GUIDEBOOK NO. 21

GEOLOGIC SETTING AND PROCESSES ALONG LAKE ERIE FROM FAIRPORT HARBOR TO MARBLEHEAD, OHIO

by

Donald E. Guy, Jr. (Ret.)
Ohio Department of Natural Resources
Division of Geological Survey

and

Laura J. Moore
Oberlin College

originally prepared for the 2006 North-Central Section meeting of the Geological Society of America

Columbus
2010

DIVISION OF GEOLOGICAL SURVEY
2045 MORSE RD., BLDG. C-1
COLUMBUS, OHIO 43229-6693
(614) 265-6576
(614) 447-1918 (FAX)
E-Mail: geo.survey@dnr.state.oh.us
World Wide Web: <http://www.OhioGeology.com>

STATE OF OHIO
Ted Strickland, Governor
DEPARTMENT OF NATURAL RESOURCES
Sean D. Logan, Director
DIVISION OF GEOLOGICAL SURVEY
Lawrence H. Wickstrom, Chief

GUIDEBOOK NO. 21

GEOLOGIC SETTING AND PROCESSES ALONG LAKE ERIE FROM FAIRPORT HARBOR TO MARBLEHEAD, OHIO

by

Donald E. Guy, Jr.
Ohio Department of Natural Resources
Division of Geological Survey (Ret.)

and

Laura J. Moore
Oberlin College

Originally prepared for the 2006 North-Central Section meeting of the Geological Society of America in Akron, Ohio

Columbus
2010

Composition and layout by Lisa Van Doren

This guidebook was prepared for a field trip, led by the authors, in conjunction with the 2006 North-Central Section meeting of the Geological Society of America. Subsequent users of this guidebook must obtain permission of the landowner to visit any of the sites that are on private property.

Co-author Laura Moore is now a faculty member in the Department of Geosciences at the University of North Carolina–Chapel Hill.

Cover photo: Sandstone block T-groins at Huntington Reservation in Bay Village, Ohio. Aerial photograph taken in 2002 by the Cuyahoga County Engineer.

CONTENTS

FIGURES

TABLES

UNITS OF MEASURE USED IN THIS GUIDEBOOK AND CORRESPONDING ABBREVIATIONS

Area

hectares	ha
square mile	mi^2
square kilometer	km^2

Length

centimeter	cm
inch	in
feet	ft
kilometer	km
meter	m
miles	mi
millimeter	mm

Mass

pound	lb
ton	t

Miscellaneous

particle-size diameter	ϕ

Time

before present	B.P.
day	d
second	s
year	yr
years before present	ybp

Volume

cubic meter	cm^3
cubic yard	yd^3
gallon	gal
liter	L
milliliter	mL
quart	qt

GEOLOGIC SETTING AND PROCESSES ALONG LAKE ERIE FROM FAIRPORT HARBOR TO MARBLEHEAD, OHIO

by
Donald E. Guy, Jr.
and
Laura J. Moore

INTRODUCTION

The Ohio shore of Lake Erie stretches about 270 mi (434 km) along the south shore of the lake, encompassing a variety of geologic and geomorphic settings (fig. 1, table 1). This field trip covers about 90 mi (144 km) of shore between Fairport Harbor and Marblehead Peninsula, providing opportunities to examine and discuss the geologic setting and processes of the southern Lake Erie shore as well as the impact of numerous shore protection structures on coastal processes. Most of this reach is moderately to heavily urbanized, and 70 to 85 percent of it is densely armored by shore protection structures (Fuller and Gerke, 2005).

From east to west, Fairport Harbor, Cleveland, Lorain, Vermilion, and Sandusky are the major urban areas found along this reach of Lake Erie. Numerous suburbs lie between Fairport Harbor and Lorain; but from Lorain to the Marblehead Peninsula, expensive lakefront homes contrast with agricultural areas and wetlands located landward of the lake road. In the five counties (Lake, Cuyahoga, Lorain, Erie, and Ottawa) covered by this field trip, about 20 percent of the homes and commercial buildings closest to the lake are within 25 ft (7.6 m) of the bluff edge (or a similar erosion reference feature) and 21 percent are between 26 and 50 ft (7.9 and 15.2 m) of the bluff edge (Ohio Division of Geological Survey, unpub. data, 1986). Some of these lakefront homes and buildings are located on top of wave-eroded bluffs, banks, and slopes, and others are located along barrier beaches. Major tributaries to the Central Basin of Lake Erie are the Grand River, Chagrin River, Cuyahoga River, Rocky River, Black River, Vermilion River, Huron River, and Sandusky River (fig. 1). In addition, there are smaller streams and numerous drainage ditches. All of the large tributaries have been developed as commercial harbors or recreational harbors or both, and many of the smaller streams and drainage ditches have been developed for recreational marinas.

Most of the harbors and marinas have jetties and breakwaters that must be maintained and many have channels that must be dredged annually. These maintenance activities are undertaken by federal, state, local, and private entities. In 2003 the volume of sediment dredged from the navigation channels ranged from 50,000 to 800,000 yd^3 (38,230–611,640 m^3; Lorain and Toledo, respectively; U.S. Army Corps of Engineers, written commun., 2003). The volume dredged annually from recreational channels averages about 2,000 yd^3 (1,530 m^3; Guy, 2000). Historically, much of the sediment dredged from harbor channels has been placed in open-lake disposal sites. However, at Cleveland Harbor and Lorain Harbor (located at the mouth of the Cuyahoga River and the mouth of the Black River, respectively), contaminant levels require that the sediment be placed in a confined disposal facility (CDF). At one time, confined disposal was required for sediments removed from Huron Harbor, but sediment quality has improved sufficiently to allow open-lake disposal. Sandy sediment dredged from channels at Fairport Harbor, Chagrin River, Rocky River, and smaller marinas is now being used to nourish the littoral system downdrift of the harbor or channel from which it was removed. Fine-grained sediment that is unsuitable for nourishment is placed upland or dumped in deep-water, open-lake disposal sites. Open-lake disposal of fine-grained sediment may be phased out as interest in beneficial reuse of dredged sediment increases. For example, it is possible to use fine-grained dredge spoil for creation of wetlands, landscaping, mine reclamation, and manufactured soil. Presently, a yard waste-recycling center near Huron manufactures soil by blending composted yard waste with fine-grained sediment dredged from local marinas.

LAKE ERIE MORPHOMETRY

Lake Erie is the smallest and shallowest of the major Great Lakes, covering about 9,910 mi^2 (25,700 km^2). The 50-mi (80-km) wide by 214-mi (342-km) long basin is subdivided into Eastern, Central, and Western Basins by a cross-lake moraine that stretches from Erie, Pennsylvania, to Long Point, Canada, and by the Lake Erie Islands that stretch from Marblehead, Ohio, to Point Pelee, Canada (fig. 2). A cross-lake moraine between Lorain, Ohio, and Point Pelee, Canada, separates the Sandusky Subbasin from the rest of the Central Basin. Average depth in the Eastern, Central, and Western Basins is 80, 60, and 30 ft (24, 18, and 9 m), respectively. The deepest point (212 ft/65 m) occurs off the tip of the Long Point sand spit on the Canadian shore of the Eastern Basin. The southwest–northeast orientation of the lake's long axis parallels the prevailing southwest winds and the northeast storm winds, making the lake particularly susceptible to wind-driven fluctuations in lake level. (See "Lake levels," p. 8.)

GEOLOGIC SETTING

Silurian dolomites and Devonian limestones, shales, siltstones, and sandstones are exposed along the lakeshore and will be visible at various field trip stops (figs. 3 and 4). Silurian dolomites crop out in the shore and nearshore around Catawba Island and the Lake Erie islands, from the Bass Islands west to West Sister Island. Devonian limestones crop out in the shore and nearshore around Marblehead Peninsula, Kelleys Island, and Pelee Island. Devonian shale crops out in the shore and nearshore in Erie, Lorain, Cuyahoga,

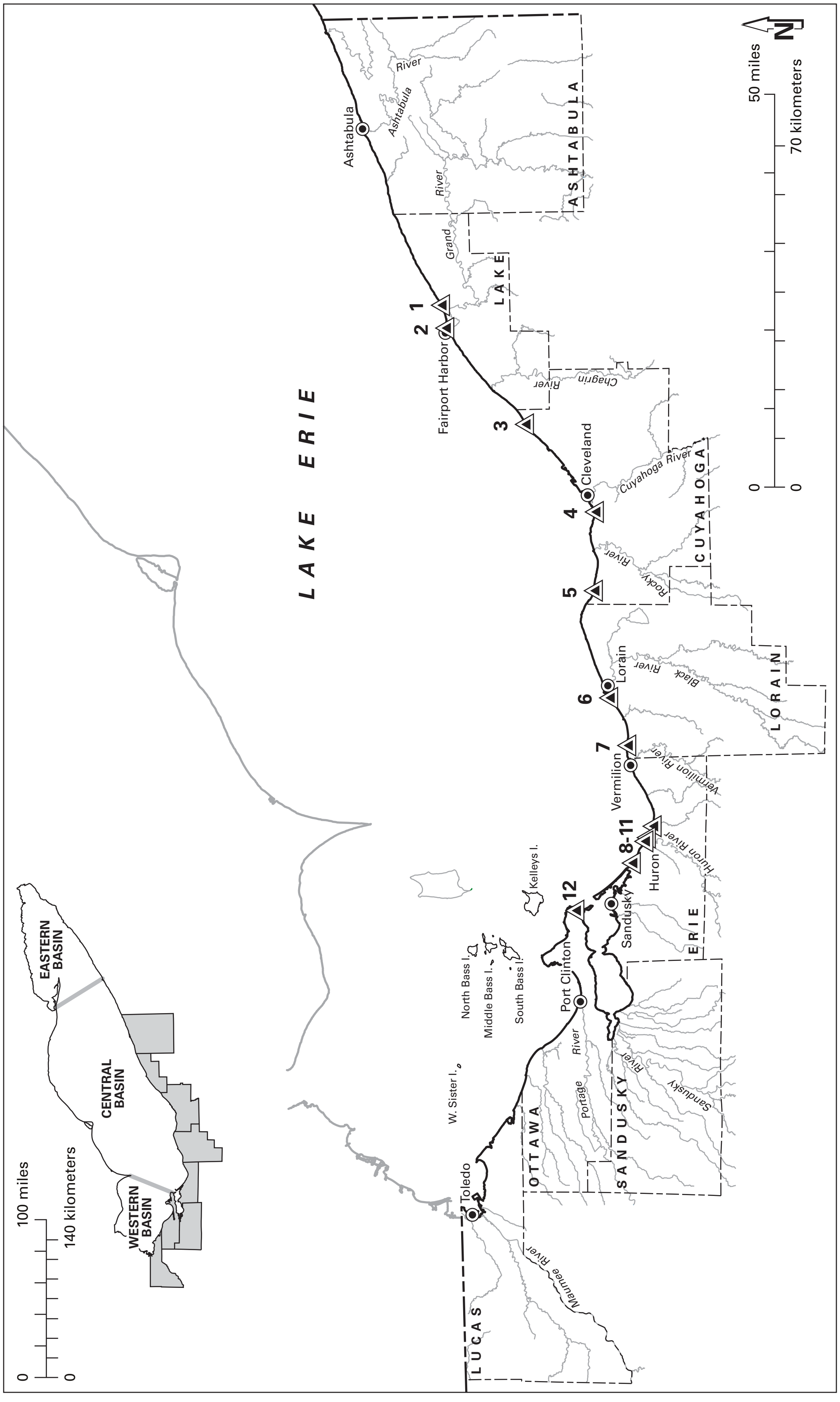


FIGURE 1.—Location of field stops along the Ohio shore of Lake Erie. Inset shows Ohio lakeshore counties and boundaries between the Eastern, Central, and Western Basins of Lake Erie.

TABLE 1.—*U.S. Geological Survey 7.5-minute quadrangles for Stops 1–12 and the Cleveland waterfront*

Field stop	U.S. Geological Survey 7.5-minute quadrangle
Painesville on-the-Lake	Perry
Headlands Beach State Park	Mentor
Sims Park	East Cleveland
Cleveland waterfront	Cleveland North, Cleveland South
Edgewater Park	Cleveland South
Huntington Reservation	North Olmsted
Lakeview Park	Lorain
Showse Park	Vermilion East
Old Woman Creek	Huron
Huron east	Huron
Huron west	Huron
Sheldon Marsh State Nature Preserve	Huron
Marblehead Quarry	Kelleys Island

Lake, and Ashtabula counties. Siltstones overlie the shale exposed in the lake bluffs in western Cuyahoga County, and sandstone occurs in one 100-ft (30-m) long outcrop in western Lorain County—the only outcrop of sandstone along the Ohio lakeshore. All of the rocks lie east of the Findlay Arch and dip gently southeastward (fig. 5).

Overlying these rocks are Quaternary deposits of till, glaciolacustrine sediments, sands, and organic deposits that record the advance of glaciers into northern Ohio about 25,000 years ago and the formation of proglacial lakes along the margin of the receding glacier between 15,000 and 12,500 years ago. When proglacial lakes occupied the Lake Erie basin, the level of the lake was up to 240-ft (73-m) higher than present Lake Erie (fig. 6). Wave-cut cliffs and sand beach ridges mark the elevation and shoreline of each of the glacial lake stages (Forsyth, 1973). These cliffs and beach ridges form such prominent geomorphic features that the lake stages that formed them have been given names such as Maumee, Whittlesey, Warren, etc. (fig. 6). When the margin of the melting glacier receded north of the glacioisostatically depressed Niagara Escarpment about 12,500 years ago (fig. 6), the proglacial lake drained catastrophically across the Niagara Escarpment. Rebounding of the escarpment gradually raised the lake to present levels.

Modern Lake Erie owes its shape to a preglacial drainage system (Forsyth, 1973), to bedrock lithology and topography, to glacial scouring, and to differential erosion of geologic deposits. Along the shore of the Central Basin, headlands occur where bedrock is near or above lake level, and broad embayments occur where cohesive clays (till and glaciolacustrine sediments) extend below lake level. Between the Central and Western Basins, islands occur where limestone and dolostone crop out in a cuesta that extends northward into Lake Erie.

From Fairport Harbor to Huron, the moderate- to high-relief shore consists of bluffs or slopes composed of glaciolacustrine sands, silts and clays, till, and/or shale (fig. 7). From Huron westward around Sandusky Bay to the Marblehead Peninsula, the shore is a low-relief plain composed of glaciolacustrine sediments and till, with outcrops of shale just west of Huron and outcrops of limestone around the Marblehead Peninsula. At Sandusky Bay, two barrier beach/sand spit complexes extend across the baymouth. The 9-mi (14.5-km) long Cedar Point spit extends northwestward across the baymouth and the 1.5-mi (2.4-km) long Bay Point spit extends southeastward across the baymouth. Around the Marblehead Peninsula and Catawba Island, low- to moderate-relief banks/bluffs are composed of rock and till. West of Catawba Island, the landscape consists of low-relief lake plain and coastal wetlands. The latter are remnants of the Black Swamp, a wetland complex that covered northwest Ohio until settlers drained the area in the 1800s. Based upon the length of Ohio's mainland shore, excluding Sandusky Bay and the islands, about 47 percent of the wave erosion zone is till, 26 percent is bedrock, 22 percent is sand, and 5 percent is glaciolacustrine silt and clay (Carter, Benson, and Guy, 1981).

Beaches typically are narrow (<50-ft [15-m] wide) to nonexistent along much of the lakeshore. Exceptions to narrow beaches occur along Cedar Point and Bay Point sand spits, at stream mouths, and where sand is trapped by shore-normal structures, such as harbor jetties, power plant intake jetties, marina breakwaters, long groins, and segmented breakwaters. Small pocket beaches occur in structurally controlled erosional embayments along the shale-bluffed shore of Cuyahoga and Lorain Counties and in shallow embayments along the carbonate-bluffed shore of Marblehead Peninsula.

Beaches are composed of rock fragments, mineral grains, calcareous shell material, and an assortment of anthropogenic materials. Rock fragments and mineral grains are derived from local bedrock and from glacial deposits. Along the Central Basin, local bedrock provides shale and siltstone clasts to the beaches. In the island area, local bedrock provides limestone and dolostone gravels to the beach. Along all of the lakeshore, till supplies igneous and metamorphic rocks derived from the Canadian Shield and shales from New York, Pennsylvania, and Ohio.

Shell content of beach sediment increased significantly following invasion of the zebra mussel in 1987 and the quagga mussel in the mid 1990s. During the spring and fall,

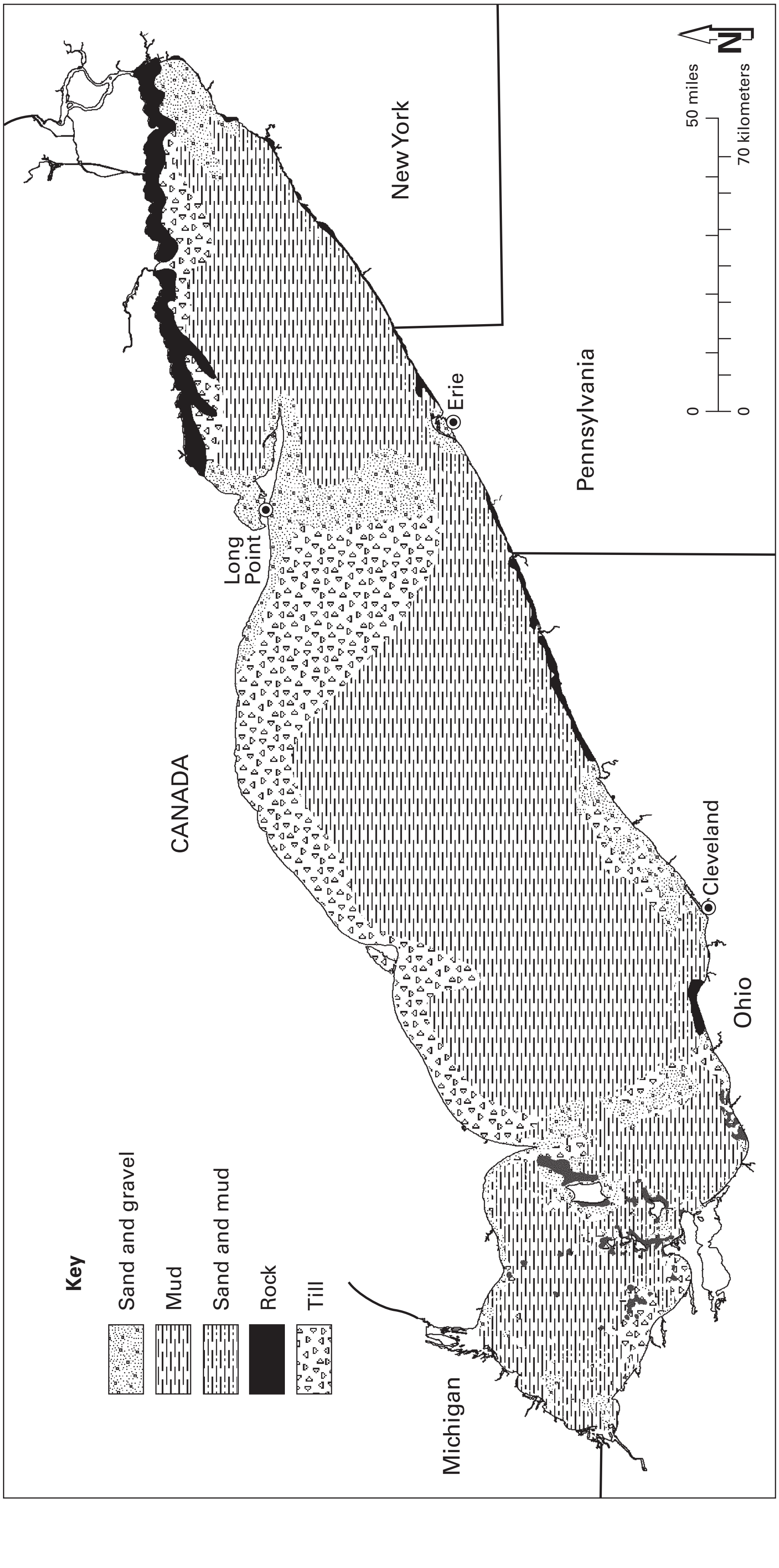


FIGURE 2.—Sediment distribution in Lake Erie (modified from Haltuch and Berkman, 1999). Note the sandy sediment on cross-lake moraines between Erie, Pennsylvania, and Long Point, Canada, and on the Pelee-Lorain moraine.

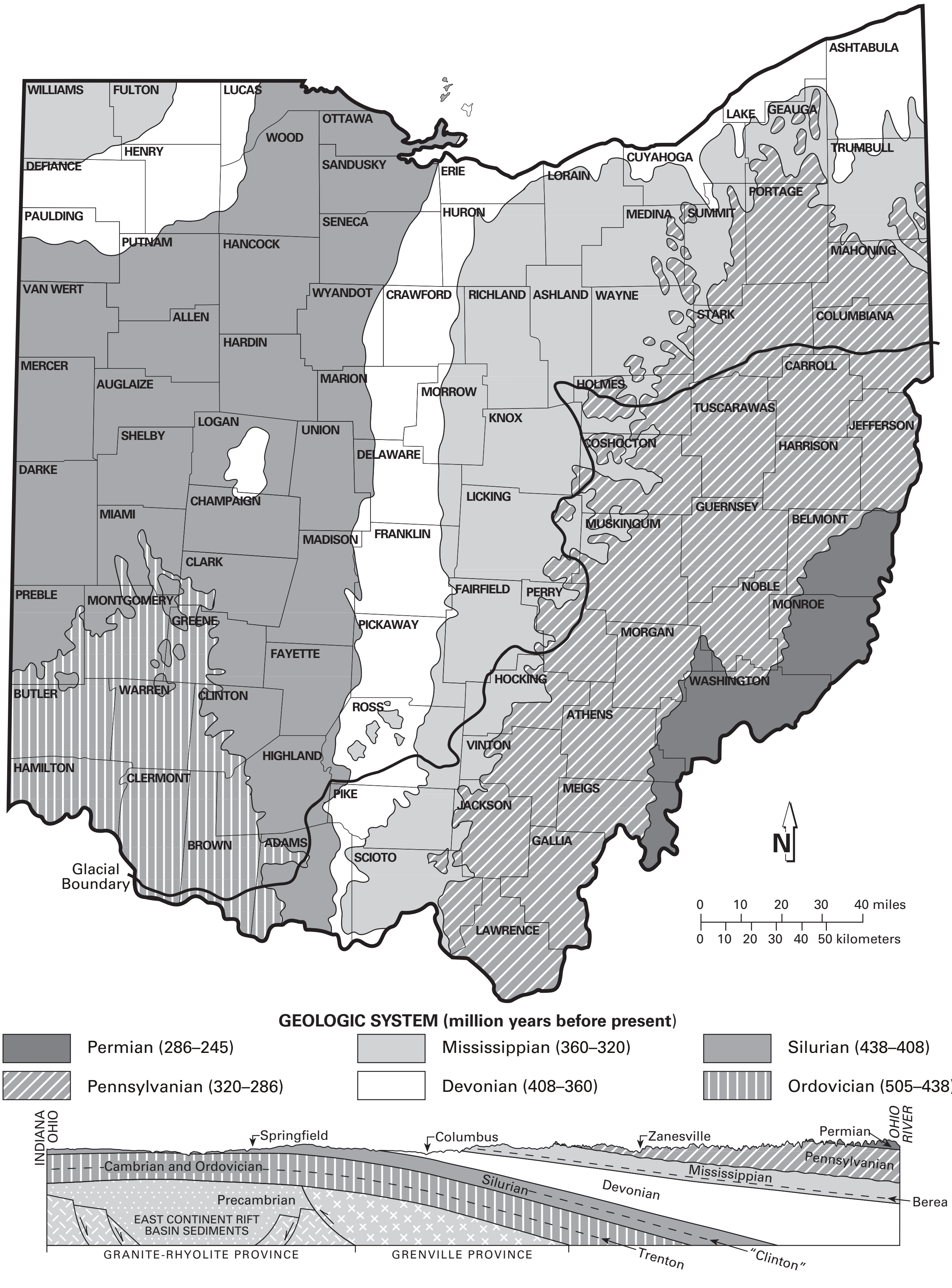


FIGURE 3.—Geologic map and cross section of Ohio (Ohio Division of Geological Survey, 2006).

