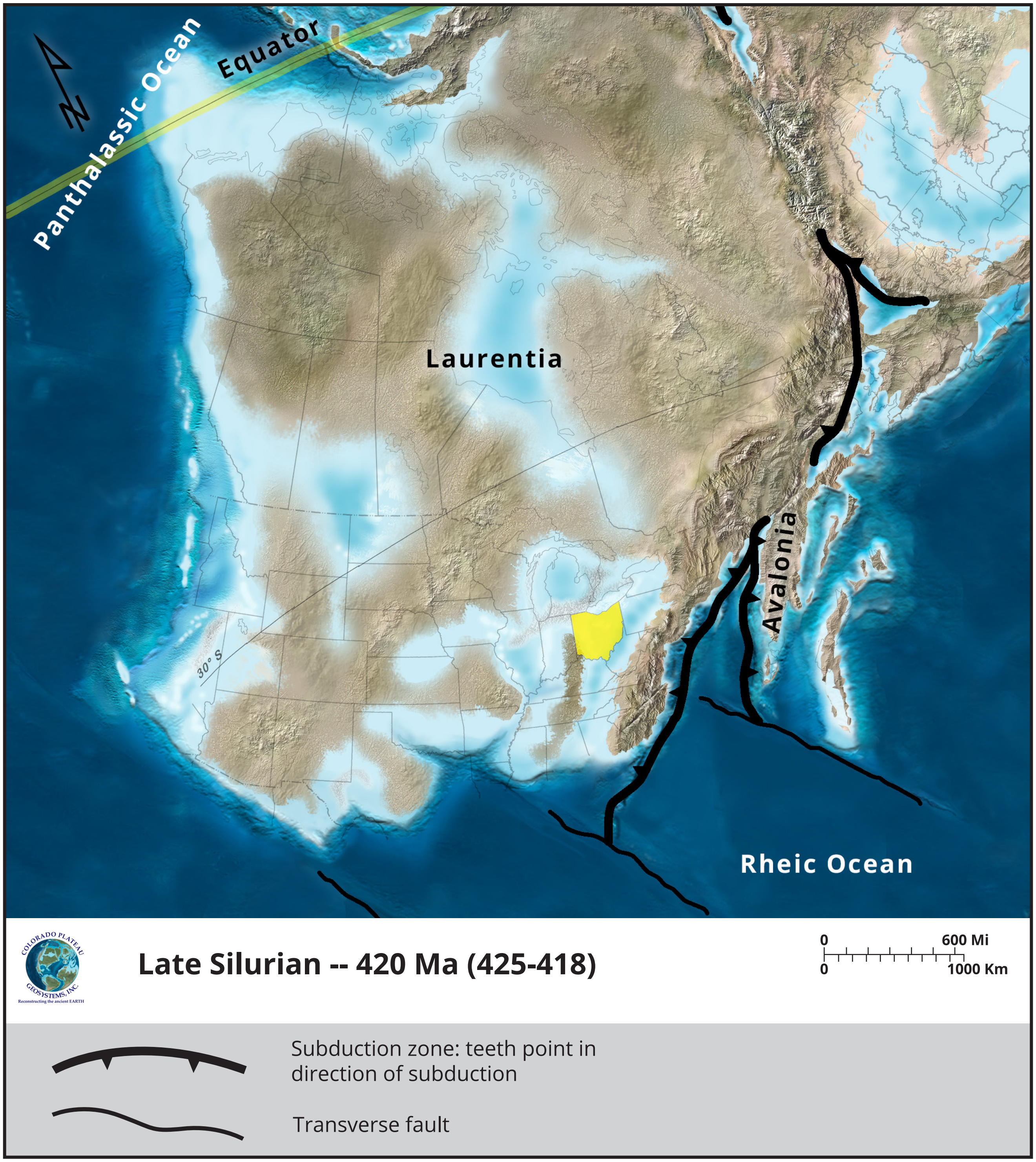

FIGURE 2. Paleogeographic map of North America during the late Silurian Period (Blakey, 2013), showing Avalonia beginning to collide with the Laurentian Plate, adding crust onto the North American continent.

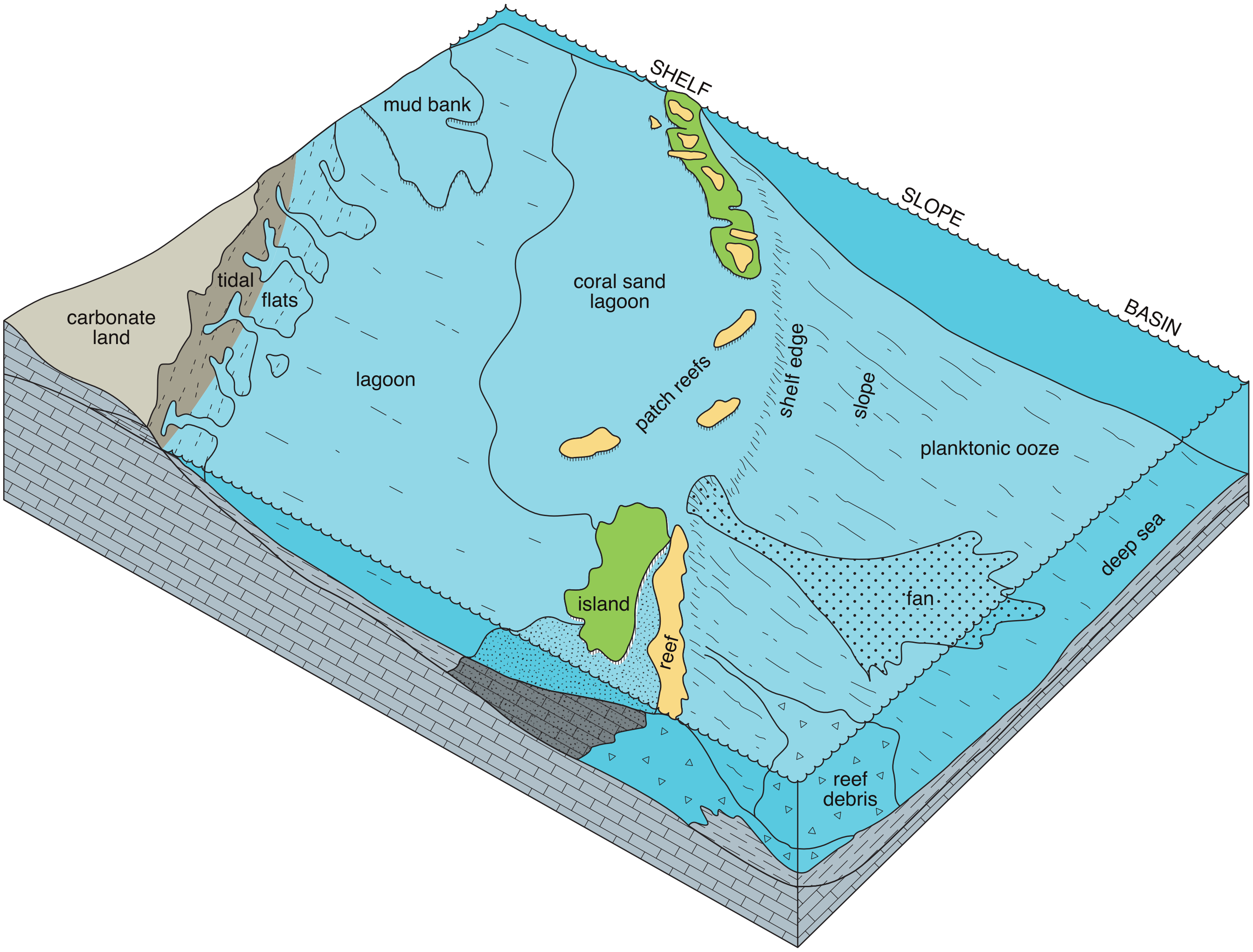

FIGURE 3. Block diagram of typical sedimentary environments of the early Paleozoic (Ordovician, Silurian, and Devonian Periods) in the Ohio-Lake Erie region. Environments ranged from emergent carbonate land (rising seafloor), to marine-margin lagoons and tidal flats, to deeper seas.

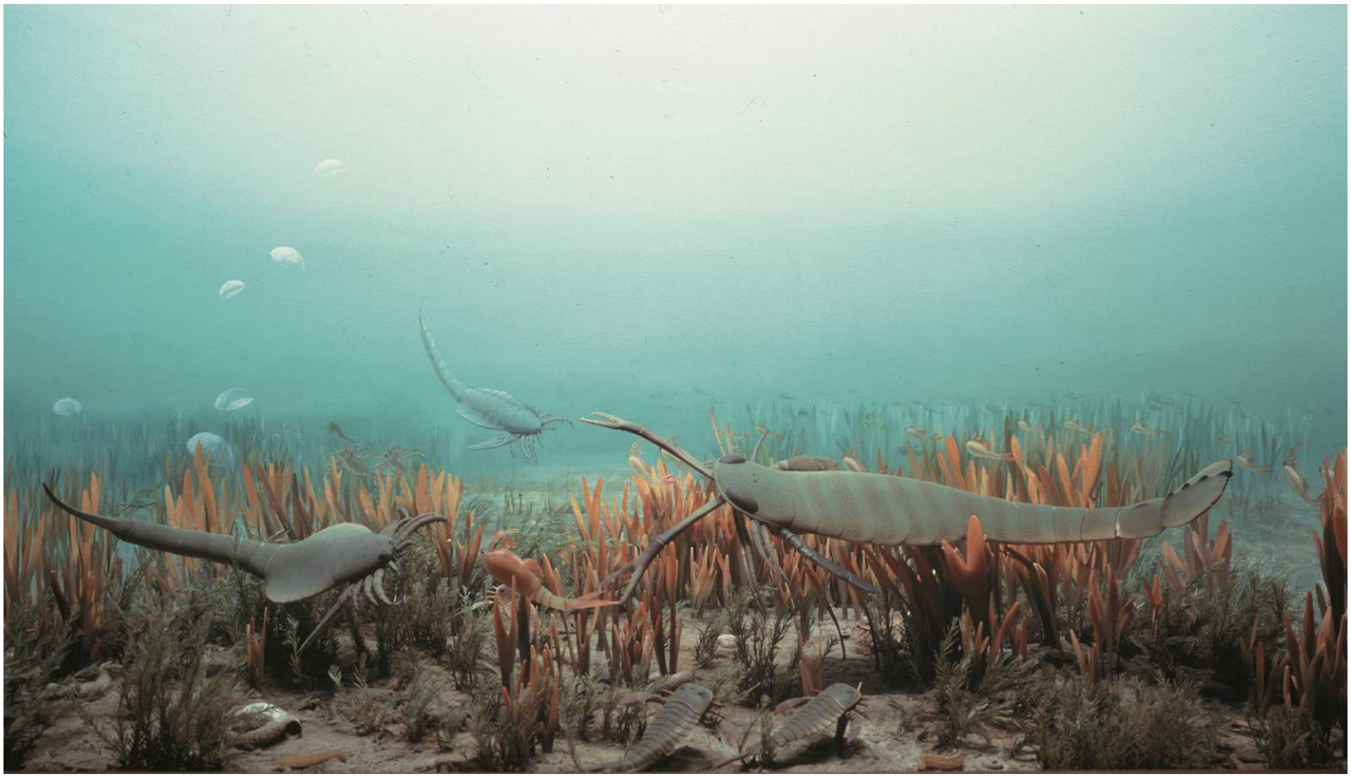

FIGURE 4. Artist's concept of a typical Silurian marine environment. Photograph courtesy of the Carnegie Museum of Natural History, Pittsburgh. First published in *Fossils of Ohio* (1996).

Several processes convert sediments and fossils into rock. Compaction of sediment under younger deposits reduces volume and forces out fluids. Chemicals dissolved in fluids **precipitate** out, cementing sediment grains together. **Tectonic** forces warp Earth's crust, deeply burying deposits under thousands of feet of younger sediments, and the resultant heat and pressure bring about further physical and chemical changes. Due to these processes, the remains of Silurian life were converted into limestone and dolomite rock. While limestone is primarily calcium carbonate, dolomite forms from limestone by the subsequent replacement of some of the calcium by magnesium. Both rock types can be quite hard when deposited as thick beds, which lends them greater erosion resistance than other sedimentary rocks. The hardness played a role in the later formation of the Lake Erie basin's shape.

Roughly concurrent with this time, the Cincinnati Arch formed (McDowell, 1983). The arch is an upward warping of the crust, that extends north from Tennessee through the Cincinnati region and into western Ohio. An arm of this structure turns northeast and is referred to as the Findlay Arch (fig. 5). The Cincinnati-Findlay Arch separates the Michigan and Illinois Basins to the west and northwest from the Appalachian Basin to the southeast and east. During the latter part of the Silurian Period, rocks referred to as the Salina Group were deposited along the flanks of the Cincinnati-Findlay Arch and would become the oldest rocks to be found at the surface in the Lake Erie region. Lake Erie's Bass Islands consist of Salina Group rocks.

Toward the close of the Silurian Period, global sea level dropped, exposing the nearshore sea bed and creating quiet-water environments such as lagoons (Schumacher and others, 2013, p. 112). Along the crest of the Cincinnati-Findlay Arch, where the sea bed elevation was higher, the Salina Group sediments experienced *subaerial* exposure (that is, to the atmosphere), leading to drying, weathering, and erosion.

The Silurian Period gave way to the Devonian Period about 419 m.y.a. Sea level rebounded to cover much of what would become Ohio, and the sea was still warm and abundant with life, which included brachiopods, bivalves (pelecypods, among others), cephalopods and gastropods), *crinoids* (animals also known as sea lilies and resembling underwater flowers), corals, trilobites, and fish (fig. 6).

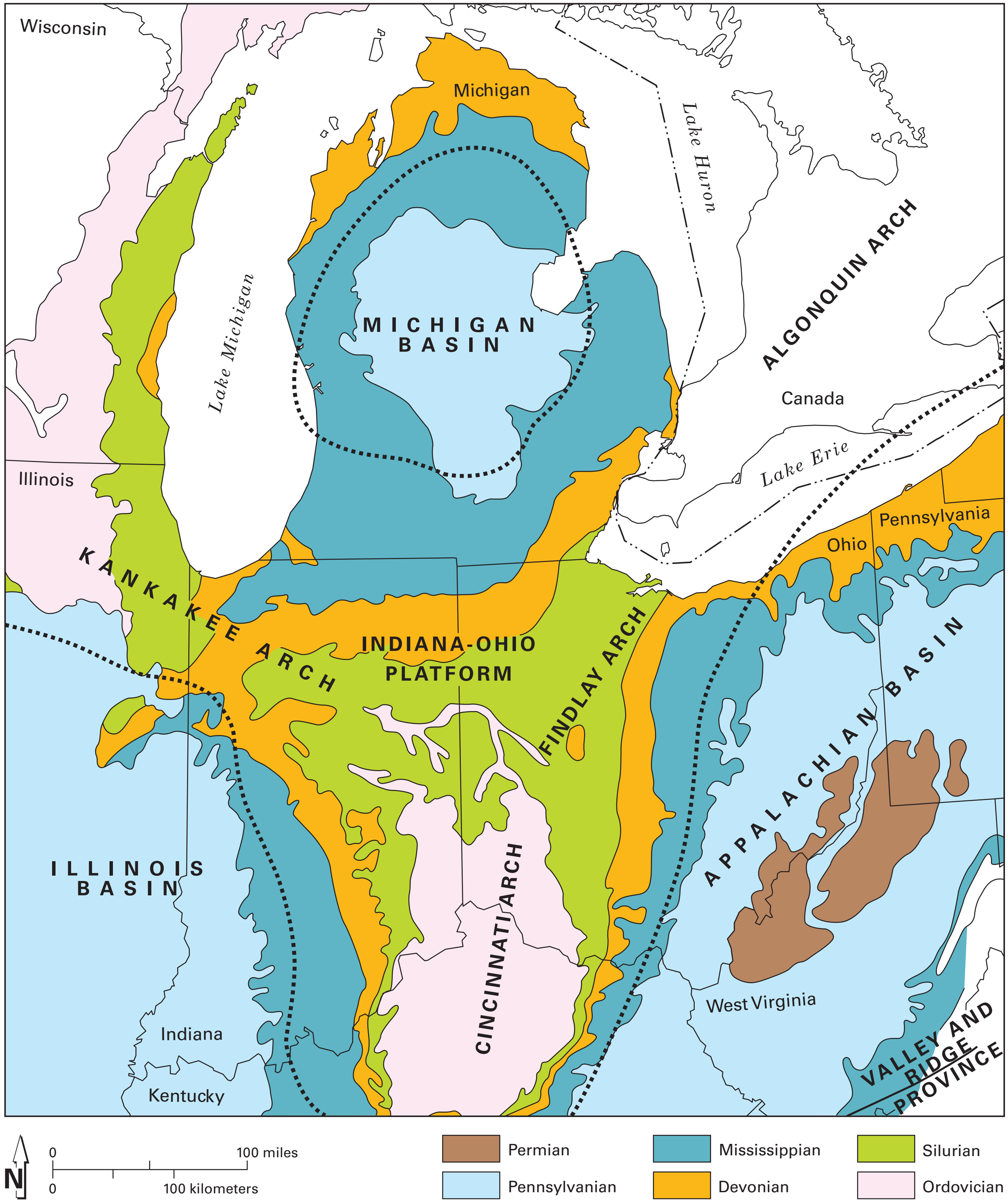

FIGURE 5. Major structural features of the Ohio and lower Great Lakes area, after Schumacher and others (2013).

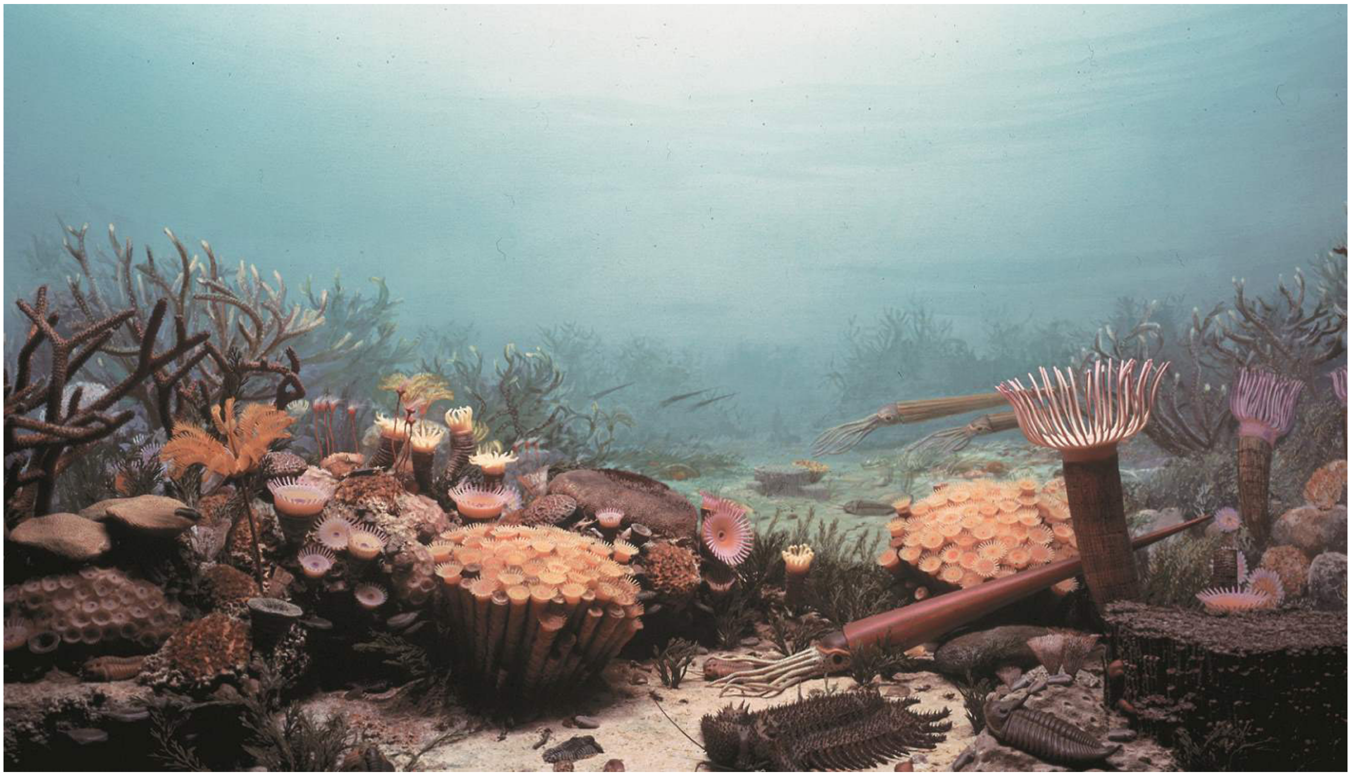

FIGURE 6. Artist's concept of a typical Devonian marine environment. Photograph courtesy of the Carnegie Museum of Natural History, Pittsburgh. First published in *Fossils of Ohio* (1996).

The Columbus Limestone, a hard, **fossiliferous** rock, was deposited during this time. The Columbus Limestone typically is found only in outcrops or under several feet or more of **overburden,** but it makes up the bulk of Kelleys Island in Lake Erie. The Columbus has been quarried for two centuries, at one time from Kelleys Island and still from the Ohio mainland, valued for its hardness and resistance to weathering. Among many other buildings, it was used in the construction of the Ohio Statehouse.

The last widespread layer of limestone to be deposited in the area was the Delaware Limestone, a layer of marine rocks thinner than the Columbus Limestone but similarly fossiliferous. In contrast to the hard Columbus just below, the Delaware occurs in thin beds that are easily eroded.

During the Devonian Period, major changes occurred in the regional depositional environment. The calcareous sediments that make up the Salina Group and the Columbus and Delaware limestones were replaced by muddier sediments, the result of a major change in the geography of the future North America. Driven by plate tectonics, Earth's continents are constantly moving, colliding and deforming; for example, the Indian subcontinent is today colliding with Asia to create the Himalayan Mountains. Similarly, chunks of crust called *island arcs*—analogous to modern-day Japan—collided with Laurentia in a succession of collisions[2] that had begun during the Ordovician Period. These collisions, occurring as a number of separate episodes, created the Appalachian Mountains.

The first episode of mountain-building concerning this discussion was the Acadian **Orogeny** (U.S. Geological Survey, 2003), the result of a collision between the Laurentian tectonic plate and an island arc called Avalonia (fig. 7). The merging of these two land masses deformed the **oceanic crust** between them, causing it to **subduct** into Earth's surface where it was recycled in the form of volcanic eruptions that built the northern Appalachian Mountains. Even while still rising, the mountains began eroding, and the resultant sediments washed into the Appalachian Basin, a trough between the Cincinnati-Findlay Arch and the Appalachian Mountains (fig. 8) that had formed in response to the crustal deformation.

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[2] While the term *collision* implies a brief, instantaneous event, in plate tectonics it means a process that may take several tens of millions of years.

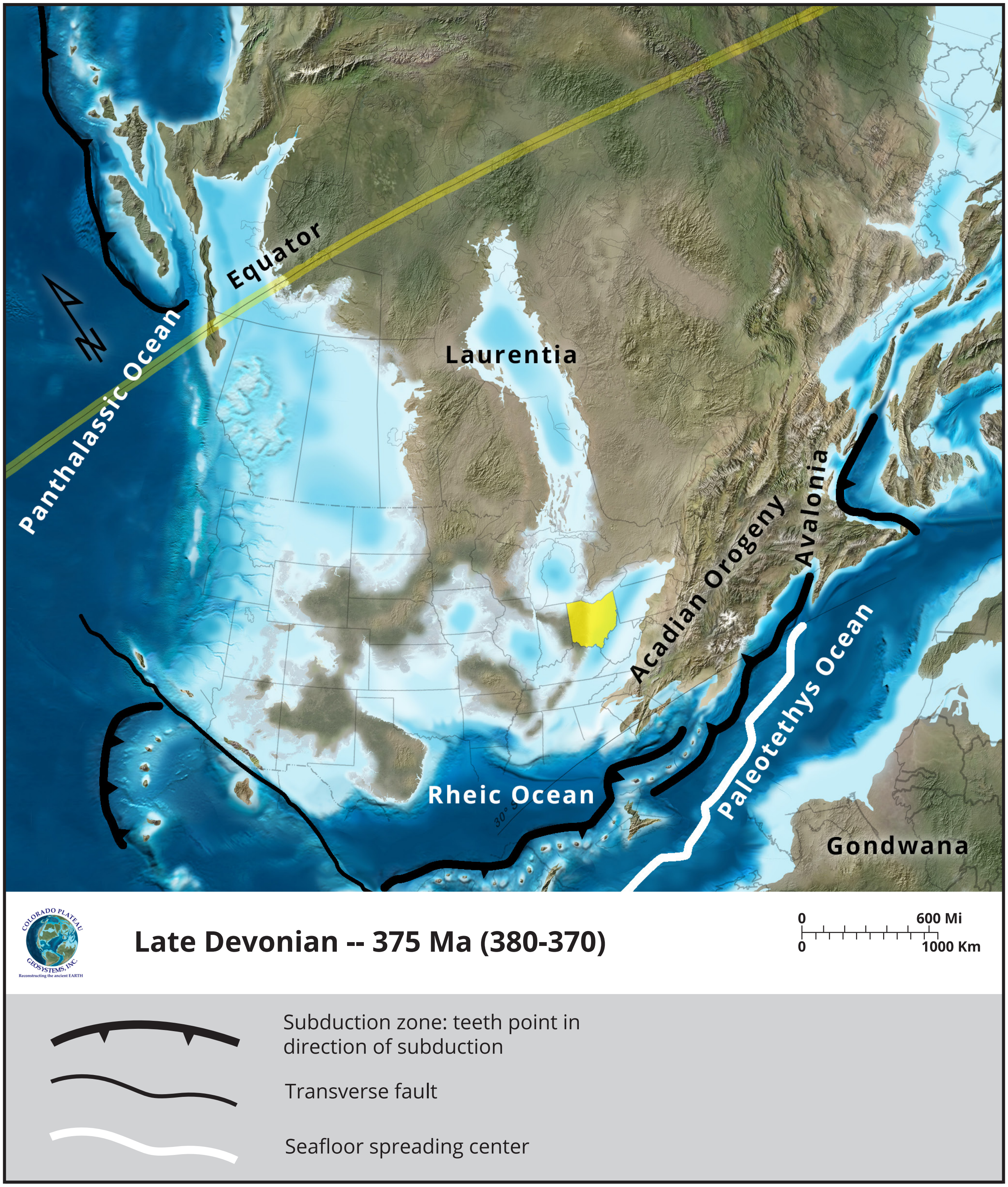

FIGURE 7. Paleogeographic map of North America during the Late Devonian Period (about 375 m.y.a). The Avalonia Plate is colliding with the Laurentia Plate, creating the northern Appalachian Mountains. Sediments eroding from these mountains are beginning to fill the Appalachian Basin. Image modified from Blakey (2013).

FIGURE 8. Partial map of present-day North America with approximate extent of Appalachian Basin during Middle Devonian time (approximately 390 m.y.a.).

FIGURE 9. Restored skull and thoracic shield of *Dunkleosteus terrelli,* an extinct placoderm fish of the Late Devonian (382–359 m.y.a.), found in the Cleveland Member of the Ohio Shale in Cuyahoga County, Ohio. Photo courtesy of the Cleveland Museum of Natural History.

Sediments reaching Ohio during this time were mostly fine clays, the only sediments light enough to be transported the distance from the Appalachians. They accumulated at the bottom of the basin as muds. The muds became **lithified** to form shales, their dark, sometimes black color an indication of the *anoxic* (oxygen-poor) chemistry of the water in which they were deposited. Anoxia can result from a number of factors, including stagnation, decaying organic matter, and changes in water density or temperature with increasing depth. Anoxic waters support little life, so most fossils in Devonian-age shales are of organisms that lived in more oxygenated zones higher in the water column and then settled to the bottom upon death. Fossils in these shales differ from the **calcareous** assemblages (corals, shelled organisms, and so on) found in the earlier Devonian limestones, consisting mainly of plant remains and, importantly, fragments of fish. While fish first appeared earlier in geologic time, during the Devonian Period fish species began to diversify and take on the appearance of modern fishes, so that the Devonian has been called the Age of Fish. One of Ohio's most famous and spectacular fossil finds was made in the Cleveland Member of the Ohio Shale, that of the **placoderm** fish *Dunkleosteus*, a fearsome predator in the Late Devonian seas (fig. 9).

The Appalachian Basin is deepest[3] in Pennsylvania and New York, where Devonian shales thousands of feet thick are a source of abundant natural gas. In the Lake Erie region of Ohio, where the basin is shallower, the same shales are at most a few hundred feet thick. The Cleveland and Chagrin Members of the Ohio Shale line the Lake Erie shore (fig. 10) from Vermilion (Lorain County) to Cleveland, where they disappear below the water. Shale appears again near the waterline east of Cleveland and gradually rises in height until it forms high lakeside cliffs in New York state.

About 359 m.y.a., the Devonian Period ended and the Mississippian Period began. The Appalachian Mountains continued to rise. At their greatest height they were as tall as the Rockies or Swiss Alps of today. Eventually, mountain-building ceased and erosion, already in progress, continued

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[3] Although it is no longer an open marine basin, the trough in the Earths' crust that defines the Appalachian Basin still exists in the subsurface, and it is therefore referred to in the present tense.

FIGURE 10. Cliff of Ohio Shale on the Lake Erie shore near Cleveland, Ohio.

to wear the mountains down. Muddy sediments washed into the Appalachian Basin as before, but in Ohio they were joined by coarser sediments—sand and silt—a sign that the basin was becoming filled, as the sea shallowed and river deltas and beaches formed on its shores (fig. 11).

About 330 m.y.a., at the start of the Pennsylvanian Period, mountain-building resumed as Laurentia collided with the future Africa (then part of the **supercontinent** Gondwana), creating the supercontinent Pangaea. This started the Alleghenian Orogeny, the final episode of Appalachian mountain-building (fig. 12). As erosion filled the Appalachian Basin with sediments from the mountains, extensive swamp areas developed at the margins of the shallowing seas across a large part of the future eastern United States, depositing clays and organic, peaty sediments that would become coal. Intense tectonic deformation of the crust near the front of the mountains folded and faulted Silurian and Devonian rocks into the rolling hills seen in western Pennsylvania and West Virginia. These hills are known to geologists as the Valley and Ridge Province, but most everyone else knows them as the Allegheny Mountains. The most intense deformation did not extend westward as far as Ohio, but it did cause the uplift of Ohio's Appalachian rocks, draining the sea away from Ohio and forming a broad, elevated platform known as the Allegheny (or Appalachian) **Plateau** (fig. 13), closing the Pennsylvanian Period and setting the stage for the Permian Period.

