THE GEOLOGIC SETTING OF LAKE ERIE

FIELD GUIDE AND EXERCISES IN SELECTED AREAS

LAWRENCE A. KRISSEK and WILLIAM I. AUSICH

DEPT. OF GEOLOGICAL SCIENCES, OHIO STATE UNIVERSITY

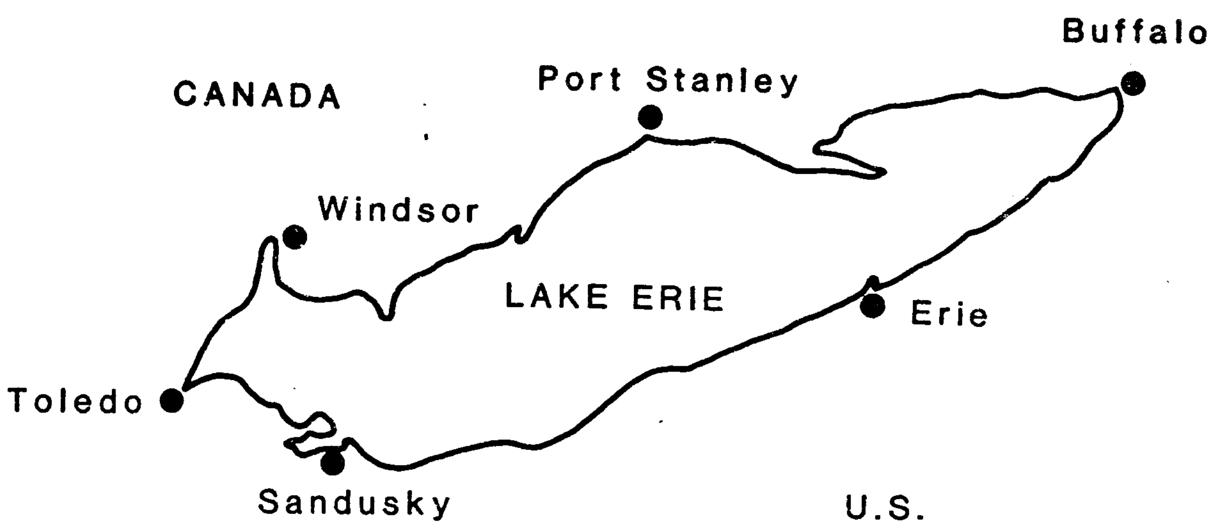


TABLE OF CONTENTS

ACKNOWLEDGEMENTS

Preparation and publication of this fieldguide were supported by a grant from the Lake Erie Protection Fund, administered by the Ohio Lake Erie Office. This support is gratefully acknowledged.

INTRODUCTION TO THE GEOLOGY OF THE LAKE ERIE REGION

The geology of the Ohio portion of the Lake Erie basin is dominated by two major types of material: Paleozoic sedimentary rocks (Fig. 1), and the overlying glacial and post-glacial deposits (Fig. 2). On this trip we will examine aspects of both of these components in Ohio, as well as their expression at the east end of Lake Erie (Niagara Falls).

The Paleozoic bedrock of Ohio is composed entirely of sedimentary rocks; igneous and metamorphic bedrock is buried at least several thousand feet below the surface throughout the state. The older part of the Paleozoic sequence (Ordovician through Devonian) is dominated by carbonates and shales, most of which were deposited in a series of shallow seas that repeatedly moved onto and off of the region that is now the midcontinent of North America. Because the area that is now Ohio was located in tropical latitudes during the Paleozoic, these warm, shallow seas often provided ideal settings for the deposition of limestone. Periodically, however, muds were supplied to these shallow seas by the erosion of adjacent mountains, and shales were deposited instead of limestones.

Sands are relatively uncommon in the Ordovician through Devonian sequence of Ohio, although some sands of this age in the subsurface are economically important reservoirs of oil and gas. The episodes of marine flooding of the region were interrupted by times of ocean retreat, which exposed the continent surface to erosion. These intervals of erosion are now represented by unconformities, or gaps in the time record carried by these rocks.