GEOLOGIC TIME (million years before present)	SYSTEM/ PERIOD	SERIES/ EPOCH	GROUP	FORMATION	MEMBER
359	Devonian	Upper		Berea Sandstone	
				Ohio Shale	Cleveland Member
					Chagrin Member
					Huron Member
		Middle		Prout Limestone	
				Plum Brook Shale	
				Delaware Limestone	
				Columbus Limestone	
				Lucas Dolomite	
		Lower		Amherstburg Dolomite	
416	Silurian	Pridoli		Bass Islands Dolomite	
			Salina Group	Undifferentiated dolomite	
		Ludlow		Tymochtee Dolomite	
				Greenfield Dolomite	

FIGURE 4.—Generalized column of bedrock units in field trip area. Adapted from Ohio Division of Geological Survey (1990).

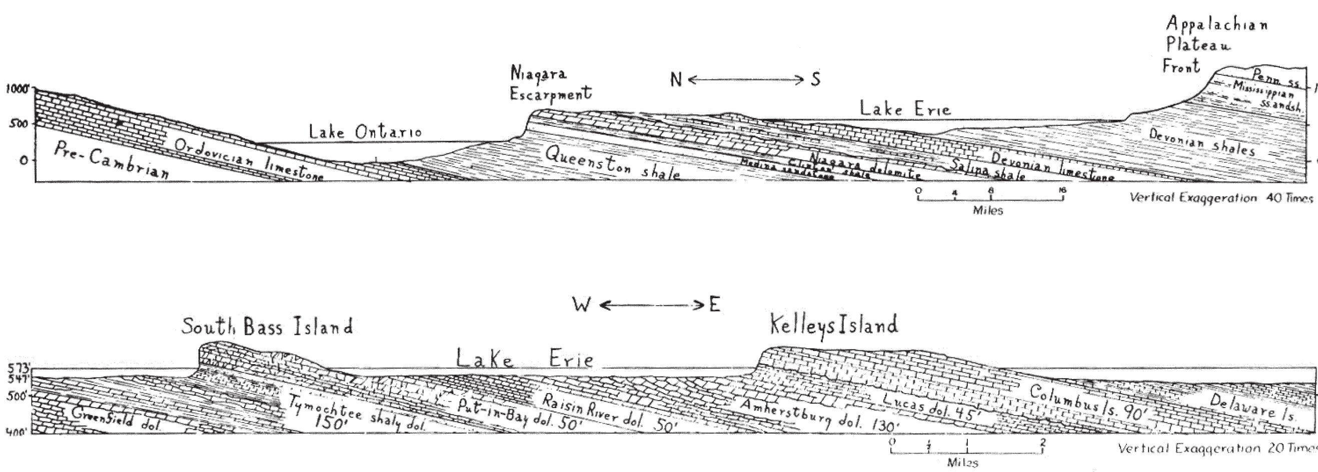


FIGURE 5.—Cross sections showing south-dipping bedrock at the east end of Lake Erie and eastward-dipping bedrock in the Island Region (from Carman, 1946). Rocks in the Island Region are on the east flank of the Findlay Arch.

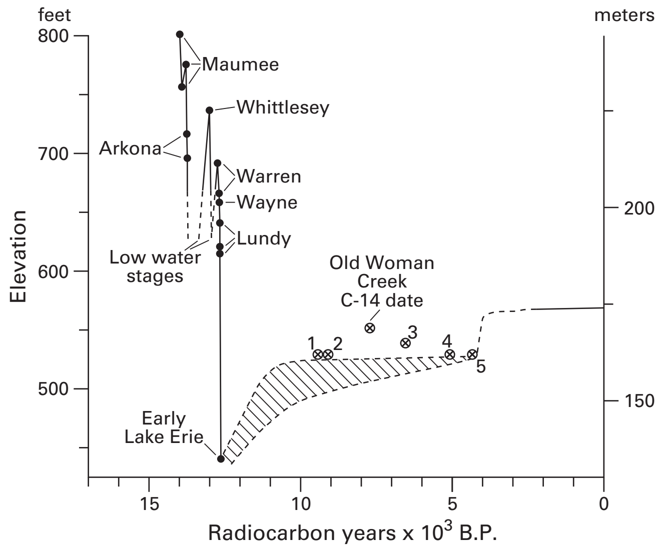


FIGURE 6.— Elevation of proglacial and postglacial lakes in the Lake Erie basin (modified from Forsyth [1959] and Lewis [1969] by Buchanan [1982]). Prominent stages of the proglacial lakes are named (Maumee, Whittlesey, etc.). Elevations of radiocarbon-dated material collected by Buchanan (1982) at Old Woman Creek shown by ⊗.

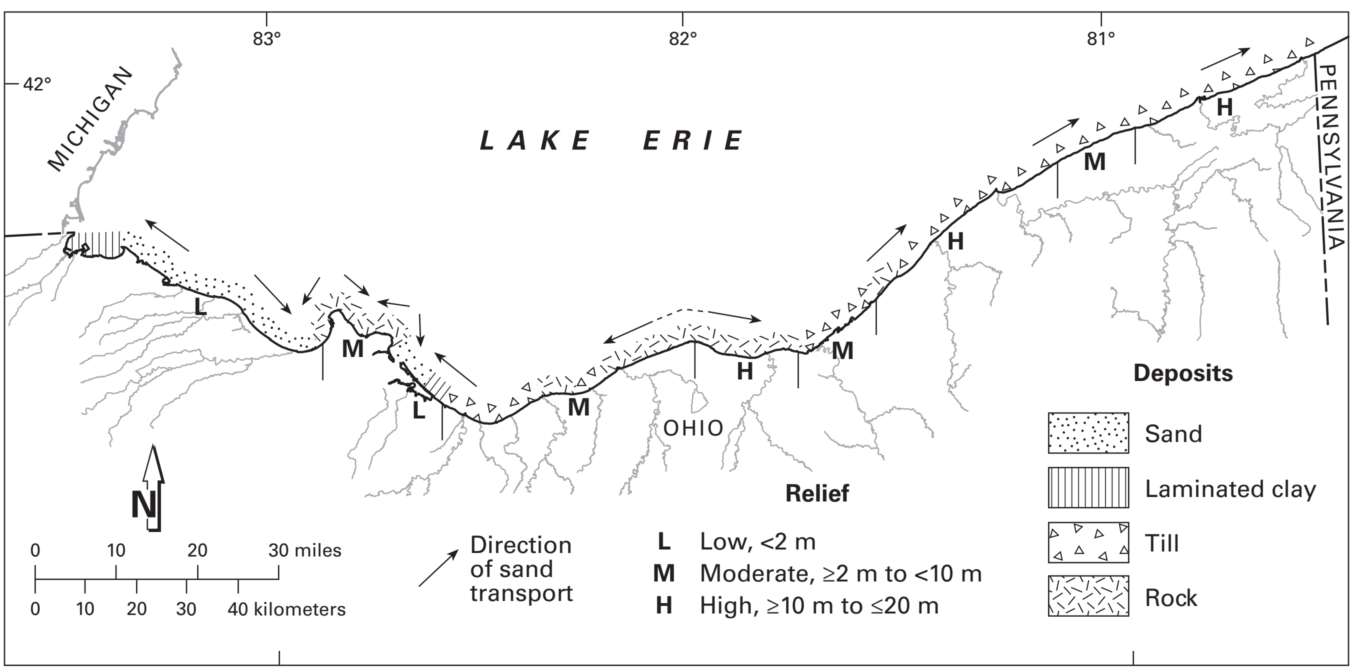


FIGURE 7.—Relief and composition of the wave erosion zone and generalized direction of sand transport along the Ohio shore of Lake Erie (modified from Carter, Guy, and Fuller, 1981).

storm waves transport vast quantities of these shells onto beaches. In places, shells of zebra and quagga mussels now make up more than 50 percent of beach sediment, which is in marked contrast to shell contents of only a few percent 20 years ago. Locally around Catawba Island, Marblehead Peninsula, the Lake Erie islands, and a stretch of shale-bluffed shore west of Huron, shells make up 100 percent of the sand-size fraction.

Numerous anthropogenic materials occur in beach sediment. The most abundant materials are concrete from roadbeds, sidewalks, and building foundations; bricks and cobblestones from buildings and roads; and slag from glass factories and steel mills. Typically these have been dumped along the shore to reclaim eroded land or to provide shore protection, but concrete, brick, and cobblestones also come from roads, sidewalks, and buildings lost to erosion. Less abundant materials include clinkers from coal-fired vessels, and taconite pellets and coal eroded from stockpiles at harbors.

Beaches may contain significant quantities of organic material. Along barrier beaches and sand spits, organic material typically is exhumed from old wetland deposits exposed in the nearshore as the barrier beach or sand spit recedes. Elsewhere, organic deposits are composed of modern aquatic vegetation blown onshore by winds or of leafy debris transported to the lake during spring floods. Typically these latter deposits are <12-in (30-cm) thick, but deposits 2–3 ft (0.6–0.9 m) thick have been observed along the shoreline at Painesville on-the-Lake.

Along much of the lakeshore, sand extends only 1,000 ft (300 m) offshore, in many areas occurring only as a relatively thin deposit over rock or cohesive clay. However, along the shore east of Cleveland, nearshore sand connects with offshore sand deposits (fig. 2). Sand also occurs on the cross-lake moraines, where relic deposits of sand and gravel are exposed on the lake bottom. Elsewhere, fine-grained sediments cover the lake bottom.

Sand and gravel in beaches come from erosion of upland deposits by streams, from erosion of shore deposits, and from erosion of nearshore deposits. In many tributaries, coarse-grained sediment transported as bedload is captured by dams or dredged from tributary mouths or both. A major exception is the Chagrin River, where coarse-grained sediments still reach the river mouth. The shore is a major source of sand found in the littoral system. Based on recession data for 1876–1973, Carter (1977) calculated that shore erosion along the Ohio lakeshore in the Central Basin contributed 138,212 yd^3/yr (105,671 m^3/yr) of sand and gravel to the littoral system, and nearshore erosion contributed an additional 26,587 yd^3/yr (20,327 m^3/yr). Based on recession data for 1876–1990, Mackey (1995) calculated that shore erosion, along the same reach of shore, contributed 206,625 yd^3/yr (157,976 m^3/yr) of sand and gravel. However, this source of sand is being rapidly cut off as more of the shore is protected to prevent erosion. As of 2005, about 80 percent of the lakeshore had dense shore protection (Fuller and Gerke, 2005). Thus, of the three potential source areas, only the nearshore remains significant, but as noted above, the volume of sand and gravel contributed by nearshore erosion is relatively small.

LIMNOLOGY

Lake levels

Lake Erie is known for its fluctuating lake levels. Fluctuations occur over several time scales. Long-term and annual fluctuations are caused by changes in the volume of the lake resulting from changes in precipitation in the Great Lakes Basin. Short-term fluctuations, on the order of hours to days, represent a tilting of the lake surface due to wind stress or barometric pressure changes.

Long-term fluctuations occur over a period of several years. Record-high levels in 1997, as well as the high levels in 1985–86, 1973, 1952, and 1943, were preceded by several years of above normal precipitation (fig. 8). Conversely, extremely low lake levels in 1934 and 1964 followed years of abnormally low precipitation. The difference in yearly mean lake level between the record high of 573.8 ft (174.89 m; International Great Lakes Datum [IGLD], 1985) in 1986 and the record low of 568.7 ft (173.34 m; IGLD, 1985) in 1934 is 5.1 ft (1.55 m). The highest monthly mean at Cleveland during the period of record (1860–2005) was 574.3 ft (175.05 m; IGLD, 1985) in June 1986, and the lowest monthly mean was 568.09 ft (173.15 m; IGLD, 1985) in February 1936, representing a difference of 6.2 ft (1.89 m; NOAA, 1986, 2006).

Annual fluctuations in lake level are caused by seasonal variations in the natural hydrologic cycle. During the spring, high runoff, high precipitation, low evapotranspiration, and low evaporation cause the lake level to rise. During the late summer and fall, decreased precipitation, high evapotranspiration, and high evaporation cause the lake level to fall (fig. 9). The annual range in lake level, from mid-winter low to mid-summer high, is about 1.2 ft (0.4 m).

Short-term fluctuations in lake level last a few hours to a few days. These fluctuations are owing to wind-driven storm surges, changes in barometric pressure, or inertial surges of water (seiches) that occur after lake level has been set up by either of the two previous agents. The greatest storm surges occur when the wind blows parallel to the long axis of the lake. Under extreme conditions, lake level at the confined ends of the lake may rise or fall more than 6 ft (2 m) from pre-storm levels (fig. 10). At Toledo, positive storm surges exceeding 2.0 ft (0.61 m) occur (on average) five times per year; negative storm surges of 3.0 ft (0.91 m) occur (on average) five times per year (Pore and others, 1975). Passage of storm systems through the Great Lakes can cause lake levels at the ends of the lake to fluctuate 10 to 11 ft (3 to 3.3 m) over a period of several days.

The most important storm surges along the western part of the Central Basin and all of the Western Basin are those generated by northeast winds, because these storm surges are accompanied by large storm waves. In November 1972 (fig. 11) and in April 1998, storm surges of 3.7 and 3.9 ft (1.13 and 1.19 m), in combination with storm waves, caused extensive damage along Lake Erie. A storm surge in April 1966 reached an elevation of 5.5 ft (1.68 m) above pre-storm levels. All of these storm surges were caused by northeast winds generated by passage of low-pressure centers, with their counterclockwise winds, south of Lake Erie.

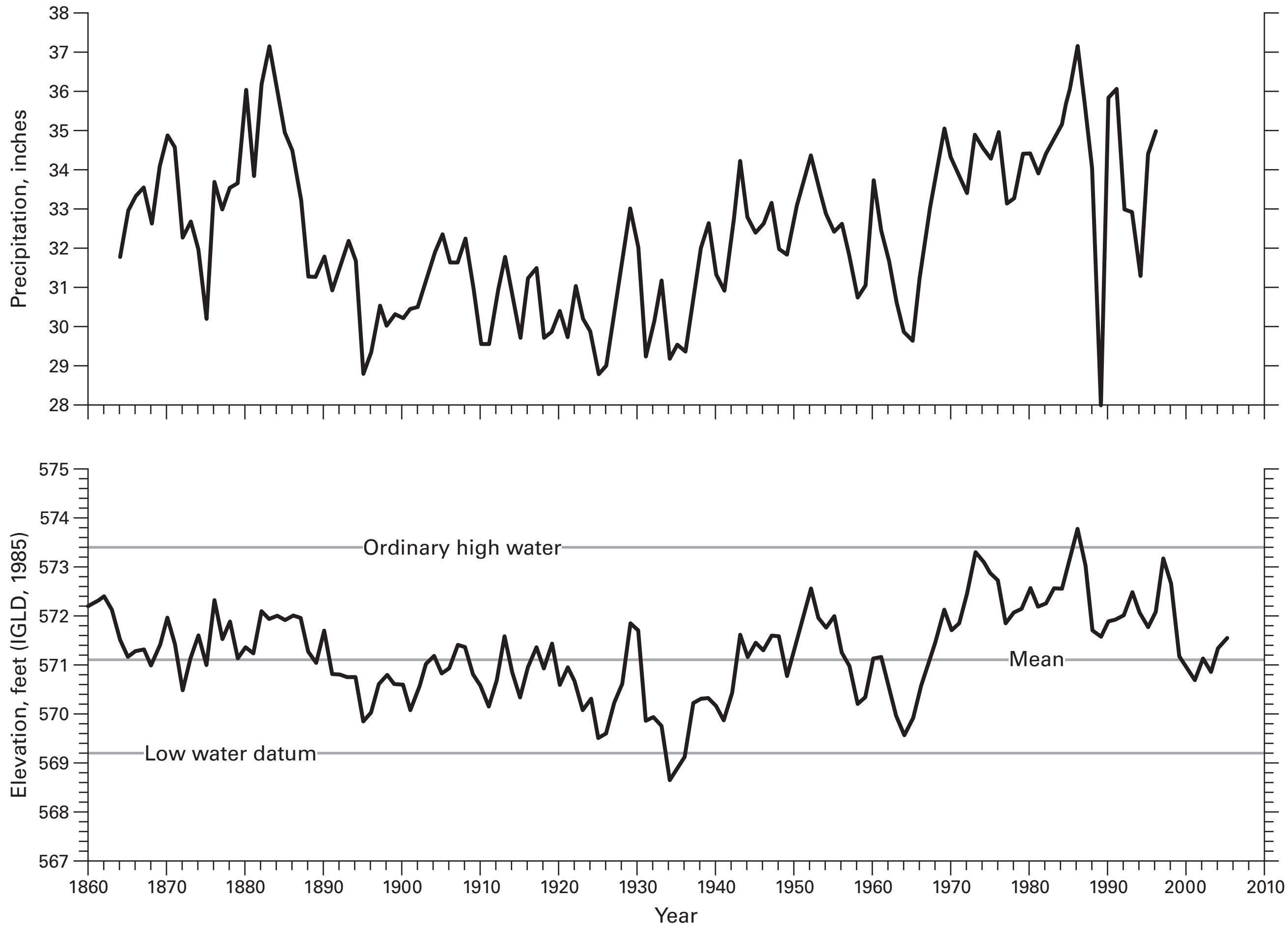


FIGURE 8.—Precipitation in the Upper Great Lakes and annual mean lake levels for Lake Erie, 1860–2005 (NOAA, 2006).

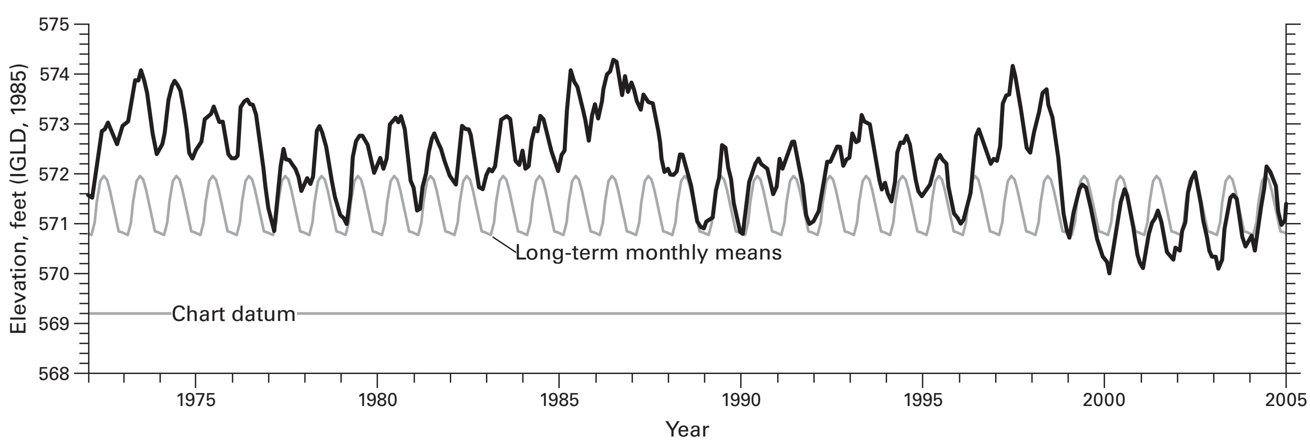


FIGURE 9.—Monthly mean lake levels for Lake Erie, 1972–2005. Note yearly rise and fall of Lake Erie levels and the dramatic drop in lake level between 1987 and 1989 and between 1997 and 2000. Lake Erie was above its long-term mean for a quarter century (NOAA, 2006).

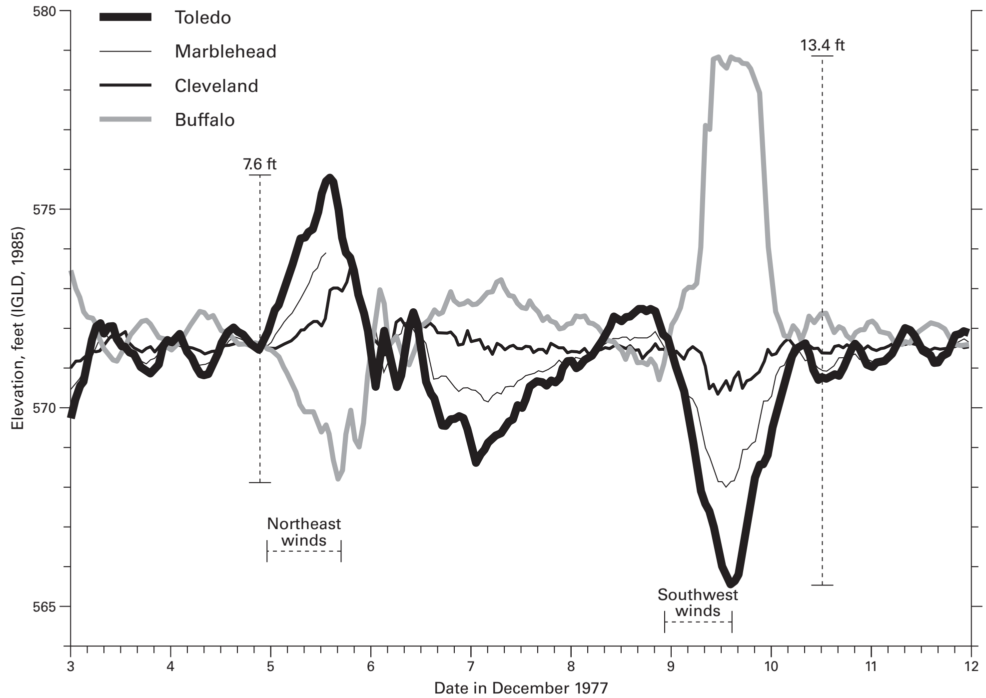


FIGURE 10.—Positive and negative Lake Erie storm surges at Toledo, Ohio, and Buffalo, New York. Smaller oscillations in lake level are inertial seiches with approximately 14-hour periods. Changes in lake level during these events cause flooding, hamper navigation, and promote exchange of water and nutrients in wetlands. Water level data are from NOAA (2006).