Rocks of the Permian Period, dating to about 299 to 253 m.y.a., are the youngest in Ohio and were mainly deposited as sediments on deltas or in lakes, wetlands, or coastal lowlands (Schumacher and others, 2013, p. 17). Not extensive in Ohio, Permian rocks occupy only a limited portion of the southeastern part of the state and are not found at all in the Lake Erie region. No further rock appears to have been deposited in the region after the Permian Period; if any rock was deposited, there is no record of it because it has been removed by erosion. With no rock record, this discussion must

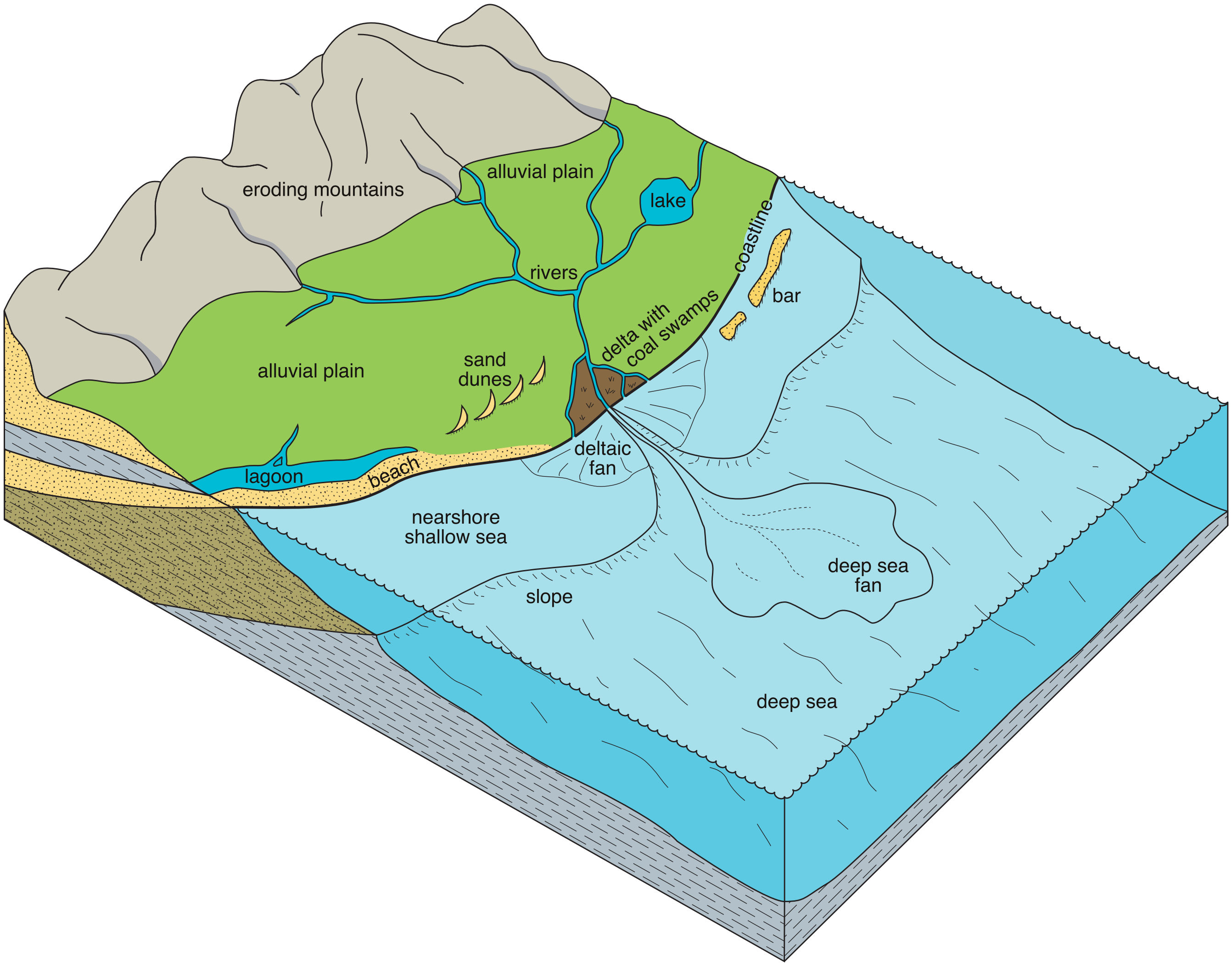

FIGURE 11. Block diagram of typical sedimentary environments of later Paleozoic time (Mississippian, Pennsylvanian, and Permian Periods) in the Ohio-Lake Erie region. Environments ranged from terrestrial alluvial plains, developed at the base of an eroding mountain front, to marine-margin lagoons, to deeper seas.

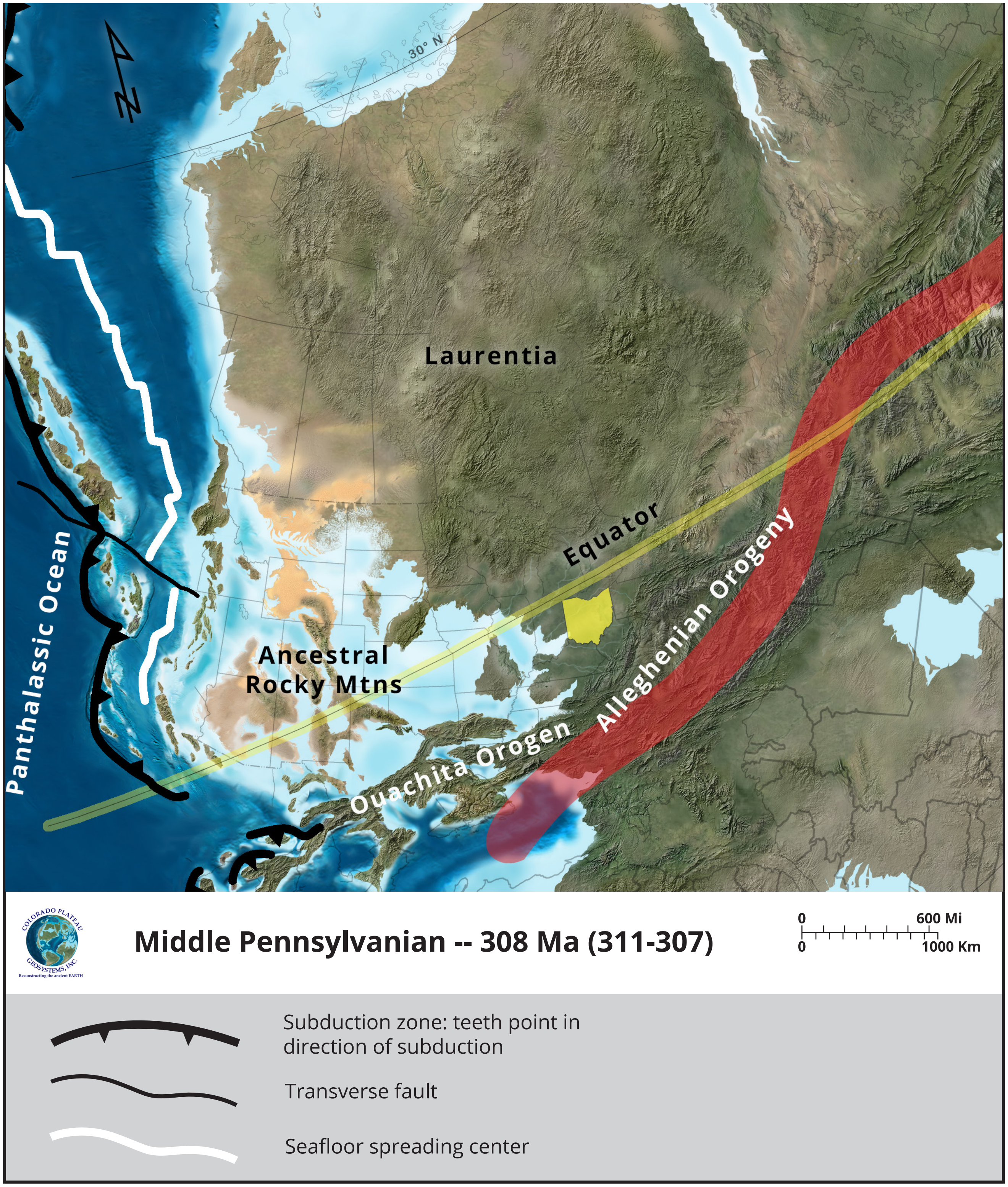

FIGURE 12. Collision of Laurentia (future North America) and Gondwana about 308 m.y.a. (middle Pennsylvanian Period). Red band shows approximate trace of the Alleghenian Orogeny. Image modified from Blakey (2013).

FIGURE 13. Extent of the Allegheny Plateau in Ohio and surrounding states. After Fenneman and Johnson (1946).

fast-forward almost 250 million years. Elsewhere in North America, the Atlantic and Gulf coastal plains developed and the Rocky Mountains formed; but in the Ohio and Lake Erie region, only erosion seems to have occurred, removing much of the rock formed during the Paleozoic Era. Rivers and streams that developed on the Allegheny Plateau, probably sometime during the Neogene Period (23 m.y.a. to 2.6 m.y.a; Hansen, 1995; Camp, 2006, p. 164), drained a large part of the eastern United States and incised deeply into the plateau.

Many of these rivers no longer exist, but their channels are still evident, and geologists have applied names to the most significant former rivers. The best-known of these was the Teays, which originated in the North Carolina mountains, flowed north into Ohio, and cut a gorge up to 150 m (500 ft) deep and up to 3.2 km or 2 mi wide before exiting Ohio west of Lima (Hansen, 1995). Most of the course of the Teays in Ohio is buried under glacial **till** and is known only indirectly from geophysical records and soil borings that reach rock more deeply than expected. Another river contemporary to the Teays is believed by some geologists to have existed north of it, cutting a valley that headed northeast between Ohio and Ontario, eventually to join the St. Lawrence River. This inferred river is called the Erigan (fig. 14).

Unlike the Teays, evidence for which is well constrained, most evidence for the Erigan's existence is circumstantial. Some geologists believe that the current depth of the Lake Erie basin requires some sort of valley or basin that pre-dated the arrival of glaciers (Camp, 2006, p. 305; Forsyth, 1987, p. 14; Kihn, 1988, p. 18). Geophysical surveys of Lake Erie (Wall, 1968; Hobson and others, 1969) do show bedrock channels under the lake mud, although their age has not been determined so they

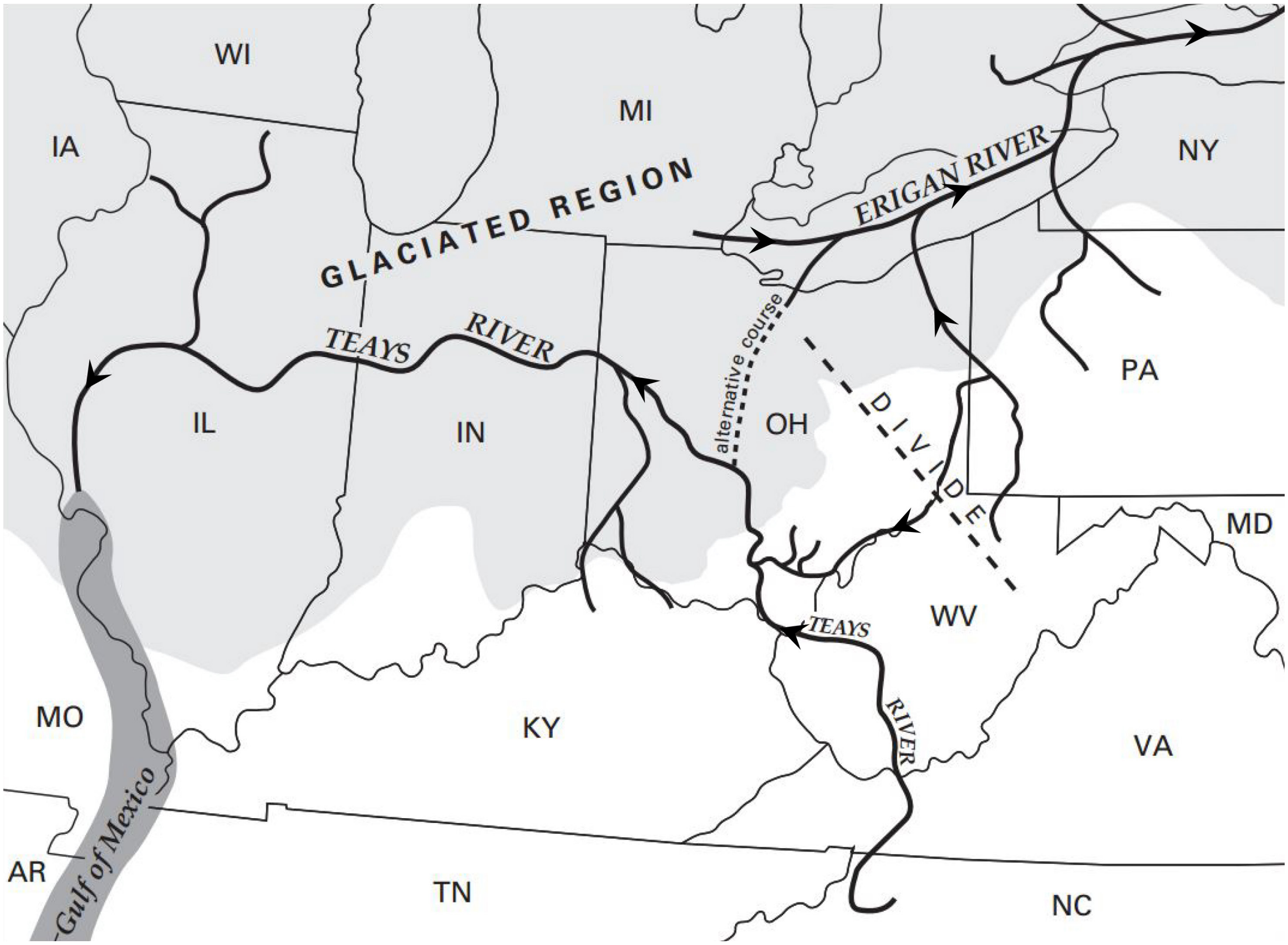

FIGURE 14. Courses of the ancestral Teays and Erigan Rivers and some tributaries (Great Lakes shown only for context; they did not yet exist). Arrowheads indicate direction of drainage. Note that the modern Ohio River follows portions of the prehistoric drainage pattern. Modified from Hansen (1995).

may or may not be evidence of preglacial drainage. But other evidence for an Erigan River includes buried bedrock channels that enter the Lake Erie basin from the south (Stout and others, 1943, p. 71) but cannot be traced to the north (Ontario) side of the basin. The largest such channel in Ohio, about 11 km (7 mi) wide and up to 61 m (200 ft) deep (Fuller and others, 1995; Stone and others, unpub. data, 1996[4]) exists under Cleveland, with a gradient showing that the river carving it flowed north. If it did not extend north into Ontario, then did it join the Erigan somewhere near the central axis of the present-day lake and head eastward?

PART II: QUATERNARY (ICE AGE) HISTORY

The arrival of the Quaternary Period 2.6 million m.y.a. brought conditions that would eventually cut off the early drainages and forever alter the landscape of the Lake Erie region. Earth's climate had been cooling for millions of years, but the start of the Quaternary Period brought on the enlargement of ice sheets in the Arctic and Antarctic regions. Ice expanded into the future United States during a number of incursions (*glaciations*). At least three glaciations (the pre-Illinoian, Illinoian, and Wisconsinan) affected Ohio, covering up to two-thirds of the state in ice.

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[4] Stone, B.D., Pavey, R.P., Fuller, J.A. and Foster, D.S., 1996, Map of surficial materials in the Lake Erie coastal area, northeastern Ohio: Ohio Department of Natural Resources, Division of Geological Survey, unpublished open file map with text, 1 p., scale 1:100,000.

Evidence shows that glaciers flowing from Canada into Ohio, rather than coming directly from the north, followed a path from the northeast to the southwest (fig. 15). This course may have been influenced by a prehistoric (Erigan?) river valley or it may have been determined by pre-existing topography. The Allegheny Plateau probably exerted some influence, as it must have presented something of an obstacle to the expanding ice lobes, guiding them southwestward. Repeated incursions by ice widened and deepened whatever preglacial valley existed, with the degree of alteration depending in part on the rock types the ice encountered. The shales and sandstones of the Appalachian Basin were relatively soft and apparently deeply eroded by ice, but harder limestones and dolomites nearer the Cincinnati-Findlay Arch were less easily eroded.

Rock and soil bulldozed by the glaciers were deposited in Ohio in the form of *glacial drift* (or till). As a glacier diminishes through the process of **ablation**, debris incorporated within the ice is liberated and deposited on the landscape. Such deposits, known as *moraines*, take a number of forms. Tall ridges that form at the margin of a glacier's greatest extent are known as *end* (or *terminal*) *moraines*. *Recessional moraines* are ridges similar to end moraines except that they mark where a receding glacier stalled for a period of time, allowing debris to build up. Between end and recessional moraines are sheets of flat to gently rolling drift known as *ground moraine*, which

FIGURE 15. Some major lobes and sublobes of the Wisconsinan ice sheet (about 14,000 to 25,000 y.a.). Maximum ice advance shown. Major lobes (between heavy lines) and sublobes (between dashed lines) that affected the Ohio-Lake Erie region are indicated. Arrows show direction of ice travel. Presence of Allegheny Plateau limited southward advance of ice in eastern half of Ohio. Great Lakes shown only for context; they did not yet exist. Modified from Schaetzl and Isard (2002).

indicate where a glacier receded as it ablated, laying down a sheet of debris as it diminished. Moraines, along with *outwash* (sand and gravel carried by streams of glacial meltwater) had blanketed much of the surface of Ohio at the end of the Pleistocene. They also filled older stream valleys, to block, reverse, and largely destroy Teays-era drainage patterns while establishing new ones in their places (fig. 16). As mentioned at the end of Part I, a large bedrock channel under the Cuyahoga River in Cleveland is filled with till and other glacial deposits and appears to be a buried remnant of an old pre-Quaternary drainage called the Dover River (Hacker, 2004, p. 181).

As the last glacier began to retreat from northern Ohio about 14,000 y.a. (Calkin and Feenstra, 1985), a basin emerged from under the melting ice, deeper to the east where it was underpinned by softer rocks (mostly shales) and shallower to the west where the bedrock was hard limestone and dolomite. Meltwater from the receding ice sheet filled the basin (fig. 17) and covered much of northern Ohio under a cold, shallow lake that extended to Fort Wayne, Indiana. Ice blocked this water from draining north and east, so it drained southwest, eventually to reach the Mississippi River.

This cold meltwater lake, Lake Maumee (fig. 18), was the first of many stages of *proglacial* (glacier-adjacent) lakes that existed as precursors to Lake Erie. Responding to fluctuations in the climate, the decaying glacial ice would sometimes recede,

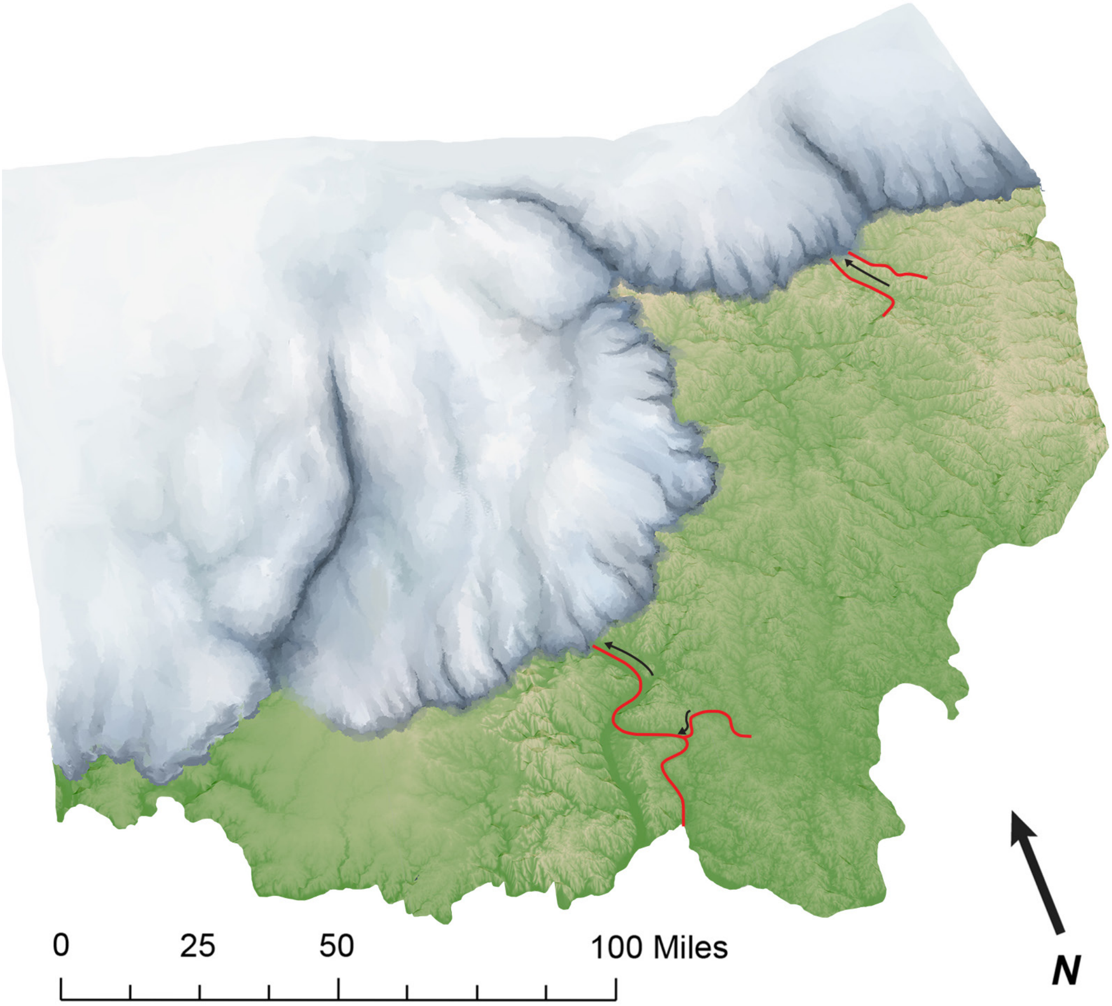

FIGURE 16. Ice sheet in Ohio at last glacial maximum, about 16,000 years ago. Ice covered two-thirds of the state and filled preglacial drainage valleys with drift, blocking and reversing drainage. Red lines indicate just some of the previously northern-flowing streams whose flow was blocked and reversed. Arrows indicate direction of preglacial flow. Modified from Norris, 2019.

FIGURE 17. Historical photo of a meltwater lake dammed by ice. Although this was taken at Baffin Island (Nunavut, Canada) in the 1950s, northern Ohio 14,000 y.a. is believed to have looked very similar. Photo credit: Richard P. Goldthwait.

FIGURE 18. Glacial Lake Maumee (blue) and receding glacier (white), overlaid on the present-day Great Lakes. After Leverett (1902, pl. 2).

sometimes remain stationary, and sometimes temporarily re-advance. When the ice receded, the proglacial lake would drop to a lower stage; if the ice readvanced, the lake would rise, although Fisher and others (2015) suggest this did not happen as frequently as once thought. These features persist in the landscape today and mark the former shores of the proglacial lakes thousands of years later (fig. 19).

One might infer from this sequence of events that as the ice melted, the proglacial lake dropped by stages to become modern Lake Erie. However, actual events were apparently not so straightforward. For example, researchers have found evidence of as many as four stages or levels of Lake Maumee (although for simplicity they are often lumped together and named as a single lake). There is a challenge in identifying various lake stages and the sequence in which they occurred, due to difficulties in identifying and dating geomorphic features. Many of them have been submerged by Lake Erie, eroded, reworked (or destroyed) by human activity, or otherwise altered. In all, about 10 to 12 named lakes have been identified prior to Early Lake Erie. Table 1 is a simplified list of these lakes, their elevations, and the outlets through which they drained.

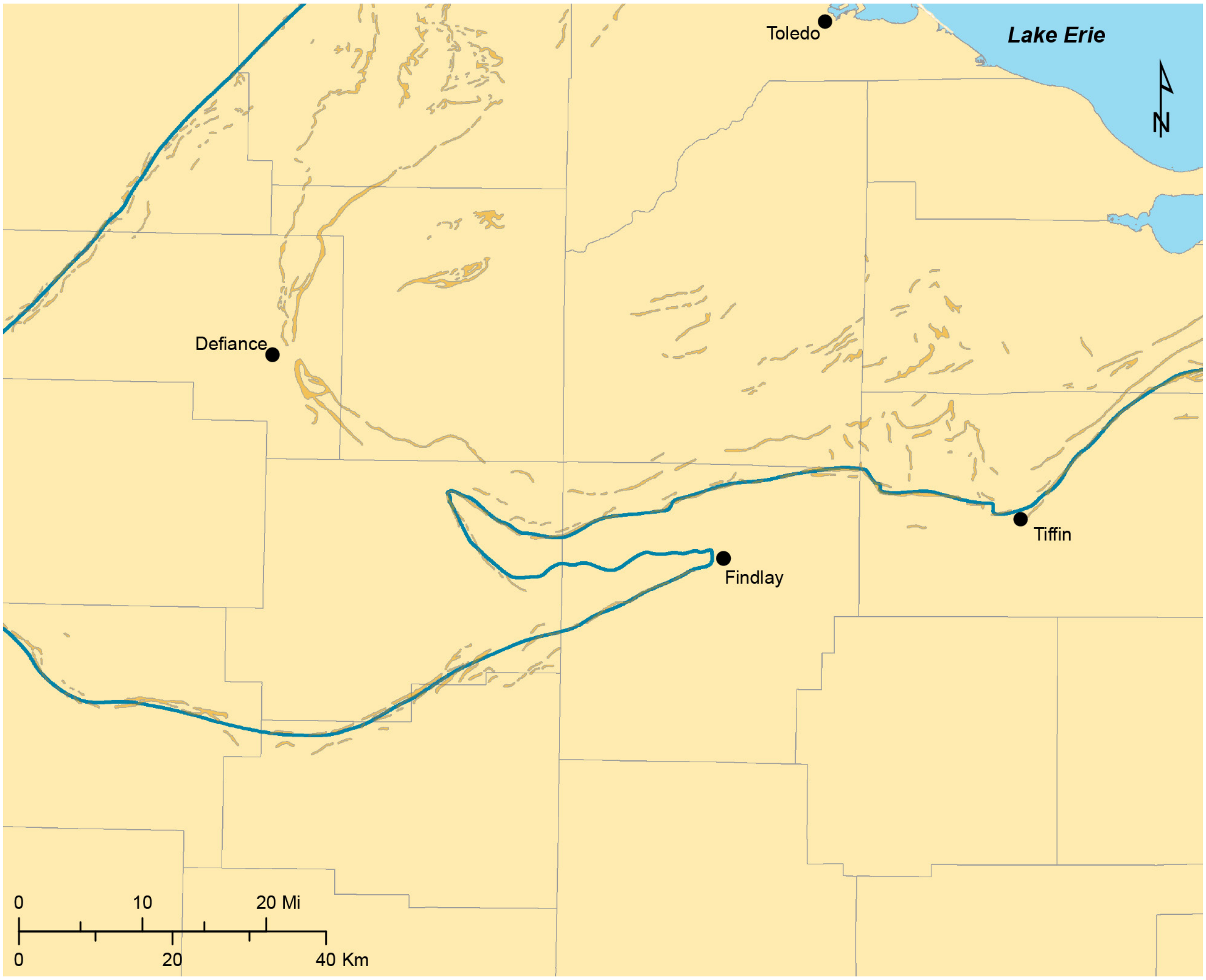

FIGURE 19. Sand ridges (yellow strands) in northwestern Ohio. Blue line indicates the extent of proglacial Lake Maumee. Sand ridges that coincide with that border mark the Lake Maumee shoreline; sand ridges within that border correspond to lower (later) proglacial lakes or may mark features such as offshore bars.

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

Lake Stage Name	Apparent Water Elevation above m.s.l.[2]	Outlet
Maumee I	244 m/800 ft	Wabash River (Indiana)
Maumee II	232 m/760 ft	Grand River (Michigan), Imlay channel
Maumee III	238 m/780 ft	Wabash River
Arkona	212–216 m/695–710 ft	Grand River, via Lake Saginaw
Whittlesey	225 m/738 ft	Grand River, Ubly channel
Warren I	210 m/690 ft	Grand River
Warren II	208 m/682 ft	Grand River
Wayne	201 m/660 ft	Mohawk (Grand River?)
Warren III	204–209 m/670–685 ft	Grand River
Lundy	187–195 m/615–640 ft	Lake Michigan
Early Lake Erie	128 m/420 ft (approx.)	Niagara River (New York)
Modern Lake Erie	174 m/571 ft	Niagara River

[1] After Leverett and Taylor (1915, p. 469), Hough (1958, table 9), and Forsyth (1973). See fig. 20 for the extents and outlets of some of the major stages.

[2] Elevations corrected to modern-day datum.

The melting ice front eventually departed the Lake Erie region, receding past what is now Buffalo, New York. Once free of ice, the Niagara River was able to drain the entire Erie basin. That seems to have happened about 12,500 y.a. (Holcombe and others, 2003), when so much drainage flowed out of the basin that the next lake to be identified was actually lower than modern Lake Erie (fig. 21). This stage (Early Lake Erie) was about one-seventh the size of today's lake in surface area, with an elevation about 12 to 18 m (40 to 60 ft) lower (Holcombe and others, 2003). Some researchers (Lewis and others, 2008) believe that increased outflow alone cannot account for the lake's shrinkage and they cite evaporation in a warm, dry climate as partly responsible for Early Lake Erie's low level.

Simultaneous to these events, the other proto-Great Lakes underwent their own evolutions. The ancestor of Lake Huron at that time did not empty into the Erie basin as Lake Huron does today; instead it found another outlet to drain into the basin of what is today Lake Ontario. Consequently, Early Lake Erie remained low and small for perhaps a few hundred years, initially occupying only the deep Eastern Basin and eventually spreading into the Central Basin. To the west, the area today known as the Western Basin was not yet submerged. Sediment cores collected in the Western Basin (Herdendorf and Braidech, 1972, p. 16) show that under the lake mud in many places is a layer of clay with peaty plant remains, indicating that marshy conditions once prevailed. The Western Basin at that time was probably a mix of land, marshes, and large ponds, crossed by precursors of the modern Maumee and Detroit rivers. What would become the Lake Erie islands were then hills separated by streams and marshy lowlands, probably easily reached by land animals and hunter-gatherer humans traveling on foot.

A final complication in the evolution of Lake Erie is **isostasy**, the tendency of Earth's crust to "float" on the underlying **mantle** in a way that conserves equilibrium. The mass of the glaciers had compressed the crust beneath them so that the underlying mantle gave way and allowed the crust to sink. When an ice sheet melts and recedes, the crust and mantle react to restore equilibrium, and the land surface rebounds slowly. This is called *isostatic rebound* (or *post-glacial rebound*). In the Great Lakes region, ice estimated at up to 1.6 km (1 mi) thick depressed the crust more than 91 m (300 ft) feet in some places (Lewis and others,

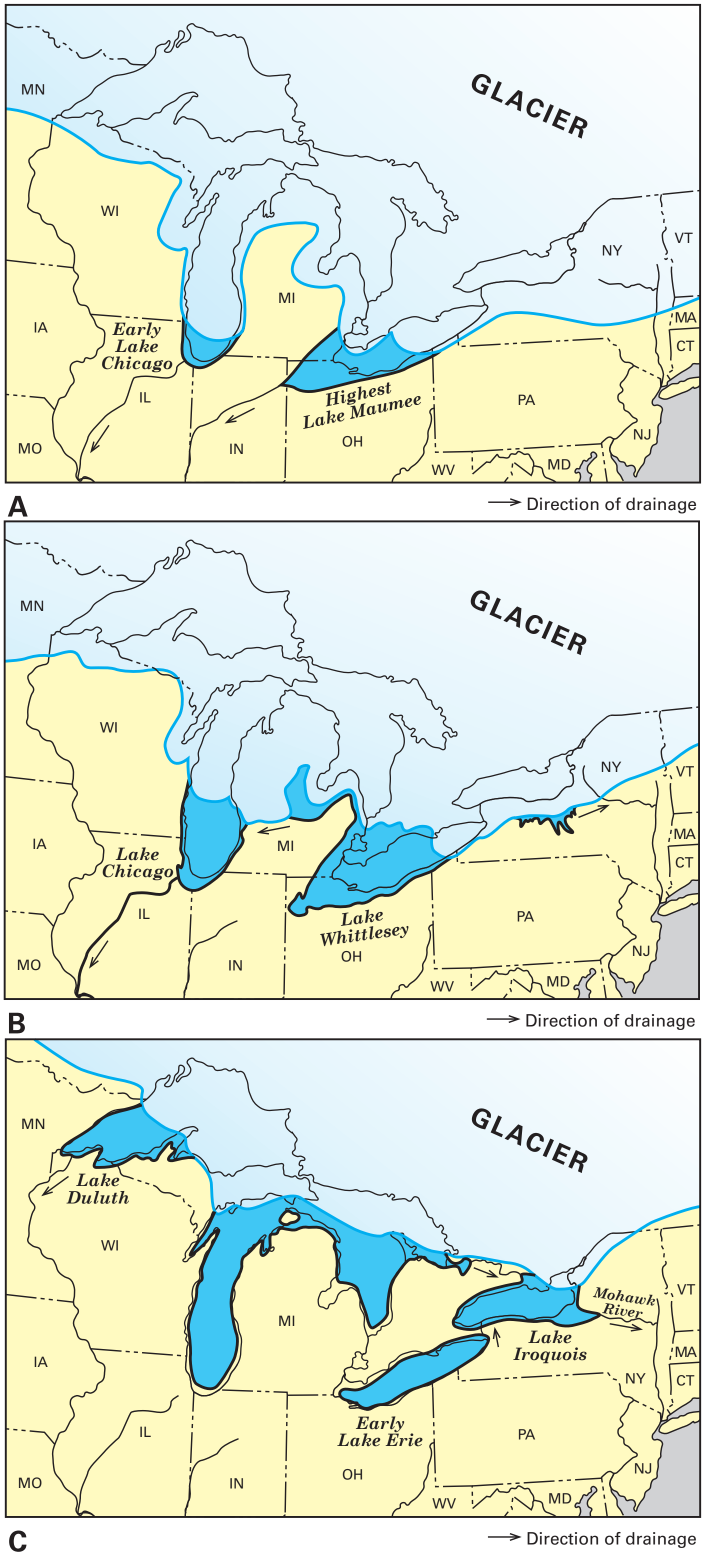

FIGURE 20. Major lake stages and outlets of the Great Lakes, modified from Hough (1958, figs. 54, 60, 69).