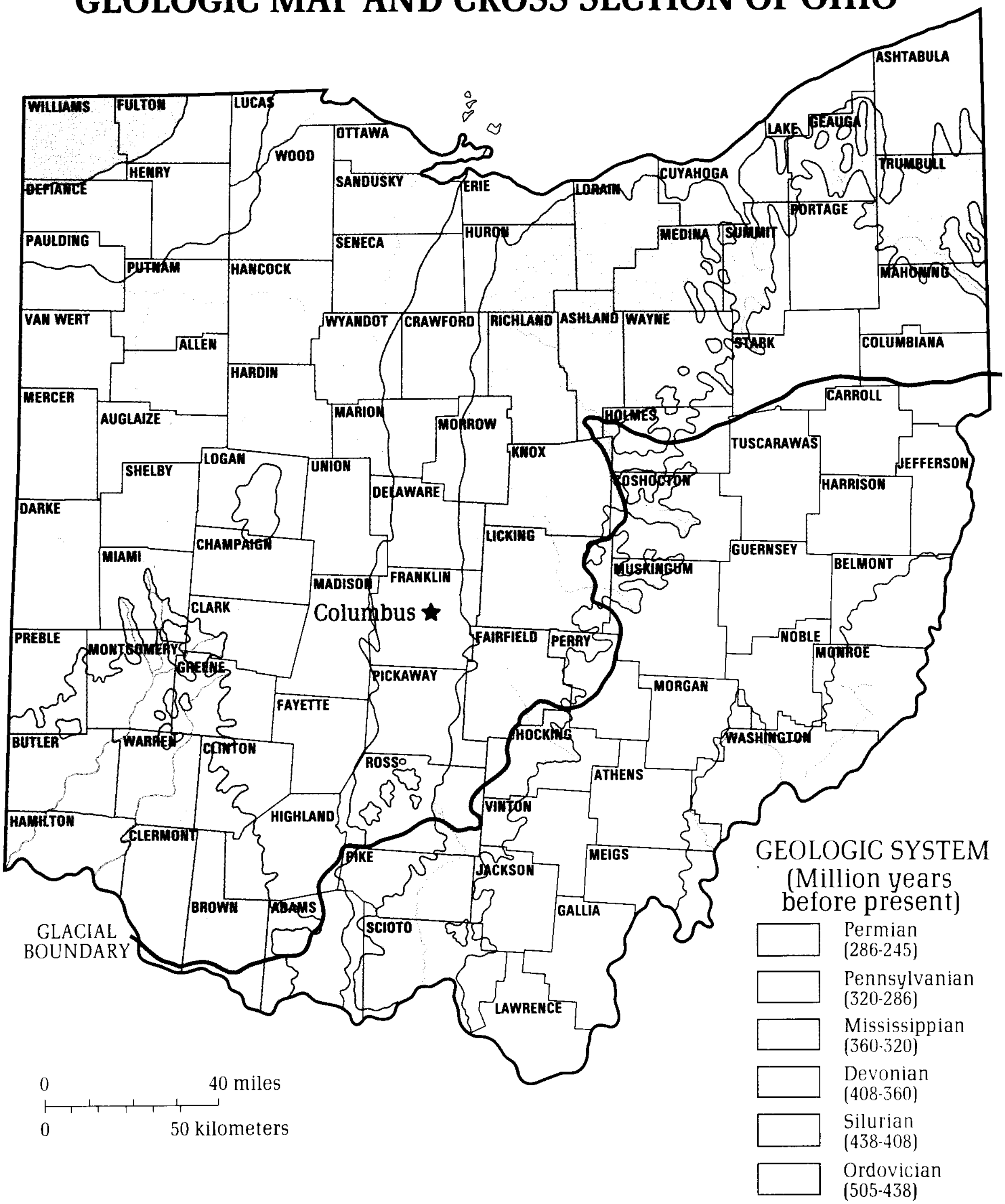
Beginning in the Late Devonian, the supply of land-derived sediment to the marine basin located in what is now Ohio increased significantly. This material was derived from the Appalachian Mountains to the east, which were being uplifted by plate convergence farther east. The land-derived sediment gradually infilled the pre-existing low, or basin, during the Late Devonian and Mississippian, so that much of the area was occupied by a low-relief coastal plain by the Early Pennsylvanian. Repeated advances and retreats of the shoreline during the Pennsylvanian deposited thin packages of sediment, each showing a relatively similar sequence of rock types. These repeated packages are termed cyclothems, and are the coal-bearing units of eastern Ohio. A limited area of Permian bedrock has been reported in Ohio, and also records the existence of terrestrial environments.