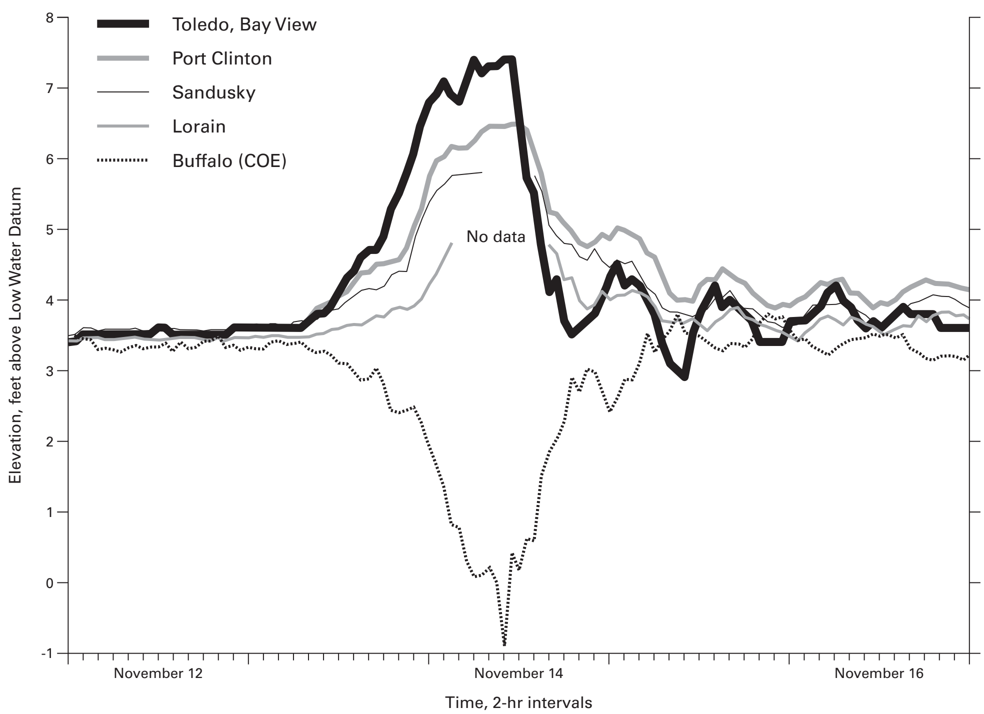


FIGURE 11.—Lake levels during a positive storm surge that breached the barrier beach at Sheldon Marsh (Ohio) on November 14, 1972. This storm caused extensive flooding in low-lying areas along the western shore of Lake Erie (see figure 14). The inertial seiche of water along the axis of Lake Erie can be seen in water levels for two days after the storm. Water level data from gages maintained by the U.S. Army Corps of Engineers and by the Ohio Department of Natural Resources, Division of Geological Survey. Low water datum is 569.2 feet (IGLD, 1985).

Negative storm surges occur at Toledo when strong southwest winds blow across the lake. On April 6, 1979, strong southwest winds lowered the lake at Toledo about 9 ft (2.74 m) and raised the level at Buffalo about 7.5 ft (2.29 m). The difference in lake levels at opposite ends of Lake Erie exceeded 16.5 ft (5.03 m). On December 2, 1985, strong southwest winds lowered the lake 8.5 ft (2.59 m) at Toledo and raised the lake at Buffalo 7.5 ft (2.29 m) to a record-high level (fig. 12). Negative storm surges at Toledo do not create erosion hazards, but they may temporarily hamper ships navigating in the Western Basin. Storm surges along the central part of the lake are less pronounced.

An inertial return surge of water, a seiche, occurs after external forces (for example, winds) have abated. The water will oscillate from one end or side of the lake to the other with decreasing setup until equilibrium is reached. The seiche period along the long axis of the lake is about 14 hours and shows up in water level data collected after storms (see figs. 10, 11).

Winds and waves

The size of wind-generated waves is a function of wind speed and duration, open-water fetch distance, and water depth. The largest waves affecting the Ohio lakeshore are those generated by storm winds from the west through northeast. Wave energy is highest from late fall through spring (fig. 13). Fortunately, this is when lake level is lowest and when shorefast ice typically forms a barrier between the waves and erodible shore materials.

COASTAL PROCESSES

Flooding

Along most of the Central Basin, lake flooding is not a significant problem except at some tributaries. However, along the low relief shore in the western part of the Central Basin and along the Western Basin, lake flooding can be significant. Inland areas may be flooded where dikes are breached or overtopped by storm waves or where storm surges raise levels in tributaries and canals. In November 1972 a severe northeast storm flooded much of the shore west of Huron (fig. 14). Subsequent northeast storms during the next 30 years of above-normal lake level also caused flooding, but the flooding was less extensive because dikes were repaired or flood control measures implemented. The last major storm to cause extensive flooding along western Lake Erie occurred April 9, 1998 (Mackey and others, 1999).

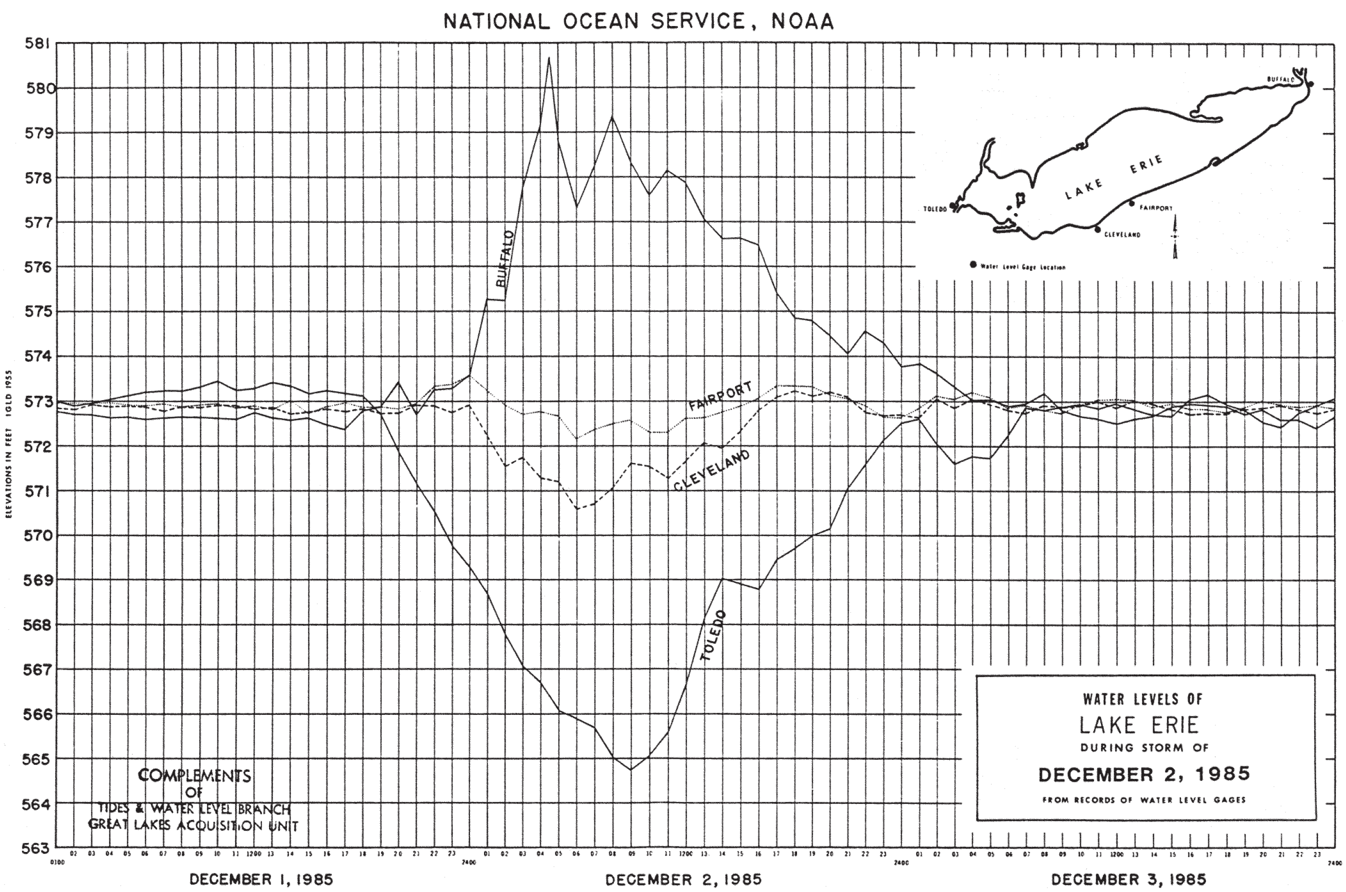


FIGURE 12.—Lake level during a storm on December 2, 1985 (from NOAA, 1985). Extremely strong southwest winds blew water to the east end of the lake, raising lake level at Buffalo, New York, and lowering lake level at Toledo, Ohio.

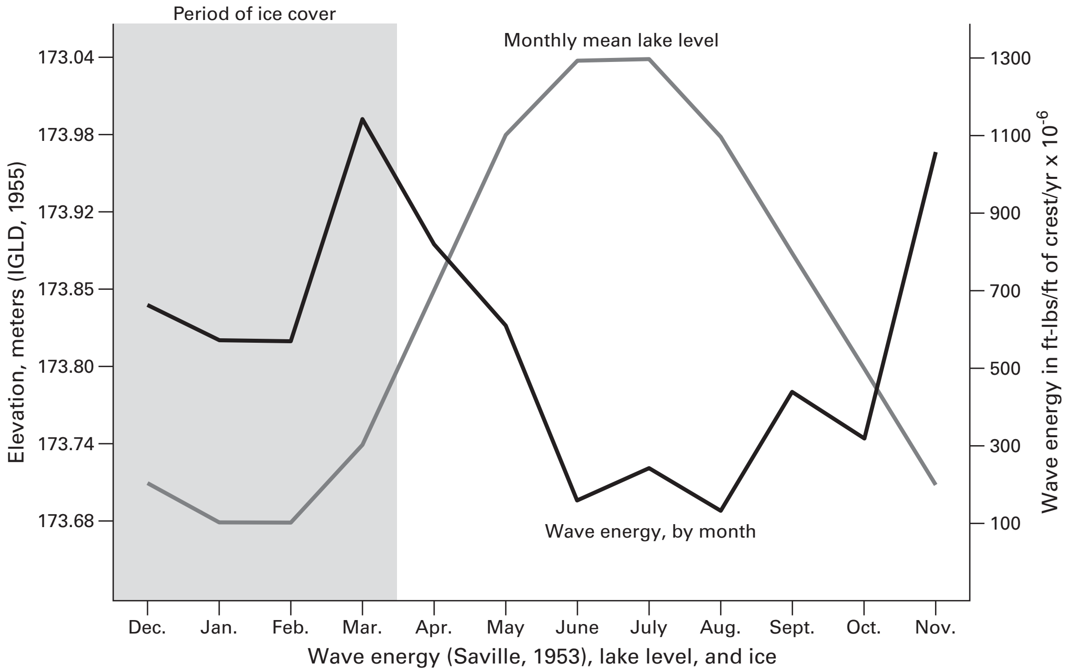


FIGURE 13.—Seasonal wave energy on Lake Erie (modified from Carter, Guy, and Fuller, 1981).

Erosion

Erosion along the Lake Erie shore is principally a result of wave action and mass wasting (the downslope movement of material due to gravity). Waves erode material from the toe of a bluff or slope, inducing mass wasting higher in the slope. The degree to which mass wasting occurs is largely dependent upon the frequency and amount of wave erosion occurring at the bluff toe. If debris is not removed from the toe of a bluff or slope by waves, a slope will reach a stable configuration and mass wasting will slow to imperceptible rates.

Along the barrier beaches and low clay banks of the Western Basin, mass wasting is not a significant process. However, along the rock-cliffed shore, gradual erosion of rock near lake level undermines the cliff, and the unsupported rock fails along joint boundaries. The resultant rock falls are episodic, with some failures occurring at decadal time scales. Along the carbonate-rock cliffs of the island area, large boulders along the base of rock cliffs and on rocky nearshore slopes are evidence of past rock falls. Where fallen rock accumulates along the base of the cliff, it helps protect the cliff from further erosion. Along the shale-bluffed shore in the Central Basin, rubble created by collapse of the shale cliff is typically broken down quickly by wave action and provides little long-term protection from wave attack.

Most wave erosion occurs during storms in early spring or late fall when the greatest amount of wave energy is expended on the shore (fig. 13). During the winter months, ice typically protects the shore from wave attack, and during the summer months, there are fewer storms. The largest waves to strike the shore are generated by onshore storm winds from the west through northeast. However, waves generated by northeast winds typically have the greatest impact on the Ohio shore because the northeast winds also generate a storm surge that raises lake level along this reach of shore.

When waves break directly on a bluff or bank, impact and hydraulic pressure quarry blocks of weathered material from the toe of the bluff or bank. As a wave washes across the toe of a bluff, sediment suspended by the breaking wave abrades the bluff face, removing additional material and leaving a smoothed, rounded surface. This erosion steepens or undercuts the toe of the bluff, steepening the bluff profile and inducing mass wasting higher in the bluff. The resultant mass wasting occurs as block falls, rotational slumps, and debris flows.

Block falls occur where till or rock bluffs have been undercut by waves, causing individual blocks to break away along fracture or joint surfaces. Rotational slumps occur in the till and glaciolacustrine sediments; typically the slip surface is a porous zone in the lower part of a bluff. Debris flows occur when glaciolacustrine sediments or sand in the upper part of oversteepened bluffs become saturated with ground water and lose their shear strength. Shore erosion shows considerable spatial and temporal variation, at both small and large scales (fig. 15). Factors that influence spatial variations in erosion include shore composition, cohesive strength, shear strength, structure (for example, fractures or joints), shoreline orientation, nearshore bathymetry, beach topography, and anthropogenic structures. Factors influencing temporal variations in erosion include lake level, storms, temperature, precipitation, and anthropogenic structures.

Another aspect of erosion along Lake Erie is downcutting (erosion) of cohesive deposits exposed in the nearshore. Studies in Canada show downcutting of cohesive nearshore deposits increases with decreasing water depth. Rates of downcutting range from 0.05 ft/yr (1.5 cm/yr) in water depths of 19.69 ft (6 m), to 0.11 ft/yr (3.5 cm/yr) in water depths of

FIGURE 14.—Flooding in Reno Beach along western Lake Erie following storm of November 14–16, 1972. A plot of lake level during the storm is shown in figure 11. Aerial photograph taken November 16, 1972, by the Ohio Department of Transportation.

7.55 ft (2.3 m), to 0.23 ft/yr (7 cm/yr) close to shore (Davidson-Arnott, 1986). At Maumee Bay State Park, at the west end of Lake Erie, about 1.6 ft (0.5 m) of downcutting occurred over a nine-year period (Fuller, 2002); this downcutting creates the concave profile found where cohesive deposits are exposed in the nearshore. Downcutting of nearshore cohesive deposits also supplies sand and gravel to the littoral system. However, downcutting of the nearshore allows larger waves to reach closer to shore and may eventually undermine the foundation of shore-protection structures.

Littoral transport

Net transport of littoral sediment (fig. 7) has been inferred from geomorphic features (spits and sand ridges) and accumulations of sand adjacent to shore-normal structures (jetties and groins). A zone of diverging littoral-transport cells occurs near Avon Point and a zone of convergence occurs at the mouth of Sandusky Bay. Along reaches of low-relief shore, there may be significant temporal changes in direction of net transport, depending more on lake level than on wave direction. During periods of high lake level, when storm surges allow waves to overtop barrier beaches and wash over low clay banks, littoral sediments may be transported shoreward rather than alongshore (Fuller, 1982; Guy, 1984b). During lower lake-level conditions, when storm surges are less likely to overtop the barriers and low banks, alongshore transport becomes more significant.

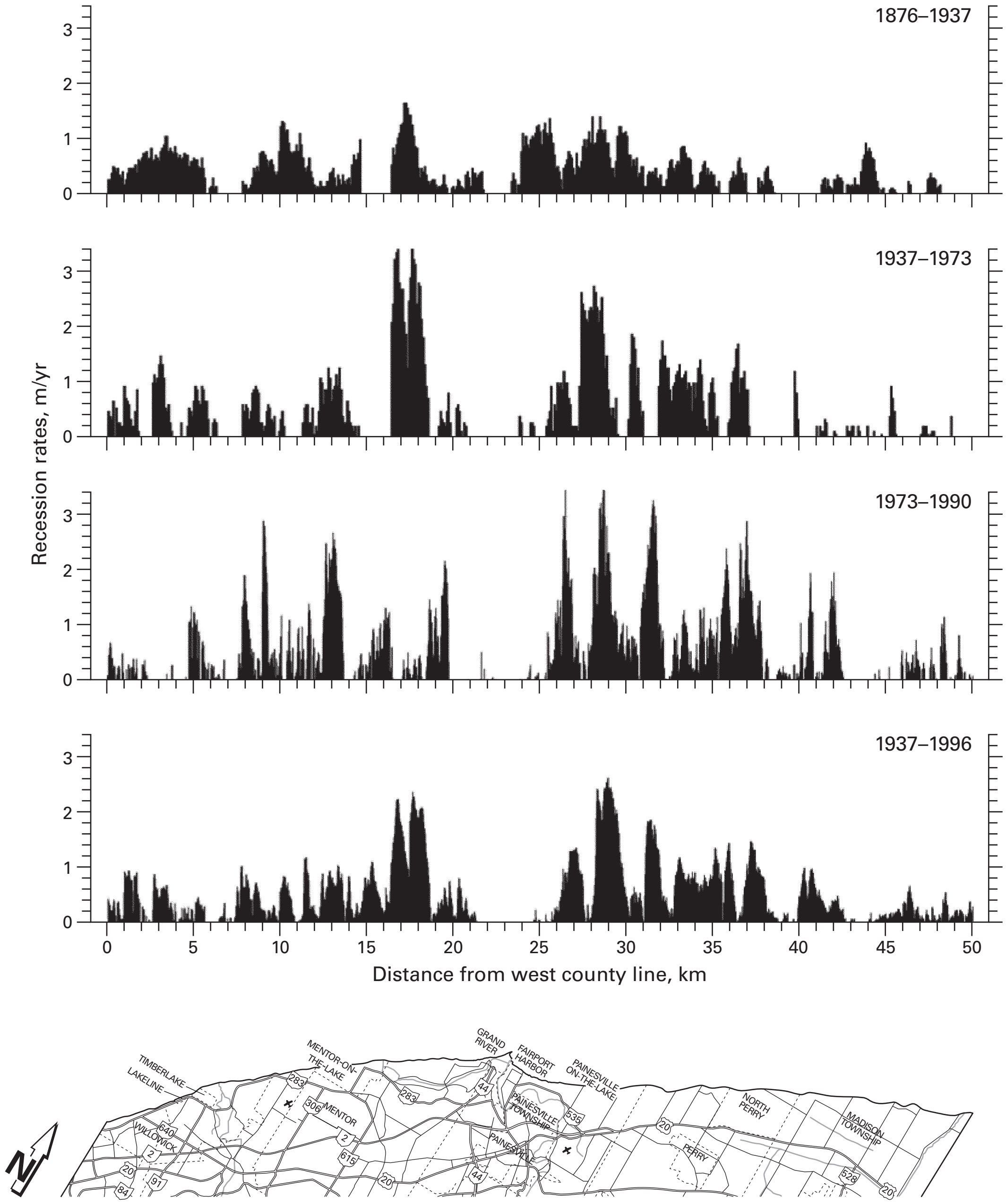


FIGURE 15.—Recession rates for Lake County, Ohio (modified from Guy, 1999). Note temporal and spatial changes in recession rates. Recession rates declined along the western half of the county as more shore protection structures were built. High rates east of Fairport Harbor result in part from interruption of sand transport by the Fairport Harbor jetties.

STOP 1: PAINESVILLE ON-THE-LAKE, PAINESVILLE TOWNSHIP

Painesville on-the-Lake is located about 4 mi (6.4 km) downdrift (east) of Fairport Harbor (fig. 16). At this stop the 60-ft (18-m) high bluff is composed predominately of Ashtabula Till (White, 1982) capped by several feet of glaciolacustrine silt and clay and several feet of sand and gravel. Two facies are present in the till: a lower lodgment facies and upper ablation facies (Pavey and others, 1995). During deposition of the lodgment till beneath the overriding ice sheet, shear stress aligned clasts in the till. In contrast, the ablation till was deposited from stagnant ice, and clasts have a more random orientation (fig. 17). Impoundment of sand updrift of the Fairport Harbor structures has significantly impacted beach and bluff erosion along Painesville on-the-Lake. The impact of erosion is best seen from the east end of Lake Road (figs. 18, 19). To the east, numerous homes and several roads have been lost. Note that beaches are narrow or absent. Steep slopes and lack of vegetation on the bluff east of Hardy Road are striking evidence of active wave erosion at the bluff toe and mass wasting in the upper bluff.

Since 1937, the bluff has receded more than 400 ft (122 m). Between 1876 and 1973, recession rates were about 4.5 ft/yr (1.4 m/yr), but between 1973 and 1990 rates were about 6.2 ft/yr (1.9 m/yr; Ohio Division of Geological Survey, 1998). Recession data for the latter time period were used to designate a 30-year coastal-erosion area at Painesville (figs. 20, 21). Wave erosion at the bluff toe steepens the profile of the lower bluff, inducing mass wasting higher in the bluff. Failures occur as debris flows, slides, and block falls. Interconnected joints in the low permeability tills found at Painesville directly influence recession of these Lake Erie bluffs (Highman, 1997). Migration of ground water along these interconnected joints, during periods of high infiltration, increases pore pressure along the joint surfaces and decreases bluff stability.

Mass wasting along this stretch of shore has occasionally involved large masses of material. Early on the morning of May 4, 1994, a massive slump (~6,500 yd^3 /~5,000 m^3) occurred involving a block about 200-ft (61-m) long and up to 25-ft (7.6-m) thick. A failure of similar scale, 180 ft by <25 ft (55 m by <7.6 m), occurred in the spring of 1954.

Groin-trapped beaches partially protect the park frontage from wave attack (figs. 18, 20). However, the protection has not been adequate, and in the last 5 years, steel bulkheads have been built along the bluff toe at Painesville Township Park. Note the lakeward rotation of the older section of bulkhead. The dissected and hummocky slope at the park is a product of successive slumps and other forms of mass wasting.

Since the late 1990s, shore-protection structures built along the bluff east of Lake Road, combined with the effect of lower lake levels, have slowed recession. However, turbid water along the bluff toe is common, even during periods of relatively low wave activity, and is a clear indication that wave erosion continues. Some of the eroded material comes from the bluff toe and some comes from downcutting of cohesive clay exposed, or only thinly covered by sand, on the lakefloor.

For nearly 150 years, sand dredged from Fairport Harbor was placed in a deepwater, open-lake disposal site. Since the 1980s, sand dredged from the harbor entrance has been placed in 25 ft (7.6 m) of water offshore of Painesville. Recent side-scan surveys at Painesville show there is little movement of sand placed at this water depth (Fuller and others, 2002).

In an attempt to mitigate the effects of sediment starvation caused by impoundment of sand at Fairport, the Ohio Department of Natural Resources recently took a more aggressive position regarding disposal of sand dredged from the harbor. In 2001, in response to pressure from the Ohio Department of Natural Resources, the U.S. Army Corps of Engineers placed 40,000 yd^3 (30,600 m^3) of sand shoreward of the 8-ft (2.4-m) depth contour offshore of Painesville at a cost of \$5.25/yd^3 (\$4.01/m^3) (fig. 22). In 2002 the U.S. Army Corps of Engineers placed 25,000 yd^3 (19,100 m^3) of sand between the 8- and 11-ft (2.4- and 3.35-m) depth contours lakeward of the west end of the 2001 disposal site, and Lake County placed 35,000 yd^3 (26,800 m^3) of sand lakeward of the east end. Bottom-dump scows were used for disposal in 2001, 2002, and 2003. In 2005 the U.S. Army Corps of Engineers used a hydraulic dredging system to pump 60,000 yd^3 (45,900 m^3) of sand from the lake-approach channel at Fairport Harbor and placed it along 1,150 ft (350 m) of shoreline west of Painesville Township Park. In July and August of 2005, the resultant 120-ft (35-m) wide by 1,265-ft (385-m) long beach covered 2.2 acres (0.9 ha; Guy and Gerke, unpub. data, 2005).

Nearshore disposal of sand presently costs more than open-lake disposal. In 2001 the Ohio Department of Natural Resources served as the local sponsor to cover the \$48,250 incremental increase in cost associated with nearshore disposal. In 2002 the U.S. Army Corps of Engineers determined there was no increase in cost associated with disposal of sand between the 8- and 11-ft (2.4- and 3.35-m) depth contours (table 2), and in 2005 the cost of shoreline disposal was competitive with nearshore disposal.