(A) Highest Lake Maumee stage (Maumee I); drainage westward into the Wabash River system.

(B) Lake Whittlesey stage; drainage westward across central Michigan.

(C) Early Lake Erie stage (lower than modern Lake Erie); drainage eastward into Lake Iroquois (predecessor of Lake Ontario) and then into the Mohawk River.

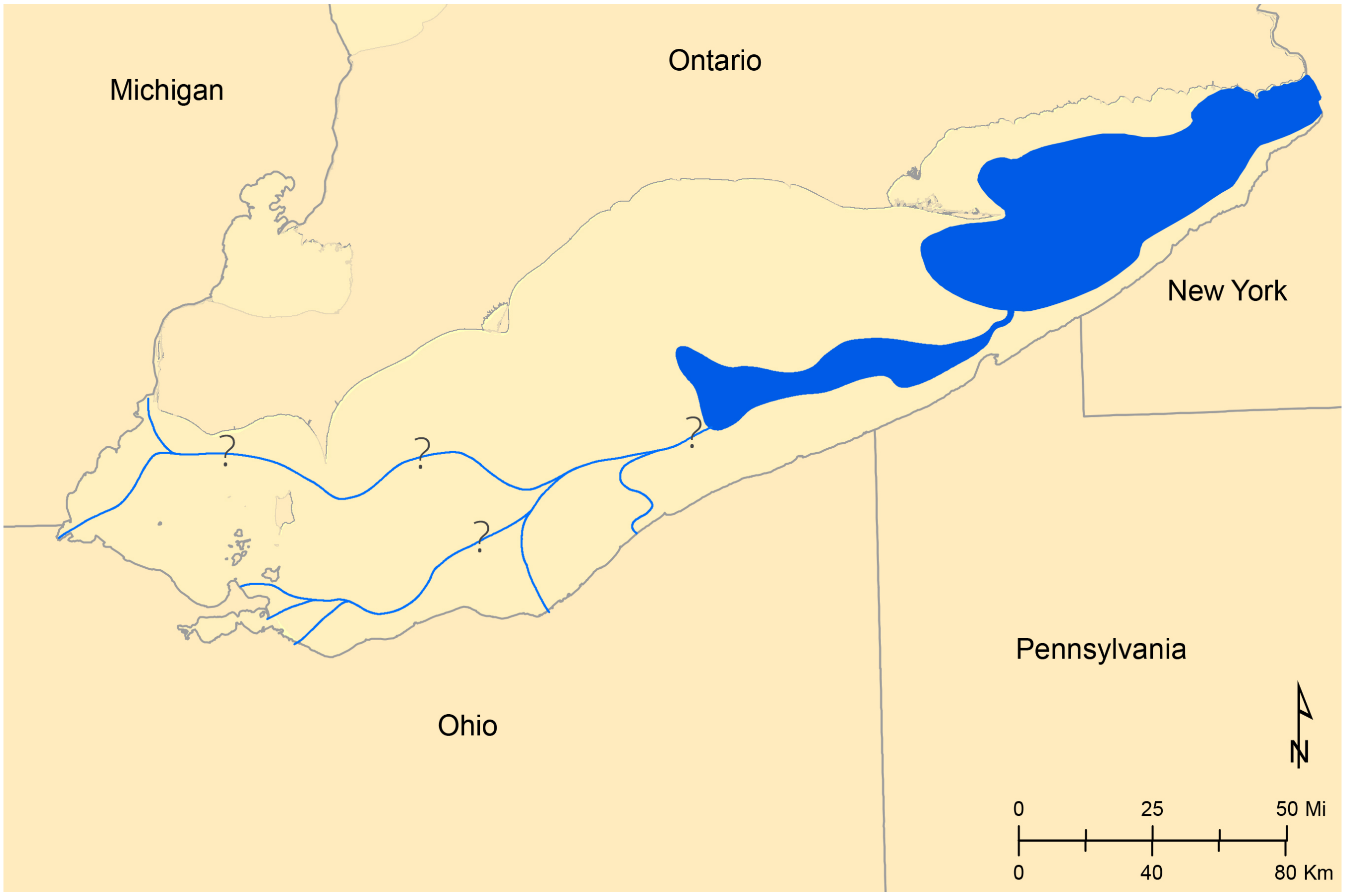

FIGURE 21. Early Lake Erie, about 12,000 y.a., after Holcombe and others (2003), with author's interpretation of possible stream channels implied by topography of glacial tills (Stone and others, 1996) below present-day lake sediment.

2012), and the crust began rebounding as soon as the ice receded. While the majority of rebound has already occurred, with careful measurements it is still possible to detect a small amount of rebound occurring today (Mainville and Craymer, 2005).

The velocity of rebound is not equal everywhere. Crustal depression was greater farther north where the glaciers were thickest, so the amount of rebound was also greater to the north. This imparts an apparent tilt to the region. An example is the Lake Whittlesey *beach ridge*, a trace of that former lake's shoreline, still visible on the modern landscape. As a marker of the lake's water level, it must have been level when it formed. The elevation of the Whittlesey ridge in Ohio is about 224 to 226 m (735 to 740 ft) above m.s.l., but it reaches an elevation of over 262 m (860 ft) above m.s.l. near Buffalo, showing the basin has warped or tilted over 30 m (100 ft) since the ridge formed. This tilting raised the Niagara River outlet, impounding water behind it like a natural dam and causing Early Lake Erie to expand. Similarly, rebound also raised the outlet that had drained ancestral Lake Huron directly into ancestral Lake Ontario. Forced to find a new outlet, ancestral Lake Huron began to drain into the Erie basin (Calkin and Feenstra, 1985). The extra influx of water, along with the rise of the Niagara outlet, appears to have raised Early Lake Erie's level rapidly, because preserved in the deep Eastern Basin of Lake Erie are the submerged traces of an old shoreline (Lewis and others, 2012). Had the water level risen slowly, these traces probably would have been eroded by waves at the edge of the rising lake, but rapid inundation submerged the old shoreline before erosion could destroy it.

By about 4,000 y.a., the outlet at the Niagara River had rebounded to near its present-day height, creating the famous falls. The level of the lake then seems to have risen to a level slightly higher than the present day, before eventually settling back to the stage we know as modern Lake Erie, about 2,000 to 3,000 y.a. (Barnett, 1985; Coakley and Lewis, 1985).

FIGURE 22. Looking north from the ~17,500-year-old shore of Lake Maumee II in Erie County. Lake Erie is 4.3 km (2.7 mi) away.

Evidence for the evolution of proglacial lakes into modern Lake Erie is abundant across northern Ohio and some of it is easily recognized without geological training. An example that thousands of Ohioans encounter on a daily basis is in the roads near the lake. The former sandy shorelines of lakes Maumee, Whittlesey, and Warren were used by Indigenous Americans and early settlers as roads, since the ridges of well-drained sand made good natural highways across a wild, marshy landscape. Many of those old beaches have been paved and still serve as roads today, including Lorain and Euclid Avenues in Cleveland, U.S. Route 20 in Lake and Ashtabula Counties, and many roads with “ridge” in their names (North Ridge Road and Center Ridge Road, to name only two). Standing on one of these east–west-running roads and facing north, if the way the terrain drops away gives you the sense of standing on the shore of a large lake, it is because you actually are (fig. 22).

PART III: THE FUTURE OF LAKE ERIE

Given how quickly Lake Erie formed relative to the history of, for example, the Appalachian Mountains, it follows that Lake Erie is subject to further changes in the near geologic future. There is no reason to believe that Lake Erie’s current form is final and fixed. Even over the last two centuries, significant changes have been recorded. Descriptions given by Whittlesey (1867, p. 482) of Lake Erie’s level in 1819 suggest that it was lower that year than it has ever been since. The lake’s rise since that time has been attributed to the effect of isostatic rebound (Moseley, 1905, p. 183). Indications are that the recent rate of lake level rise due to isostatic rebound is about 6 to 9 cm (0.2 to 0.3 ft) per century on the Ohio shore (Moore, 1948; Mainville and Craymer, 2005), totaling 15 cm (a half-foot) or more since Ohio’s statehood.

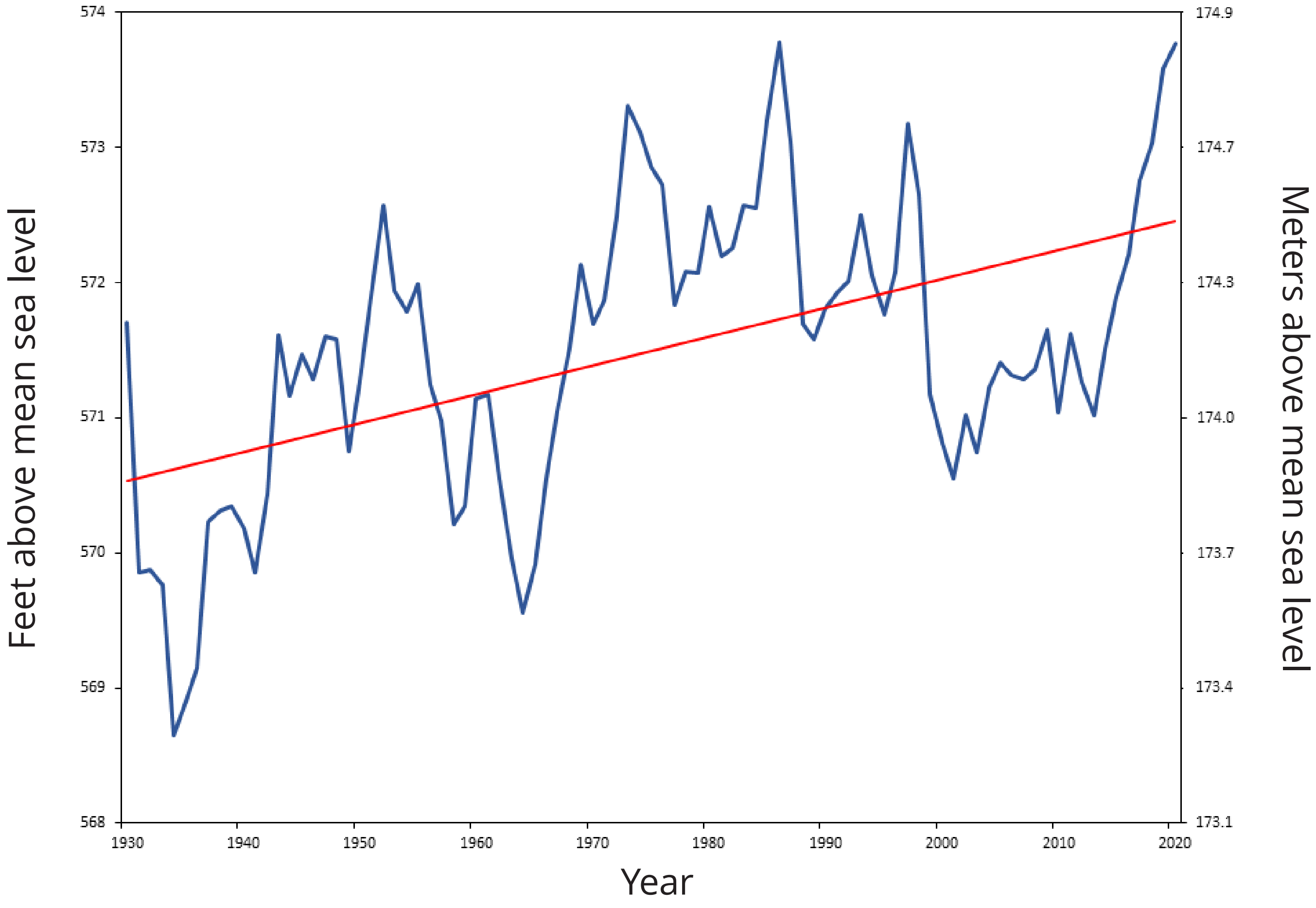

FIGURE 23. Level of Lake Erie at Cleveland, 1930–2020, with red best-fit line indicating the general trend across that period. Data provided by National Oceanic and Atmospheric Administration (2021).

A particular trend of rising lake levels from the mid-1930s to 2020 (fig. 23) appears to be correlated to precipitation and climate. These rising lake levels have significantly changed parts of the Lake Erie shoreline. Small islands known from historical maps and accounts have disappeared, and traces of drowned forests have been found (Moseley, 1899, p. 14 and 19; Moseley, 1905, p. 195; Strothers and Abel, 2001).

Isostatic rebound and climatic fluctuations are not the only forces that act upon the lake. Some scientists have proposed the naming of a new geological epoch, the Anthropocene, to acknowledge the impact that human activities have had on Earth's surficial geology (Ruddiman, 2013). Whether or not this term is formally adopted, human activities have had an impact on Lake Erie, one that will probably be detectable in the future geologic record. Some examples:

- Development and industrialization on the waterfront and in the Lake Erie watershed have altered the quantity and nature of sediments in the lake's nearshore zone. Long and wide natural beaches are a thing of the past (see **Site 3 – East Harbor State Park** for an example) and erosion of the lakeshore has accelerated as a result.
- Dredging of the Detroit River to facilitate shipping from the upper Great Lakes has permanently lowered the water levels of Lakes Michigan and Huron and has probably resulted in a small but permanent increase in the level of Lake Erie (Quinn, 1985a) – although as this guidebook shows, nothing about Lake Erie should be considered permanent, across geological timescales.
- Deforestation in the Great Lakes watershed possibly contributed to a rise in water levels during the nineteenth century (Powers and others, 1960, p. 44).

Although the tendency over the past few centuries has been for the lake to rise, that trend may be subject to a reversal: Lake Erie's level has been projected to decline 0.3 to 0.4 m (1 to 1.5 ft) by the end of the twenty-first century due to a warmer climate (Chou and others, 2012, p. 221). But a much greater change is forecast for the longer term: eventually the sill of hard Silurian dolomite at the top of Niagara Falls will erode away. Niagara Falls has already eroded upstream, by hundreds of feet since it was first sighted by Europeans in the seventeenth century and by about 11 km (7 mi) since ice receded from the region. When the bedrock sill finally erodes away—perhaps in about 15,000 years (NPC, 2015)—outflow from the lake will increase, quickly draining most of the basin. Marshland will emerge along the lake's margins and the islands will again become hills accessible without a boat. In a geologically very short time, the lake we know today will pass into history.

PART IV: GEOLOGY OF OHIO STATE PARKS IN THE LAKE ERIE REGION

Introduction

This brief opening discussion on Lake Erie physiography and water levels introduces some key concepts that are referred to repeatedly in the park-specific discussions that follow.

Lake Erie Physiography

Lake Erie is often described as having three sub-basins: the Western, the Central, and the Eastern (fig. 24). The Western Basin is shallowest, owing to the hard limestone and dolomite rock that were more resistant to erosion by continental ice sheets. Maximum water depth in the Western Basin is only about 7 m (24 ft; Herdendorf and Braidech, 1972, pl. 1). Sunlight penetrates and warms the shallow water and wind stirs oxygen into it, making the Western Basin one of the most productive fish habitats in the Great Lakes.

The Western Basin is also known for the Lake Erie islands. Before the Quaternary Period, the islands and their associated reefs were a pair of rocky ridges. The western ridge included the future Bass Islands. Kelleys Island, the Marblehead **peninsula** and Pelee Island in Canada belong to the eastern ridge, which can be traced onshore in Ohio to the Bellevue-Castalia area. Erosion and repeated incursions by ice wore the ridges down into isolated hilltops that stand today as islands above the water. Situated on the eastern flank of the Cincinnati-Findlay Arch, the bedrock dips southeast into the Appalachian Basin, imparting a **cuesta**-like form to the islands, with a gentle slope facing down-dip and a steep slope facing up-dip. (fig. 25). In Ohio, the land adjacent to the Western Basin is known as the Maumee Lake Plain (fig. 24; ODGS, 1998) and represents the former bed of Lakes Maumee and Whittlesey. The terrain is flat, with low banks and wetlands lining much of the shore; some of it is protected by erosion from dikes of limestone rubble. Limestone and dolomite bedrock, however, make up the shore from just east of Port Clinton to the mouth of Sandusky Bay.

Just east of the bedrock ridge that forms Marblehead, Kelleys Island, and Pelee Island (Canada), is the Central Basin (fig. 24). Here, the relatively soft shale and sandstones of the Appalachian Basin permitted glaciers to carve more deeply and widely. Maximum water depth is about 24 m (80 ft; Lewis and others, 2012) and the lake floor is relatively flat. Onshore, immediately adjacent to the Central Basin, the Allegheny Plateau rises. When ice advancing from Canada met the plateau, it slowed down like bicyclists climbing a hill, expending its energy. As a result, while the ice lobes in western Ohio were able to push as far south as the Ohio River, ice in eastern Ohio stopped much further north (fig. 15). The presence and shape of the Allegheny Plateau determines the southwestern-to-northeastern trend of Lake Erie's southern shore that prevails from Huron, Ohio almost to Buffalo, New York. A narrow band of land on the Allegheny Plateau was formerly the bed of Lakes Maumee and Whittlesey and is known as the Erie Lake Plain. Isostatic rebound has raised the Erie Lake Plain up to 18 m (60 ft) above the present-day lake. The bedrock of this shore is made up of Devonian-age shales capped by glacial drift and former lakebed deposits. The Cleveland Member of the Ohio Shale occurs in the shore bluffs from Vermilion (Lorain County) westward to Cleveland (fig. 10), eventually transitioning to the lighter-colored, softer Chagrin Member. East of Cleveland, the Chagrin Member may or may not be visible near or just below the lake level, depending on the water's level and clarity.

North of the city of Erie, Pennsylvania, Lake Erie deepens to form the Eastern Basin (fig. 24), where in the offshore are northern-facing submerged cliffs and a deep gorge whose bottom is 64 m (210 ft) below lake level. During the time of Early Lake Erie, this was initially the only basin to be occupied

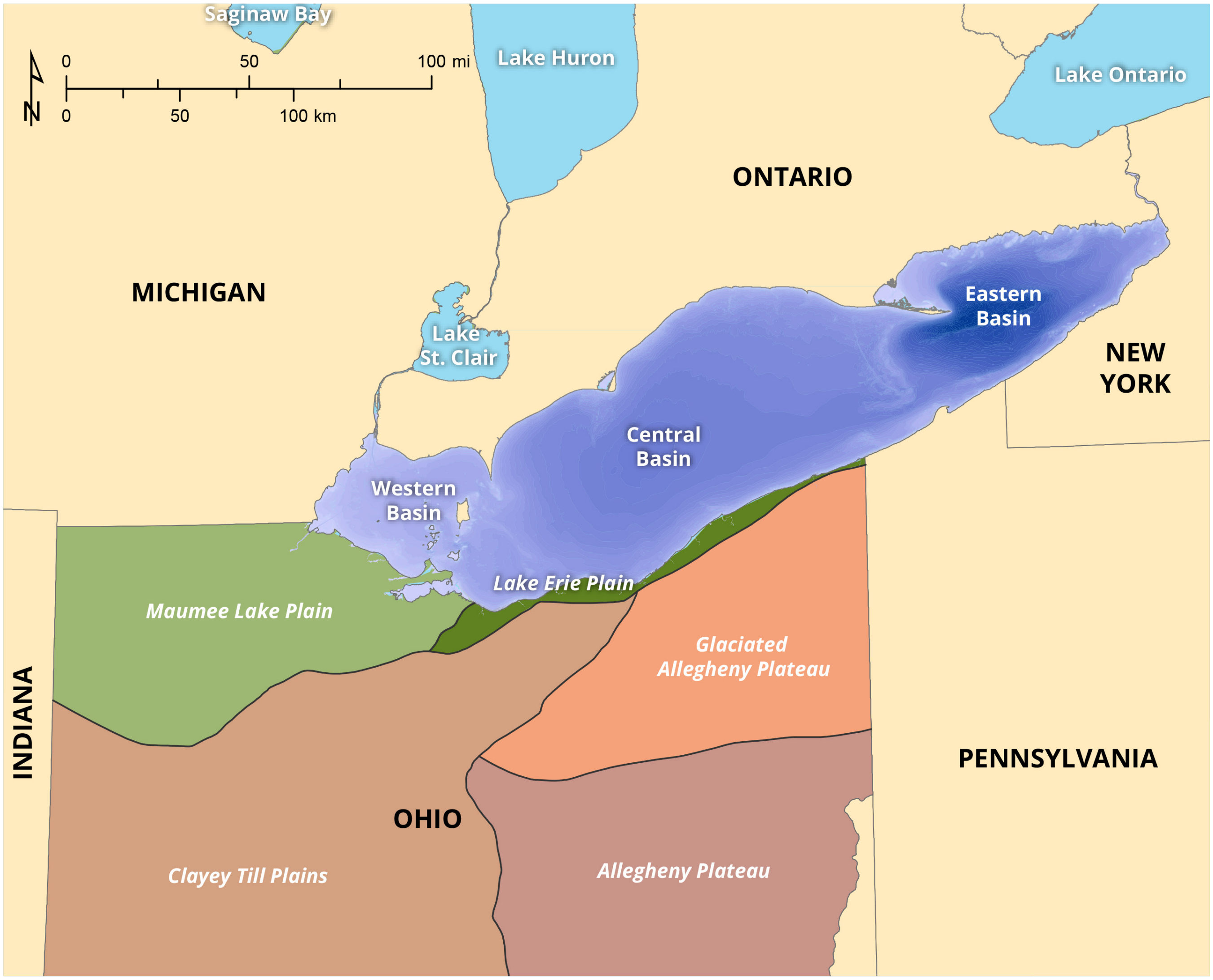

FIGURE 24. The basins of Lake Erie and major physiographic regions of Ohio.

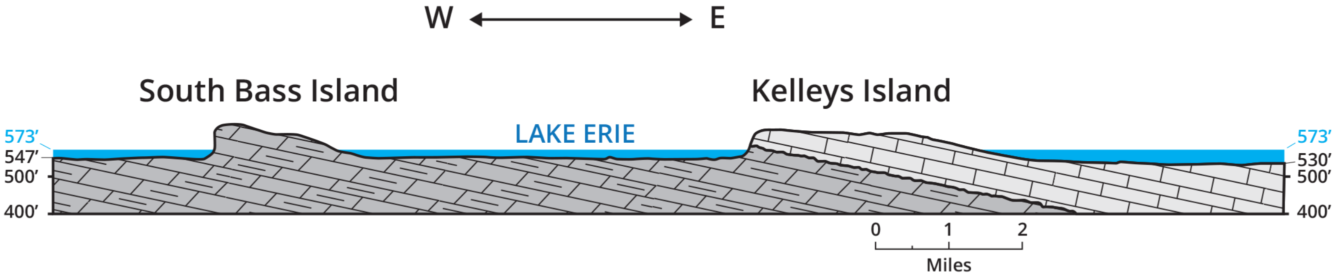

FIGURE 25. A west-to-east cross section through South Bass and Kelleys Islands, Lake Erie. A shalier dolomite facies between the islands is more easily eroded and forms the lake floor. More resistant rocks form the islands, with the dip of the rocks determining the islands' asymmetric cuesta shape (steep in the west and gentler in the east). After Carman (1946).

by water; rivers in northern Ohio flowed all the way to the Eastern Basin before finding a lake. A now-submerged channel heading northeast past the city of Erie, Pennsylvania carried the majority of this drainage into Early Lake Erie until the water level rose and Early Lake Erie expanded into the Central Basin.

Lake Erie Water Levels

This guidebook makes frequent reference to changing lake levels, so it is important to place these in context. As discussed in Part II, within the last approximately 12,500 years the lake has grown from Early Lake Erie to the lake we know today, a rise of up to 18 m (60 ft; Holcombe and others, 2003) and a sevenfold increase in area, from about 3,625 km^2 or 1,400 mi^2 to over 25,640 km^2 (9,900 mi^2; Bolsenga and Herdendorf, 1993, p. 175). But also, as previously discussed, modern Lake Erie is about two feet higher today than when surveyors from Connecticut first surveyed northeastern Ohio in 1796. If the rise from Early Lake Erie to Modern Lake Erie (about 4,000 years) represents a long-term change and the increase in lake level over the last two centuries represents a mid-term change, then the lake is also subject to short-term changes in level.

The most frequent short-term change occurs from moment to moment, as the water's surface moves constantly under the influence of winds, but this effect is highly localized. Storms may change the water level significantly over a period of hours, but this is also a localized effect, as a gain in water mass that raises the level at one location corresponds to a loss in mass that lowers the level elsewhere (this phenomenon is discussed in **Site 1—Maumee Bay State Park**). The most important short-term trend to affect the entire lake equally is seasonal and occurs because of annual cycles of precipitation and evaporation. Winter and early-spring precipitation typically contribute to higher lake levels in the spring (usually peaking in June), and summer and fall evaporation lead to lower levels in the fall and early winter. Thus, it is typical for Lake Erie water levels to vary by about two feet annually. These annual fluctuations are overlaid on longer-term trends, so even though the lake level may vary by about two feet annually, it is still on average about two feet higher than two centuries ago.

Changing lake levels have significant effects, both positive and negative, depending on one's perspective. Lower lake levels benefit waterfowl and wetland species as more marshy habitat emerges at the edge of a lowering lake. Lower levels also pose an advantage to owners of lakefront property, exposing wider beaches and decreasing the risk of erosion and flooding. However, lower lake levels pose problems for recreational boaters and marina operators as navigation channels become shallower. Shipping becomes more expensive since large freighters can carry less weight when water levels are lower, and the federal government incurs greater costs because of more frequent dredging to keep navigation channels passable. Thus, there is no "ideal" lake level that benefits all interests simultaneously.

It is important to note that Lake Erie's level is not under engineered control. Such controls exist on Lakes Superior and Ontario and were considered for Lake Erie in the 1960s and 1970s, but plans were abandoned as too expensive and unfeasible. A small amount of water is diverted to the Welland Canal (Canada) to allow vessels to bypass Niagara Falls and generate hydroelectricity (Quinn, 1985b), but this diversion is not a significant contributor to changes in lake level. The sum effect of diversion projects on the upper Great Lakes (Lakes Superior and Michigan) and the Welland Canal is estimated to reduce Lake Erie's water level by about 10 cm (4 in) (IJC, 1985, p. 21), which is much less than the aforementioned seasonal and annual variations.

Organization

The following park-specific field guides detail the geologic characteristics of each Ohio State Park bordering Lake Erie. Parks that are near to one another tend to have similar geology, so to avoid repetitive discussion, the individual park guides do not follow an identical format but are organized to give priority to the most geologically significant features at each park. Some park discussions refer to specific geologic **Field Trip Stops** in or near the park.

For parks with little to no exposed bedrock, the guides prioritize the scenic geology, Holocene history, geomorphology, or coastal processes that pertain to the park and/or the surrounding region. These discussions are under the heading **Regional Concept** and do not refer to a specific Field Trip Stop. Finally, each park discussion ends with a summary of the local **Economic Geology**.

NOTE: Some of the park-specific field guides also refer to nearby locations that may be outside state park boundaries. Unless otherwise noted, these sites are on public lands. Do not trespass on private property. Especially importantly, **never** trespass in quarries. Whether in operation or closed and abandoned, quarries are extremely hazardous.

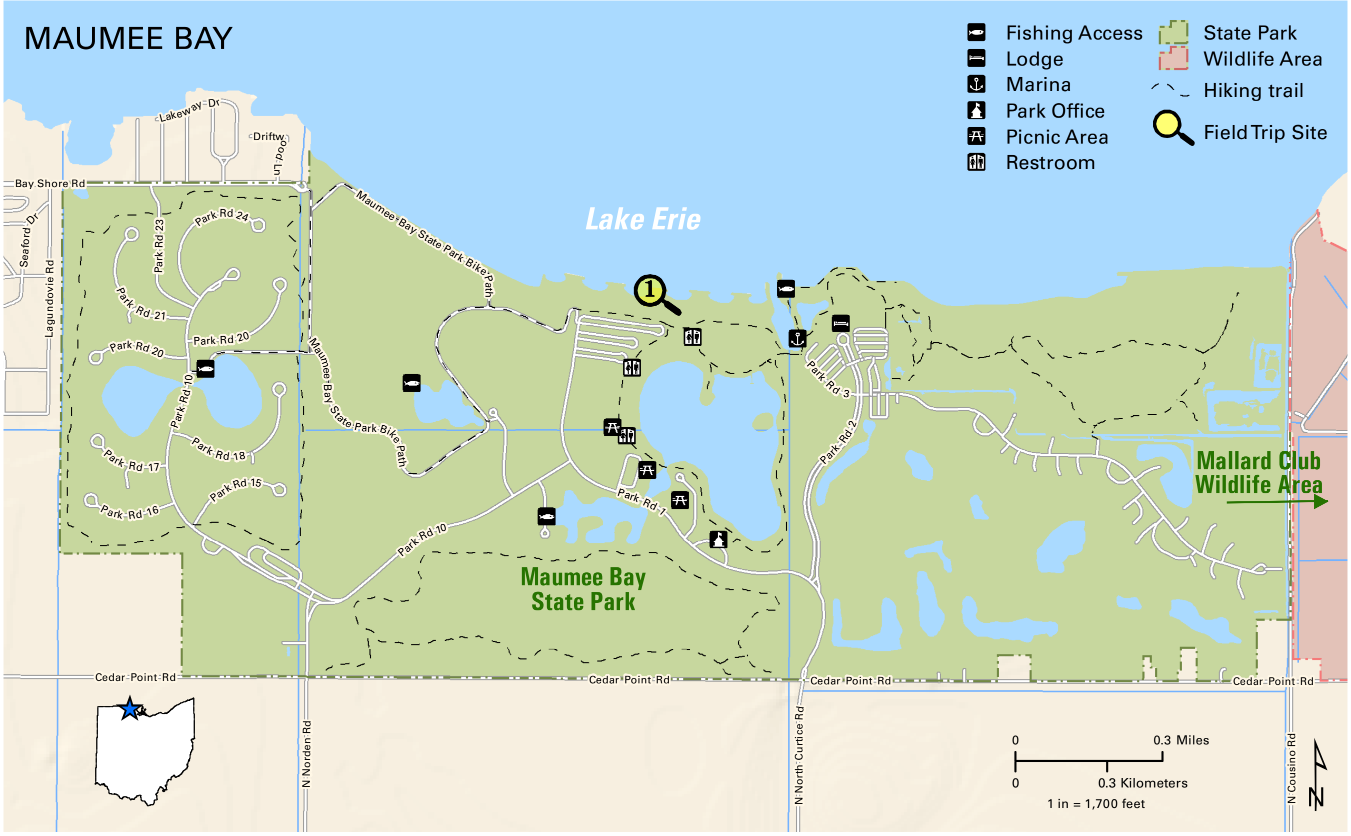

FIGURE 26. Maumee Bay State Park overview map.

Site 1 – Maumee Bay State Park

Introduction

Near the southwestern end of Lake Erie, Maumee Bay State Park (fig. 26) is 5.4 km^2 (1,336 acres) of wetlands, woods, and meadows, with a large beach, a lodge, and areas set aside for picnicking, hiking, camping, hunting, and other outdoor activities. Mallard Club State Wildlife Area and Cedar Point National Wildlife Refuge are located nearby to the east.

Regional Concept—The Black Swamp: Ohio's bygone Everglades

No bedrock is exposed at Maumee Bay State Park, the Silurian-age rocks having been smoothed by repeated glacial incursions and later mantled by glacial till. Fine sediments deposited at the bottoms of proglacial lakes cover the till. The region is flat because waves and currents on the proglacial lakes planed the deposits into a flat lakebed. As the post-Ice Age climate warmed, the flat, clayey bed of former Lake Maumee developed into a vast wetland, 3,885 km^2 (1,500 mi^2) in area, or more than twice the size of the present-day Florida Everglades. Known as the Black Swamp (sometimes as the Great Black Swamp), the wetlands extended as far west as present-day Fort Wayne, Indiana and were up to 40 km (25 mi) wide (fig. 27). The flat ground and clayey soils drained slowly, holding standing water for much of the year. Ash, cottonwood, elm, hickory, oak, linden, and maple trees grew in dense forests separated by stretches of open prairie (Kaatz, 1955). Although they probably hunted in the area, Indigenous Americans mostly avoided settling in the Black Swamp. After the Revolutionary War, settlers heading west also avoided the Black Swamp, dreading its reputation for ravenous mosquitoes and difficult, unpaved roads. The Black Swamp was among the last places in the region to be permanently settled.

The land was eventually drained and the forests were cleared for farming during the nineteenth century. Ironically, the Black Swamp itself was the source of the clay for the drainage tiles that helped to dry it out. The effort to drain the Black Swamp through a combination of drainage tiles and ditch-building resulted in Ohio becoming a market leader in the manufacture of ceramics and excavation

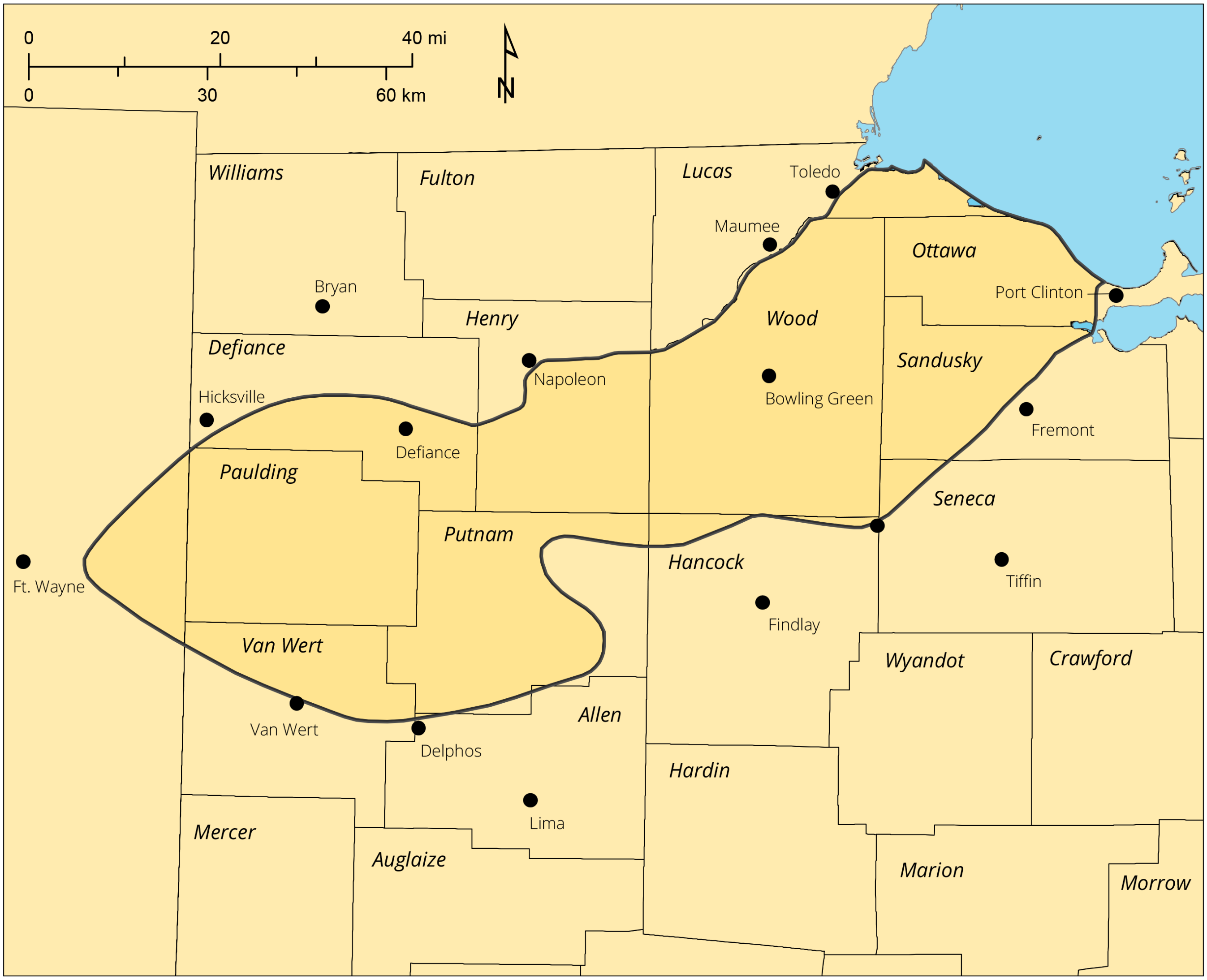

FIGURE 27. Area of the Black Swamp in relation to principal northwestern Ohio cities. Far more cities developed outside or on the edge of the swamp than within it, reflecting the difficulty of travel in the swampy terrain. Modified from Kaatz (1955).

machinery (Frost and Nichols, 1985). Most of what remains of this former wet landscape is a narrow and discontinuous swath of wetlands along the coast from Maumee Bay to Port Clinton. Near Maumee Bay State Park, the State of Ohio operates two Wildlife Areas, Mallard Club and Magee Marsh, which help preserve part of this environment. However, changed conditions threaten these small remnants of the Black Swamp. The coastal wetlands of Lake Erie historically were protected by *barrier beaches*, sand ridges that absorbed the brunt of wave energy from lake storms. However, the rise in lake levels during the mid-twentieth century (fig. 23), along with several violent storms, damaged most of these beaches and flooded the wetlands. Stone dikes have been emplaced where the beaches were, but some of the lost wetland may never be restored.

Regional Concept—Maumee Bay: A drowned river mouth

Maumee Bay is one of many so-called *drowned river mouths* on Lake Erie. During the low stage called Early Lake Erie (fig. 21), the Maumee River extended into the Western Basin, rather than ending at Toledo as it does today, and the Western Basin was not yet submerged. As evidence, core samples of lakebed sediment collected in the Western Basin showed remains of land-based plants, proving that the Western Basin was once dry or at least marshy (Herdendorf and Braidech, 1972). As the lake rose, it intercepted the Maumee

FIGURE 28. Current and former (submerged) sand spits at mouth of Maumee Bay, Toledo, Ohio. Base image copyright 2013, ESRI, i-cubed, GeoEye.

River's flow progressively nearer to the present-day site of Toledo. The Maumee and other rivers that empty into western Lake Erie, such as the Detroit, the Sandusky, and the Portage, were once adjusted to a lower *base level*, meaning their channels cut down to meet a lake of lower elevation than today. Subsequent lake-level rise has widened and drowned the mouths of these rivers, so rather than flowing rapidly, the river mouths are slack most of the time, lacking a strong current. They may even briefly flow backwards under certain wind conditions, mixing lake water with river water. Similar conditions occur in marine estuaries, such as Chesapeake Bay, and these river mouths are sometimes referred to as freshwater estuaries.

A *sand spit* (a ridge of sand attached to the shore at one end) extends into Maumee Bay from its northern (Michigan) shore. It once reached farther into the bay, and a corresponding spit reached up toward it from the southern (Ohio) shore (fig. 28). The formation of similar sand spits at the mouth of Sandusky Bay has been dated to between 5,000 and 3,800 y.a. (Guy, 1983, p. 171), when lake level appears to have risen abruptly (about 9 m or 30 ft in perhaps 100 years), submerging the Western Basin. This is consistent with other evidence (page 22) that Lake Erie rose rapidly about 4,000 y.a. Based on their height above the lakebed, the sand spits at Maumee Bay formed sometime later, probably about 2,000 y.a. (Holcombe and others, 2003), implying that Maumee Bay was not flooded until that time. The rise of the lake over the sand spits drowned the mouth of the pre-modern Maumee River and created the bay as it is today.

Rising lake levels have submerged most of the sand that comprises the sand spits. Data at the Ohio Geological Survey show that in 1848, Maumee Bay was just under 6.4 km (4 mi) wide at its mouth, from the tip of one sand spit to the other. By 2015 that width had grown to about 8.6 km (5.5 mi). Although mostly submerged today, the sand spits still exist offshore as shoals in 2 m (6 ft) or less of water, and boaters must exercise care when navigating near them, especially when lake level is lower due to seasonal effects.

Regional Concept—Erosion and other shore processes

The *glaciolacustrine* (glacial lake-derived) silts and clays that make up the shore of Maumee Bay are not erosion-resistant, and rapid erosion of the Maumee Bay shore has been recorded since the nineteenth century. In the early twentieth century, an average erosion rate of 0.3 m (1 ft) per month was calculated over a 98-year period, with as much as 12 m (40 ft) eroding in one year and 7.6 to 9.1 m (25 to 30 ft) lost in a single storm (Brindle, 1933). A number of severe storms struck the southern coast of the lake in the mid-twentieth century, culminating in a storm in November of 1972 that was the most severe Lake Erie storm of the century (Carter, 1973). A small community of summer cottages, Niles Beach (fig. 29), had been hit hard by the storms, and the 1972 event was the final blow. Niles Beach was never rebuilt, and the state park lodge occupies the site today.

FIGURE 29. Privately owned cottages at Niles Beach, now the site of Maumee Bay State Park, Lucas County, Ohio, after a severe storm in 1972.

Field Trip Stop 1—Beach (41°41′9.6″N, 83°22′35.5″W)

The beach at Maumee Bay State Park consists of sand that has been emplaced by ODNR, because in spite of the large quantity of sand offshore, natural processes alone cannot create or sustain a beach at this erosion-prone location. A set of five offshore breakwaters of heavy limestone rubble (Columbus Limestone, quarried in Ohio) protects the beach (fig. 30), and shore-perpendicular breakwaters (called terminal groins) at either end of the beach help to keep the sand in place. When storm winds blow from the north or northeast, the breakwaters dissipate wave energy and protect the beach from erosion. The spacing and offshore distance of the breakwaters were designed to ensure that the beach would develop *tombolos*, extensions of sand that connect the beach to the offshore breakwaters. The curved shape of the shore between the tombolos is a result of how incoming waves are refracted as they reach the breakwaters.

FIGURE 30. Aerial view of the sand beach at Maumee Bay State Park, Lucas County, Ohio, protected by offshore breakwaters. Image provided by the U.S. Army Corps of Engineers.

Regional Concept—Lake seiches: Erie's "tide"

Being near the extreme western end of Lake Erie, Maumee Bay is perfectly situated to receive the full effect of a lake *seiche* (pronounced "saysh"), a storm surge that occurs when wind blows down the long axis of a body of water. On Lake Erie, this involves either a southwestern or northeastern wind. A southwestern wind pushes water away from the Western Basin shore and the water level drops quickly. Docks may go dry (fig. 31) and small

FIGURE 31. Docks at East Harbor State Park, Ottawa County, Ohio, during a November 1998 seiche on Lake Erie. No boats were moored at the time.

watercraft moored at docks can become damaged or stuck in mud. Simultaneously, the water level at the northeastern end of the lake (Buffalo, New York) rises quickly. One particularly sudden and severe event in 1844 drowned 78 Buffalo residents (Meehan, 2014).

The opposite occurs when a northeastern wind pushes water against the southwestern shore, quickly raising water levels near Toledo. Severe windstorms can raise or lower water levels as much as 2.4 m (8 ft) over a few hours. Seiches typically last about 24 hours, although peak water level changes usually last for only an hour or two (fig. 32). As the storm passes, the water level returns to normal although water level monitoring may still detect end-to-end fluctuations in the lake, like water sloshing back and forth in a tub. Seiches that occur during periods of high water levels can cause considerable erosion damage and flooding. Unlike ocean tides, lake seiches are dependent upon passing weather systems and do not occur on a regular basis.

Economic Geology

The Maumee Bay region is not currently a large contributor to Ohio's minerals industry, although sand and gravel were once mined from the Maumee River. Northwestern Ohio was the location of one of the United States' earliest oil booms in the 1880s and became a leading producer of oil until the first years of the twentieth century when the region was eclipsed by production in Texas and Oklahoma. The source of oil was the Ordovician Trenton Limestone, at depths of about 366 to 396 m (1,200 to 1,300 ft). Some believe substantial reserves of oil remain in the region and that future economic conditions and technological advancements may inspire the industry to revisit the area. Farther from Maumee Bay, in Wood County, several limestone and dolomite quarries operate. The clayey soils of the former Black Swamp region were a source of clay for the ceramics industry and a few small producers still operate in northwestern Ohio, albeit far from Maumee Bay.

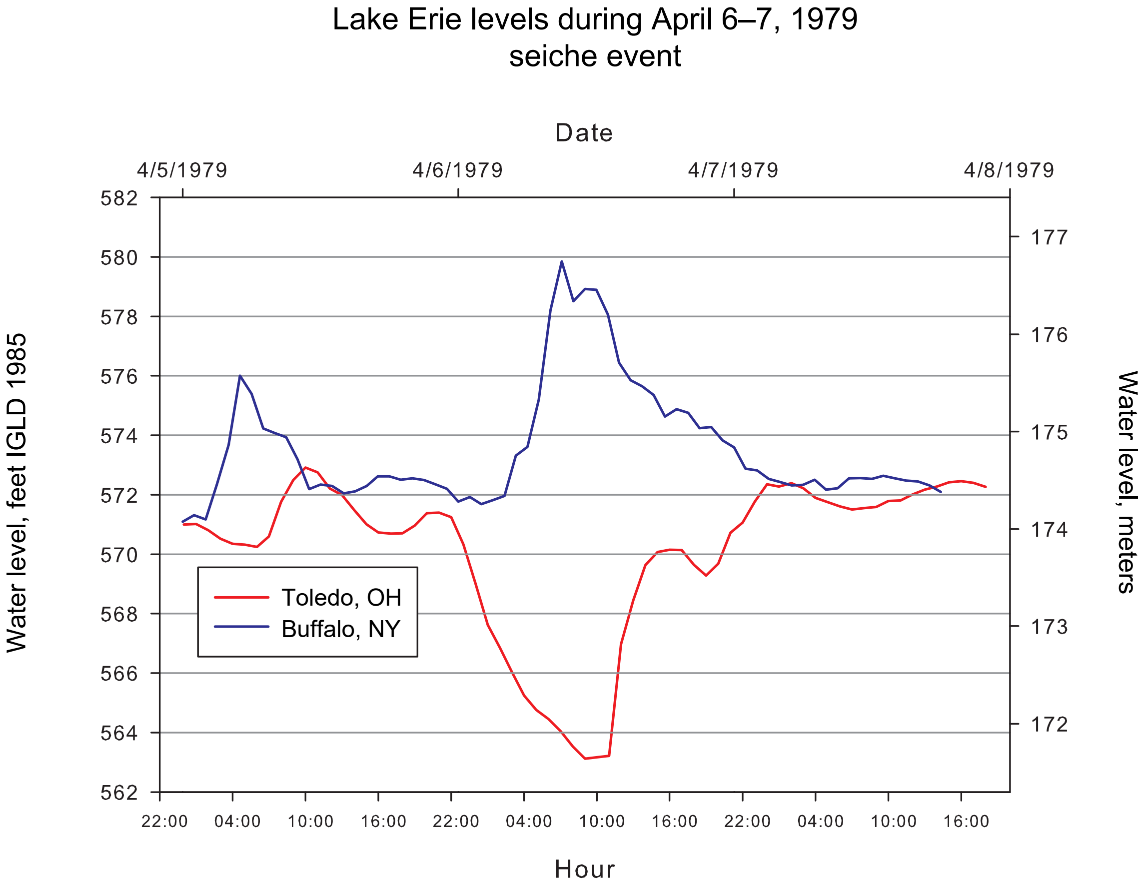

FIGURE 32. Plot of Lake Erie water levels during a storm on April 6–7, 1979. A southwestern wind pushed water away from Toledo, Ohio and toward Buffalo, New York. At the wind's peak, the difference in water level between the two cities was nearly 5 m (17 ft).

Site 2 – Catawba Island State Park

Introduction

Catawba Island State Park is a small, 40,500 m^2 (10 acres) park with boat ramps and picnic facilities located on the northwestern corner of Catawba Island (fig. 33). Not strictly an island but a peninsula jutting into Lake Erie like an upturned thumb, Catawba Island is part of a dolomite ridge that includes South, Middle, and North Bass Islands and the smaller islands near Put-in-Bay.

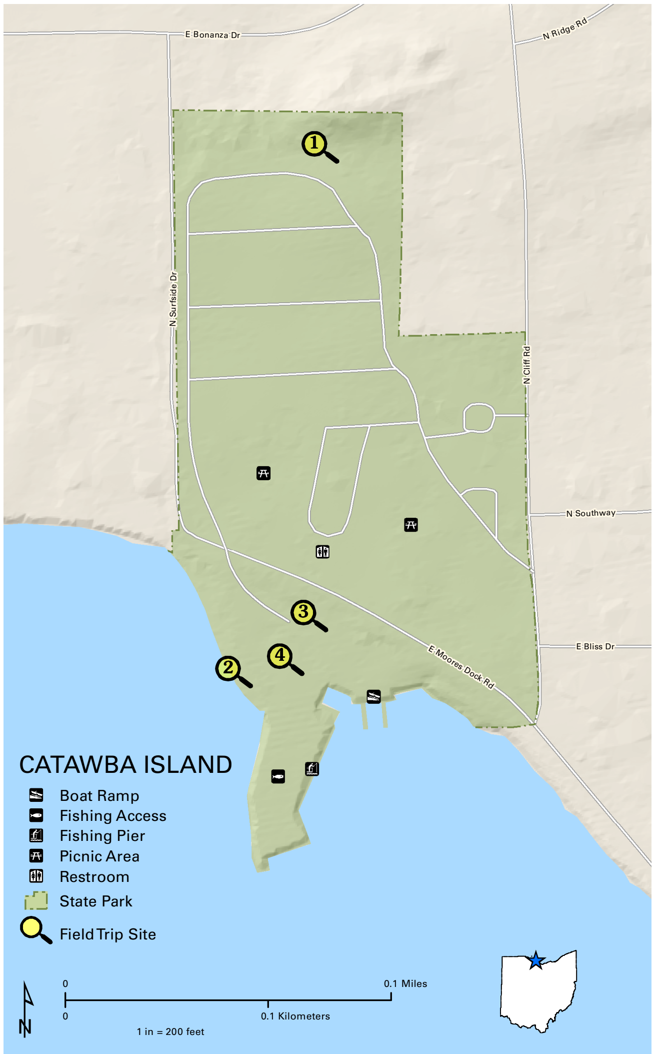

FIGURE 33. Catawba Island State Park overview map.

Field Trip Stop 1—Bedrock geology (41°34′33.7″N, 82°51′25.0″W)

Catawba Island is covered by thin soils characteristic of glacial deposits (till, outwash, and glaciolacustrine clays). Silurian-age dolomite underlies these soils. The nomenclature of the rocks has been somewhat controversial owing to uncertainty about the stratigraphic relationship between these exposures and those elsewhere (Larsen, unpub. data, 2004[5]). As of this writing, the Ohio Geological Survey's *Bedrock Geologic Map of Ohio* (Slucher and others, 2006) labels the rock of the Bass Islands as *Ss*, for the Silurian Salina Group. Schumacher and others (2013, p. 112) lists a "Bass Islands Dolomite" as being exposed in the cliffs of the Bass Islands and Catawba but notes that some geologists do not differentiate the "Bass Islands Dolomite" and instead include it as part of the upper Salina Group. Therefore, this guide will refer to the rocks of the Bass and Catawba Islands as the upper Salina Group, unless otherwise noted.

Originally recognized in Syracuse, New York, the Salina Group was deposited in tropical, nearshore environments such as lagoons, reefs, and shorelines (Schumacher and others, 2013, p. 109). The upper Salina Group found exposed in the cliffs of Catawba Island is gray to yellow gray and is described as "microcrystalline to finely crystalline dolomite that has been fractured into angular pieces and later cemented to form massive beds of brecciated dolomite" (Schumacher and others, 2013, p. 112). This *brecciated*, or fractured, character is the only feature to differentiate the "Bass Islands Dolomite" from upper Salina Group rocks, leading some geologists to reject a separate designation for the brecciated unit. The brecciated nature is thought to have resulted from collapse of upper beds of the Salina into cavities that formed shortly after the rock formed, during the Late Silurian when the area was uplifted and the rocks were exposed *subaerially* (that is, to the atmosphere). The cavities were the result of rock dissolution by acidic rainwater and runoff. This process produces **karst**, a terrain where **carbonate** rocks have been exposed to weathering and dissolution. Caves, sinkholes, and springs are common features of karst. Caves are **solution** cavities; sinkholes are caves whose roofs have collapsed, and springs are streams that flow in underground conduits in the bedrock before emerging from the ground.

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[5] Larsen, G., The Bass Islands and Salina Groups, Ohio's tale of two woes: Ohio Department of Natural Resources, Division of Geological Survey.

FIGURE 34. Sinkhole pond at Catawba Island Township Nature Preserve, near Catawba Island State Park, Ottawa County, Ohio.

FIGURE 35. Outcrop of upper Salina Group ("Bass Islands Dolomite") at Catawba Island State Park, Ottawa County, Ohio.

Subsequent burial by Devonian-age deposits limited weathering and stopped or slowed karst formation in the upper Salina Group, but post-Paleozoic **exhumation**, re-exposure to the atmosphere, and weathering during the Teays era (**Part I**—page 14) presented another opportunity for karst features to form and expand. Still another opportunity arose during the Quaternary Period, when glaciers stripped off Teays-era soil overburden, again exposing rocks before glacial soils formed. This complex history makes it difficult or impossible to determine when a given karst feature first formed or experienced collapse, but it is probable that a sinkhole that collapses in the present day began forming millions of years ago.

Catawba Island is dotted with caves and sinkholes (fig. 34), most on private property. Fortunately, Ohio sinkholes tend to be more of a nuisance than a direct threat to human life, unlike sinkholes in Florida that make news when they open suddenly and engulf property. Nevertheless, they are a recognized **geohazard**, as they threaten buildings and infrastructure and can affect water quality in areas that rely on groundwater for drinking water.

At the northern end of the parking lot at Catawba Island State Park is an outcrop of upper Salina Group rock (fig. 35). Its elevation, at about 189 m (620 ft) above m.s.l., suggests it is a cliff of proglacial Lake Lundy (table 1). This outcrop and the fallen blocks at its base show the brecciated nature of the upper Salina Group. Fossils and original sedimentary structures have been nearly obliterated by secondary deformation and re-cementation. Although hard, much of the rock resembles soft, damp clay, (fig. 36), consistent with the theory that this material represents weathered rock and soil that collapsed into karst voids.

Bluffs of upper Salina Group rocks make up the western and northern coasts of Catawba Island, although most of these bluffs are on private property and not readily accessible. If possible, it is worthwhile to take the opportunity to see the bluffs of Catawba and the Bass Islands from a boat to view some of Ohio's most picturesque rock exposures. Many of these exposures resemble rock outcrops in the Bahamas, where the rocks are similar even if the climate is not. One example of a picturesque exposure, now mostly eroded away, was the Flowerpot. This outcrop on the northwestern corner of the peninsula was once the largest Ohio example of a *sea stack*, an outcrop separated from the main shore (fig. 37).

FIGURE 36. Close-up of outcrop (see fig. 35) at Catawba Island State Park, Ottawa County, Ohio, showing deformation of the dolomite.

FIGURE 37. (A) In the 1970s, the Flowerpot was a scenic exposure of Salina Group rocks on the northwestern coast of Catawba Island, Ottawa County, Ohio. (B) It has since collapsed into a jumble of broken rock.

FIGURE 38. Cobble beach at Catawba Island State Park, Ottawa County, Ohio.

FIGURE 39. Boundary marker for the northwestern corner of Connecticut Western Reserve.

Field Trip Stop 2—Beach (41°34′25.3″N, 82°51′26.8″W)

Beaches are usually associated with sand, but where sand is scarce and wave energy is sufficient, a beach may be composed of larger granular materials. The source of sand for most Ohio beaches is glacially-derived soils, but on Catawba Island the soils are thin and relatively sand-poor. The beach at Catawba Island State Park is therefore composed mainly of cobbles (fig. 38), mostly derived from the erosion of dolomite exposed along the shore, although there is probably a smaller fraction of glacial **erratic** cobbles and boulders as well.

Field Trip Stop 3—Boundary marker (41°34′26.2″N, 82°51′25.2″W)

The boundary marker set into a block of sandstone near the picnic shelter was emplaced in 1967 by the Early Settlers Association of the Connecticut Western Reserve (ESA, 2018) (fig. 39). It is one of four that mark the four corners of the Connecticut Western Reserve. The Connecticut Western Reserve was a portion of northern Ohio granted to the colony of Connecticut by England's King Charles II under the Connecticut Charter of 1662. After the United States won its independence, the state of Connecticut sold the Reserve, about 12,140 km^2 (3 million acres), to land speculators, opening the territory to settlement. Land-surveying techniques used to lay out the boundaries of the Western Reserve were the same employed by early geologists to make geologic and topographic maps.

Field Trip Stop 4—Picnic shelter (41°34′25.5″N, 82°51′25.7″W)

The blocks making up the picnic shelter at the boat ramp are from an undetermined limestone, possibly the Delaware or a unit of the Columbus. Many of the blocks are highly fossiliferous, including solitary rugose corals (probably *Zaphrentis*); pelmatozoan echinoderm (crinoid or blastoid) stem sections; pelecypods (clams); *stromatoporoids* (sponge-like organisms); and brachiopods (probably *Chonetes*) (fig. 40).

FIGURE 40. Fossils in a block of limestone in picnic shelter at Catawba Island State Park, Ottawa County, Ohio. Large fossil is a pelecypod (clam), surrounded by other fossils. See text for further details.

Regional Concept—The lower Portage River: A case of stream capture

The Catawba Island peninsula connects to the mainland by an **isthmus** at its southwestern corner. During the evolution of Early Lake Erie into the modern lake, the Portage River, which today meets the lake at the city of Port Clinton, followed a longer course to the lake. Before about 2,000 y.a., the lake was about 3.7 to 4.0 m (13 to 23 ft) lower than today (Holcombe and others, 2003). This would have placed the shore about 4.8 km (3 mi) north of the location that would become Port Clinton. Catawba Island was then a rocky ridge probably surrounded by marsh. The Portage River, rather than ending at the present-day site of Port Clinton, flowed past that place and continued east (Moseley, 1899, p. 17; Forsyth, 1971). The river meandered along the southeastern side of Catawba Island before emptying into the lake somewhere to the east. The marina entrance channel at West Harbor appears to be part of the former river channel.

About 2,000 y.a., as Lake Erie approached its present-day level, the marshes near the future Port Clinton were inundated (Evans and Clark, 2011)[6]. The lake eventually eroded inland far enough to intercept the Portage River's flow at the site of Port Clinton, a process of *stream capture* known as *betrunking* (fig. 41). When people of European descent settled the area, Indigenous Americans dwelling there were said to have spoken of a former

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[6] Evidence for marshes offshore of Port Clinton includes clumps of peat and organic matter that occasionally wash up on the beaches there.

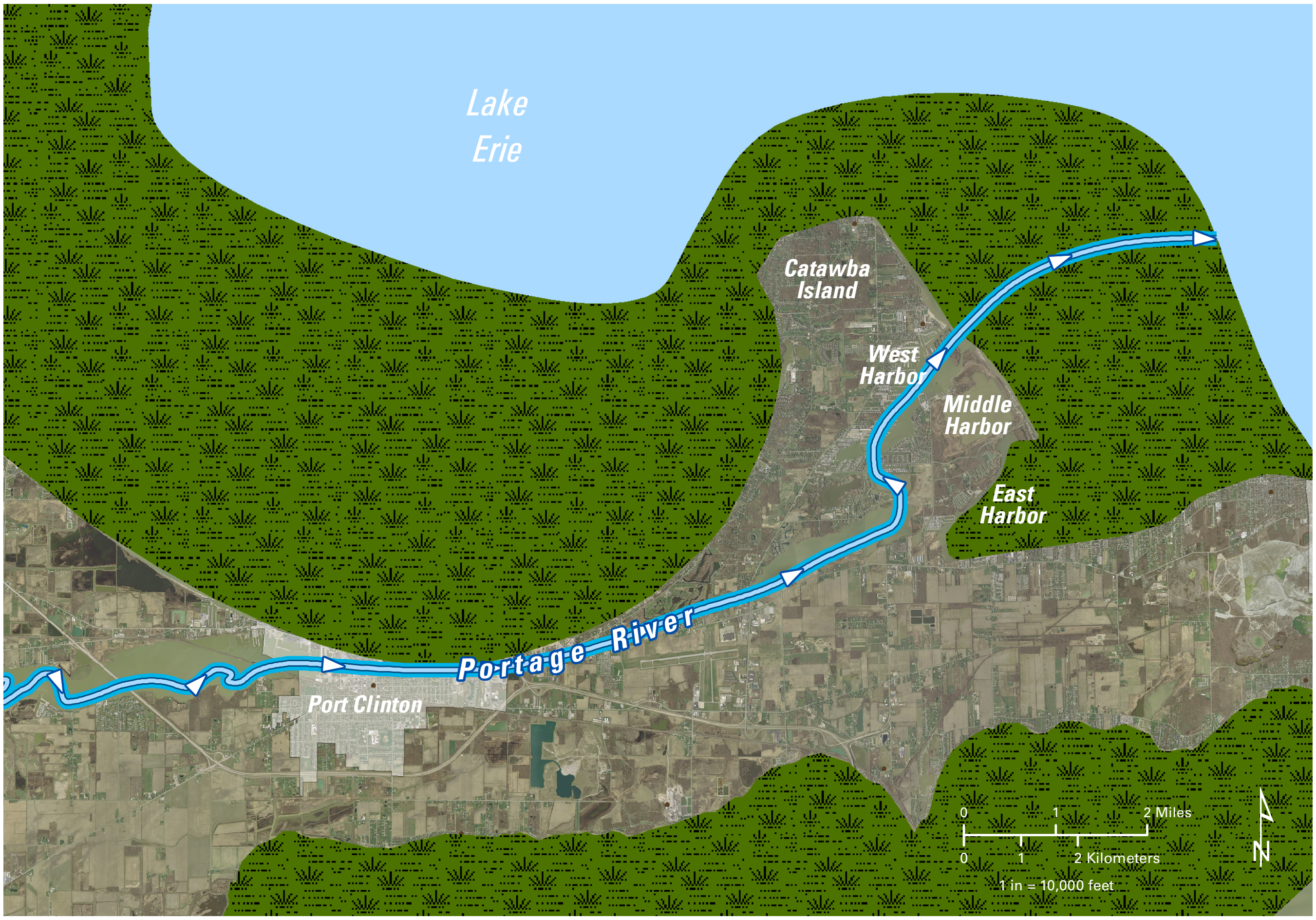

FIGURE 41. Schematic diagram of Portage River capture, Ottawa County, Ohio. About two thousand years ago, the Lake Erie shore was several miles north of Port Clinton with wetlands making up the landscape between the lake and the future site of the city. The Portage River (blue line) flowed over the isthmus that links Catawba Island to the mainland and ran through a channel at West Harbor to join Lake Erie somewhere to the east. When the lake rose, it intercepted the river at Port Clinton, which is where the mouth is today.

course for the river (Ryall, 1913, p. 443), suggesting that stream capture occurred recently enough to be a part of their oral history. Catawba appears to have been a true island during early settlement, because early maps show a continuous channel separating Catawba from the Marblehead peninsula. Later maps show a sand beach connecting Catawba Island to Port Clinton, partially filling the former river channel. State Route 53, the main access to Catawba Island, crosses the abandoned river channel (fig. 42).

Economic Geology

The East Harbor/Catawba Island region has been only a small contributor to Ohio's minerals industry. A gypsum mine operated for nearly two centuries about 9 km (5.5 mi) away on the northern side of Sandusky Bay, and there are probably other deposits of gypsum in the region; however it would take a considerable investment to open a new mine to compete against established operations (including gypsum recovery from industrial processes) elsewhere in the United States. Oil and gas production does not currently occur in this region of Ohio. The ODNR Division of Oil and Gas Resource Management identifies three *pools* (subterranean accumulations), two of oil and one of gas, beneath the western shore of Catawba Island, in the Ordovician Trenton Limestone, at a depth of 1,890 feet.

FIGURE 42. View looking east at the abandoned course of the lower Portage River in Ottawa County, Ohio, widened and drowned by Lake Erie's rise.