The benefits of nearshore disposal are difficult to quantify, because the volume of sand placed in the nearshore or along the shoreline typically is small compared to annual transport rates of >88,000 yd^3/yr (67,300 m^3/yr; Bajarunas, 1961). In addition, side-scan sonar surveys and sediment samples suggest that sand disperses from the disposal area in thin sheets that are hard to detect with side-scan sonar (Guy and Liebenthal, 2004a, 2004b, 2005). Regardless, nearshore or shoreline disposal of sand dredged from Fairport Harbor has long-term benefits. The sand and gravel will nourish the littoral system reducing erosion, increasing beach widths, increasing size and number of nearshore bars, and restoring biologic habitats.

Also of interest are a number of earthquakes that have occurred in the vicinity of Painesville (fig. 23; Hansen, 2005). Epicenters for several earthquakes have been located offshore of Painesville. The epicenter of a June 30, 2004, earthquake (3.3 magnitude) was located close to the epicenter of a 3.5 magnitude earthquake that occurred on June 30, 2003. Earthquakes in 1983, 1988, and 1992 (two quakes) had instrumental epicenters close to the June 2003 earthquake. Hypocentral depth for the earthquakes is 5 mi (8 km).

FIGURE 16.—Location map for Painesville on-the-Lake and Headlands Beach State Park, Ohio. Mentor Marsh occupies an abandoned meander of the Grand River. Aerial photograph taken in 2000 by the Lake County GIS.

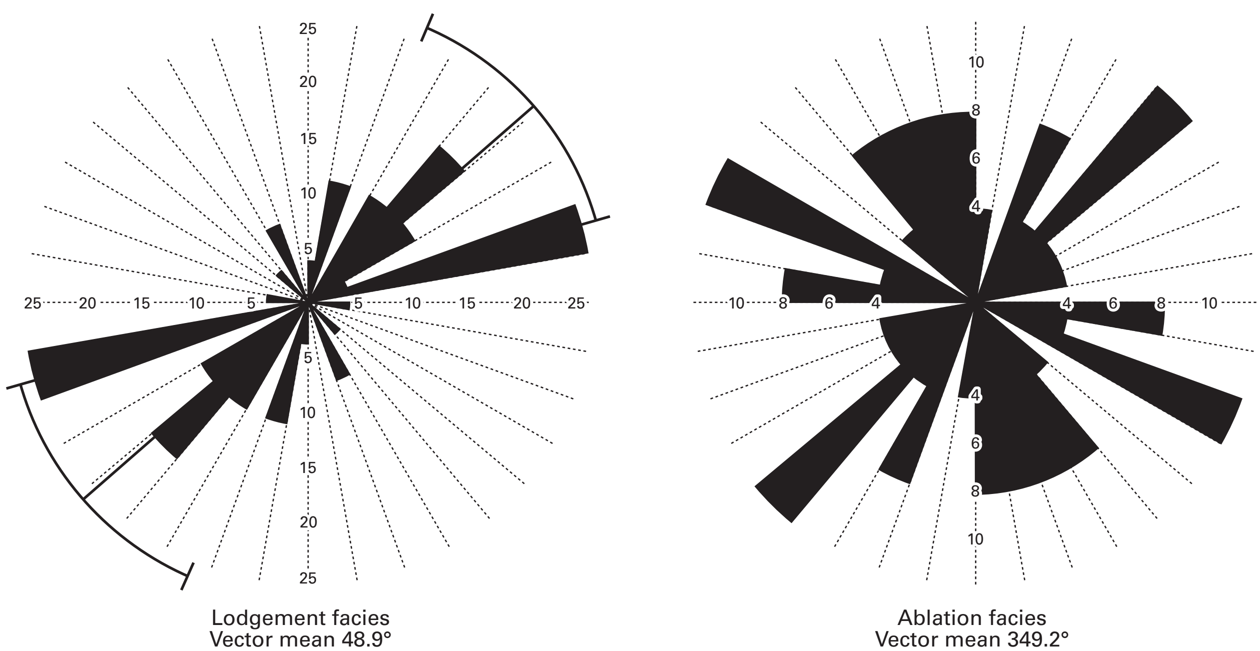


FIGURE 17.—Orientation of clasts in lodgment and ablation till at Painesville, Ohio (modified from Stone, 1994). Units on graphs are percentages.

FIGURE 18.—Painesville on-the-Lake, Ohio (west). Aerial photograph taken in 2000 by the Lake County GIS.

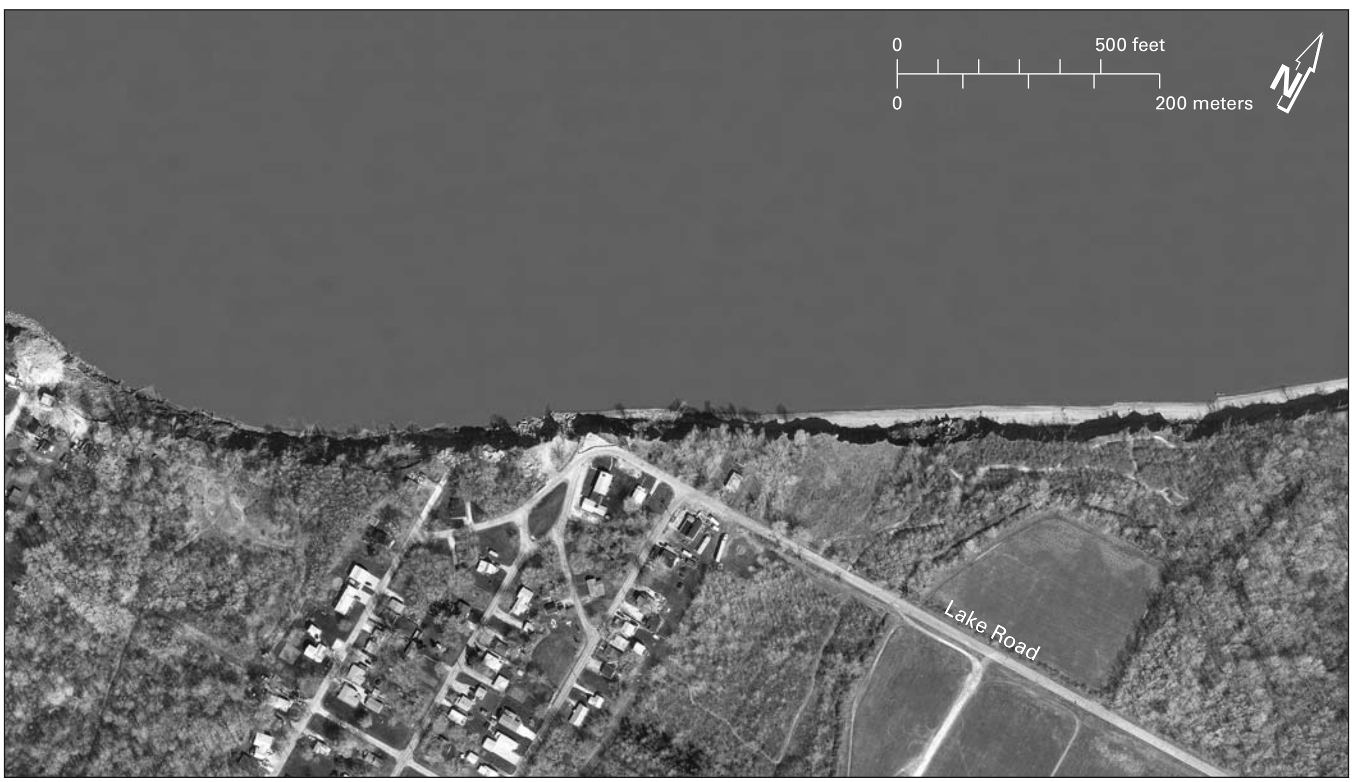


FIGURE 19.— Painesville on-the-Lake, Ohio (east). Aerial photograph taken in 2000 by the Lake County GIS.

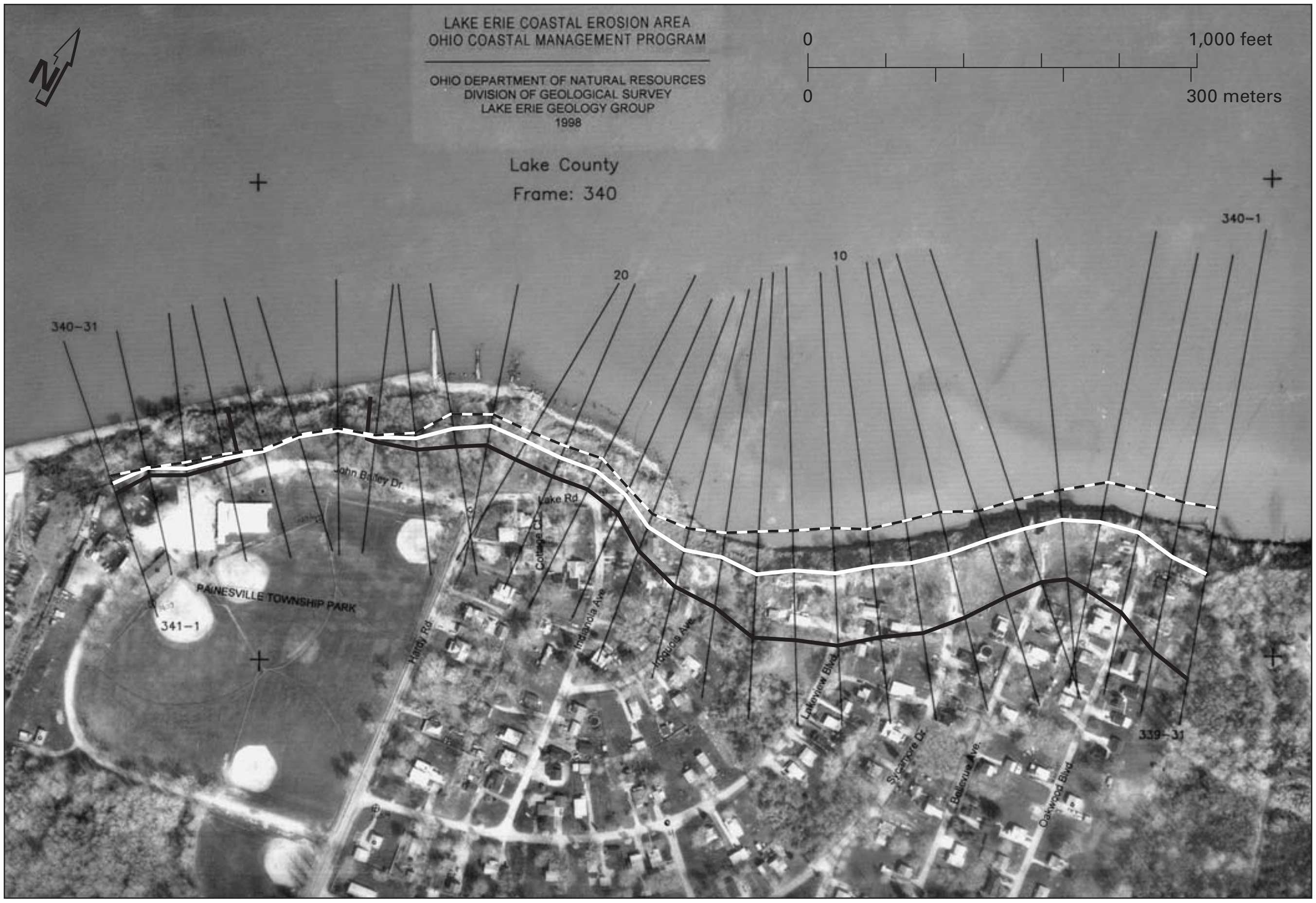


FIGURE 20.—Coastal erosion area map (Ohio Division of Geological Survey, 1998) for Painesville on-the-Lake, Ohio (west). A dashed line marks the 1973 bluff line; a solid white line marks the 1990 bluff line; and a solid black line marks the landward extent of the coastal erosion area. Aerial photograph taken in 1990 by the Ohio Department of Natural Resources.

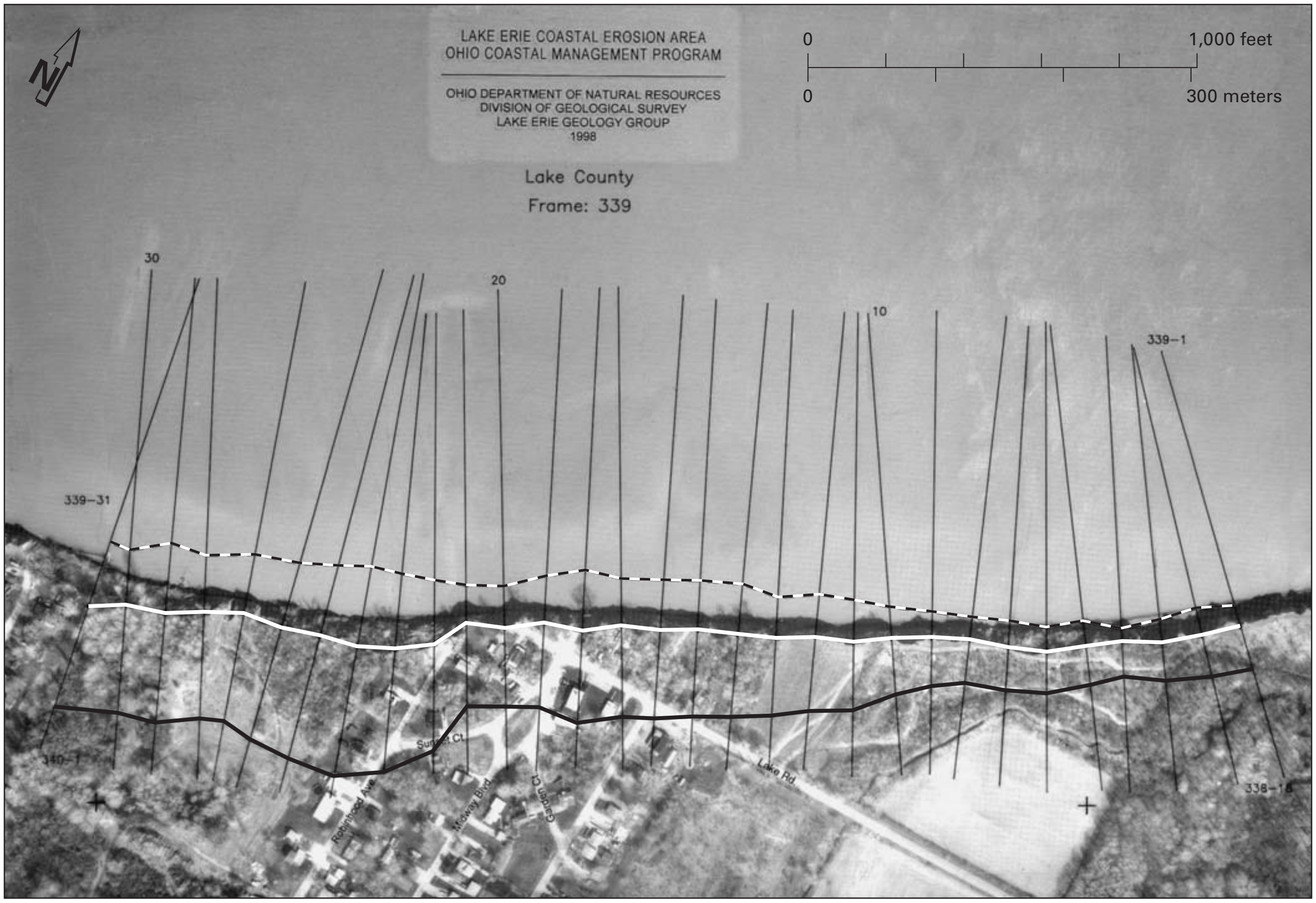


FIGURE 21.—Coastal erosion area map (Ohio Division of Geological Survey, 1998) for Painesville on-the-Lake, Ohio (east). A dashed line marks the 1973 bluff line; a solid white line marks the 1990 bluff line; and a solid black line marks the landward extent of the coastal erosion area. Aerial photograph taken in 1990 by the Ohio Department of Natural Resources.

FIGURE 22.—Painesville on-the-Lake, Ohio (2000). Length of shore used for nearshore disposal in 2001–2003 is shown with a long, dashed line. Length of shore used for onshore disposal in 2005 is shown with a short, dashed line. Aerial photograph taken by the Lake County GIS.

TABLE 2.—*Costs associated with nearshore disposal of sand dredged from Fairport Harbor, \$/yd*^{3}

	Disposal site			
Year	Open-lake	–11 feet LWD[1]	–8 feet LWD[1]	shoreline
2001	\$2.90	\$3.40	\$5.25	not bid
2002	\$4.34	\$6.80		not bid
2003	\$4.82	\$4.82	no bid	no bid
2005	\$7.36	\$6.24	\$6.24	\$5.94

[1]LWD is low water datum or chart datum. LWD is 569.2 feet (IGLD, 1985).

Data courtesy of Michael D. Asquith and Lynn M. Greer, U.S. Army Corps of Engineers, Buffalo District (written commun., 2010).

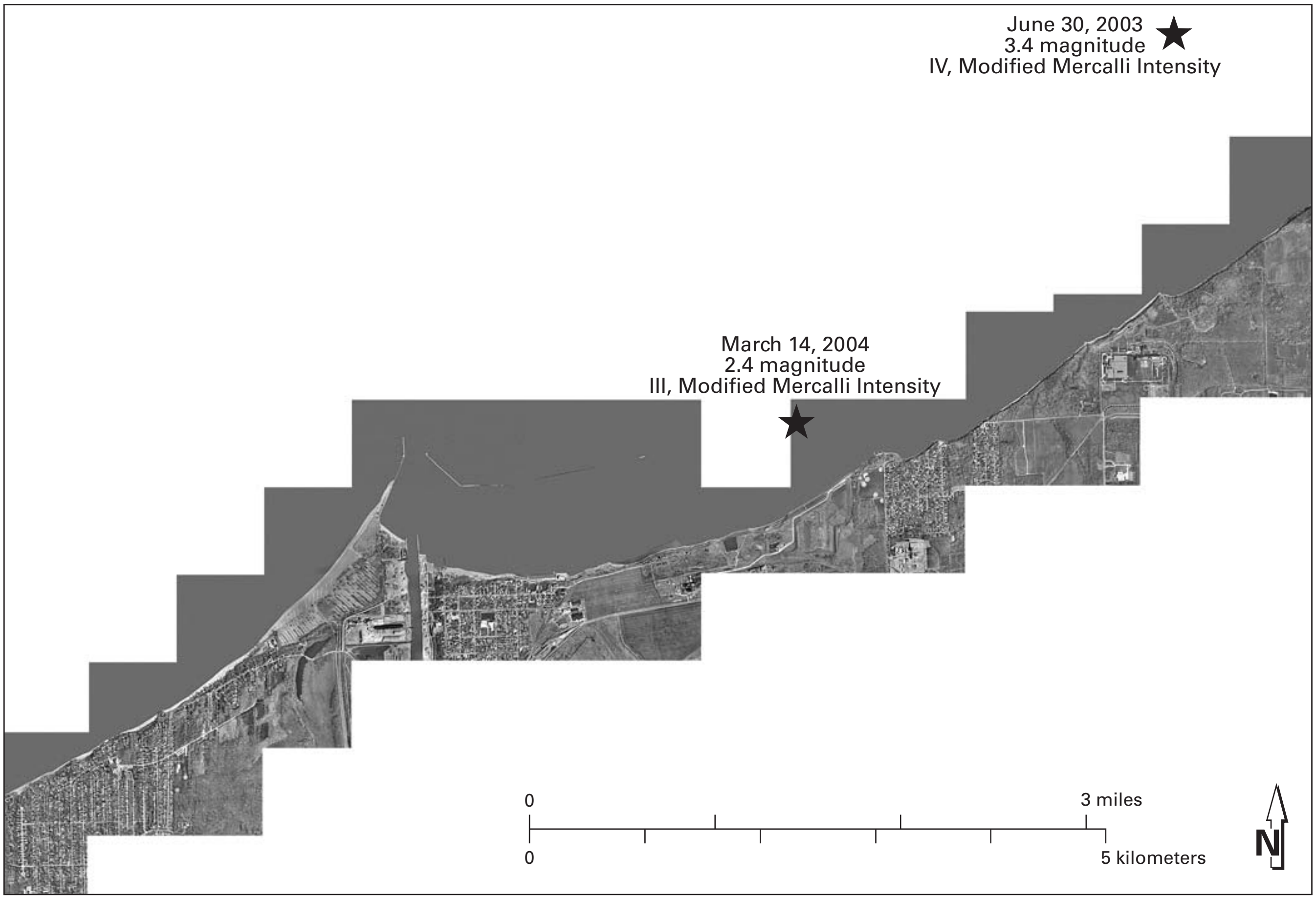


FIGURE 23.—Epicenters for recent earthquakes near Painesville on-the-Lake, Ohio. Data from the Ohio Seismic Network. Aerial photograph taken in 2000 by the Lake County GIS.

STOP 2: HEADLANDS BEACH STATE PARK, FAIRPORT HARBOR

Headlands Beach State Park is located on the sand deposit impounded updrift of Fairport Harbor (fig. 24). The first jetties were constructed at the mouth of the Grand River by 1825 (U.S. Army Corps of Engineers, 1913). By 1876, the jetties had been extended so that the west jetty was more than 2,370-ft (722-m) long, and the east jetty was about 1,765-ft (538-m) long. In the early 1900s breakwaters were added to the harbor. The west breakwater, which lies normal to, and is attached to, the shore, has a length of about 0.75 mi (1.2 km); the east breakwater, which is parallel to shore, has a length of about 1.3 mi (2.1 km).

The west breakwater annually traps 88,000–110,000 yd^3 (26,800–84,100 m^3) of sand from the net west-to-east longshore system (Bajarunas, 1961). About 7 million yd^3 (5.4 million m^3) of sand have been impounded updrift of Fairport Harbor since initial construction of the jetties (U.S. Army Corps of Engineers, 1976), which is enough sand to build a beach 50-ft (15.2-m) wide and >26-mi (>41-km) long.

The jetty has dramatically changed beach width and shoreline orientation by impacting patterns of sand transport and deposition along this stretch of coast. Beach widths have increased along 0.94 mi (1.5 km) of shore west of the harbor (Carter, 1978). The change is most marked adjacent to the west breakwater, where the shoreline advanced lakeward about 2,400 ft (730 m) between 1825 and 1975. Since 1975 the beach has advanced another 1,050 ft (320 m) lakeward along the breakwater. Impoundment of sand updrift of Fairport Harbor has cut off the supply of sand to the shore downdrift of the harbor causing a decrease in beach width along at least 3.7 mi (6 km) of shore east of the structures (Carter, 1978). Beaches east of the harbor are very narrow, and shale bedrock and cohesive clay are exposed in the nearshore (fig. 25). West of the harbor, shoreline orientation has changed from nearly east–west in 1825 to the present northeast–southwest orientation (fig. 24). East of the structures, shoreline orientation has changed little.

As beach width increased at Headlands Beach, dunes formed along the back beach. Dunes of this scale are an unusual feature along the eastern Ohio lakeshore, where typically narrow beaches (~25-ft/7.6-m wide) do not provide a sufficiently protected setting for dune development. These dunes are now part of a state nature preserve.

Plants found in the dunes include several Atlantic Coastal Plain species (sea rocket, beach pea, seaside spurge, beach grass, and purple sand grass), some unusual northeast Ohio plants (switchgrass, Canada wild rye, wafer ash, and wild bean), and many western plants (winged pigweed, clammy weed, sand dropseed, and four-o'clock). Switchgrass and beach grass are important in dune development, because once established on the upper beach, they trap wind-blown sand. Willows, cottonwoods, grape, and poison ivy colonize the more established dunes (Carter, Guy, and Fuller, 1981).

Accretion of sand west of the harbor breakwater has significantly impacted coastal processes east and west of the harbor. The signature of this impact can be seen in bluff recession rates for numerous time periods. Similar patterns appear adjacent to other shore-normal structures in Lake County (fig. 15; Guy, 1999).