Site 3 – East Harbor State Park

Introduction

East Harbor State Park is a 7.4 km² (1,831-acre) park with a beach, picnicking, fishing, boating, and camping as primary attractions (fig. 43). The park occupies a low area between two bedrock ridges, Marblehead peninsula to the southeast and Catawba Island to the northwest. East Harbor State Park itself has little exposed bedrock, although bedrock can be seen nearby on Catawba Island (Site 2) and at Marblehead peninsula (Site 4). Catawba Island is part of a ridge of Salina Group dolomite that also makes up South, Middle, and North Bass Islands and the smaller islands of Put-in-Bay. Marblehead peninsula is a ridge of Columbus Limestone that also makes up Kelleys Island and Pelee Island (Canada). Between these two ridges of resistant rocks are layers of Devonian Lucas Dolomite and Amherstburg Dolomite (together known as the Detroit River Group), both of which are less-resistant, non-ridge-forming rocks. A cross section through the islands (fig. 25) shows how the different erosional characteristics led to the formation of the islands and explains why East Harbor State Park, between the ridges, occupies a lower elevation. A *barrier beach* – a long, naturally-occurring strip of sand – separates the harbors and wetlands from the open lake. Over 3.2 km (2 mi) long, the barrier beach is actually a long set of sand dunes.

East Harbor history

Besides Lake Erie, East Harbor State Park includes two separate water bodies. The larger, on the southeastern side of the causeway, is called East Harbor. Northwest of the causeway is Middle Harbor, more of a pond than a true harbor because there are no channels leading into or out of it. West Harbor, to the northwest of Middle Harbor, is adjacent to the state park but is not a part of it. As explained in **Site 2 – Catawba Island State Park**, West Harbor appears to be a former channel of the Portage River. East Harbor may have also served as a channel at one time, but at the time of European settlement of Ohio, both of the former channels had been abandoned. An 1849 map (U.S. War Department), depicts West and East Harbors as narrow channel outlets emerging from marshes that were separated from the open lake by barrier beaches.

FIGURE 43. Overview map of East Harbor State Park and vicinity, Ottawa County, Ohio.

Historical evidence suggests that East, Middle and West Harbors have changed significantly in the past two centuries. In 1899, naturalist Edwin Lincoln Moseley wrote that a resident of Port Clinton recounted "that in 1828 [local farmer] Mr. Ramsdell made hay of the wild grass that grew on what is now the harbor west of Lakeside [that is, East Harbor], and that there was very little water then where it has since been four feet [1.2 m] deep" (Moseley, 1899, p. 18). A survey of historical maps from 1849 to 1966 (Moore, 1973, p. 170) confirms that East, Middle, and West Harbors underwent changes as a result of the sand beach becoming breached periodically, opening Middle Harbor directly to Lake Erie or allowing the individual harbors' waters to coalesce into one or two combined water bodies.

Field Trip Stop 1—Barrier Beach (41°33'34.8"N, 82°48'17.7"W)

The barrier beach at East Harbor State Park is a feature similar to the Cedar Point spit and Bay Point, both long ridges of sand near Sandusky, about 11 km (7 mi) to the southeast. All of these beaches are also somewhat similar to barrier beaches and sand spits that line the East Coast of the United States and extend around the rim of the Gulf of Mexico, such as the Outer Banks of North Carolina and Miami Beach. Barrier beaches at the margins of the sea are believed to have originated from sea level rise following the end of the Pleistocene (Ritter, 1986, p. 524), and similarly the barrier beaches and sand spits of Lake Erie formed as modern Lake Erie rose about 4,000 years ago.

East Harbor State Park was opened to the public in 1946 and its bathing beach became a destination for tens of thousands of people on a typical summer weekend (Henry, 2006). In 1954, park attendance was over 800,000 people (ODNR, 1954, table A). About 3.2 km (2 mi) long, the beach was up to 30 m (100 ft) wide in 1957 (fig. 44). The gently-sloping lakebed just offshore of the beach afforded a swimming area that was not only long but wide, so that even children could wade safely for a considerable distance offshore. For contrast, at Mentor Headlands beach in Lake County, a tall man would be in over his head before he could wade 30 m (100 ft) into the lake, but at East Harbor the water would be less than waist deep at that distance. In the 1950s, the long, wide beach and large wading area eased crowding conditions on busy weekends. But lake levels rose through the 1950s and 1960s, followed by powerful northeastern storms in 1969 and 1972 that stripped away most of the beach sand (Moore, 1973, p. 65). By 1973, there was no beach at all. Today, stairs in the breakwall that once gave access to the wide bathing beach now lead down to open water (fig. 45), and the foundations of now-demolished bathhouses are the only clues to how popular the shorefront once was.

The beach at East Harbor State Park has never entirely recovered to its mid-twentieth century width and is unlikely to do so as long as lake levels remain higher than they were at the peak of the park's popularity. East Harbor provides a clue as to the future that awaits ocean coast beaches if sea levels rise as they are predicted to. However, a 520-m (1,700-ft) long portion of the park's beach has been restored. As at Maumee Bay State Park, the restored beach is protected by a set of rubble mound breakwaters. Twenty-one breakwaters were originally proposed for the entire length of the park shore, although only four were built. As at Maumee Bay State Park, the breakwaters restrict incoming wave energy and protect the beach from erosion.

Field Trip Stop 2—Glacial grooves (41°32'32.9"N, 82°48'59.7"W)

Near the southernmost campgrounds there is an assemblage of glacial grooves (fig. 46). While not as spectacular as those found on Kelleys Island, they are typical of grooves that are usually found in the vicinity of Lake Erie. The bedrock has a gently undulating surface with a distance of perhaps a 0.3 m (1 ft) or more between ridge crests, on which is superimposed a profusion of fine grooves and scratches, and all features have the same azimuth, about 078°, indicating the direction from which the responsible ice lobe came. This azimuth corresponds with the large glacial groove on Kelleys Island.

Economic Geology

The East Harbor/Catawba Island region has been only a small contributor to Ohio's minerals industry. A gypsum mine operated for nearly two centuries about 9 km (5.5 mi) away on the northern side of Sandusky Bay, and there are probably other deposits of gypsum in the region; however it would take a considerable investment to open a new mine to compete against established operations (including gypsum recovery from industrial processes) elsewhere in the United States. Oil and gas production does not occur in this region of Ohio. There are many water wells drilled on the Marblehead and Catawba peninsulas, developed in limestone and dolomite to produce generally adequate supplies of water for domestic use.

FIGURE 44. The beach and breakwall at East Harbor State Park, Ottawa County, Ohio, in 1957 and in 2018.

FIGURE 45. Ramp at East Harbor State Park, Ottawa County, Ohio, that once led to a sand beach (see fig. 44) but now leads only to water.

FIGURE 46. Glacial grooves at East Harbor State Park, Ottawa County, Ohio.

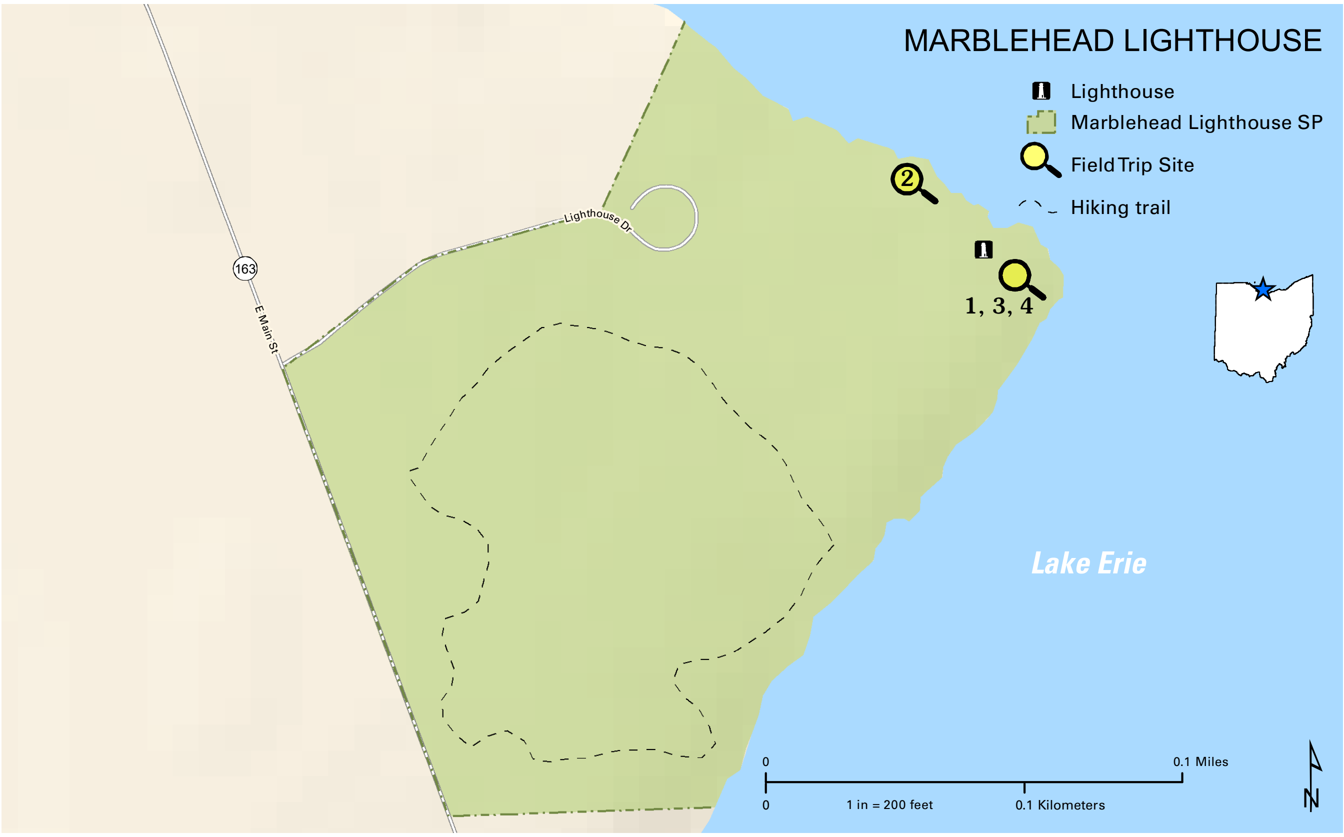

FIGURE 47. Overview map of Marblehead Lighthouse State Park, Ottawa County, Ohio.

Site 4 – Marblehead Lighthouse State Park

Introduction

Marblehead Lighthouse State Park is a small park on the tip of the Marblehead peninsula, with a trail, picnicking and fishing access in addition to the lighthouse itself (fig. 47). Marblehead, meaning "limestone headland," is named for the rock that comprises the peninsula. Although the precise definition of *marble* is metamorphosed calcite, in popular usage the word has also been a synonym for limestone. A *headland* is a body of land that juts into a body of water.

Regional Concept—Bedrock geology

The bedrock at Marblehead Lighthouse State Park is Early Devonian Columbus Limestone. The Columbus has been quarried since the nineteenth century from central to north-central Ohio for use in the construction industry, mainly as aggregate, but also as *dimension stone* (large, pre-cut blocks) and rubble for erosion protection. On Marblehead, LaFarge North America operates a large quarry, moving stone by overhead conveyor across State Route 163 (Main Street in the Village of Marblehead) to a dock next to the Kelleys Island ferry dock. From there it is shipped out over water. In 2022, over 3.0 million metric tons (3.4 million tons) of stone were produced from this quarry (Wright, 2023). (The quarry is privately-owned and not part of the state park; do not trespass.) Lake Point Park, at 11257 East Bayshore Road, about 1.0 km (0.6 mi) south of the Marblehead Lighthouse, occupies land once occupied by a quarry.

The Columbus Limestone outcrops in a 1.6 to 8 km (1 to 5 mi) -wide belt from southern Pickaway County north to Pelee Island in Canada, with the farthest northern occurrence reported at a quarry in Ingersoll, Ontario, and the greatest thickness of about 32 m (105 ft) in central Ohio (Stewart, 1955, p. 155). On Marblehead peninsula, the thickness at the LaFarge quarry is 12.5 m (41 ft; Forsyth, 1971). The Columbus is correlated with the Onondaga Limestone of western New York (Milici and Swezey, 2006). Several subdivisions are recognized, in ascending order, as the Bellepoint, the Marblehead, the Venice, and the Delhi Members, with only the first three occurring in northern Ohio. The Bellepoint Member is brownish and higher in magnesium than the other members. The Marblehead Member is gray to light brown, finely crystalline and fossiliferous, and the Venice Member is bluish gray, thin-bedded, *argillaceous* (clay-containing), fossiliferous, and locally **chert**-containing.

Field Trip Stop 1—Fossils (41°32′10.7″N, 82°42′41.7″W)

Fossils in the Columbus Limestone include brachiopods, bivalves, corals, cephalopods, crinoids, gastropods, bony fish remains, stromatoporoids (sponge-like organisms), trilobites, and *trace fossils* (burrows and tracks of sediment-dwelling organisms). Some of these, especially **silicified** corals, are visible at Marblehead Lighthouse State Park, although the rock there has been exposed to weathering and foot traffic for a long time, obscuring some of the fossils (fig. 48).

FIGURE 48. Silicified and highly worn colonial coral fossil *(Syringopora tabulata)* in Columbus Limestone at Marblehead Lighthouse State Park, Ottawa County, Ohio.

Field Trip Stop 2—Concretions and weathering (41°32′11.9″N, 82°42′43.5″W)

Also apparent in the limestone at Marblehead Lighthouse State Park are **concretions** and **honeycombing**, or **honeycomb weathering**. Concretions (fig. 49) are particularly common in the Devonian shales of Ohio; their occurrence here in limestone is somewhat unusual. They result from the precipitation of minerals around some core or nucleus, such as a piece of shell or other organic matter; they are often much harder than the surrounding rock and their composition is usually dominated by a single mineral, such as chert or **pyrite**.

FIGURE 49. Concretion in Columbus Limestone near base of Marblehead Lighthouse, Ottawa County, Ohio.

There are several forms of weathering called **honeycombing** occurring in different types of rock. The honeycomb weathering found at Marblehead (fig. 50) appears to be the result of weathering having created pits, probably by acting upon pre-existing voids. The voids and pits become enlarged, a form of **karst** weathering. The honeycomb weathering is quite apparent in the rocks near the base of the lighthouse. Finding similar pitting at Kelleys Island, Fisher (1922, p. 10) claims it occurred following glacial retreat, finding the affected rocks bear glacial grooves.

FIGURE 50. Honeycomb weathering in Columbus Limestone near base of Marblehead Lighthouse, Ottawa County, Ohio.

Field Trip Stop 3—Jointing (41°32′10.7″N, 82°42′41.7″W)

Fractures in rock along which no displacement (movement) has occurred are called *joints*. (A joint where movement has occurred is called a *fault*). Joints are often found in parallel groups that can be traced over a broad area, sometimes for hundreds of miles. Such systematic jointing occurs in response

FIGURE 51. Systematic joint set (highlighted by yellow lines) in Columbus Limestone at Marblehead Lighthouse State Park, Ottawa County, Ohio.

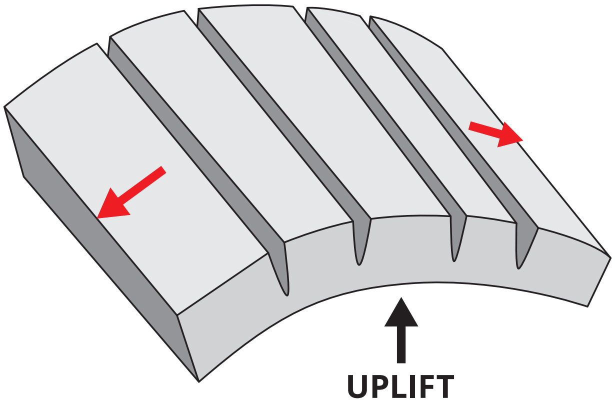

FIGURE 52. Possible model (no scale implied) for the formation of systematic joint sets in fig. 51. Uplift (black arrow) of the Findlay Arch causes tension (red arrows) in the overlying rocks, leading to fracturing along the axis of uplift.

FIGURE 53. Glacial markings in Columbus Limestone at the LaFarge North America quarry, Marblehead, Ohio. Colonial coral fossil *(Syringopora tabulata)* in foreground.

to regional tectonic forces. A prominent set of systematic joints, trending about 026° to 030°, is found under the trees between the lighthouse and the water (fig. 51). These joints are roughly parallel to joint sets trending 030° found in Columbus Limestone on Kelleys Island. All these joint sets are roughly parallel with the Findlay Arch (fig. 5), whose axis is about 29 km (18 mi) west. It may therefore be that the regional tectonic uplift that created the arch resulted in tension that fractured these rocks, creating the joint sets (fig. 52).

In addition to providing clues to tectonic stresses, joints determine how rock erodes and serve as conduits that can be followed by groundwater, streams, and glacial ice. Consequently, weathering, erosion, and soil development are influenced by regional joint trends. The shape of Lake Erie may be partly a result of regional joints that were sculpted by water and ice into the current basin. Miller (1996, p. 81) found a set of joints in Devonian shale across northern Ohio and in the Bellefontaine Outlier (Logan County) with an average trend of 057°, which is roughly parallel to the trend of the central and eastern Lake Erie basins, about 058° to 062°.

In an older portion of the LaFarge quarry, operations to remove the glacial soil and overburden exposed a surface of glacial **striations** and shallow grooves (fig. 53). The direction of the striations trends northeast–southwest, closely coincident with the grooves on Kelleys Island, and indicates the direction of travel of the ice that created them. This area is under private ownership and is not accessible without special permission from the site owner, so do not trespass. The most impressive glacial grooves—in Ohio, and probably in the world—are publicly accessible on Kelleys Island.

Like the dolomite of the Salina Group (Sites 2 and 5), Columbus Limestone is subject to the formation of **karst**, although there is little evidence of sinkholes, caves, or similar features at Marblehead. However, the privately-owned Seneca Caverns, less than an hour south in Bellevue (Seneca County), are developed in Columbus Limestone and are open to the public.

Field Trip Stop 4—Marblehead Lighthouse (41°32’10.7”N, 82°42’41.7”W)

The 12 m (50 ft) -high lighthouse was built in 1822, at a cost of $6,250, of Columbus Limestone quarried locally on Marblehead peninsula. A layer of stucco covers the limestone. The original lightkeeper’s house (Wolcott House), now owned by the Ottawa County Historical Society and about 4.0 km (2.5 mi) southwest of the lighthouse at 9999 East Bayshore Rd., is also built of Columbus Limestone, but is not covered by a veneer. (The lightkeeper’s house adjacent to the lighthouse was built at a later date.)

As the oldest continuously-operated lighthouse on the Great Lakes, the lighthouse has shown remarkable longevity, especially given its location directly at the tip of Marblehead peninsula, where northeastern winds blow over as much as 346 km (215 mi) of open lake before making landfall. (If you stand at the point of land at the base of the lighthouse and face northeast at a bearing of 063°, there is only water between you and Buffalo, New York.) Because of the long **fetch**, northeastern storms are some of the most destructive to strike the Ohio shore, but the lighthouse has endured here for two centuries. Being sited directly on Columbus Limestone lends a measure of natural protection, although some limestone boulders have also been emplaced for additional protection. Some of the larger limestone slabs (probably the Venice Member of the Columbus Limestone) along the shore are not ***in situ****;* they came from offshore and were shoved into their current places by winter ice.

Field Trip Stop 5—Lakeside Daisy State Nature Preserve (41°32’1.1”N, 82°43’37.9”W, pets prohibited)

About 1 km (0.6 mi) west of Marblehead Lighthouse State Park is the Lakeside Daisy State Nature Preserve. From the lighthouse, head north (turn right) on State Route 163 into the village of Marblehead, then turn south onto Alexander Pike. The nature preserve is on the eastern side of the road about 0.7 km (0.4 mi) south of State Route 163. The Lakeside Daisy State Nature Preserve was set aside from formerly quarried land to protect the federally-protected Lakeside Daisy. The Lakeside Daisy (*Hymenoxys herbacea*) has been listed as an endangered species since 1980 and it has an extremely limited geographic range—the only natural population of this species in Ohio occurs on Marblehead Peninsula, although the ODNR Division of Natural Areas and Preserves has established a population on Kelleys Island as well. Limestone quarrying destroys the daisy’s habitat, which is also threatened by the expansion of woody vegetation that blocks the daisy’s exposure to sunlight (USFWS, 2019). The daisy grows on nearly bare limestone and produces bright yellow flowers that bloom in May. The type of environment the daisy depends on—nearly barren limestone with little to no soil—is called an *alvar*, and hosts a number of rare plant species. The North Shore Alvar State Nature Preserve on Kelleys Island is another example of a publicly-accessible alvar.

Economic Geology

The Marblehead peninsula has been quarried for Columbus Limestone and Lucas Dolomite since at least the nineteenth century. Gypsum was produced at a surface mine about 15.5 km (9.6 mi) west of the lighthouse, on the northern side of Sandusky Bay, from 1822 until the 2000s. Oil and gas are not produced anywhere in the region. Over one hundred water wells have been drilled within 6 km (3.7 mi) of the lighthouse, ranging in depth from 6 to 85 m (20 ft to 280 ft) or more, and have been tested to produce water from 3.8 L to 1,890 L (1 to 500 gal) per minute. About 19 L (5 gal) per minute is usually considered the minimum needed for domestic use.

Site 5 – State Parks of the Bass Islands (South Bass, Oak Point, Middle Bass, North Bass)

Introduction

The Bass Islands are an **archipelago** consisting of Silurian-age dolomites of the Salina Group. All these islands belong to the same stratum of bedrock, which also includes Catawba Island. In the preglacial past, this stratum was a fairly prominent ridge on the landscape, albeit somewhat dissected by stream erosion. Repeated incursions by glaciers during the Quaternary Period eroded the ridge, widening the stream channels and leaving isolated hilltops that became islands when Lake Erie rose. Kelleys Island was formed similarly, although its composition is Devonian Columbus Limestone, so it sits higher on the stratigraphic column (fig. 25).

Regional Concept—Karst and caves

The Bass Islands are covered by thin layers of soils characteristic of glacial deposits, essentially tills, outwash, and glaciolacustrine (glacial lake) clays. Beneath those soils is dolomite, deposited in tropical, nearshore environments such as lagoons, reefs, and shorelines (Schumacher and others, 2013, p. 112). Similar to Catawba Island, the upper Salina Group rocks making up the Bass Islands are susceptible to **karst**-forming processes (see **Site 2 – Catawba Island State Park**) that began during the Paleozoic Era and have continued into the Holocene Epoch. South Bass Island is dotted with sinkholes, and over 30 caves are known to exist on the island (Verber and Stansbury, 1953), although most are small and not open to the public. Karst topography is evident in the form of hummocky topography (not pictured) along Mitchell Road and West Shore Boulevard. Privately-owned caves open to the public (for a fee) are Perry's Cave and

FIGURE 54. Celestine crystals in Crystal Cave on South Bass Island in Lake Erie. Image credit: Sean Munson.

Crystal Cave. The latter is so named for being lined by crystals of celestine as large as 46 cm (18 in) long (fig. 54). Celestine is the mineral form of strontium sulfate ($SrSO_4$; Wolfe, 2014). Before Crystal Cave was opened to the public, the celestine crystals were mined and sold to fireworks makers as a source of strontium, which generates the red incandescence in fireworks.

How most of the caves on South Bass Island formed is not fully understood because the mode of formation seems to differ from caves on Ohio's mainland. Mainland caves formed from the dissolution of rock along pre-existing joints. The joints often serve as narrow passages connecting caves at different levels (Cottingham, 1919). In contrast, most of the caves on South Bass Island are not connected by passages and are otherwise dissimilar in form and shape from mainland caves. Specifically, they show evidence that their roofs and floors were once contiguous, suggesting the cavities formed by separation of the dolomite layers rather than by dissolution of rock.

The proposed mechanism of separation is the swelling of gypsum (Cottingham, 1919; White, 1926, p. 85; Verber and Stansbury, 1953). Gypsum occurs in the upper and middle Salina Group and was mined near Port Clinton for about 180 years (Wolfe, 2001, p. 3). Gypsum forms when lens-shaped deposits of anhydrite (calcium sulfate; $CaSO_4$) react with water and swell, increasing the anhydrite's volume by 33 percent or more (Cottingham, 1919). Such swelling forces the bounding rock layers apart (fig. 55). Subsequent dissolution of the gypsum leaves cavities with domed roofs in various states of collapse, such as the caves on South Bass Island. As with the karst found at Catawba Island and elsewhere, it is uncertain when in geologic time this process occurred.

As with Catawba Island, rock exposures on the shores of the Bass Islands make for attractive scenery best appreciated from the water. Warped bedding and cavities with dome-shape roofs are visible from offshore and make it easy to visualize how collapse caverns formed (fig. 56).

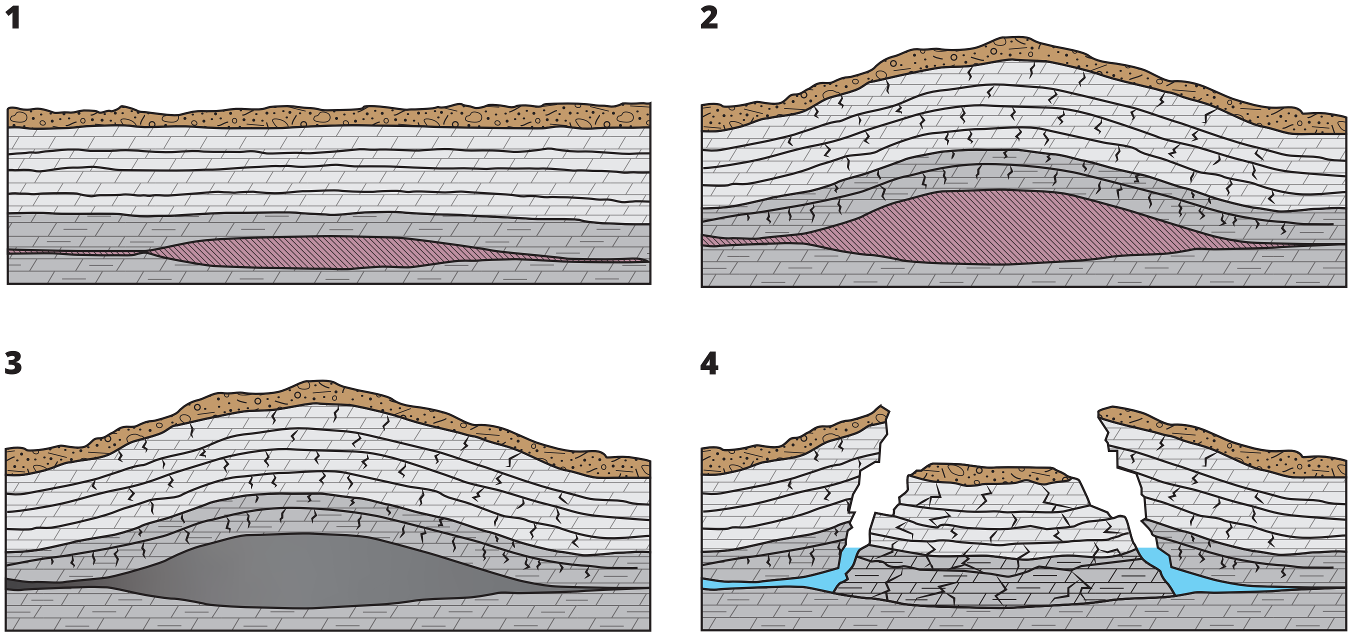

FIGURE 55. Theory of formation of caves on South Bass Island in Lake Erie. (1) Undisturbed bedding with anhydrite. (2) Anhydrite absorbs water, becomes gypsum, and swells. (3) Gypsum is dissolved, leaving a cavity. (4) The roof of the cavity collapses. After Verber and Stansberry (1953).

FIGURE 56. Scenic outcrop of Salina Group Dolomite as commonly observed in the Bass Islands of Lake Erie. The voids at the waterline are thought to result from the expansion of layers of anhydrite, which distorted the overlying beds of dolomite and were then dissolved away by groundwater, leaving dome-shaped voids.

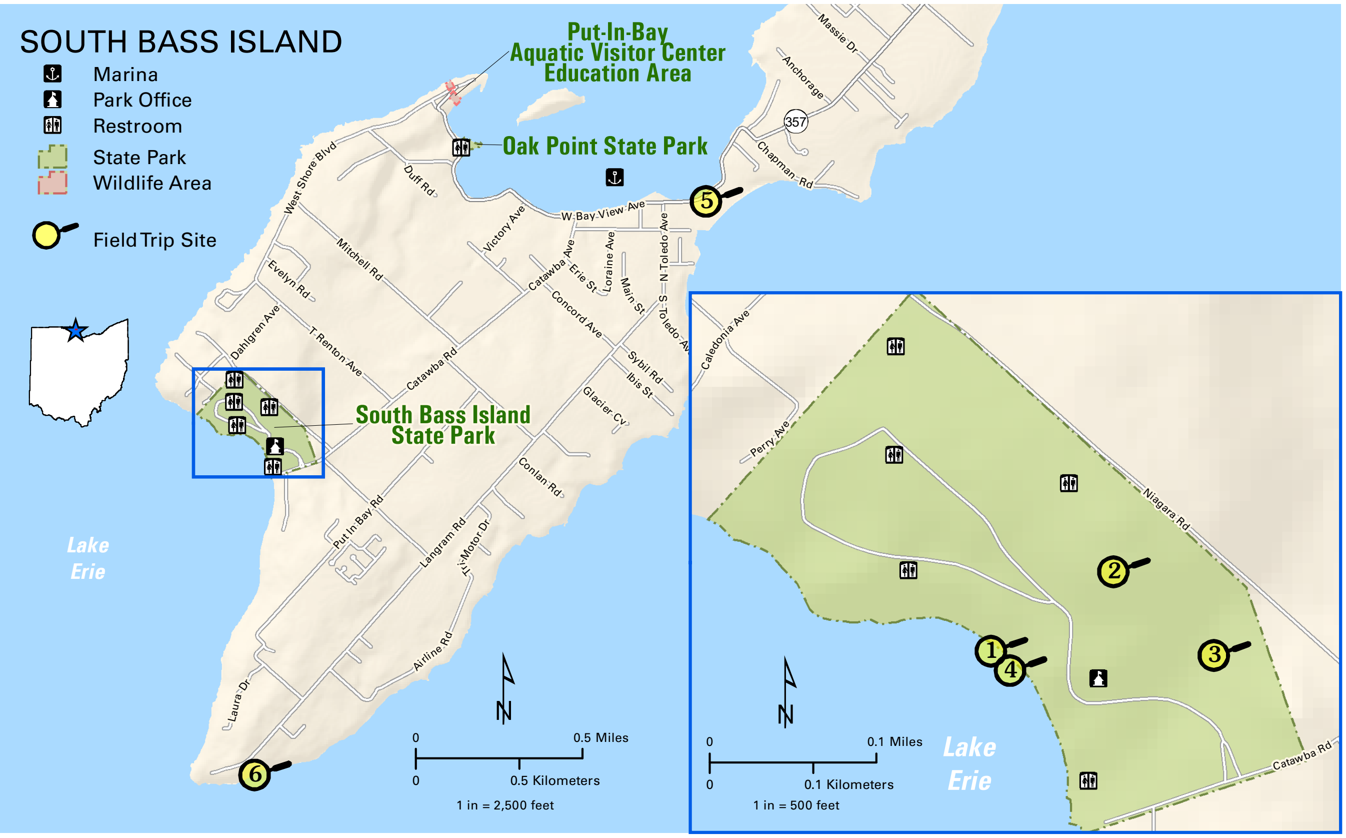

FIGURE 57. Overview map of South Bass Island State Park, Ottawa County, Ohio.

Site 5.1 – South Bass Island State Park

This park occupies 33 acres on the western side of South Bass Island (fig. 57) with the rocks of the upper Salina Group being exposed almost continuously along the shore. Smaller exposures are scattered throughout the woods and camping areas of the park. The outcrops at higher elevations in the campground expose examples of the so-called Bass Islands Dolomite, the brecciated unit described in the section on **Site 2 – Catawba Island State Park**.

Field Trip Stop 1—Bedrock geology (41°38′37.3″N, 82°50′17.2″W)

South Bass Island has the form of a **cuesta**, a bedrock ridge with a gentle slope on one side and a steep slope on the other. The elevation rises gradually from east to west, the ground at the northeastern tip of the island being barely above the lake at about 175 m (575 ft) above m.s.l., whereas in the southwest the surface rises to over 194 m (635 ft) above m.s.l. Cliffs on the western side of the island plunge back to lake level almost vertically. The island owes this **morphology** to the regional eastward dip of the bedrock (fig. 25).

A note on the stratigraphic nomenclature: As noted in the section on **Site 2 – Catawba Island State Park**, the Ohio Geological Survey recognizes the rocks exposed at the surface in the Bass Islands region as the upper Salina Group, with the term Bass Islands Dolomite accepted by some to refer to an uppermost stratum of Silurian dolomite filling ancient **karst** voids in the upper Salina Group. Once thought to represent a different depositional environment, the infilling rock is now understood to be a post-deposition alteration of upper Salina Group rocks and therefore not deserving of its own separate designation. However, older literature and field guides (Sparling, 1970; Forsyth, 1971) refer to a Bass Islands Formation, of which the rocks at South Bass Island State Park were considered to be a subunit, called the Put-in-Bay Dolomite. The shoreline outcrop at the state park is the *type section* (location of the first published description) of the Put-in-Bay Dolomite; however, this name is no longer in formal use, the rocks now being grouped with the upper Salina Group.

FIGURE 58. Outcrop of upper Salina Group rocks at South Bass Island State Park, Ottawa County, Ohio. Note distortion of thin beds near the base.

The best exposures of rock are seen heading northwest from the state park boat ramp, although vegetation obscures some of the exposures. Be careful of poison ivy. Nearest the boat ramp, the bank is low and only a small amount of thin-bedded dolomite mudstone is exposed, but the outcrop becomes higher farther northwest. A unit of more massive dolomite, 0.3 to 0.6 m (1 to 2 ft) thick, eventually appears, separating the thin-bedded dolomites. (fig. 58).

Also see **Site 2 – Catawba Island State Park**, for a description of the upper Salina Group bedrock.

Field Trip Stop 2—Glacial grooves (approx. 41°38′39.8″N, 82°50′12.1″W)

Although much less spectacular than at Kelleys Island, there is an exposure of glacial grooves in the campground area. Note the sign restricting vehicular access to the campgrounds to vehicles with camping passes.

Field Trip Stop 3—Former shorelines (41°38′37.2″N, 82°50′7.9″W)

Heading up from the boat ramp to leave the park, one sees to the left a set of four octagonal cabins (referred to by Ohio State Parks as “cabents”) cantilevered at the top of a ridge. The ridge extends into the wooded section of the park and is probably the shoreline bluff of a pre-modern lake (fig. 59). The crest of this feature is about 184 to 186 m (605 to 610 ft) above m.s.l., the same elevation as the bluff overlooking the Miller Ferry dock at the southern tip of the island. Interestingly, there does not appear to be a named lake associated with this elevation. Lake Lundy is associated with the elevation of 189 m (620 ft), and figure 2 of Calkin and Feenstra (1985) identifies a lake at 183 m (600 ft) but does not give it a name. This bluff may represent a stage of Lake Lundy that existed briefly before lake levels dropped down to form Early Lake Erie.

Field Trip Stop 4—Cobble beach (41°38′36.7″N, 82°50′16.4″W)

Beaches are usually associated with sand, but where sand is scarce, a beach may be composed of other materials. Wide sand beaches are rare in the Lake Erie islands because the source of most sand, the glacial soil, is thin and only sparsely sandy. At South Bass Island State Park, there is a cobble beach instead (fig. 60), its materials derived directly from the erosion of the dolomite exposed along the shore. A few glacial erratic cobbles and boulders are found as well.

FIGURE 59. Cabins located at the crest of an old lake bluff at South Bass Island State Park, Ottawa County, Ohio.

FIGURE 60. Cobble beach along the Lake Erie Shore at South Bass Island State Park, Ottawa County, Ohio.

Field Trip Stop 5—Perry's Victory and International Peace Memorial (41°39'15.6"N, 82°48'41.5"W)

Perry's Victory and International Peace Memorial (more commonly known as the Perry Monument) deserves mention although it is a property of the U.S. National Park Service and is not an Ohio state park. Standing 107 m (352 ft) high, the monument is faced with granite quarried in Milford, Massachusetts (U.S. National Park Service, 1957), the same material used in the façades of iconic New York City buildings such as the American Museum of Natural History and the original (1910–1963) Penn Station. The light-gray to pale pink color of the granite derives from the minerals orthoclase feldspar and quartz, with clusters of biotite (black mica) forming the black specks (fig. 61). An igneous rock dated at about 630 million years of age (U.S. Geological Survey, 2015), the granite is about 200 million years older than the dolomite making up South Bass Island itself. To find granites occurring natively in Ohio, one must drill down through up to 4,270 m (14,000 ft) of Paleozoic sedimentary rocks.

Field Trip Stop 6—Lime kiln (41°37'45.7"N, 82°50'15.2"W; permission required)

At the southern tip of South Bass Island beside the Miller Ferry dock is an antique structure, a lime kiln (fig. 62). Lime kilns are used to manufacture quicklime (calcium oxide, or CaO) by the combustion of limestone or dolomite. The probable use of the quicklime was to make mortar for stone buildings on the island. It is not known when this lime kiln was last operated, but it has almost certainly been out of operation for more than a century. (The kiln is on land owned by the ferry operator but is easily visible to the left as you disembark from the ferry; please do not approach the kiln without first obtaining permission).

FIGURE 61. Close-up photograph of granite in Perry's Victory and International Peace Memorial on South Bass Island in Lake Erie. Lens cap for scale.

FIGURE 62. Old lime kiln beside ferry dock on southern tip of South Bass Island in Lake Erie.

FIGURE 63. Overview map of Oak Point State Park, Ottawa County, Ohio.

Site 5.2 – Oak Point State Park

At only 0.6 hectares (1.5 acres), Oak Point State Park is the smallest of Ohio's state parks, offering dockage, fishing, picnicking, and an excellent view of Put-in-Bay and Gibraltar Island (fig. 64).

Field Trip Stop—Alligator Reef (41°39'23.2"N, 82°49'30.5"W)

The bay between Oak Point and Gibraltar Island is very shallow, as little as 0.6 m (2 ft) deep. It is shallowest along a narrow gravel bar, called Alligator Reef, that connects Oak Point to Gibraltar. During a seiche event (see **Site 1 – Maumee Bay State Park**), with strong southwestern winds, the water level may drop enough to expose the bottom of Put-in-Bay here (fig. 64).

FIGURE 64. View of Gibraltar Island from Oak Point on South Bass Island during a seiche event in 1998 (top) and under normal conditions in 2016 (bottom). Ridge of gravel exposed at low water is Alligator Reef. Top photo courtesy of Bob Danklefsen.

FIGURE 65. Overview map of Middle Bass Island State Park, Ottawa County, Ohio.

Site 5.3 – Middle Bass Island and North Bass Island State Parks

Middle Bass and North Bass islands (figs. 65 and 66) have the same geologic makeup as South Bass and Catawba Islands, all being members of the same bedrock ridge or escarpment that extends up into Lake Erie. The bedrock is upper Salina Group dolomite. Small glacial grooves and scratches, similar to those found on South Bass Island and the mainland, may be found occasionally. The topography of Middle Bass and North Bass Islands is flatter than that of South Bass and Catawba Islands. Karst terrain appears to be less common on Middle Bass and North Bass as well, although there may be a few sinkholes. The state park holdings on Middle Bass Island are concentrated in the southern extent of the island and are not all adjacent to one another, so be aware of this when hiking and do not trespass on private lands.

Fox's Marsh Wildlife Area, in the southwestern quadrant of North Bass Island, is an example of a natural coastal wetland and provides habitat for the Lake Erie water snake, fox snake, and various waterfowl, shorebirds and songbirds. The Lake Erie water snake was once listed as a federally endangered and threatened species, although it remains protected under Ohio law.

Honey Point Wildlife Area, at the extreme southeastern corner of North Bass Island, contains a small wetland area that serves as waterfowl, shorebird and songbird habitat. The wildlife area is not accessible by road although paddlers may access the area.

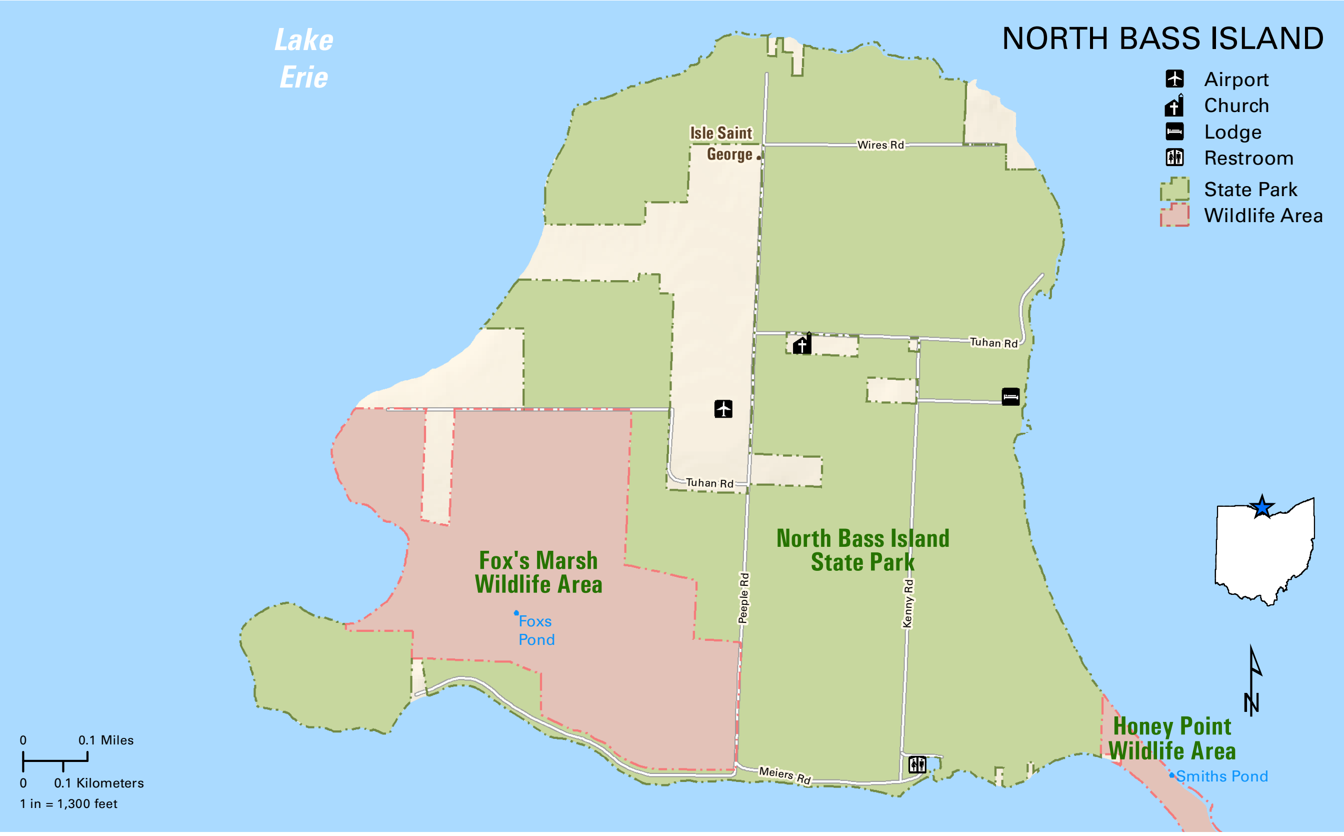

FIGURE 66. Overview map of North Bass Island State Park, Ottawa County, Ohio.

Economic Geology

Small in size, the Bass Islands have had only a tiny impact on the state's minerals industry. A small quarry operated near the southern end of South Bass Island for a few years in the 1980s, producing crushed stone for concrete aggregate. As noted under **Regional Concept—Karst and caves**, celestine was once mined as a source of strontium, but other countries have since outpaced the United States as a celestine source and it is no longer mined from the island. Oil and gas are not produced on the island or in the region. There are almost 300 water wells on the island, which are developed in limestone or dolomite at depths from 8 to 62 m (27 to 205 ft), and when tested produced water from 3.8 L to 380 L (1 to 100 gal) per minute. About 19 L (5 gal) per minute is usually considered the minimum needed for domestic use.

FIGURE 67. Overview map of Kelleys Island State Park, Erie County, Ohio.

Site 6 – Kelleys Island State Park

Introduction

Kelleys Island State Park is 2.7 km^2 (677 acres) spread mainly throughout the central and northwestern parts of the island, with camping, water-based recreation, and hiking as major activities (fig. 67). (If hiking, please be aware of the park extents and do not trespass on private land.) 5.6 km (3.5 mi) north of Marblehead Peninsula, Kelleys Island is the largest Lake Erie island in U.S. waters (Pelee Island in Canada is largest overall) with an area of about 11.3 km^2 (2,800 acres), and is composed mainly of Columbus Limestone with a small exposure of the uppermost Lucas Dolomite occurring near the waterline on the western shore (see **Site 4 – Marblehead Lighthouse State Park** for a description of the Columbus Limestone). The island is part of a bedrock ridge that stretches from Pelee Island south through Marblehead, Johnson Island, and onto the Ohio mainland. Before the Quaternary Period and the formation of Lake Erie, this ridge was dissected by streams and erosion, and the islands at that time were bedrock hills. Glacial incursions widened and deepened the stream cuts and as modern Lake Erie formed, the rising waters separated the islands from the Ohio mainland.

As your ferry approaches the island, note that the boat basin behind the ferry dock was formerly a natural pond or embayment, and that the paved area where vehicles line up to board the ferry was formerly a **baymouth bar**—a natural sandbar that separated the bay from the lake. The practice of converting natural bays, coves, and stream mouths into boat basins, marinas, and harbors is common in the Great Lakes.

Field Trip Stop 1—Glacial Grooves Geological Preserve (41°36′58.7″N, 82°42′23.4″W)

The Glacial Grooves Geological Preserve features the last of some of the largest and most spectacular glacial grooves known in the world. Most of the grooves occur in a single trough, about 130 m (425 ft) long, termed a *megagroove* (Goldthwait, 1979; fig. 68). The megagroove was once 150 m (500 ft) longer than today and was only one of a population of deep grooves on the island. Amazingly, most of the grooves were deliberately destroyed by quarrying operations during the nineteenth century[7]. Knowledge of the other grooves comes only from written descriptions and photographs from that period. Such disinterest in preserving these features seems unbelievable today, but cultural imperatives were much different during the Industrial Revolution, when the demand for raw materials was rising rapidly and the natural world's capacity to provide them seemed limitless. Fortunately, the parcel of land containing the last surviving megagroove was donated to the State of Ohio in 1925 and has been preserved ever since.

When donated to the state, the megagroove had been filled in with quarrying debris, which rested on a layer of natural till that had never been disturbed (fig. 69). A section of the megagroove about 11 m (35 ft) long was partially exhumed during the 1930s by the Depression-era Works Progress Administration. The groove was not

FIGURE 68. The megagroove at Glacial Grooves Geological Preserve on Kelleys Island in Lake Erie.

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[7] Samples of the grooves were also cut out and sent to the Field Museum of Natural History (Chicago, Illinois) and the Smithsonian Institution in Washington, D.C., and the author has personally seen a small sample of the grooves displayed outside the Carnegie Building on the campus of Oberlin (Ohio) College.

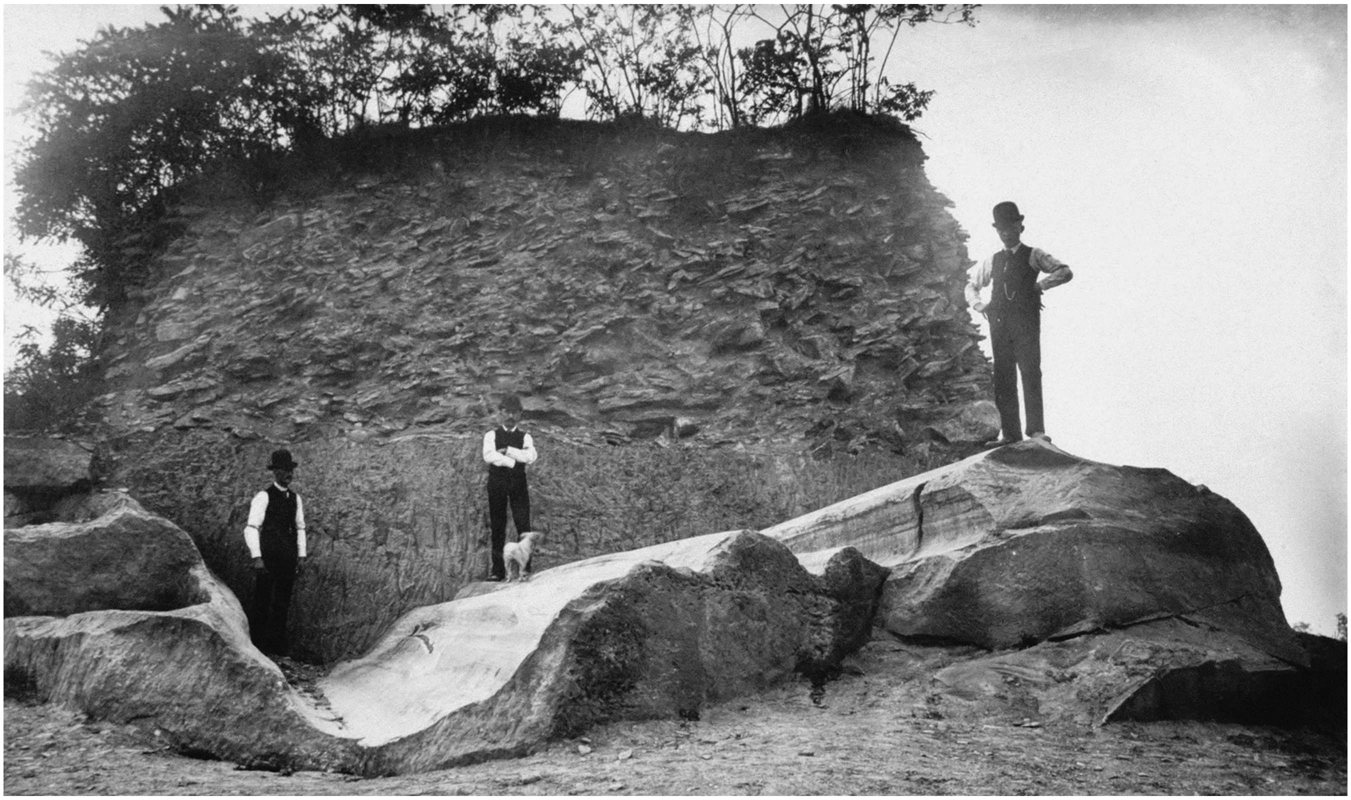

FIGURE 69. Historical photograph of the megagroove on Kelleys Island in Lake Erie, before it was fully excavated.

fully exhumed until the early 1970s, the work done partially by student-provided hand labor (Goldthwait, 1979). When the glacial deposits were removed, the newly-exposed surfaces of the megagroove were reported to have a glazed appearance, suggesting that fine clays at the base of a moving glacier had polished the rock surface like jeweler's polish. Within one season of exposure to the atmosphere, the polish disappeared (Hansen, 1988).

Like the majority of glacial markings in the Lake Erie Islands/Marblehead region, the megagroove is oriented northeast–southwest, indicating the direction of ice travel. But whereas most other markings are mere striations—essentially scratches in the rock—the megagroove is an extremely complex feature of another class entirely. Not actually a single structure, the megagroove is a set of grooves which themselves consist of subordinate features, including shallower grooves, striations, and streamlined forms (fig. 70) that have been described as "whalebacks," "water-melon ends" (Goldthwait, 1979), "cigar-headed ridges" (Snow and others, 1991), and most eloquently as "so many Corinthian columns lying side by side" (Ver Steeg and Yunck, 1935). Historical photographs[8] of the grooves that were destroyed show that some of them meandered like streams, which may be a clue to their origin.

Like the gorge of the Niagara River and the Grand Canyon, the megagrooves were first hypothesized in the nineteenth century to have formed when the waters of Noah's flood drained into the ocean basins. The flood hypothesis was discarded with the development of glacial theory, which better accounts for features such as glacial grooves, till, proglacial lakes, moraines, and isostatic rebound. However, the specific mechanism that carved the grooves is still debated.

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[8] The Ohio History Connection, The Rutherford B. Hayes Presidential Library (Fremont, Ohio), and the Orton Geological Museum of the Ohio State University maintain collections of historical photography from Kelleys Island that include the early, destroyed grooves.

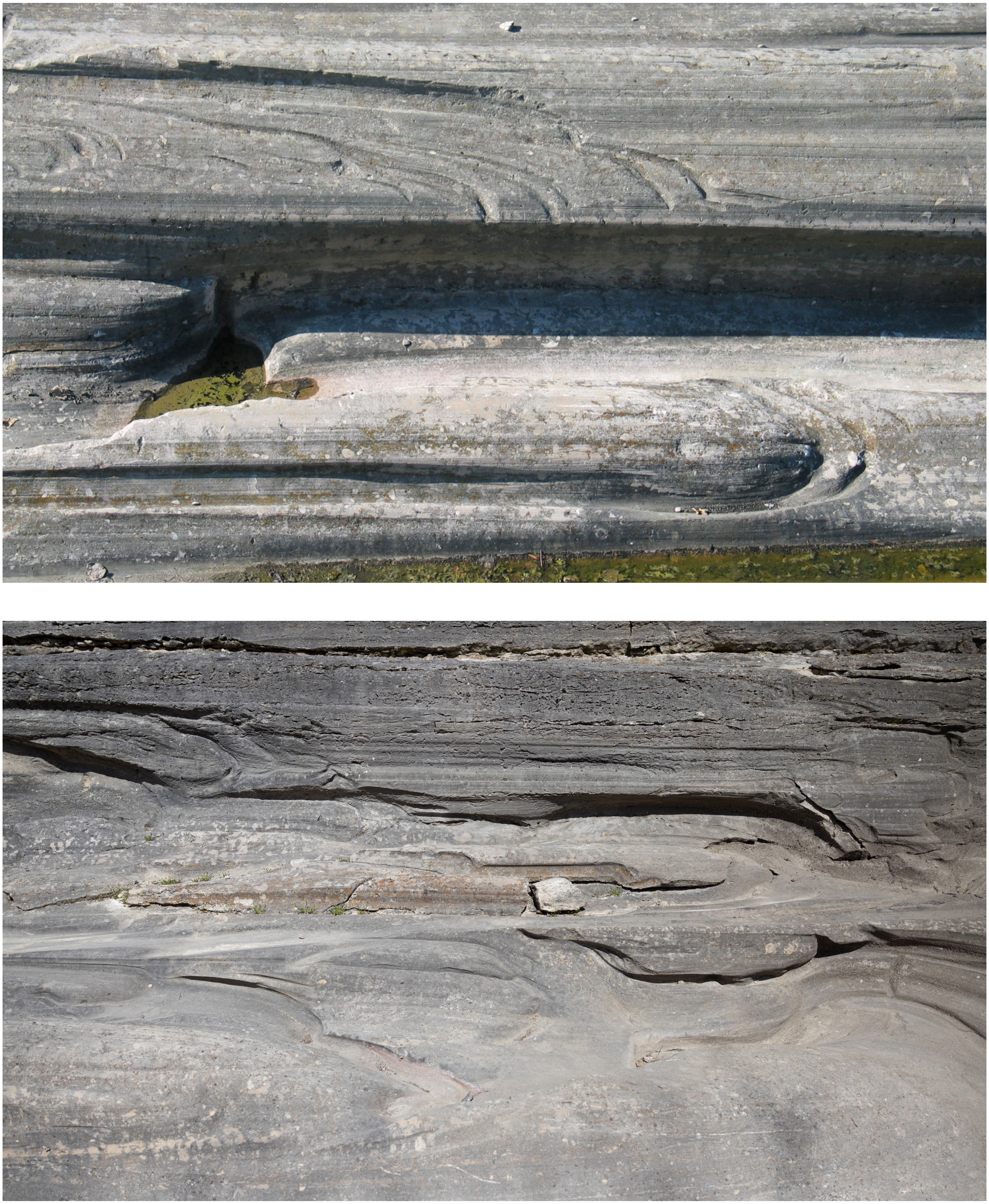

FIGURE 70. Complex features found inside the megagroove at Glacial Grooves Geological Preserve on Kelleys Island in Lake Erie. The megagroove is a set of grooves which themselves consist of subordinate features, including shallower grooves, striations, and streamlined forms that have been described as "whalebacks."

Simplified, the debate comes down to ice versus liquid meltwater. Advocating for ice, Carney (1910) proposed that the grooves were gouged primarily by slow-moving ice with rocky debris frozen in it. Goldthwait (1979) essentially agreed with this hypothesis while offering additional details. However, later researchers have argued that some features in the megagroove, such as a pothole and a subgroove with an overhanging lip, are better explained by flowing water than by slow-moving ice (Snow and others, 1991). Munro-Stasiuk and others (2005) proposed that the megagroove was created by a fast-flowing slurry of subglacial meltwaters heavily charged with glacial sediment. They hypothesized that, confined under a glacier's mass, such a fluid would be highly pressurized, extremely abrasive, and capable of carving streamlined channels and grooves into limestone. An analogue would be the feature in Ohio's Hocking Hills called the Devil's Bathtub (fig. 71), a pothole in which vortices of water, charged with abrasive sediment, have carved smooth, fluid contours into the bedrock.

The mode of formation is not the only uncertainty regarding the megagroove. Others are:

- Why there were so many megagrooves in a small area; and
- How long it took to create the megagrooves—were they created slowly over thousands of years, or rapidly in a catastrophic outrushing of glacial meltwaters?

FIGURE 71. "Devil's Bathtub," a feature at Hocking Hills State Park (Hocking County, Ohio) that may be an analogue for how some of the features in the megagroove of Kelleys Island were formed.

With regard to the second question, evidence for glacially-derived, catastrophic flooding on a massive scale (known as *outburst flooding)* has been found elsewhere in North America, such as the Missoula Floods in Washington state (Baker, 1973) and the Maumee Torrent in Fort Wayne, Indiana (IDNR, 1996, p. 37). That such a flow might be responsible for the Kelleys Island megagrooves would not be unprecedented.

Regional Concept—Quarries

Kelleys Island was quarried for Columbus Limestone from 1833 until about 1940, with production resuming later but shutting down entirely about 2008. A substantial portion of the island was at one time or another given over to quarrying. The North Side quarry is the oldest and was the source of massive stone blocks used in buildings and breakwaters; stone was also used for lime production (Fisher, 1922, p. 46; Ver Steeg and Yunck, 1935). The North Side quarry was also the location of the largest megagrooves, now destroyed, and a portion of the quarry is visible from the highest point of the Glacial Grooves Geological Preserve. The boat launch at the state park is the location of an old dock where lumber and limestone were loaded onto ships, and a long, L-shaped building near the North Shore Loop Trail is the ruins of the rock crusher. Not apparent today is how extensive the quarry complex was. In addition to the rock crusher and boat dock, quarry operations included sixteen lime kilns, warehouses and workshops, housing for laborers, railroad spurs, and a locomotive house (Labadie and Herdendorf, 2004, p. 15). Few traces of these structures remain.

There is another closed quarry on the western side of the island; owned by LaFarge, it last reported production in 2008 of just less than 289,000 metric tons (319,000 tons) of material from the Columbus Limestone and the underlying Lucas Dolomite. Today it is flooded and none of it is open to the public; it is visible from Bookerman Road, but **do not trespass**.

Field Trip Stop 2—East Quarry (41°36′24.9″N, 82°41′55.8″W)

The East Quarry (at the center of the island on Ward Rd.) is part of the state park and is open to the public. The East Quarry was devoted to mining the uppermost layers (Venice Member) of Columbus Limestone; thin beds and abundant jointing enabled easy removal of rock. For this reason, the East Quarry is only about 6 m (20 ft) deep and

FIGURE 72. Ripple-marked Columbus Limestone at the former East Quarry in Kelleys Island State Park, Erie County, Ohio.

is comparatively safe to access[9], although good quarry safety practices should of course always be observed. In particular, the highwall on the southern rim of the quarry is hazardous and the rocks there should not be climbed.

Field Trip Stop 3—Rippled hardground (41°36′14.7″N, 82°41′52.2″W)

Park in the small parking area on Ward Rd. at Kaempfe Ln., about 1.1 km [0.7 mi] east of Division St., and walk the East Quarry Trail around the shallow lake to the ripple marks on the southern rim of the East Quarry; about 1.1 km [0.7 mi] of hiking.

Ripple marks have been noted at various locations in the upper portion of the Columbus Limestone in Ohio (Orton, 1888, p. 753; Fisher, 1922, p. 10; Bates, 1971; Bjerstedt and Feldmann, 1987) and a set exists in the limestone on the southern rim of the East Quarry, directly along the hiking path (fig. 72). Relatively common in sandstones and siltstones, ripple marks are rare in limestones. The ripples at this site are shallow and broadly spaced (about 0.6 m [2 ft] apart), and being eroded, they lack sharp crests. Their orientation is about 015°, and in their orientation and spacing they agree with other instances of rippled Columbus Limestone in central Ohio. They are interpreted as oscillation ripples that occurred in shallow water, probably formed by winds blowing across the water surface and setting up standing waves that reworked the bottom sediment (Bates, 1971). Evidence indicates that shortly following formation of the ripples the seabed became cemented, creating a surface known as *hardground*. Hardground represents a period when no deposition took place. Hence, this rippled hardground represents a shallow seafloor reworked by winds into a rippled surface, which then became cemented and partially abraded by the scouring of bottom currents.

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[9] Those interested in seeing a deeper section into the Columbus Limestone may visit the Castalia Quarry Metropark (part of the Erie County park system) on the mainland. A former quarry, it is open to the public and affords easy access. However, as always, exercise caution and follow good quarry safety practices.

Field Trip Stop 4—Former shoreline (41°36′25.1″N, 82°42′30.0″W)

Traces of former proglacial lakeshores are found at several locations on Kelleys Island. During the Quaternary Period, the entire island was submerged under at least 15 m (50 ft) of water by the proglacial lake stages Maumee, Arkona, Whittlesey, Warren, and Wayne. As the lakes lowered, the emergent surfaces of the island became temporary shorefront, and traces of some of the better-constrained lake stages are preserved in the island's topography. The most recognizable is near the center of the island, where a rise in Division Street just north of Ward Road is actually a low bluff that once overlooked a former lake (fig. 73). The elevation of this bank, 183 to 187 m (600 to 615 ft) above m.s.l., is close to the lowest level of Lake Lundy (187 m or 615 ft; see table 1). Lake Lundy is a stage recognized as older than Early Lake Erie but younger than the aforementioned proglacial lakes; its age is probably between 11,200 and 12,000 years (Calkin, 1970). Most traces of Lake Lundy shore are sandy, but this location is cut into bedrock and is therefore a wave-cut face rather than a beach ridge. Titus Rd., just south of the Glacial Grooves Geological Preserve, is also apparently a former shoreline.

FIGURE 73. Wave-cut shore on Division Street on Kelleys Island, in Lake Erie, possibly a shoreline feature of the proglacial Lake Lundy.

FIGURE 74. Historical photograph of Inscription Rock on Kelleys Island in Lake Erie, circa 1900. From Van Tassel (1901).

Field Trip Stop 5—Inscription Rock (41°35’34.0”N, 82°42’24.4”W)

Inscription Rock (East Lakeshore Drive at Addison Street, fig. 74) is a boulder of Columbus Limestone on the southern shore of the island bearing numerous Indigenous American **petroglyphs**, carvings that may pre-date Indigenous American contact with Europeans. Their age is unknown. Older historical accounts (for example Fisher, 1922, p. 43) claim the inscriptions depict contact between Indigenous Americans and Europeans and conflict between the Erie and Iroquois tribes. However, these accounts may be attempts to fit the inscriptions to known historical events; later scholarship suggests the inscriptions are a product of the Sandusky Culture of Indigenous Americans (A.D. 1200–1650; Ohio History Connection, 2017). Unfortunately no longer legible, the petroglyphs are severely worn; evidence suggests they were already succumbing to erosion shortly after the island was settled, long before the wooden shelter was erected in 1969. In early accounts, the boulder was covered by soil that linked it to the mainland (Korenko, 2009, p. 59). However, it does not appear to be *in situ* (in its original position of formation) and erosion has long since separated it from the upland. There was reportedly once another inscription-bearing rock on the northern side of the island, but it may now be submerged or perhaps was destroyed by quarrying.