Recession rates between 1876 and 1937, and between 1937 and 1973, show a decrease in bluff recession rates for about 0.75 mi (1.2 km) west of the harbor entrance; little change in the rates for the first 1.8 mi (2.9 km) east of the harbor entrance, where the shore is partly protected by the shore-parallel east breakwater; and a marked increase (2 to 4 times the long-term average for 1876–1973) for the next 2 mi (3.2 km) to the east. In general, increased beach width west of the structures has reduced wave energy reaching the bluffs west of the structures, and decreased beach width east of the structures has allowed more wave energy to reach the bluffs east of the harbor, leading to the observed alongshore patterns in historical bluff recession.

Every one to two years, 25,000–40,000 yd^3 (19,200–30,800 m^3) of sand is dredged from the lake-approach channel. Until recently, this sand was dumped in the open lake. Starting in the 1980s, sand from the approach channel was placed in 25 ft (7.6 m) of water east of the harbor near Painesville on-the-Lake. Since 2001, more than 163,000 yd^3 (124,500 m^3) of sand has been placed in shallow water or at the shoreline at Painesville. (See "Stop 1: Painesville on-the-Lake" for more about nearshore sand disposal.)

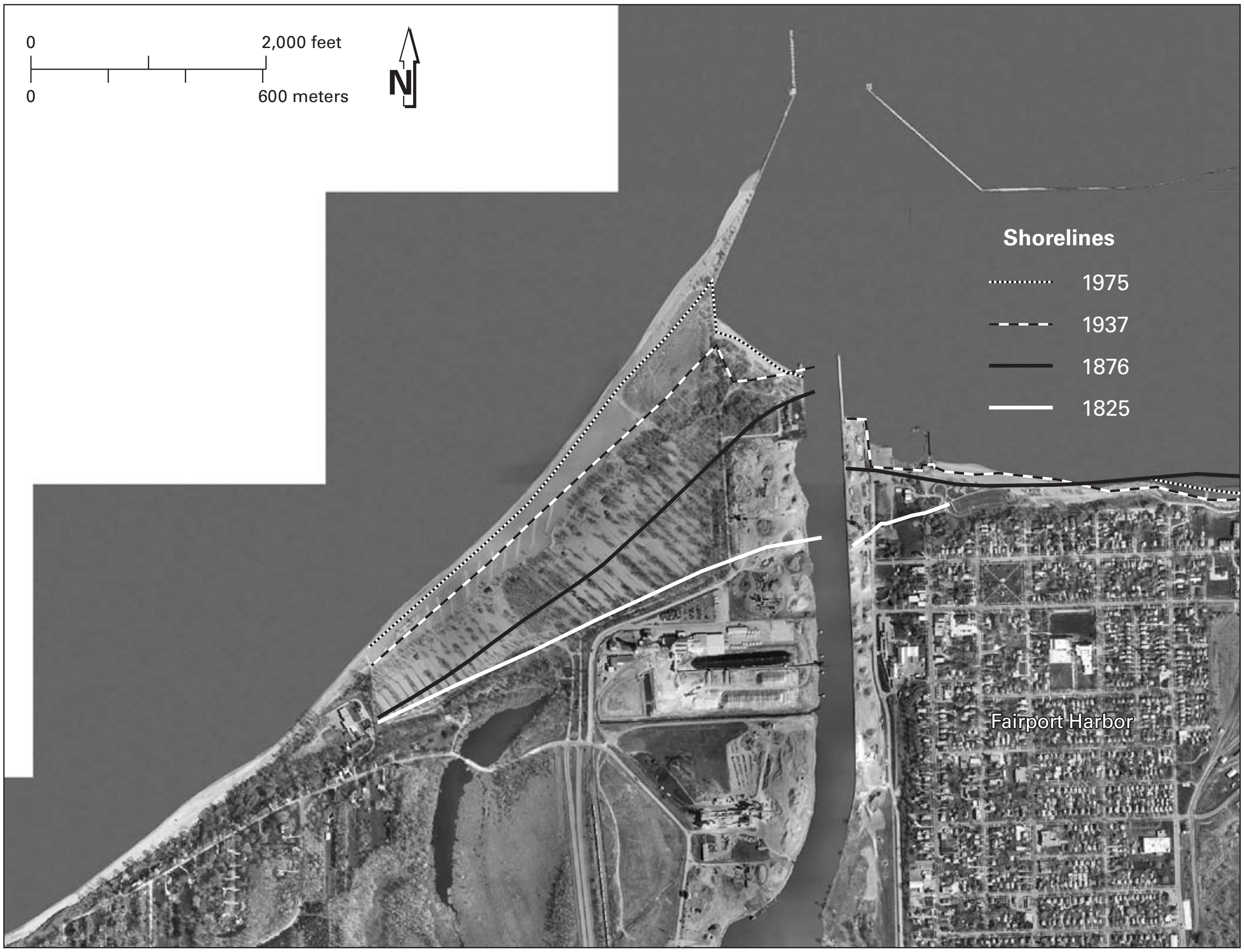


FIGURE 24.—Headlands Beach State Park near Fairport Harbor, Ohio. Historical shorelines adapted from Carter (1978). Aerial photograph taken in 2000 by the Lake County GIS.

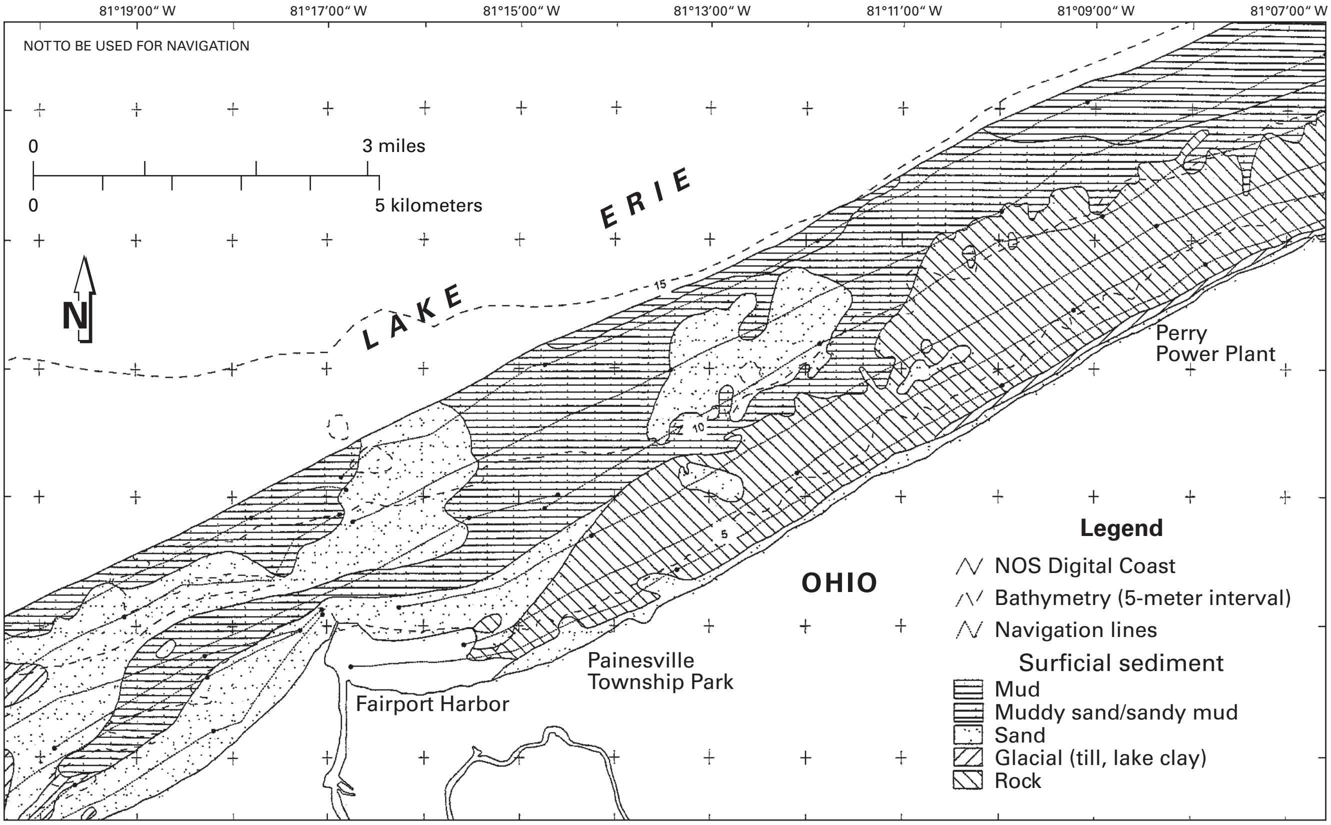


FIGURE 25.—Surficial sediments from Fairport Harbor to Perry, Ohio (modified from Fuller, 1996). Sediment distribution was mapped with sidescan sonar. Note the lack of nearshore sand downdrift (east) of Fairport Harbor.

STOP 3: SIMS PARK, EUCLID

Follow the walkway northward to the sewer outfall. From there, look westward across the beach-fill project at the park and eastward past the eroding till bluff to the filled slopes in the distance (figs. 26, 27).

Until the late 1980s, shale and two tills were exposed along the park (Carter, Guy, and Fuller, 1981). The shale, probably the Chagrin Member of the Ohio Shale (Cushing and others, 1931), exhibited current ripples (flow to west) and glacial striations (WNW–ESE and NNE–SSW). A lower, stony gray till and an upper, brown till with flow structures overlie the shale (Ford, unpub. data, 1974). The contact between shale and till rises to the west and decreases to the east. At Moss Point, 1,000 ft (300 m) to the west, shale makes up the entire bluff. Along the embayment east of the park, shale is below lake level and the bluff is composed entirely of till. An example of this can be seen in the eroded till bluff to the east of the outfall. Recession rates west and east of the park reflect the difference in erodibility of shale and till, with higher recession rates along the till bluffs to the east. Also note that the beach is narrow or absent, even at presently lower lake levels.

In the 1980s three segmented, rubble-mound breakwaters and two terminal groins were built to reduce erosion at Sims Park and to provide a recreational beach (figs. 27, 28). The structures are constructed of Columbus Limestone quarried near Sandusky and are similar to breakwaters built at other Lake Erie parks. To create a beach, about 34,000 yds^3 (26,000 m^3) of sand from an upland deposit was placed as fill, and an additional 1,700 yds^3 (1,300 m^3) are added annually to maintain the beach (U.S. Army Corps of Engineers, 1989; Michael Mohr, U.S. Army Corps of Engineers, oral commun., 2006). Further east, large areas of fill stabilize the shore and reclaim land lost to erosion.

Interesting variations in sediment texture and composition occur from foreshore to backshore and from the filled beach to the natural beach to the east. Foreshore sediment consists of coarse-grained sand to pebbles and typically contains abundant shell material. If the beach has not been recently groomed, a deflation lag of granules and pebbles may blanket the underlying sand. At the back beach, aeolian deposits composed of fine sand typically lack shell material. The cross-beach changes in sediment texture and composition at Sims Park contrast markedly with the gravelly beach sediment found along the till-bluffed shore to the east.

Cleveland waterfront

The drive from Sims Park to Edgewater Park crosses the Cleveland waterfront on the Cleveland Memorial Shoreway (I-90, State Route 2, U.S. Routes 6 and 20), passing a number of noteworthy features. The Shoreway is built on filled land (fig. 29). South of the highway, the slope marks the approximate position of the 1870s bluff and shoreline; Whittlesey's diagram of rotational slumps at Cleveland suggests this bluff was actively eroding (fig. 30). The present shoreline lies up to 2,600-ft (800-m) north of the 1870s shoreline.

Since 1876, more than 893 acres (361 ha) have been filled along the Cleveland waterfront (Guy and others, unpub. data, 1984). Between 1876 and 1938, 455 acres (184 ha) were filled, and between 1938 and 1973, 427 acres (177 ha) were filled. At present, the only fill activities on the Cleveland waterfront involve placement of contaminated sediment in CDFs.

Each year, the U.S. Army Corps of Engineers dredges about 200,000 yd^3 (152,900 m^3) of sediment from federal channels in the harbor and Cuyahoga River. At the present rate of dredging, the current CDF (Dike 10B) has 2 years of capacity remaining (Lynn M. Greer, U.S. Army Corps of Engineers, oral commun., 2005). To extend the life of the CDF until a new facility can be constructed, the U.S. Army Corps of Engineers will use sediment excavated from the CDF to construct a berm that will “vertically expand” the facility, which will increase the capacity of the CDF, adding 2 to 3 years to its life.

Although much of the sediment dredged from the Cuyahoga River is fine grained, some muddy sand accumulates in the turning basin located at the upstream end of the navigation channel (Scott Pickard, U.S. Army Corps of Engineers, oral commun., 1985). For several years in the mid 1980s, the U.S. Army Corps of Engineers placed this sandy sediment in the littoral system offshore of Bratenahl. However, testing in 2002 showed the levels of contaminants in the sandy sediment were too high for nearshore disposal, so the sediment is now placed in Dike 10B. In cooperation with the Ohio Department of Natural Resources, the U.S. Army Corps of Engineers places the sediment in the western part of the facility where the hydraulic discharge process segregates the sand from the fine-grained sediment. Efforts are under way to recover and use this sand to nourish the littoral system east of Cleveland Harbor. However, testing in 2005 revealed that further remediation of contaminants is necessary prior to placement of the sand in the nearshore. Starting in 2006, some of this sandy sediment will be used to build the berm along the south side of the CDF to vertically expand the CDF (Lynn M. Greer, U.S. Army Corps of Engineers, oral and written commun., 2005).

Along the Cleveland waterfront, public access to Lake Erie is blocked by the Shoreway, and the only parks are Gordon Park on the east and Edgewater Park on the west (both of which are part of Cleveland Lakefront State Park system). Of these two parks, only Edgewater Park has a recreational beach at present. A number of marinas built along the waterfront provide access for recreational boaters. To make the waterfront more accessible, the city of Cleveland is developing a master plan to move the Shoreway southward to create space for parks and public areas along the waterfront. To see these plans, check the Cleveland City Planning Commission Web site, <http://planning.city.cleveland.oh.us/lakefront/cpc.html>.

FIGURE 26.—Sims Park in Euclid, Ohio, is located on a broad headland of Devonian shale. Shale crops out in the lower part of the bluff along the western half of the photo but drops below lake level in the eastern part of the photograph. Even though shale is more resistant to erosion than the till found to the east, much of the shale headland is now armored to prevent erosion. To the east, large amounts of fill have been dumped over the bluff edge to reclaim land lost to erosion and to protect the shore. Aerial photograph taken in 2002 by the Cuyahoga County Engineer.

FIGURE 27.—Segmented breakwaters and terminal groins at Sims Park in Euclid, Ohio. The breakwaters are spaced so that tombolos develop. The beach was filled with sand obtained from an upland sand pit. Aerial photograph taken in 2002 by the Cuyahoga County Engineer.

FIGURE 28.—Sims Park in Euclid, Ohio, in 1986, prior to construction of breakwaters and groins. Aerial photograph taken by the Ohio Department of Natural Resources.

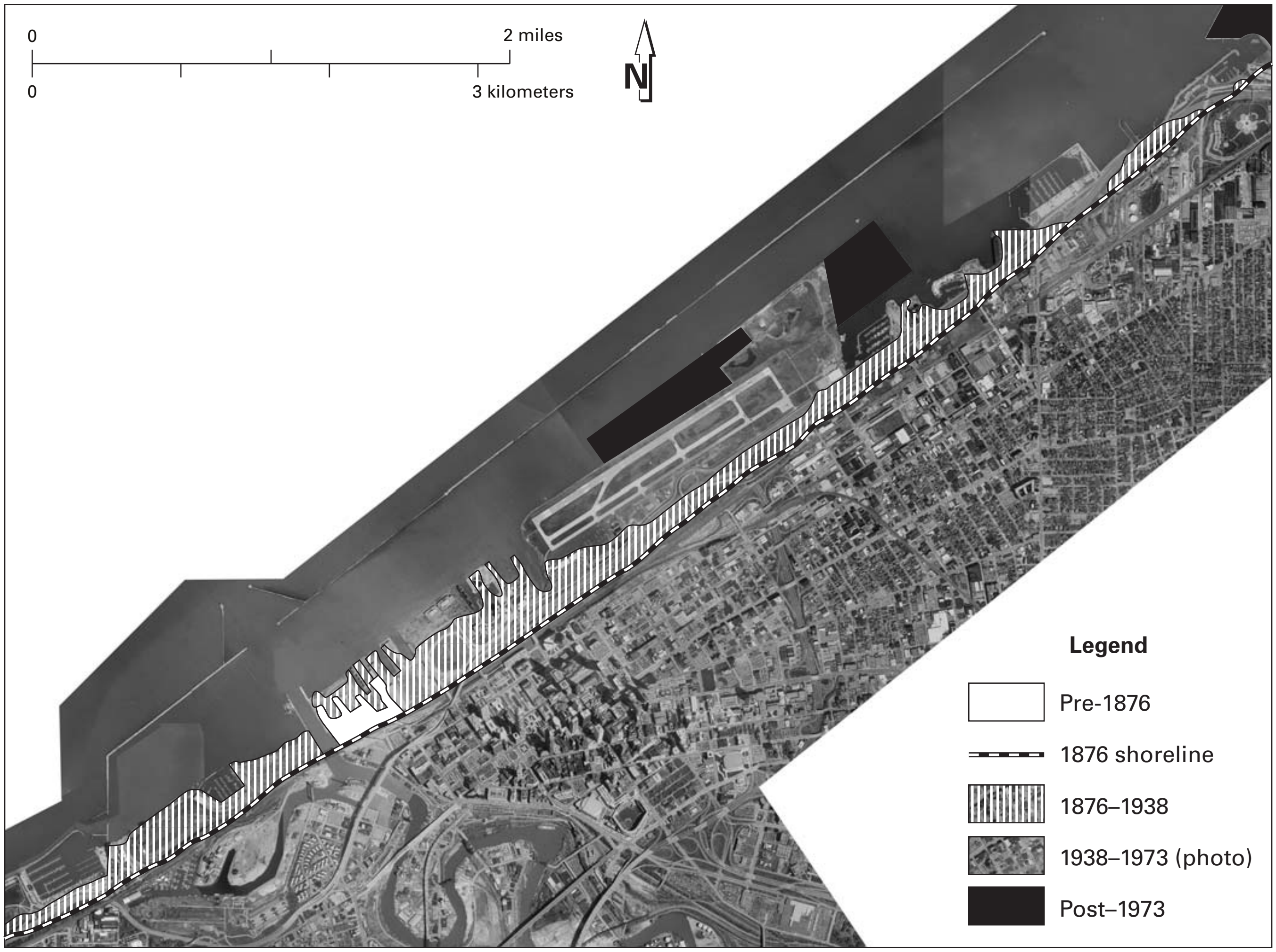


FIGURE 29.—Filling of the Cleveland waterfront from the 1800s to 2002 (modified from Guy, 2002a). Shoreline from 1876 (Guy and others, unpub. data, 1984) converted to shapefile by D. A. Foye (Ohio Division of Geological Survey). Aerial photograph taken in 1997 by the Ohio Department of Natural Resources.

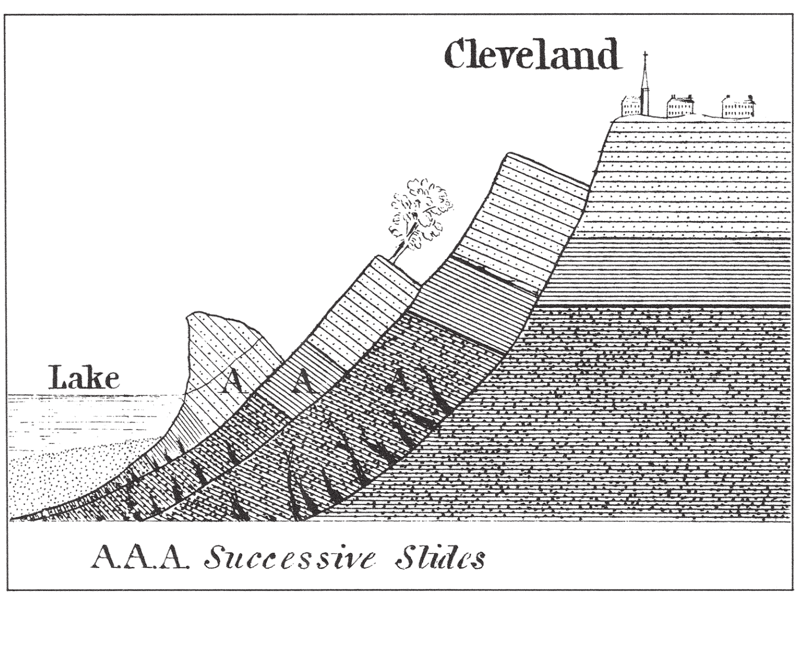


FIGURE 30.—Whittlesey's diagram of rotational slumps at Cleveland (from Mather, 1838). Filling along the Cleveland waterfront now protects the bluffs from wave attack.

STOP 4: EDGEWATER PARK, CLEVELAND

Edgewater Park, located at the west end of the Cleveland waterfront (fig. 31), is one of several parks making up the Cleveland Lakefront State Park system. Between May and September of each year, nearly 783,000 people visit this heavily used urban beach (Brooke Fischbach, ODNR Division of Parks, written commun., 2005).

Part of the park is built on filled land, and the old lake bluff is located near the Shoreway south of the park. The bluff rises about 59-ft (18-m) above lake level and is composed of shale, till, and glaciolacustrine sediment. Although these materials are covered along most of the park by grading, filling, and shore protection structures, exposures are present at the western end of the park. The shale at Edgewater Park is the Chagrin Shale (Prosser, 1912; Cushing and others, 1931; Hannibal and Feldmann, 1983). Sand is impounded at the park by groins and a breakwater structure at the east end of the beach. Based on location and shape of the beach, net transport is inferred to be eastward, though a local reversal is apparent on the east side of the large groin in the center of the beach. The sandy beach, shale bluffs, and shore protection structures are responsible for the low rates of bluff recession at this site. Long-term bluff recession rates are about 0.98 ft/yr (0.3 m/yr) along the west part of the park (Guy and others, unpub. data, 1984).

Beach sand here is finer than that at previous stops, which may be due to the presence of Lake Elkton glaciolacustrine sediments in the bluff and nearshore west of Huntington Reservation (Stop 5; Kleinhample, 1952). These glaciolacustrine silts and sands have a more uniform texture than the till that supplies sand to beaches at previous stops. Because of its fine texture, winds blow this sand into the parking lot and upslope onto the Shoreway.

Pollution, particularly *E. coli*, is often a problem at urban beaches. To create a predictive model for *E. coli* concentrations, the U.S. Geological Survey has been studying the distribution of *E. coli* in water and sediments at Edgewater Park. Some interstitial water from subsurface sediment near the swash zone at Edgewater Park had *E. coli* concentrations as high as 100,000 colonies per 0.11 qt (100 mL; Francy and others, 2002). In contrast, lake-bottom sediments outside the bathing area did not contain significant concentrations of *E. coli*.

FIGURE 31.—Beach sand at Edgewater Park in Cleveland, Ohio, is trapped by a bulkhead and a groin. Note wind-blown sand near the Shoreway and southwest of the parking lot. The eastern part of the park, shoreward of the stone bulkhead, is all filled land. An oval parking lot at the western end of the park sets atop a small headland composed of Chagrin Shale. West of the headland, groins at Perkins Beach have deteriorated and no longer trap much sand. Aerial photograph taken in 2002 by the Cuyahoga County Engineer.

STOP 5: HUNTINGTON RESERVATION, BAY VILLAGE

Huntington Reservation of Cleveland Metroparks is named after John Huntington, who bought the land in the mid-1800s after making money in the stock market. He was a roofer who had been paid in Standard Oil stock by John D. Rockefeller. At the east end of the parking lot is an 800-gal (3,000-L) water tower that held lake water to irrigate Huntington's 100-acre (40-ha) farm (Carter and others, 1981).