Inscription Rock is the most visible sign of prehistoric habitation on Kelleys Island but it is not the only one; about 60 archaeological sites have been recorded on the island, including mounds and villages, spanning the Paleoindian, Archaic, Western Basin Middle Woodland, Late Woodland, and Late Prehistoric cultural periods, or about 12,000 BCE to A.D. 1650. (Jackson and others, 1993).

Field Trip Stop 6—North Pond State Nature Preserve: Drowned woods (41°36’40.7”N, 82°41’57.1”W; pets prohibited)

Southeast of the campground and boat launch is the North Pond State Nature Preserve, a 0.2 km^2 (45 acres) wetland and pond occupying a low area between the campgrounds to the northwest and Ward Road to the south. Access the area either by walking the trail from the state park campground, or park on Ward Road in the small parking lot 0.8 km (0.5 mi) east of Division Street and cross Ward Road at the crosswalk to find the head of the trail that leads down to the nature preserve.

Approaching North Pond State Nature Preserve on the trail from Ward Road, at a short distance into the woods one passes a short bedrock ledge (fig. 75) which is a former shore cliff of Lake Lundy. It corresponds to the wave-cut bank seen on Division Street (**Field Trip Stop 4**, fig. 73).

A sand beach divides North Pond from Lake Erie and protects the wetland from storm waves. A narrow channel out of the pond empties into the lake and some seepage probably percolates through the beach as groundwater. North Pond is one of few coastal wetlands in Ohio to maintain this sort of natural hydrologic relation with the lake. Most other coastal wetlands are separated from the lake by stone and earthen dikes.

On the beach are several tree stumps that stick out of the sand or water (fig. 76). These are not driftwood but are *in situ* remnants of woods that were wiped out by high lake levels and storms

FIGURE 75. Rock cliff in North Pond State Nature Preserve on Kelleys Island, Lake Erie, marking the former of shoreline of Lake Lundy.

FIGURE 76. *In-situ* tree stump in beach near North Pond State Nature Preserve on Kelleys Island in Lake Erie. The stump marks where the wetland was in the 1970s, before encroachment of the lake forced the beach to migrate landward, shrinking the wetland and leaving the stump on the lake-facing side of the beach.

in the early 1970s. The stumps mark where trees stood behind the beach, at the edge of the wetland. The beach has retreated about 18 m (60 ft) since 1973, and about 46 m (150 ft) since the 1870s, shrinking the wetland and leaving the tree stumps where they grew, now in front of the beach, partially or fully submerged. This is reminiscent of other examples from the Great Lakes region, including many in Ohio (for example, Moseley, 1899, p. 14 and 19; Moseley, 1905, p. 195; Strothers and Abel, 2001) where stands of submerged tree trunks have been found, providing evidence that lake levels have risen notably.

Field Trip Stop 7—North Shore Alvar State Nature Preserve: stromatoporoid bioherm and Lucas Dolomite (41°37′12.3″N, 82°42′39.7″W; pets prohibited)

An *alvar* is a type of environment developed on a limestone plain with little or no soil. The most recent glaciation stripped soils and vegetation from Kelleys Island, and while most of the island re-developed a thin soil profile, storms and lake ice have assured that the bedrock on a portion of the northwestern corner of the island remains barren of soil. In the absence of soil, native plants must grow and shelter in fissures in the rock. The North Shore Alvar State Nature Preserve preserves this scarce environment, where several Ohio-rare plant species are found, including balsam squaw-weed, Kalm's lobelia, Pringle's aster, and the endangered northern bog violet.

To access the North Shore Alvar State Nature Preserve, park near the boat ramp north of the campgrounds and follow the North Loop/Alvar Trail, passing the ruins of the rock crusher (the trail is actually the remnant of an old railroad line used to move rock from the quarry to the docks). Turn right at the earliest opportunity to follow the trail to a point marked "**C**" on a signpost, and approach the northern shore of the island. Where the trail turns westward to head parallel to the shore, continue down a side trail leading directly to the shore. The focus of this discussion is a broad, flat, bare exposure of dolomite just above lake level. Be careful of mossy rock surfaces that are extremely slippery when wet.

The rock exposed on the northwestern shore of the island is the uppermost Lucas Dolomite (a member of the Detroit River Group), a shallow-water marginal marine deposit that was gradually overtopped by deeper water as deposition transitioned to the Columbus Limestone (Feldmann and Bjerstedt, 1987). It was formerly mined from the bottom of the LaFarge quarry. At this site it is marked with glacial grooves and striations. Also exposed at this site are *bioherms*, mound-like, fossilized accumulations of extinct marine invertebrates known as stromatoporoids, which were similar to sponges. The bioherms are recognizable as buff-colored, irregularly shaped mounds that stand slightly above the surrounding blue-gray dolomite to give the exposure a hummocky appearance (fig. 77).

FIGURE 77. Bioherms exposed on the northwestern shore of Kelleys Island in the Lucas Dolomite. Lens cap at center for scale.

Regional Concept—Shipwrecks

Although not visible from shore, shipwrecks near Kelleys Island deserve mention (fig. 78). Lake Erie is treacherous to navigation, with 1,750 known wrecks throughout the lake, 600 of which are in Ohio waters. Near the islands, bedrock reefs[10] and the shallowness of the lake are a principal threat; storms can also develop quickly over the lake. Some wrecked vessels were carrying limestone quarried at the island when they were lost. For these reasons, geology is partially implicated as the cause of many of the wrecks around Kelleys Island. The Ohio Geological Survey has specifically located nine wrecks around the island, although many more are known to exist in the area (Liebenthal and others, 2006). Storm waves and lake ice scatter the remains of some wrecks so that they are never found.

Shipwrecks are protected by laws forbidding the plunder of artifacts; those interested in diving can find more information on wrecks and regulations from the Maritime Archaeological Survey Team **(ohioshipwecks.org).**

Economic Geology

Kelleys Island's primary industrial mineral products have been Columbus Limestone and Lucas Dolomite from the quarries, producing at various times dimension stone, lime, and crushed stone. About 1.3 km^2 (318 acres) of the island's surface were quarried between 1830 and the end of quarrying operations in about 2008. Oil and gas are not produced on the island or in the region. There are about 39 water wells on the island, which are developed in limestone or dolomite at depths from 8.5 to 54 m (28 to 178 ft), and when tested produced water from 3.8 L to 170 L (1 to 45 gal) per minute. About 19 L (5 gal) per minute is usually considered the minimum needed for domestic use.

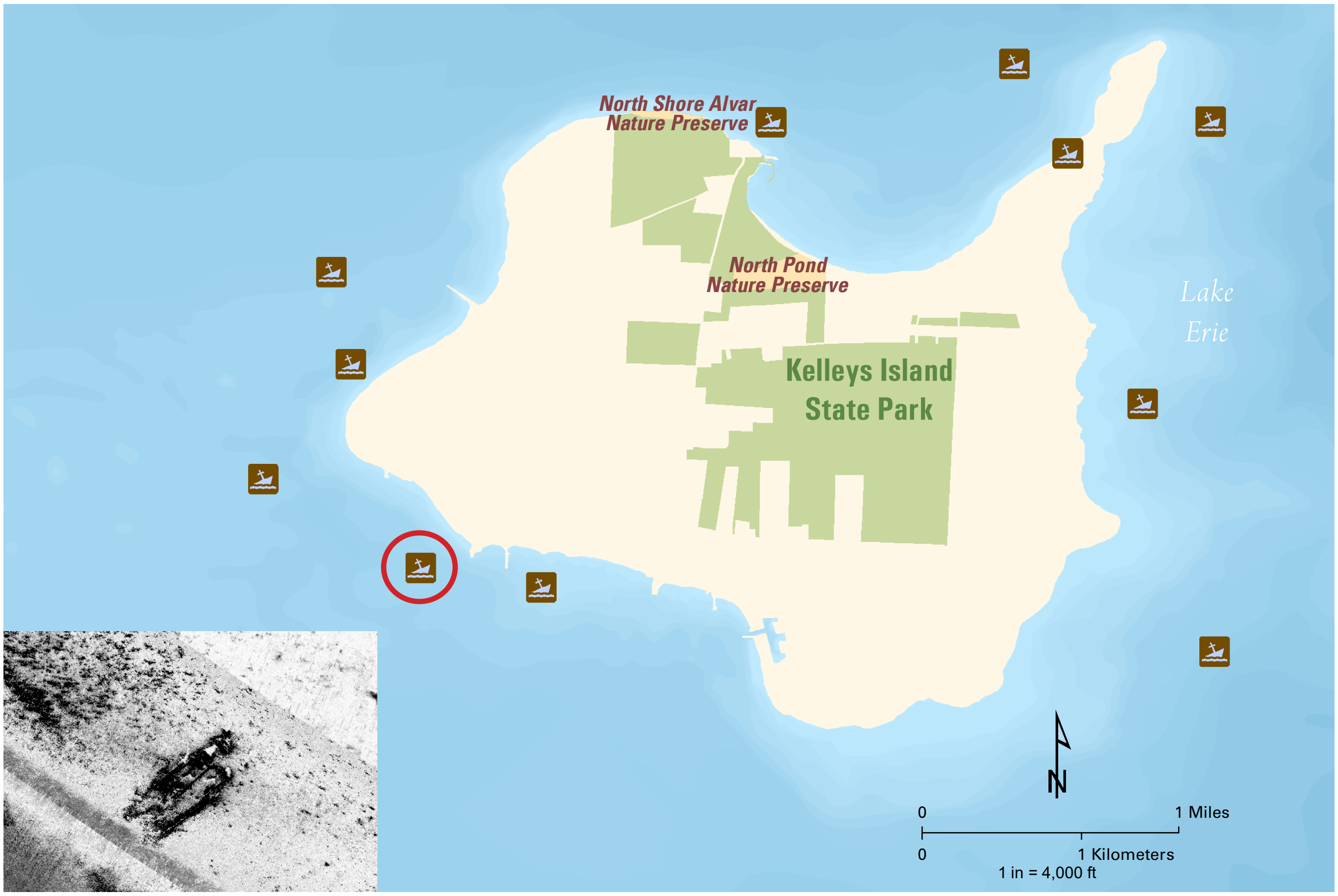

FIGURE 78. Locations of some of the known shipwrecks (brown ship icons) around Kelleys Island. Circled icon is the wreck of the *Plummer.* The inset shows a sidescan sonar image of that wreck.

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[10] "Reef" in this instance does not refer to a coral reef but is a boater's term for a submerged bedrock knoll that may be fish habitat and/or a navigation hazard. Geologically, however, many such features are the remains of ancient tropical reefs.

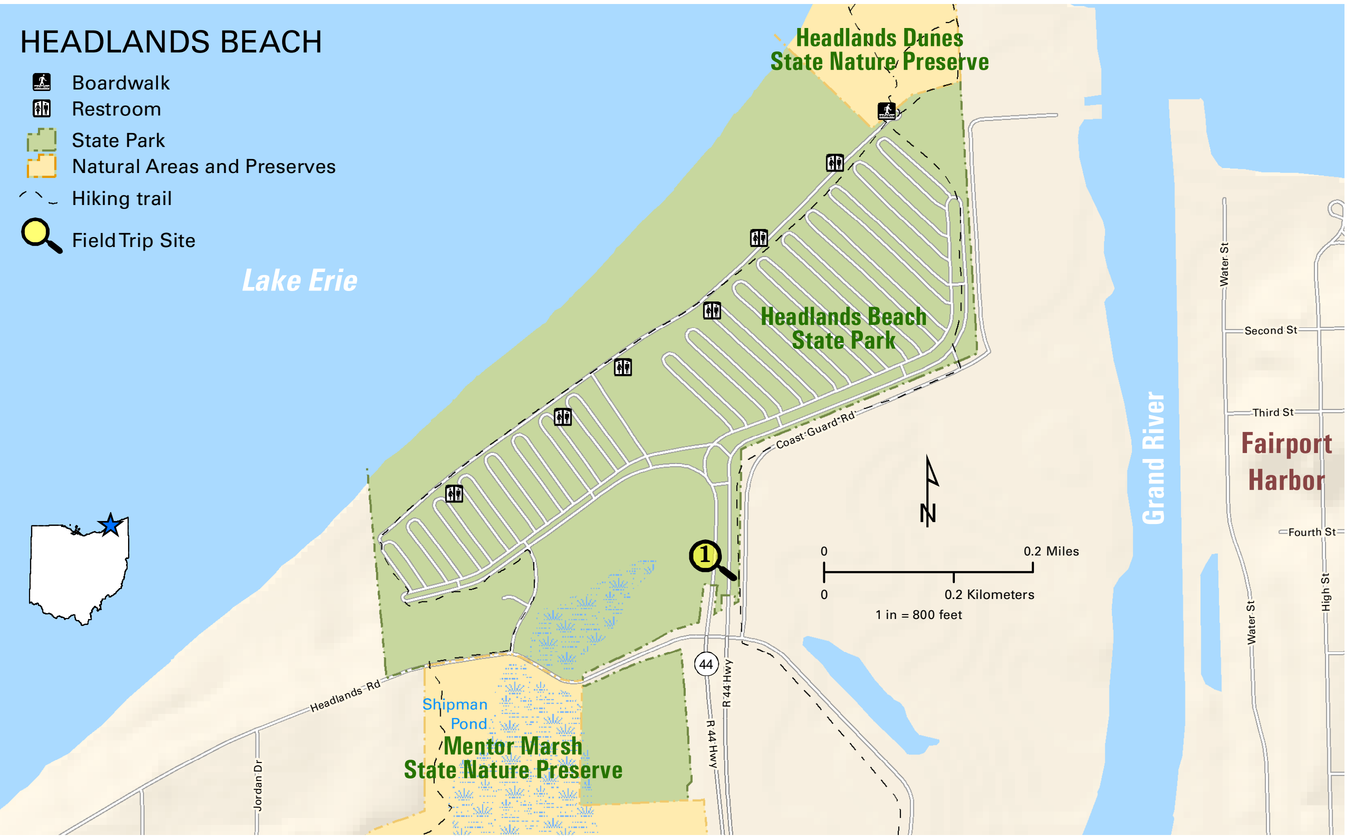

FIGURE 79. Overview map of Headlands Beach State Park, Lake County, Ohio.

Site 7 – Headlands Beach State Park

Introduction

Headlands Beach State Park's main attraction is the sand beach, 1.6 km (1 mi) long and up to 183 m (600 ft) wide (fig. 79). Fishing, hiking trails, and picnicking are also offered, and the adjoining Headlands Dunes State Nature Preserve and Mentor Marsh State Nature Preserve are important ecological resources. No bedrock is exposed in the immediate vicinity of Headlands Beach, the bedrock surface (the Devonian Chagrin Member of the Ohio Shale) being about 9 m (30 ft) or more under glacial till. However, gorges developed in the shale can be seen nearby at Lake County Metropark's Big Creek at Liberty Hollow (6735 Fay Road, Concord Township, 41°41′13.7″N, 81°13′20.2″W).

Regional Concept—Coastal processes

The dominant feature at Headlands Beach is the beach itself, the longest and widest in Ohio. The source of the sand is primarily the erosion of glacial soils onshore. The glacial till averages roughly 20 percent sand by volume, which results in a significant amount of sand being released into the lake as the shore erodes. Most of the sand ends up in the lake's nearshore zone—analogous to the surf zone of an ocean coast—where it is transported by lake waves. Erosion is therefore not only a destructive process; it also builds beaches which offer natural protection against further erosion.

Sand in the nearshore migrates along the shore by *longshore current* (also known as *longshore drift* or *littoral current*). Not a continuous current in the sense of a river, longshore current is a series of small motions that occur as waves strike the shore obliquely. The uprush and backwash of waves has the sum effect of moving sand grains parallel to the shore (fig. 80). Because longshore current is a shore-parallel motion it can have two directions, but in most places one direction dominates. Along the Erie shore from Cleveland almost to Buffalo, New York, the dominant direction of longshore current is to the northeast. Sand in the nearshore at Headlands Beach, for example, is moved by longshore current towards Pennsylvania.

Sand **entrained** in the longshore current can continue moving alongshore even when it reaches the mouth of a stream or river that intersects with the shore. If the river is slow-moving (as are most rivers entering Lake Erie), sand fills in the river mouth, eventually forming a bar that extends most or all of the way across the mouth. (Even the Cuyahoga River, which now accommodates gigantic ore freighters and ocean-going vessels, had a sandbar across its mouth when settlers from Connecticut first arrived in the Cleveland area in 1796.) The sandbar poses a problem if the river mouth is to be used for navigation, because sand must be continually removed to allow vessels to pass.

Objects that jut into the lake perpendicular to the shore can disrupt longshore current. For example, a fallen tree lying across a beach alters the current, and sand, unable to pass the tree, accumulates on its up-current side. Coastal engineers seeking to keep river mouths clear of sand have made use of this effect for at least two centuries. Engineers with the United States Army built jetties at the mouth of the Grand River in 1825 (USACE, 1913) to keep the mouth clear of sand. Sand immediately began to accumulate on the up-current (western) side of the jetties and has continued to accumulate ever since. As sand accreted and a beach developed, the jetties were lengthened to prevent sand from passing them, allowing more sand to accrete. A comparison of the shoreline in 1825 versus 1876, 1937, and 2011 shows how much sand has accumulated over the last two centuries (fig. 81). In 1825, the shore east and west of the river were in essentially the same position, but at every date since, the shore has advanced considerably farther lakeward on the western side of the river. Thus, while the beach at **Site 3 – East Harbor State Park** is thousands of years old, most of the sand at Mentor Headlands has been there less than 200 years.

A major but unintended effect of how the beach at Mentor Headlands formed is that the shore on the downdrift side (east) of the jetties is deprived of the sand that once passed freely along the shore. Without the sand to form beaches, erosion of the bluff downdrift of the jetties increases at the same time that a wide beach accumulates updrift. Lacking the protection of beach-building sand, the shore a few miles downdrift of Headlands Beach has been some of the fastest-eroding shore in Ohio, receding up to 277 m (800 ft) since the 1870s. It is therefore important to carefully manage sand as a natural resource, balancing the need for safe navigation with the need for maintaining beaches and preventing erosion.

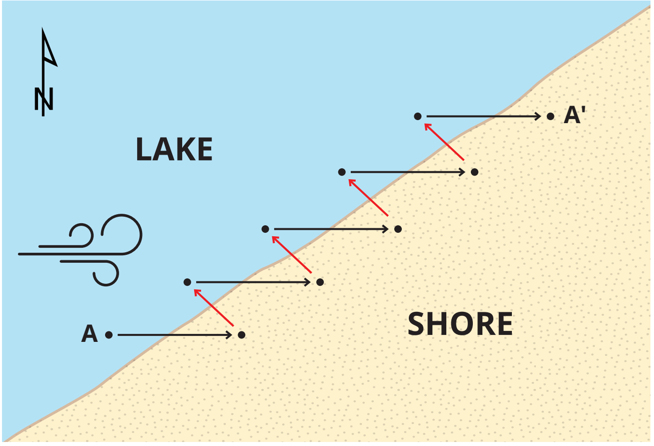

FIGURE 80. Diagrammatic example of longshore current. A sand grain (A) is moved onshore by waves (black arrows) which are generated by prevailing winds from the west. Backwash moves the sand grain back into the lake (red arrows) along the shortest path, which is perpendicular to the shore. Through repetition of these movements, the result is to move the sand grain along the shore to a new location (A').

FIGURE 81. Historical shorelines superimposed on a 2011 aerial photograph of Headlands Beach and the mouth of the Grand River, Fairport Harbor, Ohio. Mentor Marsh is south of Headlands Beach. After Guy and Moore (2010, fig. 24).

A 0.1 km^2 (25 acre) plot of dunes adjacent to Headlands Beach is known as the Headlands Dunes State Nature Preserve. The preserve is habitat for plant species such as beach grass, beach pea, purple sand grass, sea rocket, and seaside spurge (Guy and Moore, 2010, p. 22). Native to the Atlantic Coastal Plain, these species are believed to have dispersed into the Great Lakes region sometime following glacial retreat. Because these species are not found farther inland in Ohio, the exact mechanism of their dispersal is uncertain; it may have involved seeds incidentally carried by migrating birds (Reznicek, 1994). The plants help stabilize the sand dunes, preventing erosion and promoting the continued accretion of wind-blown sand. So stabilized, the dunes eventually come to support trees. Cottonwood and willow are common tree species on the Ohio shore.

Longshore current continues to transport a limited quantity of sand past the jetties and into the mouth of the Grand River. Along with sand washed down the river from upstream, this requires the U.S. Army Corps of Engineers to dredge the river every year or so, removing from 19,100 to 30,600 m^3 (25,000 to 40,000 yd^3) of sand (Guy and Moore, 2010, p. 22). Until the 1980s, this sand was disposed of in the open lake, where natural processes have little chance of returning it to the shore. More recently, ODNR and the U.S. Army Corps of Engineers have cooperated to ensure that the dredged sand is now disposed of in shallower water nearer the shore, where lake waves can disperse and redistribute the sand in the nearshore, helping to preserve beaches and to slow erosion downdrift of Headlands Beach.

Field Trip Stop 1—Mentor Marsh: An example of river capture (41°45’13.2”N, 81°17’18.1”W)

South of Headlands Beach is the Mentor Marsh State Nature Preserve (fig. 79). Coastal marshes are common from Toledo to Huron (see **Site 1 – Maumee Bay State Park**) where the low shore allows marshes and the lake to exchange water with one another, but they are rare in eastern Ohio where the lake plain (fig. 24) sits well above the lake itself. Mentor Marsh is a former bed of the lower Grand River. The marsh formed when the Grand River found a shorter route to Lake Erie (Fineran, 2003, p. 44). The latitude-longitude given for this Field Trip Stop is where park visitors drive over the old, abandoned channel—now just a ditch—when entering or leaving Headlands Beach by the main entrance off State Route 44 (fig. 82). When the longer route to the lake was abandoned, sand closed off the old river mouth at the shore 6 km (3.7 mi) to the west, and the channel, no longer free-flowing, became a wetland. This is similar to the process of river capture that occurred at the Portage River (see **Site 2 – Catawba Island State Park**). Industrial salt contamination that occurred from the 1950s to the 1970s has altered the types of plants that grow in the marsh, which is now dominated by the salt-tolerant grass *Phragmites*.

FIGURE 82. Abandoned channel of the Grand River, now just a ditch with a concrete culvert, just east of Mentor Marsh near Fairport Harbor, Ohio.

Regional Concept—Earthquakes

Headlands Beach is near a zone of seismic activity, the Northeast Ohio Seismic Zone (Dart and Hansen, 2008), the second most-active seismic zone in the state[11]. From 2010 to 2019, a number of earthquakes over magnitude 2.0 occurred with epicenters in this area (fig. 83). Most were not felt, although in the historical record there have been a few felt quakes in this zone, some with minor damage. Most of the quakes have had a focal depth of 5 km (3.1 mi) or greater. The reason for the seismicity is not fully known, but it probably relates to faults in the **Precambrian** rocks, which are about 1,770 m (5,800 ft) deep at this location.

Economic geology

Just to the east of the entrance to Headlands Beach State Park is the Morton salt mine (private property). Since 1959, halite, or rock salt (sodium chloride [NaCl]), has been mined at this location from a Silurian horizon about 580 m (1,900 ft) underground. The mine is directly under the park and extends over 3.2 km (2 mi) under Lake Erie. (Mining under the lake simplifies the process of obtaining mining rights, since there is only one landowner to deal with—the State of Ohio—rather than multiple owners). Although it is 580 m (1,900 ft) below ground surface, the salt mined here—the F_1 layer of the Salina Group (fig. 84)— is stratigraphically near the dolomites making up the Bass Islands, 126 km (78 mi) west (See **Site 2 – Catawba Island State Park** and **Site 5 – State Parks of the Bass Islands**). This demonstrates the degree to which the rocks dip (about 4.5 m per km, or 24 ft per mi) into the Appalachian Basin. The F_1 layer at the mine is about 7.6 m (25 ft) thick, although its typical thickness is 15 to 24 m (50 to 80 ft) elsewhere (Clifford, 1973, p. 85). Halite from

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[11] The Anna Seismic Zone (western Ohio) is the most active.

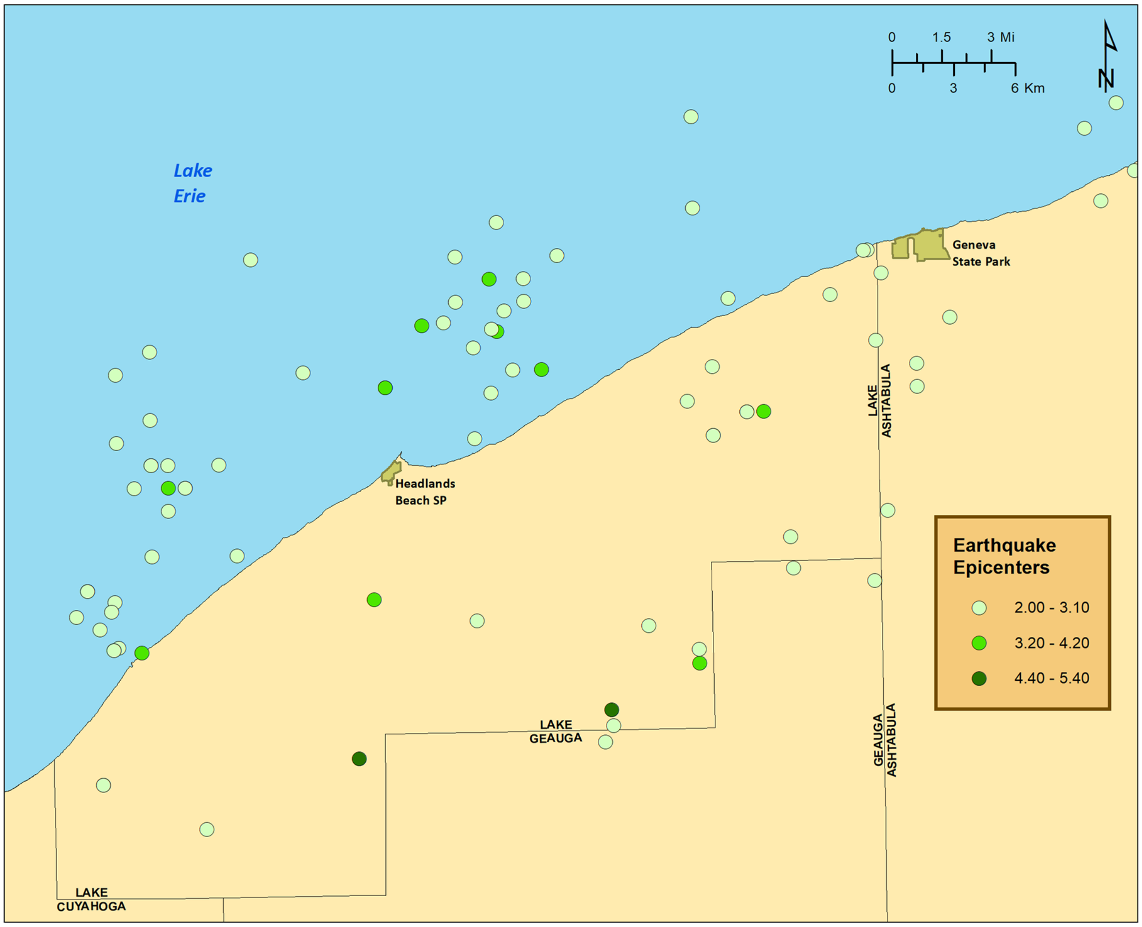

FIGURE 83. Epicenters of earthquakes greater than 2.0 magnitude that were recorded from 2010 to 2015 in the Northeast Ohio Seismic Zone.

this mine is removed primarily for road salt that is sold to northern Ohio cities and counties, with small amounts sold as water softener and other products.

The F_1 halite layer is one of approximately two dozen layers of salt identified in the Salina Group in Ohio, interbedded with layers of dolomite, shale, and anhydrite. Some of these layers are traceable across the Michigan and Appalachian Basins and have also been mined underground at Cleveland, Detroit, and in New York state and Ontario. The paleoenvironment represented by the repeated layers of halite and anhydrite is not fully understood because there are no modern analogues with which to compare them. They may have been deposited in reef-enclosed basins as sea water periodically evaporated in the tropical Silurian climate, or they may have precipitated out of deeper sea water that was supersaturated with brines (Clifford, 1973, p. 10).

Upon learning that there are salt mines under Lake Erie, some ask if the lake could ever leak into the mines and what would happen if it did. This question is probably prompted by memory of the 1980 Lake Peigneur disaster, in which an oil-drilling platform on a lake in Louisiana accidentally penetrated a salt mine, draining the lake into the mine. The State of Ohio would not permit oil drilling or any similar activity over a salt mine, for the very reason as what occurred in Louisiana. As for natural causes, such as cracks in bedrock, the mine's depth of 580 m (1,900 ft), most of which is **tight** shale, prevents the formation of any sort of continuous conduit that would allow leakage between the lake and the mine.

In contrast to state parks in the Western Basin of Lake Erie, Headlands Beach is located near a moderately active region for natural gas production. The nearest producing well to the park is about 3.0 km (1.9 mi) to the southeast and in 2018 it produced 20,950 m^3 (740,000 ft^3) of natural gas from the lower Silurian Clinton Formation, at about 888 to 913 m (2,915 to 2,995 ft) of depth. There is little to no oil production in the region. Brine production occurred for a number of years south and southeast of Headlands Beach, in the form of operations that pumped water underground to the depth of the Salina Group, where halite was dissolved and then pumped to the surface. Brine produced in this way can be used for the manufacture of chlorine, water softener salt and table salt, among other uses. No other industrial mineral production occurs near the park. Most water wells in the region are developed in shallow sand and gravel deposits of glacial origin, the underlying shales being a poor source of groundwater.

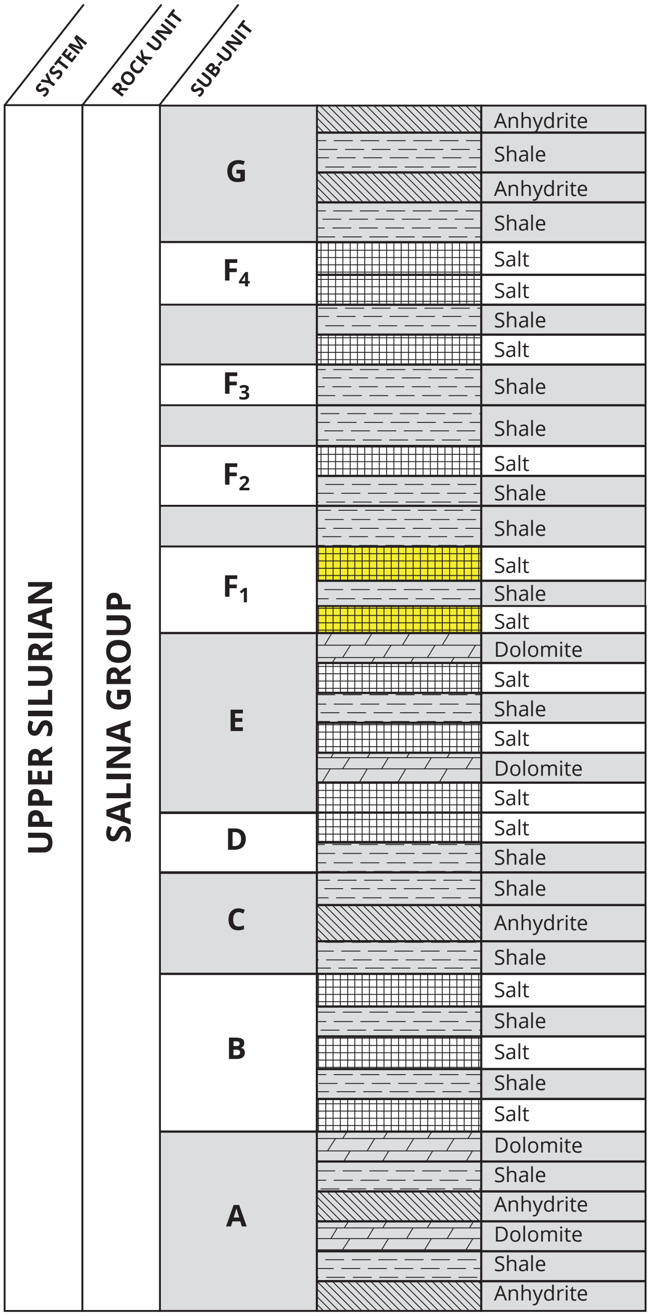

FIGURE 84. Simplified stratigraphic column of the Salina Group in Ohio showing position of F1 salt (yellow) mined near Headlands Beach State Park in Fairport Harbor. After Clifford (1973).

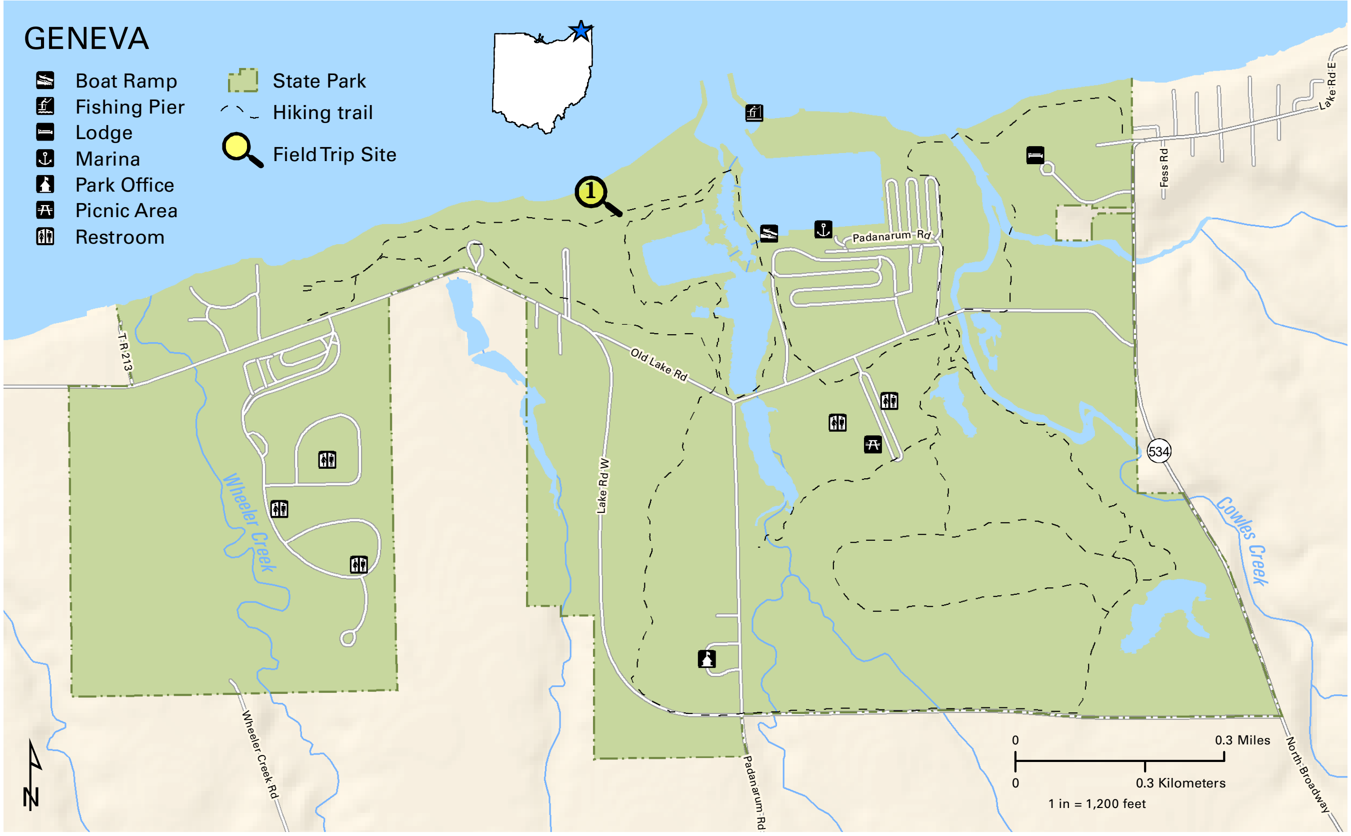

FIGURE 85. Overview map of Geneva State Park and surrounding Ashtabula County, Ohio.

Site 8 – Geneva State Park

Introduction

Geneva State Park (fig. 85) is a 2.8 km^2 (700 acre) lakeside park in Ashtabula County overlooking Lake Erie's Central Basin and offering a lodge, a beach, a marina, cabins, and trails. Geneva State Park is situated on the Erie Lake Plain, essentially the old bed of proglacial lakes such as Wayne and Warren, but in contrast to **Site 1 – Maumee Bay State Park**, the lake plain in northeastern Ohio is narrow, elevated up to about 18 m (60 ft) above the modern lake, and more deeply dissected by streams. Like Maumee Bay and Headlands Beach State Parks, there is no bedrock exposed at Geneva State Park; more so than any other state park in the region, glacial processes at Geneva State Park dominate over other forms of geology. Therefore, this discussion will focus on the park's glacial and post-glacial history.

Regional Concept—Glacial geology

Glacial deposits at Geneva State Park are exposed in shoreline bluffs that stand up to 9 m (30 ft) above the lake (Jones and Hanover, 2014). The coastal bluffs at Geneva State Park are relatively low; to the northeast and southwest of the park, bluff heights are commonly 15 m (50 ft) or more; 23-m (75-ft) bluffs occur near the Ohio–Pennsylvania state line. The high lake water levels of the mid-1980s resulted in erosion that produced steep bluff exposures, but the exposures have since been softened by slow **slumping** of the relatively soft sediments into more stable, vegetated slopes as of this writing. The Devonian Chagrin Member of the Ohio Shale, a soft, gray, silty shale (Stone and others, 1996), is exposed in the shoreline nearby, but it is just below water level at Geneva State Park (Fuller and Foster, 1998).

The last glacial surge into the Erie Basin—by a mass of ice known as the Erie Lobe—occurred around 14,000 y.a. This ice advance extended only as far as Cleveland to the southwest. In the region of Geneva, only a few miles southeast, this advance formed the youngest moraine in Ohio, the Ashtabula-Painesville Moraine (White and Totten, 1979, p. 11 and pl. 1). Also known as the Lake Escarpment Moraine (Goldthwait and others, 1961), it extends across eastern Cuyahoga, Lake, and Ashtabula Counties. Field evidence indicates that this last glacial advance scoured away all previous glacial deposits, and the deposits left by the Erie Lobe rest directly on the Chagrin Shale bedrock.

The makeup of the Ashtabula Till deposited by this last advance is siltier (>50 percent) and less clayey, at about 35 percent, than the previous ice advance (White, 1982, p. 49). This is a consequence of the incorporation of large amounts of siltstone beds from the Chagrin Shale bedrock substrate that was eroded and sheared into the debris zone at the base of the ice. Most *clasts* (rock fragments) greater than sand size in the Ashtabula Till are pieces of Chagrin Shale.

In the coastal bluffs at Geneva State Park, two **facies** of the Ashtabula Till are observed. Some postulate that the two facies represent two separate ice advances. Bruno (1988, p. 146) demonstrated that the two coastal facies have the same silt and clay content, with the differences between the facies indicated by other physical characteristics. The lowermost facies, resting directly on bedrock, is the **lodgment** facies of the Ashtabula Till, deposited directly from the base of moving ice and compacted by shear pressure into a hard, typically massive, deposit. At the park, this facies generally is less than 6 m (20 ft) thick. Overlying the lodgment facies is the **meltout** facies. A meltout till facies is deposited from the melting of stagnant ice, after an ice advance has reached its maximum extent. Without the consolidation pressure of moving ice, this facies is not as dense as a lodgment facies till. It varies in thickness of about 6 m (20 ft) in the eastern park bluffs, but it is thin or absent along the western park shoreline.

Shear stacking of multiple layers of debris-rich ice resulted in roughly horizontal slabs of till, commonly separated by sorted sediment layers ranging in grain size from clays to boulders. Most of these sorted layers are merely **partings**, but thicker **lenses** do exist, resulting from deposition in temporary meltwater channels in or at the base of the remaining unmelted ice. This depositional environment indicates that melting at the base of the ice from geothermal heating was the dominant mode of ice destruction, rather than *ablation* (ice destruction from the top down by evaporation, melting, and wind erosion). Ablation till facies do not appear in the coastal geologic setting at Geneva State Park.

The relatively flat upland south of the shoreline is largely thick lacustrine silt and clay, deposited on top of the Ashtabula Till in the deep waters of the higher proglacial lakes that were precursors of Lake Erie (table 1). Above these deposits are discontinuous patches of sand deposited in the shallow nearshore waters of the proglacial Lake Lundy stages, as Geneva State Park is entirely at a lower elevation than the lowest Lake Lundy.

Field evidence indicates that the Ashtabula Till ice advance was the ice that bounded Lake Maumee I (244 m or 800 ft, see table 1) on the east, forcing Lake Maumee to drain westward towards Fort Wayne, Indiana. On the modern upland from Cleveland westward, abundant evidence of the 244 m (800 ft) shoreline is preserved as beach ridges, offshore shallow-water sands, estuary fills, and wave-cut cliffs. East of Cleveland, including the region around Geneva State Park, this evidence is absent, indicating that ice, rather than Lake Maumee, occupied the area at that time. Subsequent proglacial lakes formed after Ashtabula ice retreated eastward out of Ohio.

Since the end of glacial events and the establishment of modern Lake Erie, several short streams have eroded ravines through the glacial sediments to the level of the lake. Wheeler Creek occurs near the western boundary of the park, and Cowles Creek meanders between the marina and the park lodge. The marina itself is built in a low area that is probably an abandoned mouth of Cowles Creek (see **Site 2 – Catawba Island State Park** and **Site 7 – Headlands Beach State Park** for other examples of river mouth abandonment).

Economic geology

The Geneva State Park region is not endowed with abundant mineral resources. The impermeable glacial and shale bedrock strata are a very poor source of groundwater; water wells yield from zero to only 11 L (0 to 3 gal) per minute. No industrial mineral production (such as sand and gravel pits) occurs in the region of the park. Several gas wells occur near the park; a well just inside the southern boundary of the park produced about 128,000 m^3 (4,525,000 ft^3) of natural gas in 2022 from the lower Silurian Clinton Formation, at about 823 to 853 m (2,700 to 2,800 ft) of depth. There is little to no oil production in the township.

Regional Concept—Beach ridges and other former lake traces

A cross section (fig. 86) shows that some of the roughly twenty distinct shoreline features (beach ridges, terraces, and wave-cut cliffs) that have been identified in Ashtabula County (White and Totten, 1979, p. 27) occur near Geneva State Park. Beach ridges represent periods when proglacial lakes

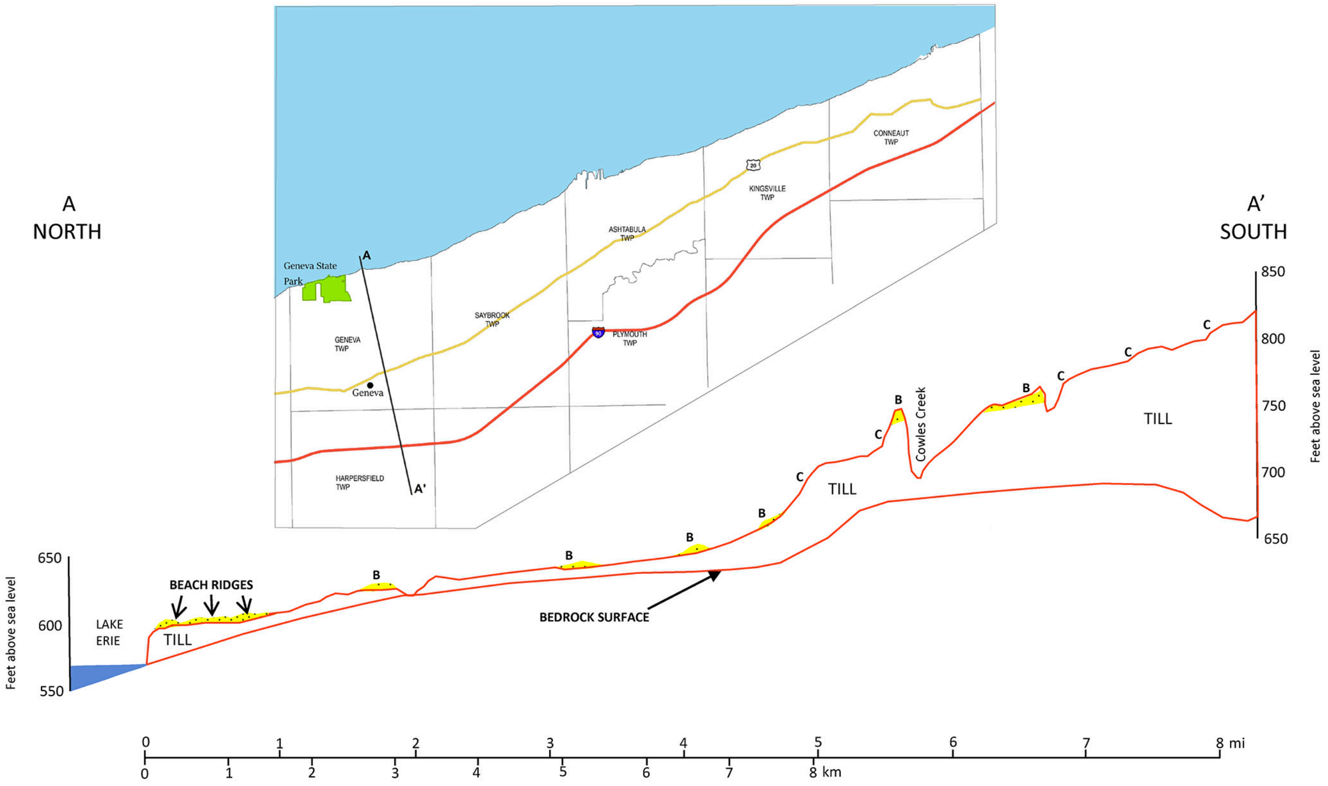

FIGURE 86. Cross section through Geneva and Harpersfield townships (A–A' on inset map) near Geneva State Park, Ashtabula County, Ohio, showing traces of proglacial lakes; beach ridges (B); and wave-cut cliffs (C). Vertical exaggeration about 53x. After White and Totten (1979).

developed beaches as Lake Erie does today; cliffs represent episodes when wave erosion cut into till or rock. U.S. Route 20, 6.4 km (4 mi) south of Geneva State Park, is one of the most prominent examples of a road built on a beach ridge. Its elevation, about 204 m (670 ft) above m.s.l., identifies it as a beach of Lake Warren III.

Field Trip Stop 1—Beach morphology and erosion (41°51'24.6"N, 80°58'41.3"W)

For a time, erosion was a problem at Geneva State Park. High lake levels during the 1970s and 1980s took a toll on the mostly-unprotected bank. Similar to **Site 7 – Headlands Beach State Park**, the wide swimming beach at Geneva State Park is made possible by a jetty structure built out into the lake that keeps sand out of the marina entrance channel. The dominant longshore current moves towards the northeast, trapping sand against the western jetty, creating a wide beach there but starving the shore down current and accelerating erosion (figs. 87 and 88). Remnants of shore protection structures visible several feet out in the water east of the jetties mark how far the bank has eroded since the 1970s. Erosion was especially severe near the footbridge between the marina and the lodge. Heavy Columbus Limestone riprap placed on either side of the bridge now protects the bank, and ODNR has periodically pumped sand through a buried pipe from the up-current side of the marina to the vicinity of the footbridge. This operation is called *bypassing*, because it allows trapped sand to bypass the jetty structures and continue to flow east with the longshore current.

Regional Concept—Magnetite and garnet sands

On many Ohio beaches, a zone of dark sands is found on the shoreface near the top of the wave **swash zone** (fig. 89). The sands are black with a hint of dark red and people may mistake them for some form of pollution or contamination. They are actually grains of magnetite (black) and garnet (red). The majority of Ohio beach sand is quartz, with a specific gravity of about 2.6–2.7 and a characteristic tan color. Garnet and magnetite are heavier, with

FIGURE 87. Low-angle aerial view of the beach and marina entrance channel at Geneva State Park, Ashtabula County, Ohio. Arrows show the net direction of longshore current, which is from west to east. Most sand is trapped at the western jetty and does not continue eastward.

specific gravities of 3.5–4.3 for garnet and 5.18 for magnetite (Klein and Hurlbut Jr., 1985). Mineral grains suspended in moving water are sorted by weight. As a wave runs up the shoreface, heavier grains are first to settle out of the water. As the wave washes back into the lake, lighter grains settle last. This eventually leads to a zone of concentrated dark sand that stretches along the beach. The ultimate origin of most minerals in the beach sand is the *Canadian Shield*, a plateau of Precambrian **igneous** and **metamorphic** rocks. Ice sheets expanding southwest and south from northern Canada crossed the Canadian Shield, removing, transporting, and breaking down these rocks into the components of glacial till, and the sands are some of the remnants.

Another colorful material found on the shore is beach glass, which seems to be more abundant in Ashtabula County than elsewhere in Ohio (fig. 90). Blue glass appears to be the most common, probably because it is the most easily noticed, but white, brown, and clear glass also occur. The source of most the glass was probably discarded bottles and jars. Before plastics came to dominate household trash and when waste disposal was still poorly regulated, it was common to dump trash in ravines and along the lakeshore. Trash easily found its way into the lake. Subsequent battering and transport in the swash zone have worn the glass fragments into frosted, pebble-like fragments that catch the eye when one walks the beach. Given the southwestern-to-northeastern direction of the longshore current, some of this glass may have come from as far as Cleveland. Other human-made, water-worn debris on the beach includes brick, tile, and lumber, reworked by waves into shapes that resemble natural cobbles (fig. 90). Some of these debris derives from houses and building foundations that have been destroyed by erosion of the lake bluff.

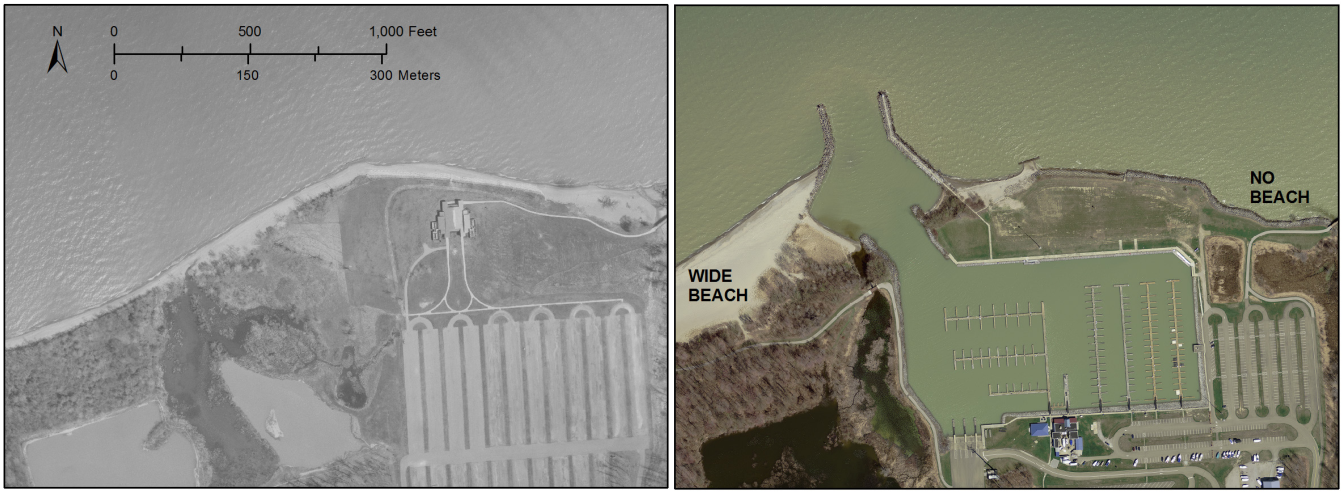

FIGURE 88. Two aerial views of Geneva State Park, Ashtabula County, Ohio, before (1980, left) and after (2004, right) the marina was built.

FIGURE 89. Example of wave-sorting of dark sands (mainly the heavy minerals magnetite and garnet). When waves bearing sand reach the top of the beach, the heavier sand grains are the first to drop out of suspension and settle, while lighter-weight quartz grains wash back down the beach face.

FIGURE 90. Natural and human-made materials found on Great Lakes beaches, including glass (1), brick (2), wood (3), slag (4), and natural rock (5).

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GLOSSARY

ablation – destruction of glacial ice by evaporation, melting, and other processes
alluvium – mixed, unconsolidated sediment deposited by streams in riverbeds and valley bottoms
anoxic – depleted in oxygen as a result of microbial decay of organic matter (said of water)
archipelago – a group of islands
argillaceous – containing mainly clay
baymouth bar – a sand spit across the mouth of a bay or natural harbor
base level – the elevation to which a stream or river cuts (erodes) as it flows
barrier beach – a long, narrow band of sand, parallel to the shore, that separates and protects a lagoon or wetland from the open lake or sea
beach ridge – a ridge of sand that was formerly the beach of a proglacial lake
betrunking – a form of stream capture that results from removal of a stream's lower course by coastal erosion so that the upper course flows directly into a lake or sea
bioherm – a calcareous sedimentary rock formed from a mound of fossilized organisms such as algae, corals, etc.
body fossil – fossil remains consisting of a cast of all or part of an organism's body, rather than tracks or traces left behind by the organism
brachiopod – a class of shelled, marine organism; it has a significant presence in the Ohio's fossil record
brecciated – a description for rocks that have been broken into angular fragments called *breccia*
bypassing – the practice of mechanically moving beach sand past an obstacle that has disrupted natural longshore current
calcareous – principally containing calcium carbonate
carbonate rock – umbrella term for limestone or dolomite (which consist primarily of calcium carbonate)
chert – a sedimentary rock consisting of microcrystalline quartz; often synonymous with *flint*
clast – one of the individual fragments that make up a sedimentary rock
concretion – a mass of sedimentary rock that is harder and usually mineralogically distinct from the surrounding rock
crinoids – a class of marine organisms; in their mature form they are attached to the sea bottom and are also known as sea lilies
cuesta – a ridge of rock having a steep slope on one side and a gentle slope on the other; it indicates that the rocks making up the ridge are tilted; also called a *scarp* or an *escarpment*
drowned river mouth – a river mouth that has been submerged by rising water levels
end moraine – a ridge of glacial till deposited at the end of a stationary glacier; also known as a *terminal moraine*
entrain – to pick up (sediment) by flowing current, as on a shore or the bottom of a body of water
erratic – a rock that has been carried from its original location of formation by glacial ice
exhumation – a process whereby buried rocks are uncovered by erosion
facies – a set of qualities characterizing a rock or sediment that differentiate it from nearby rocks or sediments and pertain to the environment of formation
fault – a joint (rock fracture) along which displacement (movement) has occurred
fetch – the distance wind blows over open water, creating waves
fossiliferous – particularly rich in fossils
geohazard – a hazard based on geologic characteristics that poses a risk to life, health, property, or infrastructure; Ohio examples include landslides, rockfalls, sinkholes, earthquakes and shore erosion
glacial drift – general term for soil deposited by glacial ice, may consist of clay and rocks in any proportion
gastropods – a class of animals that includes snails
glaciolacustrine – derived of glacial or glacial-lake origin (said of soils)
ground moraine – a sheet of glacial till deposited by an ablating glacier, typically producing rolling topography
honeycomb weathering – a form of weathering that produces rocks with regular voids or pits
igneous – one of the three primary rock types (the others being sedimentary and metamorphic), consisting of rocks that formed directly from molten material (magma)
in situ – Latin term meaning "in place"
island arc – a curved belt of crust that forms over a subduction zone due to repeated volcanic eruptions, also called a volcanic arc
isostasy – a property of Earth's crust that preserves equilibrium as the load on the crust changes; when weight (such as glacial ice) loads the crust, the crust sinks; when weight is removed, the crust lifts (rebounds)

isostatic rebound – the tendency of Earth's crust to rise after being depressed by a great mass; also known as *post-glacial rebound* when the mass was glacial ice

isthmus – a narrow strip of land, surrounded by water, that connects two larger bodies of land

joint – a rock fracture

karst – a type of terrain characterized by sinkholes, caves, springs and similar features; caused by carbonate rocks becoming dissolved by groundwater and/or infiltrated surface water

lens – a thin deposit of sediment enclosed in a larger mass of sediment or soil; has a roughly lens-like shape in cross-section

lithify – to become rock (said of sediments)

lodgment – a type of till deposited at the base of a moving glacier, directly on bedrock or older tills

longshore current – the force that moves sand along (parallel to) the shore by waves washing in and out

mantle – a zone of the Earth's interior, below the crust and above the core, about 2,900 km (1,800 mi) thick; although mostly solid, it is hot and is where rock melts to become magma

meltout till – a type of till deposited by a melting (rather than a moving) glacier

metamorphic – one of the three primary rock types (the others being igneous and sedimentary), consisting of rocks that have been altered by heat, pressure, or both

moraine – a deposit of unsorted and unstratified glacial till, typically takes a ridge-like form (except for ground moraine)

morphology – the general shape or form of geologic features, such as hills, islands, mountains or plains

oceanic crust – the rock that makes up the Earth's ocean basins, which is denser, thinner and chemically different from continental crust

orogeny – an episode of mountain building

outwash – sand, gravel, cobbles and boulders discharged by glacial meltwaters

overburden – general term for loose, soil-like materials over bedrock

parting – thin surface (in soil or rock) along which separation occurs, usually between layers

peninsula – a body of land nearly surrounded by water except where attached to a larger body of land

petroglyphs – rock carvings that consist of pictures but not writing

placoderms – a class of fishes (late Silurian to Devonian in age) having jaws and heavy, bony armor

plateau – a large area of raised land

pool – a subterranean accumulation of oil or gas

Precambrian – the earliest part of Earth's history, spanning from Earth's formation about 4.6 billion years ago to about 541 m.y.a.

precipitate – to deposit as a solid from a solution, such as salt from seawater

proglacial – positioned directly in front of a glacier

protocontinent – a continent known from geologic evidence to have existed in the past and that is an ancestor to one of today's continents

pyrite – the mineral iron disulfide (chemical formula FeS_2); well-formed crystals of pyrite are sometimes called "fool's gold"

recessional moraine – a ridge of glacial till deposited adjacent to a receding glacier

sand spit – a low ridge of sand that extends into a body of water but is attached to land at one end

sea stack – an isolated rock outcrop that is near the shore and too small to be considered an island

seiche – a large-scale movement of water mass generated by winds blowing along the axis of a body of water; also known as a *wind tide*

silicified – having a makeup in which all minerals have been replaced by silica (said of fossils)

slumping – an erosional process in which a large block of soil or rock slides as a single mass

solution – the act of dissolving, as acidic water does to rock

striations – general term for straight lines made by geologic processes, such as moving ice

stream capture – the process by which a stream is diverted from its course by changes occurring to the land over which it flows

stromatolite – a mound of fossilized algae and sediment, common in Ohio's carbonate rocks

stromatoporoid – a group of sponges, now extinct, in Ohio found mainly in Silurian and Devonian rocks

subaerial – exposed to open air, rather than submerged in water or buried

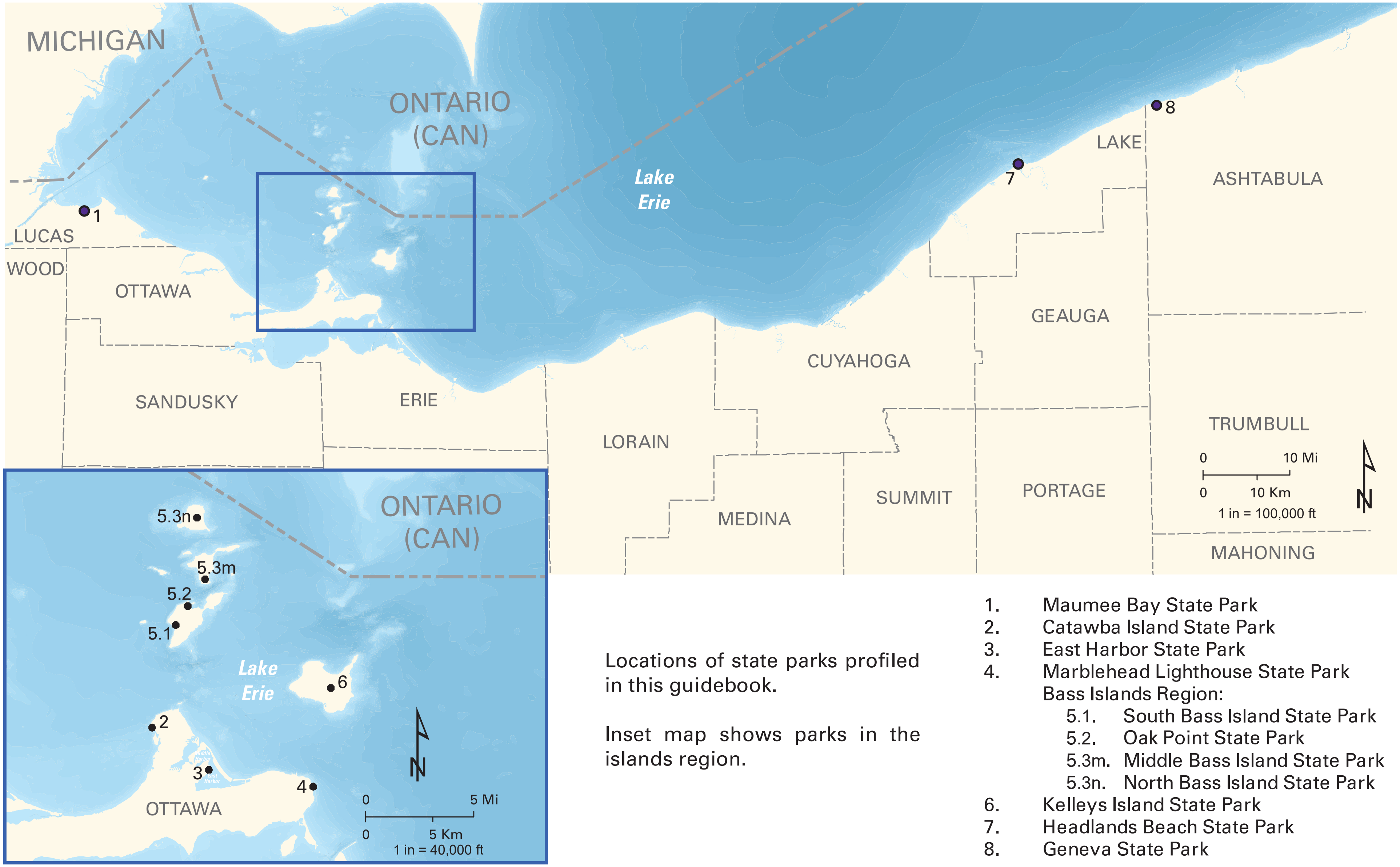
subduct – to sink (as a layer of Earth's crust) under another layer of crust, where the heat of the mantle melts and destroys the sunken layer

supercontinent – one of the several large landmasses, no longer in existence, formed by collisions of continents in the distant past, including Pangaea and Gondwanaland

swash zone – the portion of a shore where waves wash in and out, so that the beach is alternately covered and uncovered by water

tectonic – related to the structure of the Earth's crust, especially to the physics that shape or deform it

terminal groin – a built structure that extends perpendicularly from the shore
tight – impervious to the passage of fluids; leak-proof (said of shale and similar rocks)
till – a glacial deposit consisting of clay, silt, sand, pebbles, cobbles and boulders in any proportion; synonymous with *glacial drift*
tombolo – a mass of sand that extends from the shore to an offshore island or breakwater
trace fossil – a fossil preserving evidence of an organism's movement but not the organism itself, such as a track, footprint, or burrow
type section – an exposure of rock from which the first published description of that rock is created
unconsolidated – loose, not cemented (said of sediments such as silt, sand, and gravel)



Locations of state parks profiled in this guidebook.

Inset map shows parks in the islands region.

1. Maumee Bay State Park
2. Catawba Island State Park
3. East Harbor State Park
4. Marblehead Lighthouse State Park
   Bass Islands Region:
   - 5.1. South Bass Island State Park
   - 5.2. Oak Point State Park
   - 5.3m. Middle Bass Island State Park
   - 5.3n. North Bass Island State Park
6. Kelleys Island State Park
7. Headlands Beach State Park
8. Geneva State Park

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Jones, D. Mark • Geologic Guidebook to Ohio State Parks in the Lake Erie Region • Guidebook 24