Walk to the water tower for a view of Lakewood to the east and Avon Point to the west (fig. 32). Note the five dimension-stone groins that trap sand along the park. Follow the walkway west along the top of the bluff. Part of the walkway was relocated in the 1990s because of mass wasting in the glaciolacustrine sediments. Proceed westward to the next set of steps and walk down to the beach. Walk eastward along the beach to Porter Creek and the shale cliff east of the park.

The dimension-stone groins were built at the park in 1933 using local Berea Sandstone. These groins, the longest of which extends 500-ft (152-m) offshore, trap sand moving west-to-east alongshore. The resulting beach typically protects the bluff from erosion during storms. However, during the high water of 1985 and 1986, the beach was narrower, allowing storm waves to erode the bluff toe and expose fresh material. The beach was typically narrowest along the section of bluff now subject to mass wasting. Water discharging from the bluff may be ground water or it may be water leaking from water lines. Given the extent and age of infrastructure along the lake, both are possible.

The 49-ft (15-m) high bluff at the park is composed of shale, till, and glaciolacustrine sediments. East of Porter Creek, Cleveland Shale makes up most of the bluff, but west of the stream, shale crops out only in the lower part of the bluff. From about the water tower to about 6,000-ft (1,830-m) west of the park, the shore is composed of glaciolacustrine sediments overlying till. Further west, shale rises above lake level and makes up the entire bluff at the prominent shale headland.

Long-term recession rates have been relatively slow (≤0.98 ft/yr [0.3 m/yr]) along this stretch of shore. Low rates of recession along the shale bluff east of the park are due to the natural resistance of the shale and to the presence of a sandy beach. Low rates west of the park are due to shore protection structures, which heavily armor the till and glaciolacustrine sediments. Where these structures failed in the early 1970s, recession threatened a number of homes. To reclaim land and to protect house foundations exposed by recession, fill material was dumped on the bluff face.

Beach sands at Huntington Reservation have a median grain-size of about 2ϕ (0.25 mm) and a sorting value of ~1.2ϕ (0.44 mm) units (Kleinhample, 1952). Much of this sand may be locally derived; Kleinhample (1952) found that modal grain size at Huntington Reservation corresponded to the modal grain size of Lake Elkton sediments exposed in the bluff west of the park.

As part of his study, Kleinhample (1952) investigated six frequently occurring heavy minerals (hornblende, garnet, diopside, limonite-pyrite, and magnetite-ilmenite). Based upon the concentration of heavy minerals in the fine (0.25–0.125 mm) and very-fine (0.125–0.0625 mm) sand fractions, he concluded magnetite-ilmenite concentrations varied directly with the amount of garnet and that concentrations of both groups varied inversely with the amount of hornblende. In the fine sand at Huntington Reservation, hornblende made up ~32 percent of the total heavy minerals and garnet made up ~13 percent. In the very fine sand, magnetite-ilmenite made up ~56 percent of the total heavy minerals and garnet made up 25 percent. In the fine and very-fine sands, 90 percent of the heavy minerals occurred in the very-fine-sand fraction. In the 1950s the carbonate content of the sand ranged from 4 to 6 percent, a marked contrast to the shell-enriched sand now found at the park.

FIGURE 32.—Huntington Reservation in Bay Village, Ohio. Sandstone block groins trap sand to form beach. West of the park, a variety of structures protect the slope of till, glaciolacustrine sediment, and fill. East of the park, the shale cliff is unprotected. Aerial photograph taken in 2002 by the Cuyahoga County Engineer.

STOP 6: LAKEVIEW PARK, LORAIN

Lakeview Park is located on the west side of Lorain Harbor (fig. 33). The shore at this site rises 16.4-ft (5-m) above lake level and is composed of till. At one time, six groins and a concrete seawall protected the park (fig. 34). Partial destruction of the seawall, and erosion of the beach in the early 1970s, led to construction in 1977 of a new seawall and three 250-ft (76-m) long breakwaters, modification of two of the groins, and placement of 109,200 yd^3 (84,000 m^3) of sand (fig. 35; Pope and Rowen, 1983). Sand used to nourish the beach was dredged from a relict Pleistocene deposit located 6-mi (10-km) offshore on the Pelee-Lorain cross-lake moraine (Michael Mohr, U.S. Army Corps of Engineers, written commun., 2005). Rehabilitation of the park was a cooperative project involving the City of Lorain, the Ohio Department of Natural Resources, and the U.S. Army Corps of Engineers.

Sand placed at the park has now moved eastward, giving the beach a more westward-facing orientation. Between 1977 and 1980, natural accretion of sand behind the breakwaters added 5,000 yd^3 (3,822 m^3) of sand to the project (Joan Pope, U.S. Army Corps of Engineers, written commun., 1980). Reorientation of the shoreline and accretion of sand suggest that net transport along this stretch of shore is from west to east, which is opposite of the regional transport direction. The reversal occurs because of the presence of harbor structures, the first of which (jetties) were constructed at the mouth of the Black River in 1835. The long breakwaters east of the park were completed in 1921. These structures shelter the park from waves generated by northeast storm winds. As a result, waves generated by the prevailing westerly winds exert a greater influence on local sand transport, causing the local west-to-east transport of sand.

Lorain Harbor, at the mouth of the Black River, was a major commercial harbor until the 1980s. Foundries and steel mills located 2.6-mi (4.2-km) upstream were a source of contaminants still present in the harbor sediment. As a result, sediment dredged from the Black River has for years been placed in the CDF located on the east side of the harbor (fig. 33). As with many of the CDFs along the lakeshore, the U.S. Army Corps of Engineers will use sediment from the CDF to construct a berm around the facility in order to add 2 to 3 years to its life (Lynn M. Greer, U.S. Army Corps of Engineers, oral commun., 2005).

FIGURE 33.—Lorain Harbor and Lakeview Park in Lorain, Ohio. The confined disposal facility (CDF) attached to the east breakwater is nearly filled. Note sand in southwest corner of harbor. Aerial photograph taken in 1999 by the Lorain County Auditor.

FIGURE 34.—Lakeview Park in Lorain, Ohio, in April 1973. Compare size of beaches at the park and in the harbor with those in 1999 (fig. 35). Aerial photograph taken by the Ohio Department of Transportation.

FIGURE 35.— Lorain Harbor and Lakeview Park in Lorain, Ohio, in 1999. The segmented breakwaters are designed to form salients rather than a tombolos. Compare size and shape of beaches at the park and inside harbor with beaches in 1973 (fig. 34). Aerial photograph taken by the Lorain County Auditor.

STOP 7: SHOWSE PARK, VERMILION

Shale and till can be seen in the 20-ft (6-m) high bluff at this public park and on private property to the west (fig. 36). The best exposure of shale is to the west of the sewer outfall and the best exposure of till is to the east. To get to the exposures, walk down the path in the middle of the park. (IMPORTANT NOTE: Please do not collect samples of shale from private property. Also be careful walking on concrete rubble.)

The black shale has well-developed vertical joints, pyritic concretions, a bed of cone-in-cone limestone, and beds of blue-gray shale, all of which typify the basal part of the Cleveland Member of the Upper Devonian Ohio Shale (Herdendorf, 1963; Potter and others, 1980). Joints and cone-in-cone limestone are typically most easily seen east of the groin, and a reverse fault is present near the west edge of the park. Fracturing of shale along the fault weakens the shale, leading to formation of an erosional embayment. Numerous fault-controlled embayments occur between Showse Park and Vermilion (Hartley, 1962; figs. 37, 38). These faults probably result from the "contemporary stress field . . . in conjunction with flexural stresses due to glacial loading" (Plankell, 2000).

Two Wisconsinan tills overlie shale along the eastern section of the park. The lower, gray till is the Millbrook Till and the upper, brown till is the Hayesville Till (S. M. Totten, Hanover College, oral commun., 1985; R. R. Pavey, Ohio Division of Geological Survey, oral commun., 1985). The shale breccia at the base of the Millbrook Till and the planar upper surface, marked by a boulder line on the Millbrook Till, may be due to basal sliding of the ice sheets that deposited the Millbrook Till and Hayesville Till, respectively (S. M. Totten, Hanover College, oral commun., 1980).

The groin/outfall was constructed before 1957 and strongly influenced the distribution of sand at the park until the late 1970s, when erosion finally outflanked the outfall. Prior to the late 1970s, during periods of predominantly westerly winds, waves would deposit sand west of the groin and erode sand from the beach east of the groin. Conversely, during periods of predominantly northeasterly winds, waves would deposit sand east of the groin and erode sand from the beach west of the groin. For this reason, over a period of 1 to 2 days, beach width could vary up to 49 ft (15 m). The rubble-filled gap shows how much erosion has occurred since 1976. As the gap widened over time, waves were able to transport more sand around the shoreward end of the groin, thereby reducing the influence of the groin on beach widths. High lake levels, which facilitate transport of sand across the groin, also reduced the effectiveness of the groin.

Recession of this shore is typically very slow with long-

FIGURE 36.—Showse Park in Vermilion, Ohio. Aerial photograph taken in the 1999 by the Lorain County Auditor.

term (1876–1973) recession rates ≤1 ft/yr (0.3 m/yr; Benson, unpub. data, 1978). However, short-term (1973–1990) rates ranged from 0.5–3.5 ft/yr (0.1–1.1 m/yr; Ohio Division of Geological Survey, 1998). Higher recession rates between 1973 and 1990 are due in part to 17 years of above-normal lake levels. Between 1975 and 1986, recession occurred at rates 2.2 times the long-term average (Carter and Guy, 1988). Up to 2.3 ft (0.7 m) of shale were eroded from the bluff toe during a single year and up to 1.6 ft (0.5 m) during a single storm.

FIGURE 37.—Fault-controlled erosional embayments along the shale-bluffed shore in Vermilion, Ohio (1999). See figure 38 for orientation of faults. Aerial photograph taken in 1999 by the Lorain County Auditor.

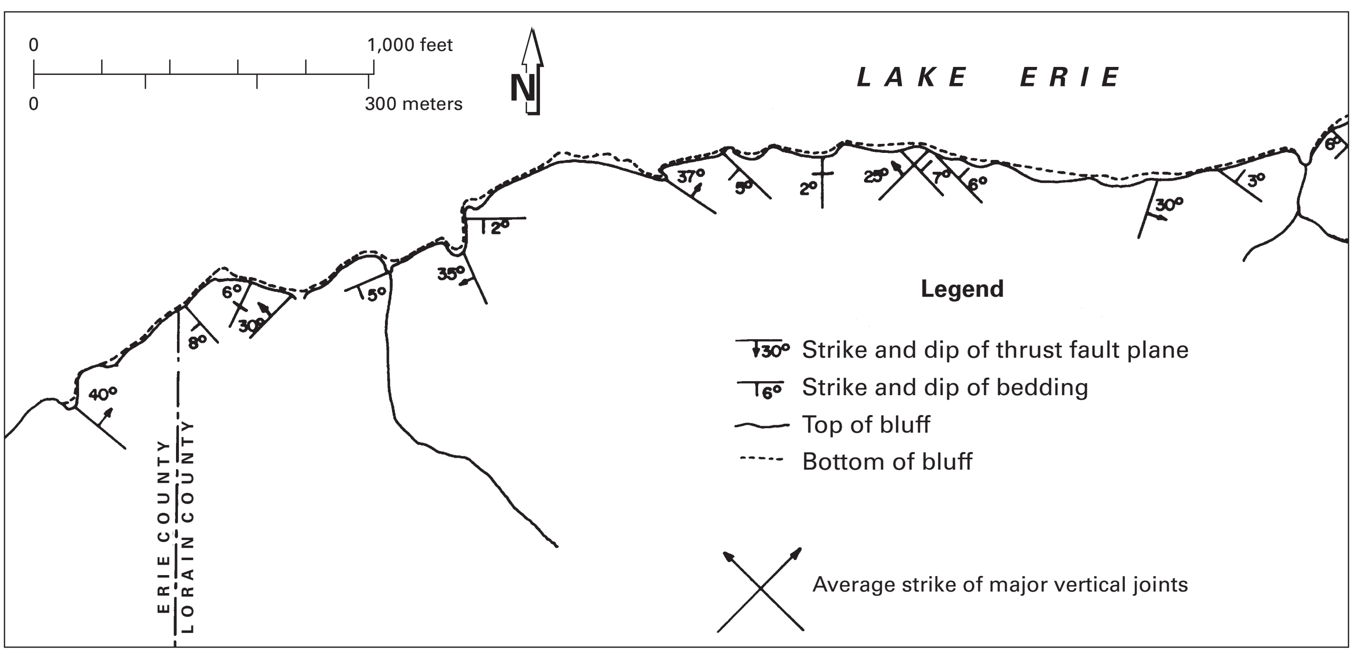


FIGURE 38.—Strikes and dips of faults in erosional embayments along the shale-bluffed shore in Vermilion, Ohio (modified from Hartley, 1962). Area shown is equivalent to Figure 37.

STOP 8: OLD WOMAN CREEK, HURON

Old Woman Creek is located a short distance west of the southernmost point (41°22'51" N, 82°29'19" W; Bruce Gerke, Ohio Department of Natural Resources, written commun., 2006) in the Great Lakes (figs. 39, 40). A freshwater estuary (Brant and Herdendorf, 1972) occupies about 148 acres (60 ha) at the mouth of the 26.6-mi^2 (69-km^2) watershed of Old Woman Creek (Buchanan, 1982; Herdendorf and others, 2004), which is one of the few undeveloped streams along the Ohio lakeshore. In 1976 the State of Ohio purchased the estuary and many of the surrounding properties to preserve this unique habitat as part of its nature preserve system. A research center at Old Woman Creek has been part of the National Oceanic and Atmospheric Administration's (NOAA) National Estuarine Research Reserve System since 1980 and supports scientific research on a variety of topics.

For the majority of the year, the mouth of Old Woman Creek is open to the lake. However, about 40 percent of the year, a stream-mouth bar blocks the mouth of this freshwater estuary (Herdendorf and others, 2004). When the mouth is closed, water levels in the estuary rise as much as 4-ft (1.2-m) above lake level until the bar is breached by stream discharge or eroded by storm waves. In either case, breaching of the bar results in a torrent of water discharging from the estuary. When the stream mouth is closed, water impounded by the stream-mouth bar seeps lakeward through the sand at a velocity of ≤5.9 ft/d (1.8 m/d) or a volume of 0.80 yd^3/s (0.61 m^3/s; Eaker, 1990; Matisoff and Eaker, 1992).

Old Woman Creek presently discharges at the west end of the stream-mouth bar, but in the 1970s the stream discharged at the east end. Under natural conditions, the mouth would probably migrate back and forth. However, since 1976 the stream has been "encouraged" to discharge to the west by manually excavating a shallow channel across the bar.

A number of interesting sedimentary structures can be seen in the beach and the bar. Foreset, topset, and backset beds may be present on the beach and bar, and layers of heavy-mineral sands are often present on the beach and in the stream-cut bank on the west side of the stream mouth. In the bank, heavy minerals accentuate fluid escape features present in the sand (fig. 41). Occasionally, weakly formed beach cusps with a wavelength of 3 ft (1 m) are visible on the beachface (fig. 42).

Sand and gravel at the mouth of Old Woman Creek are derived primarily from eroding bluffs and nearshore areas to the east. Worthy (1980) used repetitive bathymetric surveys to estimate a net westerly transport rate of 7,000–50,000 yd^3/yr (5,350–38,225 m^3/yr).

The bluff 2,000-ft (610-m) east of Old Woman Creek is composed of flow till overlain by highly deformed glacial-lake sediments. These highly deformed lake sediments have been deformed by over-riding ice.

This bluff was the site of a 10-year study of wave erosion by Carter and Guy (unpub. data, 1982). For much of the study period, a beach >45-ft (14.7-m) wide protected the bluff from storm waves. Based on swash widths measured during storms at other wide beaches, maximum uprush of storm waves is typically about 45 ft (14.7 m; Guy, unpub. data, 1984). If all of Ohio's beaches were >45-ft (14.7-m) wide, erosion would be greatly reduced.

FIGURE 39.—Lake Erie shore from the southernmost point in the Great Lakes to Huron Harbor, Huron, Ohio. In 2004 the southernmost point was at about 41º22'51" N, 82º29'19" W (Bruce Gerke, Ohio Department of Natural Resources, written commun., 2006). Aerial photograph taken in 2003 by the Erie County Auditor.

FIGURE 40.—Old Woman Creek in Huron, Ohio. The abandoned stream channel from the 1970s appears on the east side of the floodplain. Westward displacement of the stream mouth suggests a net east-to-west transport of sand along this reach of shore. Aerial photograph taken in 2003 by the Erie County Auditor.

FIGURE 41.—Heavy-mineral sands in the stream-cut bank on the west side of the Old Woman Creek floodplain. Photograph taken by Laura J. Moore.

FIGURE 42.—Beach cusps along the beach at Old Woman Creek in Huron, Ohio. Cusp wavelength is about 3 ft (1 m). Photograph taken by Laura J. Moore.

STOP 9: HURON EAST—NICKEL PLATE BEACH

Construction of harbor structures at Huron began in 1827 (U.S. Army Corps of Engineers, 1932), and the west jetty now extends about 3,410-ft (1,039-m) offshore (fig. 43). An east "breakwater" was added to the harbor in the 1930s, and a CDF was constructed on the west side of the west jetty in the mid 1970s.

Accretion of sand east (updrift) of the harbor forms the beach now known as Nickel Plate Beach. Beach width and shoreline orientation suggest that sand impounded by the breakwater extends about 1,500-ft (460-m) eastward. Along much of this distance, dunes have developed on the back beach during periods of low lake level or low wave energy or both. Some dunes have been allowed to grow; others have been graded to improve access to the shoreline and to improve the view of Lake Erie. Removal of dunes suggests that the role of these features in nourishing lake beaches during periods of higher lake level and high wave energy is not fully appreciated along the lakeshore. To the west of the harbor structures, seawalls have been constructed to reduce erosion resulting from disruption of littoral transport by the harbor structures.

The U.S. Army Corps of Engineers dredges about 150,000 yd^3 (114,700 m^3) of fine-grained sediment from the harbor every few years. Sampling of channel sediment near the terminus of the east breakwater has not encountered significant deposits of sand, which is unexpected given the relatively short length of the east breakwater and the close proximity of sandy beach and nearshore sediments. Lack of significant sand deposits in the channel may result from mixing of the sand with fine-grained river sediment.

At one time, Huron was a major commercial harbor for transshipment of coal and iron ore. Now the major commodities are grain and limestone. Each year about 500,000 tons of metallurgical grade limestone (derived from the Dundee Formation) are brought in by ship from Alpena, Michigan. The limestone is offloaded on the east bank of the river for processing in the Huron Lime plant. Smoke and steam from this coal-fired plant make a prominent landmark along Lake Erie.

FIGURE 43.—The west jetty at Huron Harbor, Huron, Ohio, extends about 3,410-ft (1,039-m) offshore, blocking littoral transport of sand. A wide beach of sand impounded by the east breakwater extends about 3,300 ft (1,000 m) and is wide enough to support dune development. Beaches west of the harbor tend to be very narrow and seawalls are needed to prevent erosion of the low bank. Aerial photograph taken in 2003 by the Erie County Auditor.

STOP 10: HURON WEST—HURON CITY PARK

Huron City Park is located west (downdrift) of the Huron harbor jetty (fig. 44). For many years, erosion was a problem along the shore west of Huron, and the landward end of the jetty was armored to prevent breaching (U.S. Army Corps of Engineers, 1932). Between 1877 and 1937, recession rates west of the jetty averaged 1.5 ft/yr (0.46 m/yr; Carter and Guy, 1980). Since the 1930s, armoring of the shore has slowed recession, and between 1973 and 1990 recession rates ranged from 0 to 1.8 ft/yr (0 to 0.5 m/yr) except for an 1,800-ft (550-m) stretch where rates reached 8.1 ft/yr (2.5 m/yr; Ohio Division of Geological Survey, 1998).

The beach at the city park is one of the few beaches remaining west of the Huron Harbor complex. For many years, a beach occurred only landward of the sandstone-block (Berea Sandstone) breakwater located about 100-ft (30-m) lakeward of the bank (fig. 45). However, construction of a CDF in 1976 altered the wave climate along the shore just west of the jetty, creating a local reversal in regional sand transport. This local reversal transports sand eastward into the sheltered area shoreward of the CDF, supplying additional sand for the beach. Deposition of sediment shoreward of the CDF has significantly reduced water depths making it possible to wade from the park beach to the south side of the CDF.

The CDF was designed with a 10-year capacity of 2 million yd^3 (1,529,110 m^3). By the early 1980s, sediment quality in the Huron River had improved sufficiently to permit open-lake disposal of sediment dredged from the river. As a result, 30 years after construction, the CDF is only about half full. The U.S. Army Corps of Engineers is reluctant to fill the CDF with the 150,000 yd^3 (114,700 m^3) of unpolluted sediment dredged from the harbor every few years, in case the capacity remaining in the CDF should be needed for contaminated sediment in the future.

FIGURE 44.—Nickel Plate Beach to the east of Huron Harbor and Huron City Park to the west, in Huron, Ohio. The beach at the city park is protected by a sandstone breakwater. Steam and smoke from the limekiln make a prominent landmark for boaters. Aerial photograph taken in 2003 by the Erie County Auditor.

FIGURE 45.—View from Huron City Park, Huron, Ohio, looking lakeward across the beach and a sandstone-block breakwater at a CDF built to contain contaminated sediment dredged from Huron Harbor. Trees are growing on sediment placed in the facility. To the right are piles of limestone brought in by ship for use in a local lime plant. Photograph taken by Laura J. Moore.

STOP 11: SHELDON MARSH STATE NATURE PRESERVE, HURON

The stop at Sheldon Marsh begins with a 0.8-mi (1.3-km) walk from an old lake plain, through a coastal wetland, to a modern barrier beach. The roadway through the wetland was originally the access road to Cedar Point. More recently the roadway provided access to a water pumping station built to supply water to a NASA test facility south of Sandusky.

The barrier beach at Sheldon Marsh is part of the much larger Cedar Point spit complex that stretches 9 mi (14 km) across the southeast side of Sandusky Bay (figs. 46, 47). Edwin Moseley, a local high school teacher and naturalist, studied Cedar Point in the early 1900s and divided the spit complex into an eastern barrier-beach section, a central-dune section, and a western beach-ridge section (Moseley, 1905). Sheldon Marsh is part of the barrier-beach section.

In the early 1900s, the property, owned by the Boeckling Company, provided an access road to Cedar Point. In the 1940s, erosion of the barrier beach undermined the roadway running along the barrier beach, and the roadway was abandoned; timber pilings driven to protect the roadway can still be seen during periods of low water. Dean Sheldon, a local nature-lover, purchased the property from the Boeckling Company (former owner of Cedar Point Amusement Park) in the 1940s. The property remained in the Sheldon family until 1976, when it was sold to the Ohio Department of Natural Resources for a state nature preserve. Now, this barrier beach is one of the few unprotected barrier-beach wetland complexes remaining along the Ohio lakeshore.

As along most of the lakeshore, Sheldon Marsh has not escaped the impacts of coastal development. The Huron Harbor jetties, located several miles (several kilometers) to the east, intercept sand eroded from till bluffs to the east. In addition, seawalls built along the shore west of Huron have reduced the volume of sand supplied to the littoral system by bank erosion west of Huron. As sand supplies west of Huron were depleted, there was insufficient sand to maintain the barrier. In 1885 Albert Judson documented recession of 12–20 rods (198–330 ft [60–100 m]) since Almon Ruggles' 1807 survey of the shore between Rye Beach and midway out Cedar Point (Moseley, 1905). More recent maps and photographs document continued, often dramatic recession (fig. 48).

Since 1934, a long-term rise in lake level has compounded the problem of decreasing sand supply. When vertical aggradation of a barrier cannot keep pace with rising water level because of insufficient sand supply, the barrier retreats (Dillon, 1970). The most recent episode of rapid recession began November 14–16, 1972 (fig. 11), when 60-knot northeast winds caused a storm surge and generated large storm waves that washed over the full length of the barrier. During the storm, the barrier breached at its west end, just east of the Point Retreat Condominiums (fig. 49). The following spring, lake levels rose to record-high levels and remained generally 1–2.5-ft (0.3–0.8-m) above mean lake level for nearly a quarter century. At these high lake levels, even small storm waves easily washed over the barrier beach. Today the barrier is more than 1,310-ft (400-m) landward of its 1972 position (fig. 48). Since 1997, lake levels have been near the long-term mean. Sand has accreted along portions of the barrier, but slow erosion continues just east of a large washover fan (fig. 47) formed during storms on March 20–21 and April 9, 1998. When lake levels rise above the long-term mean, recession of the barrier will probably accelerate.

The nearshore at Sheldon Marsh is underlain by peat beds, glaciolacustrine clays, and till (Bray, 1988: Fuller and others, 2002; Todd Thompson, Indiana Geological Survey, written commun., 2004). During storms, exposed peat is eroded and deposited on the beach in large blocks (some 2-ft [0.6-m] long) or as a mat of fine organic debris. The peat beds were deposited in wetlands when the barrier beach was located further lakeward. According to a reconstruction of paleotopography based on elevations of cohesive and consolidated deposits beneath and offshore of Sheldon Marsh and Cedar Point, early Lake Erie probably did not inundate this area until about 3,500 ybp (Guy, 1984a; fig. 50). At that time, the barrier beach would have been about 0.3-mi (0.5-km) lakeward of its present position.

Preserving and conserving natural resources and processes in the nature preserve has been and continues to be a challenge. Without some intervention, the barrier and wetland could be destroyed in the next high-water cycle, but intervening in a way that minimizes environmental and aesthetic impacts will be difficult. One option recently proposed by the U.S. Army Corps of Engineers (2004) involves installation of submerged breakwaters, augmented with beach fill and a terminal groin at the northwest end of the barrier beach. The proposed structures could be funded by the U.S. Army Corps of Engineers using Section 227 funding for innovative shore protection, because the submerged breakwater has an innovative checkerboard design. The structure has been designed to reduce the size of storm waves but to allow normal waves to reach shore. If the 552-ft (168-m) long, submerged breakwater functions well, the structure could be extended the full length of the barrier using Section 1135 funding authority for environmental restoration.

Dramatic recession of the barrier beach at Sheldon Marsh is comparable to the dramatic recession of Bay Point, a sand spit on the north side of Sandusky Bay (fig. 46). In the mid 1800s, Bay Point receded 1,200–1,800 ft (365–550 m) despite rock-filled timber cribs built along the west side of the spit. Remnants of this cribbing form a prominent bathymetric feature on the lakebed 1,200–1,800-ft (365–550-m) offshore of the present spit and mark its former position (Guy, 1983). During the high water of the 1970s to 1990s, Bay Point experienced considerable erosion along its east side. Dramatic recession of Bay Point in the mid 1800s and of Sheldon Marsh in the 1970s through the 1990s leaves the remaining section of Cedar Point out of equilibrium with the sand spit to the northwest and the barrier beach to the southeast, setting the stage for possible dramatic erosion and breaching of Cedar Point. During a northeast storm in November 1972, waves eroded the dune and attacked segments of the Cedar Point roadways. Following the storm, rock rubble was placed along much of Cedar Point to protect the roadway, and over the years, additional structures have been added to protect the sand spit.

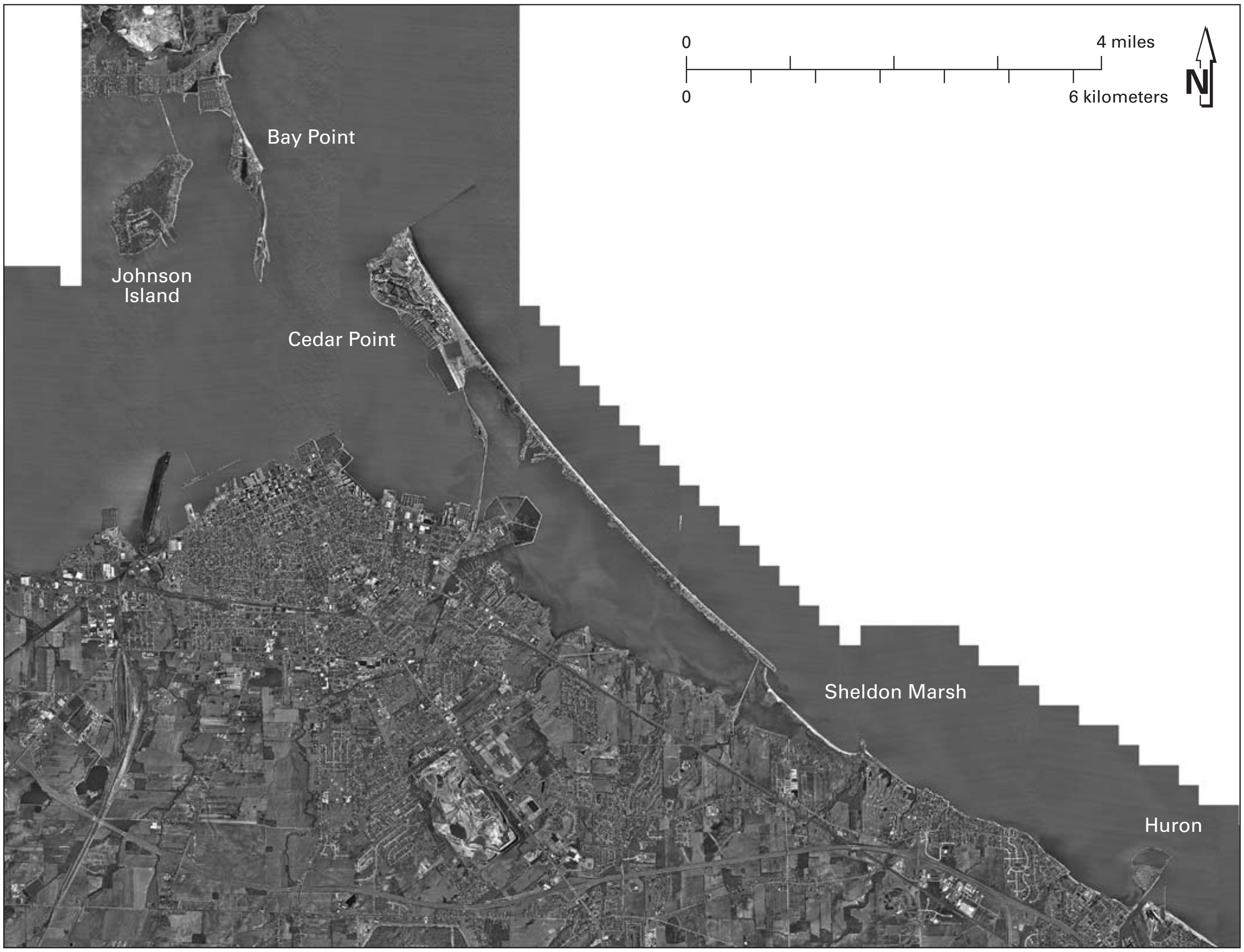


FIGURE 46.—Cedar Point and Bay Point sand spits at the mouth of Sandusky Bay, Sandusky, Ohio. Aerial photographs taken in 2003 by the Erie County Auditor.

FIGURE 47.—Barrier beach at Sheldon Marsh Nature Preserve in Huron, Ohio. The large washover fan along the western part of the barrier formed during a storm in April 1998. The barrier just east of the washover fan continues to erode more rapidly than other parts of the barrier. Aerial photograph taken in 2001 by the Erie County Auditor.

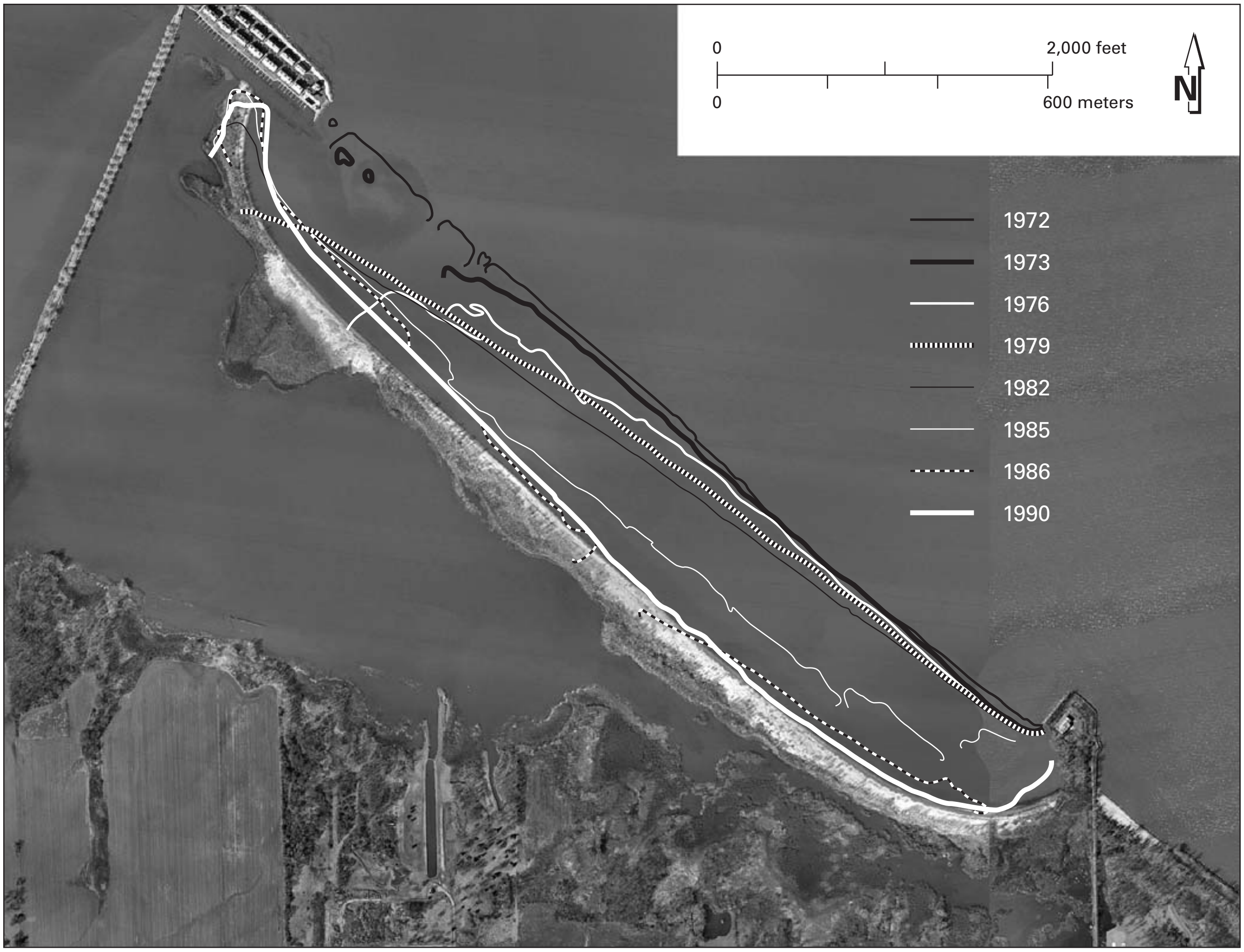


FIGURE 48.—Recession of Sheldon Marsh in Huron, Ohio, since 1972 (modified from Guy, 2002b). Aerial photograph taken in 2005 by the Erie County Auditor.

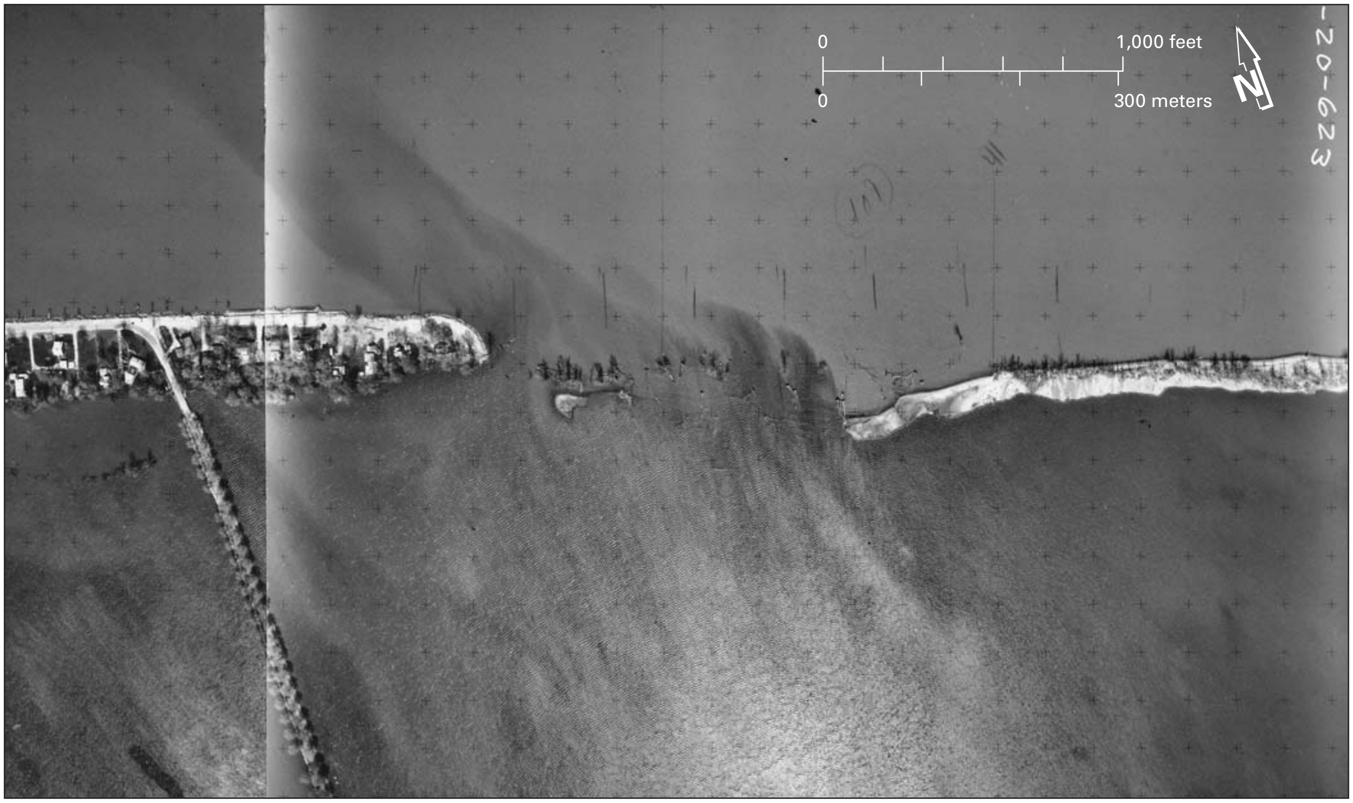


FIGURE 49.—Breached barrier beach at Sheldon Marsh, Huron, Ohio, in April 1973. Aerial photograph taken by the Ohio Department of Transportation.

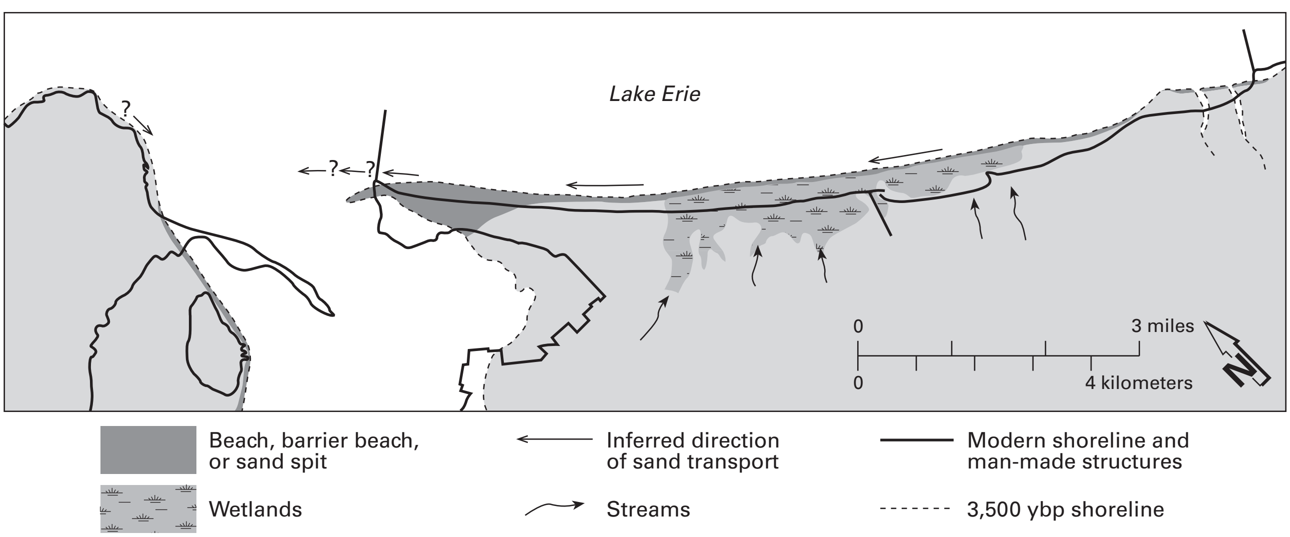


FIGURE 50.—Development of a barrier beach and wetlands near Sheldon Marsh in Huron, Ohio, 3,500 ybp, when lake level was about 10-ft (3-m) below present level (modified from Guy, 1984a).

STOP 12: MARBLEHEAD QUARRY, MARBLEHEAD

The Marblehead Quarry, operated by the LaFarge Company, is one of the largest limestone quarries in Ohio (fig. 51). In 2005, 4.2 million tons of crushed Columbus Limestone was removed from the quarry (Wolfe, 2006), and annual production averages about 4 million tons (Mineral Information Institute, 2006). The Columbus Limestone, one of several Lower to Middle Devonian carbonates deposited on the southeastern flank of the Findlay Arch, correlates regionally with the Onondaga Formation of New York and the Detroit River Group of Michigan (Sparling and Rickard, 1985; Oliver, 1976). The limestone was deposited in a subtidal marine environment. The facies exposures are highly fossiliferous, containing solitary rugose corals, colonial corals, encrusting stromatoporoids and corals, planispiral gastropods, and brachiopods (Snow and others, 1991).

Quarry operations, which began in the late 1800s, have uncovered the limestone surface in the vicinity of this stop, exposing approximately 4.9 acres (2 ha) of a glacially planed surface. Although glaciers flowed through the Lake Erie basin in a range of directions, Ver Steeg and Yunck (1935) report distinct ice movements across the western end of the basin. The ice flowed first to the southwest, reaching a southern flow direction during the full glacial, and yielded to a southwest–west flow direction during recession. At the Marblehead Quarry, prominent parallel striations trending 255° (SW) run across the bedrock surface (fig. 52) while a secondary set of striations trending 150–155° (SSE) is also present, though more difficult to detect. Fracture marks are also present within some of the larger striations and on bedrock slopes dipping to the east (Snow and others, 1991).

A particularly interesting feature of this stop are the erosional remnants known as crag and tail features (fig. 53). These are positive ridges that extend down-current from obstacles. For this reason, they are useful in determining flow direction. The large rugose corals in this location are highly resistant obstacles that protected the bedrock to the west from erosion as glaciers passed over the region. The crags stand up to 4-in (10-cm) above the bedrock surface while the tails become progressively lower over a distance of several feet (several meters; Snow and others, 1991). Depressions, or furrows, are also present along the sides, or in front of, some of the crags and tails (Snow and others, 1991).

FIGURE 51.—Quarries on Marblehead Peninsula, Ohio. Aerial photograph taken in 2002 by the Ottawa County Auditor.

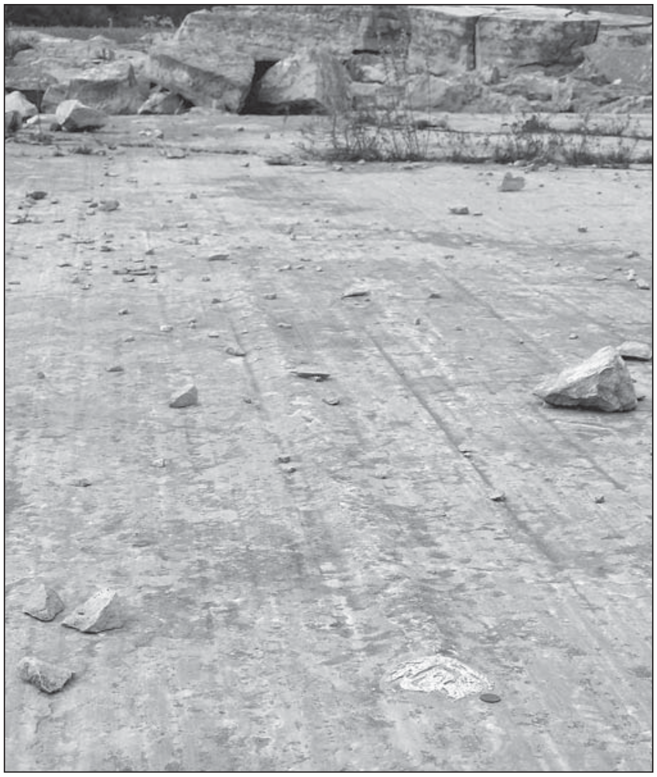


FIGURE 52.—Crag and tail and glacial grooves on Columbus Limestone in Marblehead Quarry, Marblehead, Ohio. Photograph taken by Laura J. Moore.

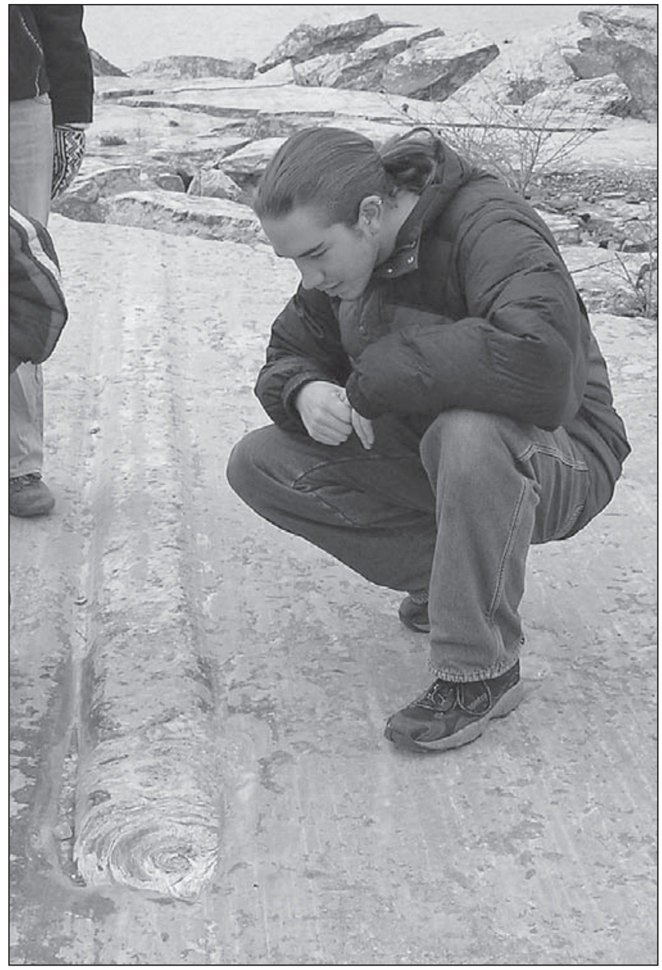


FIGURE 53.—A visitor closely examines a crag and tail and glacial grooves on Columbus Limestone in Marblehead Quarry, Marblehead, Ohio. Photograph taken by Laura J. Moore.

ACKNOWLEDGMENTS

Portions of this field guide are adapted from earlier field guides prepared by the ODNR Division of Geological Survey, including those by Anderhalt and others (1983), Carter (1973), Carter and Forsyth (1979), Carter and Guy (1984), Guy and Fuller (1986), and informal guidebooks authored by J. A. Fuller, D. E. Guy, Jr., J. W. Haines, S. D. Mackey, S. Root, D. A. Stith, and R. J. Varga. The authors thank Steve Dress, Lafarge North America, for access to the Marblehead quarry; Joseph T. Hannibal, Cleveland Museum of Natural History, for constructive comments and editing; and Lisa Van Doren for help with graphics and guidebook layout. The authors also thank the individuals and agencies that provided information as oral and written communications.

REFERENCES CITED

Anderhalt, R.W., Guy, D.E., Jr., and Harrell, J.A., 1983, Aspects of the sedimentary geology along the southwestern shore of Lake Erie: Annual Ohio Sedimentary Geology Field Excursion, 5th, Port Clinton, Ohio [Proceedings], 23 p.

Bajarunas, Leonas, 1961, Littoral transport in the Great Lakes: Coastal Engineering Conference, 7th, The Hague, Netherlands, 1960 [Proceedings], p. 326–341.

Brant, R.A., and Herdendorf, C.E., 1972, Delineation of Great Lakes estuaries, in Conference on Great Lakes Research, 15th, Madison, Wis., 1972, Proceedings: Ann Arbor, Mich., International Association for Great Lakes Research, p. 710–718.

Bray, T.F., Jr., 1988, The sedimentology and stratigraphy of a transgressive barrier at Sheldon's Marsh State Nature Preserve, Erie County, Ohio: Akron, Ohio, University of Akron, M.S. thesis, 125 p.

Buchanan, D.B., 1982, Transport and deposition of sediment in Old Woman Creek Estuary, Erie County, Ohio: Columbus, Ohio State University, M.S. thesis, 198 p.

Carman, J.E., 1946, The geologic interpretation of scenic features in Ohio: Ohio Journal of Science, v. 46, no. 5, p. 241–283. [Reprinted 1964, 1972, and 1991 as Ohio Department of Natural Resources, Division of Geological Survey Reprint Series No. 3, 42 p.]

Carter, C.H., 1973, Natural and manmade features affecting the Ohio shore of Lake Erie: Columbus, Ohio Department of Natural Resources, Division of Geological Survey Guidebook 1, 34 p.

Carter, C.H., 1977, Sediment-load measurements along the United States shore of Lake Erie: Columbus, Ohio Department of Natural Resources, Division of Geological Survey Report of Investigations 102, 24 p.

Carter, C.H., 1978, Fairport Harbor (Lake County, Ohio) structures—150 years of structural influence [abs.], *in* Proceedings of the Fourth Annual Coastal Society Conference, Burlington, Ontario, September 26–28, 1978: Williamsburg, Va., The Coastal Society, p. 217.

Carter, C.H., Benson, D.J., and Guy, D.E., Jr., 1981, Shore protection structures—Effects on recession rates and beaches from the 1870's to the 1970's along the Ohio shore of Lake Erie: Environmental Geology, v. 3, p. 353–362.

Carter, C.H., and Forsyth, J.L., 1979, Physical setting and processes along the central Ohio shore of Lake Erie (Marblehead Peninsula to Lorain): Ohio Academy of Science and National Association of Geology Teachers, Geology Field Trip, April 22, 1979, 14 p.

Carter, C.H., and Guy, D.E., Jr., 1980, Lake Erie shore erosion and flooding, Erie and Sandusky counties, Ohio—Setting, processes, and recession rates from 1877 to 1973: Columbus, Ohio Department of Natural Resources, Division of Geological Survey Report of Investigations 115, 130 p.

Carter, C.H., and Guy, D.E., Jr., 1984, Field guidebook to the geomorphology and sedimentology of late Quaternary lake deposits, southwestern Lake Erie, *in* Annual Field Conference of the Great Lakes Section, 14th, 1984, Proceedings: Society of Economic Paleontologists and Mineralogists, p. 1–57.

Carter, C.H., and Guy, D.E., Jr., 1988, The effect of stillwater levels on shore erosion—Examples from Lake Erie [abs.]: Geological Society of America Abstracts with Programs, v. 20, p. 338.

Carter, C.H., Guy, D.E., Jr., and Fuller, J.A., 1981, Coastal geomorphology and geology of the Ohio shore of Lake Erie, *in* Roberts, T.G., ed., GSA Cincinnati '81 Field Trip Guidebooks, v. 3, Geomorphology, hydrogeology, geoarcheology, engineering geology (Field Trip No. 7): Falls Church, Va., American Geological Institute, p. 433–456.

Cushing, H.P., Leverett, Frank, and Van Horn, F.R., 1931, Geology and natural resources of the Cleveland district, Ohio: U.S. Geological Survey Bulletin 818, 138 p.

Davidson-Arnott, R.G.D., 1986, Erosion of the nearshore profile in till: rates, controls, and implications for shoreline protection, *in* Skafel, M.G., ed., Proceedings of the Symposium on Cohesive Shores, May 5–7, 1986, Burlington, Ontario: Ottawa, National Research Council of Canada, p. 137–149.

Dillon, William, 1970, Submergence effects on a Rhode Island barrier and lagoon and inferences on migration of barrier: Journal of Geology, v. 78, p. 94–106.

Eaker, J.P., 1990, Groundwater advection and sediment-water chemical exchange at Old Woman Creek freshwater estuary: Cleveland, Ohio, Case Western Reserve University, M.S. thesis, 157 p.

Forsyth, J.L., 1959, The beach ridges of northern Ohio: Columbus, Ohio Department of Natural Resources, Division of Geological Survey Information Circular 25, 10 p.

Forsyth, J.L., 1973, Late-glacial and post-glacial history of Western Lake Erie: The Compass of Sigma Gamma Epsilon, v. 51, no. 1, p. 16–26.

Francy, D.S., Gifford, A.M., and Darner, R.A., 2002, *Escherichia coli* at Ohio bathing beaches—Distribution, sources, wastewater indicators, and predictive modeling: U.S. Geological Survey Water-Resources Investigations Report 02-4285, 47 p.

Fuller, J.A., 1982, A tracer sand study of littoral transport, Maumee Bay State Park, Lucas County, Ohio: Columbus, Ohio Department of Natural Resources, Division of Geological Survey, Open File Report 82-1, 9 p.

Fuller, J.A., 1996, Distribution of surficial sediments in Ohio's nearshore (Lake Erie) as interpreted from sidescan sonar and 3.5 KHz subbottom data: U.S. Geological Survey Open-File Report 96-520, 20 p., 3 tables, 7 figures, 16 maps.

Fuller, J.A., 2002, Bank recession and lakebed downcutting—Response to changing water levels at Maumee Bay State Park, Ohio: Journal of Great Lakes Research, v. 28, p. 352–361.

Fuller, J.A., and Gerke, B.G., 2005, Distribution of shore protection structures and their erosion effectiveness and biological compatibility: Columbus, Ohio Department of Natural Resources, Division of Geological Survey, Open-File Report 2005-02, 32 p.

Fuller, J.A., Liebenthal, D.L., Mackey, S.D., and Guy, D.E., Jr., 2002, Mapping nearshore substrates with side scan sonar at six Great Lake sites, *in* A comprehensive study of Great Lakes shorelines, Appendix II: Chicago, Great Lakes Protection Fund, Project no. 470, 31p.

Guy, D.E., Jr., 1983, Origin and evolution of Bay Point sand spit, Lake Erie, Ohio: Bowling Green, Ohio, Bowling Green State University, M.S. thesis, 205 p., 5 pls.

Guy, D.E., Jr., 1984a, Formation of sand spits at Sandusky Bay, Lake Erie, Ohio [abs.]: Geological Association of Canada, Program with Abstracts, v. 9, p. 70.

Guy, D.E., Jr., 1984b, Retreat of a Lake Erie barrier beach, 1972–1982, Cedar Point, Ohio [abs.]: Ohio Journal of Science, v. 84, no. 2, April Program Abstracts, p. 18.

Guy, D.E., Jr., 1999, Erosion hazard area mapping, Lake County, Ohio, *in* Crowell, Mark, and Leatherman, S.P., eds., Coastal erosion mapping and management: Journal of Coastal Research, Special Issue 28, p. 185–196.

Guy, D.E., Jr., 2000, Beneficial use of sandy sediment dredged from channels along the Ohio shore of Lake Erie [abs.]: Ann Arbor, Mich., International Association for Great Lakes Research, Program and Abstracts, p. A-40.

Guy, D.E., Jr., 2002a, Cleveland's waterfront from 1835–2002, setting and processes [abs.], *in* Hexter, K.W., and Grabenstein, M.H., eds., Climate and shoreline educational issues forum, part of Northeast Ohio's Waterways Lakefront Planning Issue Forums, November 7, 2002 [Proceedings]: Cleveland, Ohio, Cleveland State University, Maxine Goodman Levin College of Urban Affairs, p. 3–5.

Guy, D.E., Jr., 2002b, Lakeshore tour from Oberlin Beach to Sheldon Marsh State Nature Preserve, Erie County, Ohio, *in* AIPG Ohio Section Quarterly Meeting, July 26, 2002: [Sandusky, Ohio], Ohio Department of Natural Resources, Division of Geological Survey, 24 p.

Guy, D.E., Jr., and Fuller, J.A., 1986, Geomorphology of the Lake Erie shore in northeast Ohio, *in* Coogan, A.H., Field Trip No. 3 Guidebook, Geological Society of America North-Central Section Meeting, Kent, Ohio, 1986: Kent State University, Department of Geology, 24 p.

Guy, D.E., Jr., and Liebenthal, D.L., 2004a, Movement of sand placed in a nearshore disposal area at Painesville Township Park, Lake County, Ohio—2001 to 2002: Report submitted in partial fulfillment of NOAA Award nos. NA170Z1134 and NA17OZ2347, 20 p.

Guy, D.E., Jr., and Liebenthal, D.L., 2004b, Preliminary results from monitoring of a nearshore disposal area at Painesville Township Park, Lake County, Ohio—2002 to 2003: Report submitted in partial fulfillment of NOAA Award nos. NA170Z1134 and NA17OZ2347, 5 p., 2 plates.

Guy, D.E., Jr., and Liebenthal, D.L., 2005, Progress report sand resources, Painesville, Ohio—2004: Report submitted in partial fulfillment of NOAA Award no. NA04NOS4190052, 9 p.

Haltuch, M.A., and Berkman, P.A., 1999, Guide to Lake Erie geographic information system—Bathymetry, substrates, and mussels: Columbus, Ohio Sea Grant College Program OHSU TS-029, 1 CD.

Hannibal, J.T., and Feldmann, R.M., 1983, Arthropod trace fossils, interpreted as echinocarid escape burrows, from the Chagrin Shale (Late Devonian) of Ohio: Journal of Paleontology, v. 57, p. 705–716.

Hansen, M.C., 2005, Recent Ohio earthquakes: Columbus, Ohio Department of Natural Resources, Division of Geological Survey, Ohio Geology, 2005, no. 1, p. 2–5.

Hartley, R.P., 1962, Relations of shore and nearshore bottom features to rock structures along Lake Erie: Ohio Journal of Science, v. 62, no. 3, p. 125–131.

Herdendorf, C.E., 1963, The geology of the Vermilion Quadrangle, Ohio: Athens, Ohio University, M.S. thesis, 175 p.

Herdendorf, C.E., Klarer, D.M., and Herdendorf, R.C., 2004, The ecology of Old Woman Creek, Ohio—An estuarine and watershed profile: Columbus, Ohio Department of Natural Resources, Division of Natural Areas and Preserves, 448 p.

Highman, T.A., 1997, A study of soil joints in relation to bluff erosion along the Lake Erie shoreline, northeast Ohio: Kent, Ohio, Kent State University, M.S. thesis, 162 p.

Kleinhample, F.J., 1952, Sedimentary processes along the Lake Erie shore from four miles east of Lorain, Lorain County, to Huntington Beach Park, Cuyahoga County, Ohio: Columbus, Ohio State University, M.S. thesis, 129 p.

Lewis, C.F.M., 1969, Late Quaternary history of lake levels in the Huron and Erie basins: Conference on Great Lakes Research, 12th, Ann Arbor, Mich., 1969, Proceedings: Ann Arbor, Mich., International Association for Great Lakes Research, p. 176–191.

Mackey, S.D., 1995, Lake Erie sediment budget, *in* Folger, D.W., ed., 3rd annual U.S. Geological Survey and Ohio Division of Geological Survey Lake Erie Coastal Erosion Study Workshop, St. Petersburg, Fla.: U.S. Geological Survey Open File Report 95-224, p. 34–37.

Mackey, S.D., Foye, D.A., and Guy, D.E., Jr., 1999, Impacts and mitigation of the April 9, 1998 storm [abs.]—Ohio's Western Basin coastal area: Conference on Great Lakes Research, 42nd, Cleveland, Ohio, 1999: Ann Arbor, Mich., International Association for Great Lakes Research, Program and Abstracts, p. A-75.

Mather, W.W., 1838, First Annual Report on the Geological Survey of Ohio: Columbus, Samuel Medary, Printer to the State, 134 p.

Matisoff, Gerald, and Eaker, J.P., 1992, Summary of sediment chemistry research at Old Woman Creek, Ohio: Journal of Great Lakes Research, v. 18, p. 603–621.

Mineral Information Institute, 2006, Reclamation success—Marblehead Quarry: Mineral Information Institute Web site, last accessed January 23, 2006, at <http://www.mii.org/ReclStories/Marblehead/Marblehead.html>.

Moseley, E.L., 1905, Formation of Sandusky Bay and Cedar Point, *in Proceedings of the Ohio State Academy of Science, Thirteenth Annual Report*: Columbus, Ohio Academy of Science, v. 4, p. 179–238.

National Oceanic and Atmospheric Administration (NOAA), 1985, Water levels of Lake Erie during storm of December 2, 1985: Silver Spring, Md., National Ocean Service, Tides and Water Levels Branch.

National Oceanic and Atmospheric Administration (NOAA), 1986, Great Lakes water levels, 1860–1985: Rockville, Md., U.S. Department of Commerce, 260 p.

National Oceanic and Atmospheric Administration (NOAA), 2006, Great Lakes water levels: [Washington, D.C.], NOAA Tides and Currents Web site, Center for Operational Oceanographic Products and Services (CO-OPS) Web page, last accessed March 1, 2010, <http://tidesandcurrents.noaa.gov/>.

Ohio Division of Geological Survey, 1990, Generalized column of bedrock units in Ohio: Columbus, Ohio Department of Natural Resources, Division of Geological Survey, 1 p. [Revised 2000, 2004.]

Ohio Division of Geological Survey, 1998, Coastal erosion area maps: Columbus, Ohio Department of Natural Resources, Division of Geological Survey, 465 maps.

Ohio Division of Geological Survey, 2006, Geologic map and cross section of Ohio: Ohio Department of Natural Resources, Division of Geological Survey, page-size map, 1 p. scale 1:2,000,000.

Oliver, W.A., 1976. Noncystimorph colonial rugose corals of the Onesquethaw and lower Cazenovia Stages (Lower and Middle Devonian) in New York and adjacent areas: U.S. Geological Survey Professional Paper 819, 156 p.

Pavey, R.R., Stone, B.D., and Bruno, P.W., 1995, Coastal lithologies of the Perry Quadrangle, Lake County, Ohio, *in* Folger, D.W., ed., 3rd Annual USGS and Ohio Division of Geological Survey Lake Erie Coastal Erosion Study Workshop, St. Petersburg, Fla.: U.S. Geological Survey Open File Report 95-224, p. 42–49.

Plankell, E.T., 2000, The origin of small-scale surficial folds and faults in northeastern Ohio and northwestern Pennsylvania: Columbus, Ohio State University, M.S. thesis, 137 p.

Pope, Joan, and Rowen, D.D, 1983, Breakwaters for beach protection at Lorain, Ohio: [Vicksburg, Miss.], U.S. Army Coastal Engineer Research Center, Reprint 83-12, p. 753–767.

Pore, N.A., Perrotti, H.P., and Richardson, W.S., 1975, Climatology of Lake Erie storm surges at Buffalo and Toledo: Silver Spring, Md., NOAA Technical Memorandum NWS TDL-53, 27 p.

Potter, P.E., Maynard, J.B., and Pryor, W.A., 1980, Final report of special geological, geochemical, and petrological studies of the Devonian shales in the Appalachian Basin: University of

Cincinnati, prepared for U.S. Department of Energy Contract No. AC21-76ET12140, 86 p.

Prosser, C.S., 1912, The Devonian and Mississippian formations of northeastern Ohio: Columbus, Geological Survey of Ohio, Fourth Series, Bulletin 15, 574 p.

Saville, Thorndike, Jr., 1953, Wave and lake level statistics for Lake Erie: U.S. Army Corps of Engineers, Beach Erosion Board Technical Memorandum 37, 76 p.

Snow, R.S., Lowell, T.V., and Rupp, R.F., 1991, A field guide—The Kelleys Island glacial grooves, subglacial erosion features on the Marblehead Peninsula, carbonate petrology, and associated paleontology: Ohio Journal of Science, v. 91, p. 16–26.

Sparling, D.R., and Rickard, L.V., 1985, Correlation of the subsurface Lower and Middle Devonian of the Lake Erie region—Alternative interpretation and reply: Geological Society of America Bulletin, v. 96, p. 1213–1220.

Stone, B.D., 1994, Till fabric at Painesville on-the-Lake, fig. 13, *in* Mackey, S.D., Guy, D.E., Jr., Haines, J.W., and Stith, D.A., 1994, Geology of Ohio's Lake Erie Coast and Morton Salt Mine at Fairport: Association of American State Geologists Field Trip No. 2, 18 p.

U.S. Army Corps of Engineers, 1913, Fairport Harbor, Ohio: Washington, D.C., U.S. Congress, 63rd, House Document 206, 14 p.

U.S. Army Corps of Engineers, 1932, Huron Harbor, Ohio: Washington, D.C., U.S. Congress, 72nd, House Document 478, 34 p.

U.S. Army Corps of Engineers, 1976, Preliminary report on Section 111 study of Fairport Harbor, Ohio: Buffalo, N.Y., U.S. Army Corps of Engineers, 24 p.

U.S. Army Corps of Engineers, 1989, Small beach erosion project, Sims Park, City of Euclid, Cuyahoga County Ohio—Finding of no significant impact and environmental assessment: Buffalo, N.Y., U.S. Army Corps of Engineers, 17 p., appendices.

U.S. Army Corps of Engineers, 2004, Sheldon Marsh Nature Preserve—Section 227 Huron, Ohio: Buffalo, N.Y., U.S. Army Corps of Engineers, 60% Reconnaissance Report, 74 p.

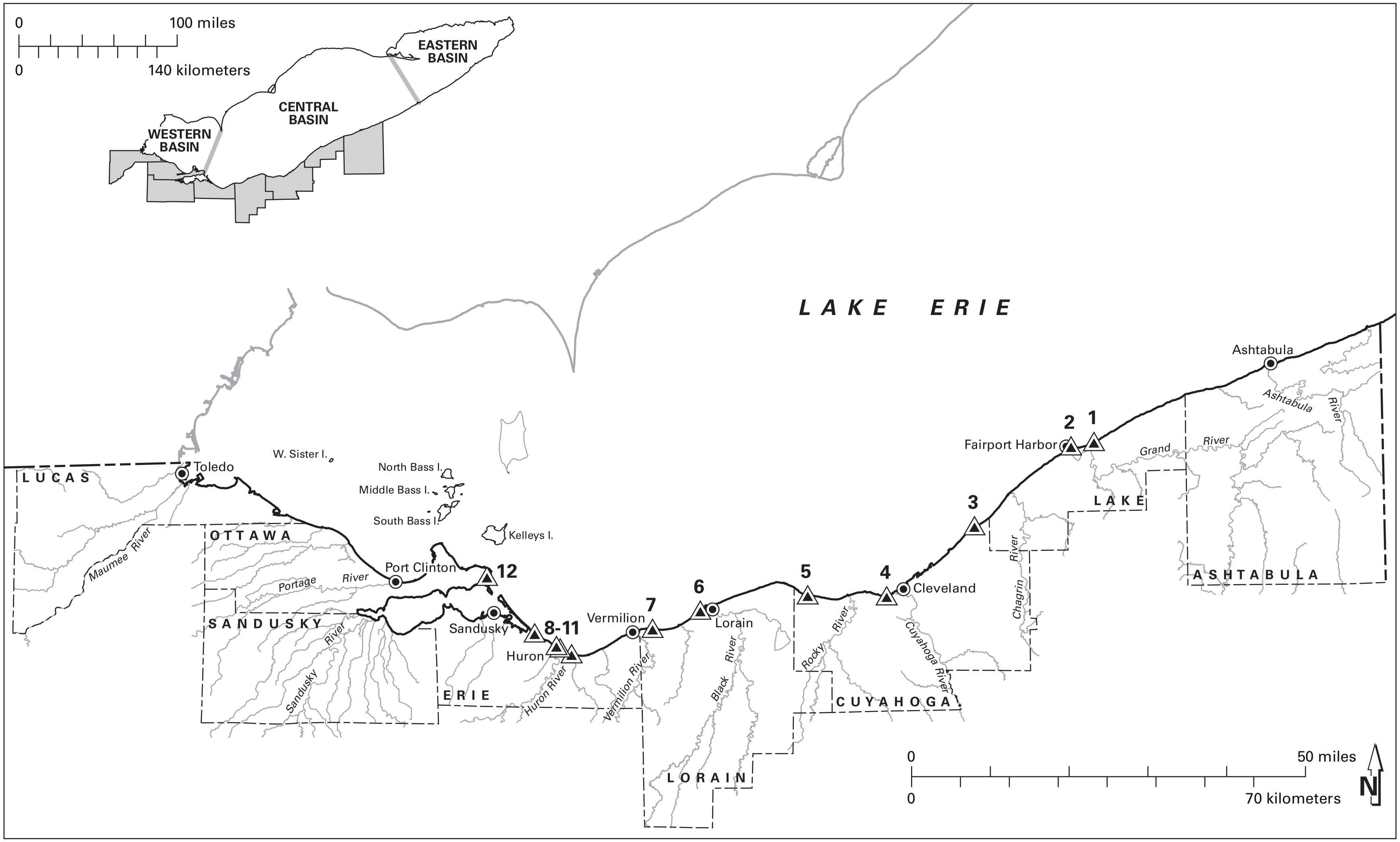
Ver Steeg, Karl, and Yunck, George, 1935, Geography and geology of Kelley's Island Ohio: Ohio Journal of Science, v. 35, no. 6, p. 421–433.

White, G.W., 1982, Glacial geology of northeastern Ohio: Columbus, Ohio Department of Natural Resources, Division of Geological Survey Bulletin 68, 75 p.

Wolfe, M.E., 2006, 2005 Report on Ohio Mineral Industries: Columbus, Ohio Department of Natural Resources, Division of Geological Survey, 102 p.

Worthy, M.C., 1980, Littoral zone processes at Old Woman Creek: Columbus, Ohio State University, M.S. thesis, 199 p.

Guy & Moore—GEOLOGIC SETTING AND PROCESSES ALONG LAKE ERIE FROM FAIRPORT HARBOR TO MARBLEHEAD, OHIO—
Ohio Division of Geological Survey Guidebook No. 21



FIELD TRIP MAP AND STOPS