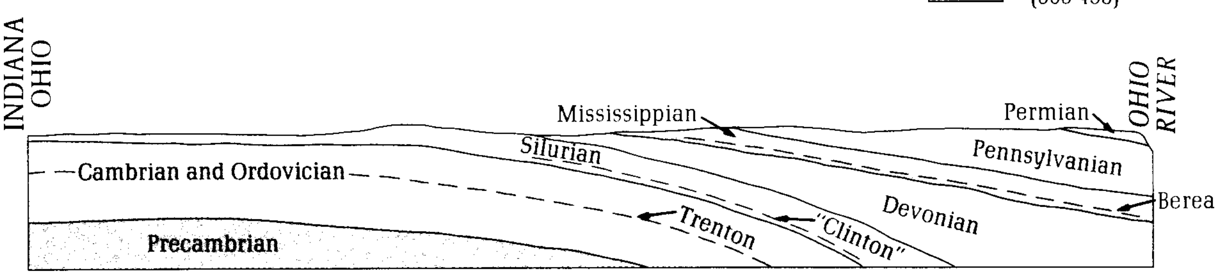
In a general sense, the Paleozoic bedrock of Ohio is often viewed has having a "layer cake" stratigraphy, with layers of successively younger rocks stacked vertically and extending uniformly across the state. In detail, however, we know that this view is incorrect, as indicated by changes in the rock units of a given age across the state (Fig. 3). This additional complexity within each "layer" results from lateral changes in physical environments at any time.

The distribution of the various bedrock "layers" at the surface in Ohio is largely controlled by the presence of an up-bowed region, known as the Cincinnati Arch, and an adjacent down-bowed region, known as the Appalachian Basin (Fig. 1). During and after formation of the Cincinnati Arch, the up-bowed bedrock layers were planed off by erosion, exposing an edge-on view of each layer. Because the older layers were originally deeper within the up-bowed region, the edges of those layers are now exposed closer to the crest of the Arch; the exposed layers become younger away from the crest of the Arch. For that reason, we will gradually work our way from older to younger rocks as we move from South Bass Island and Kelleys Island to the Cleveland area.

The glacial and post-glacial sediments in Ohio have been deposited during approximately the last 1.6 million years, both by advances and retreats of large glaciers from the north and by accompanying changes in river volume, river drainage patterns, and the like. In northern Ohio, the ice-influenced sediments include ice-contact deposits (e.g., till), outwash sand and gravels, and deposits of ice-influenced lakes (beach ridges, lake clays, etc.). These deposits are important today both for the glacial record they contain and for their response to modern processes along the lakeshore.

GEOLOGIC MAP AND CROSS SECTION OF OHIO





STATE OF OHIO
George V. Voinovich, Governor

DEPARTMENT OF NATURAL RESOURCES
Donald C. Anderson, Director

DIVISION OF GEOLOGICAL SURVEY
Thomas M. Berg, Chief

GLACIAL DEPOSITS OF OHIO

Kames and eskers

Outwash

Lake deposits

WISCONSINAN
(14,000 to 24,000 years old)

Ground moraine

End moraine

ILLINOIAN
(130,000 to 300,000 years old)

Undifferentiated morainic drift

PRE-ILLINOIAN
(older than 300,000 years)

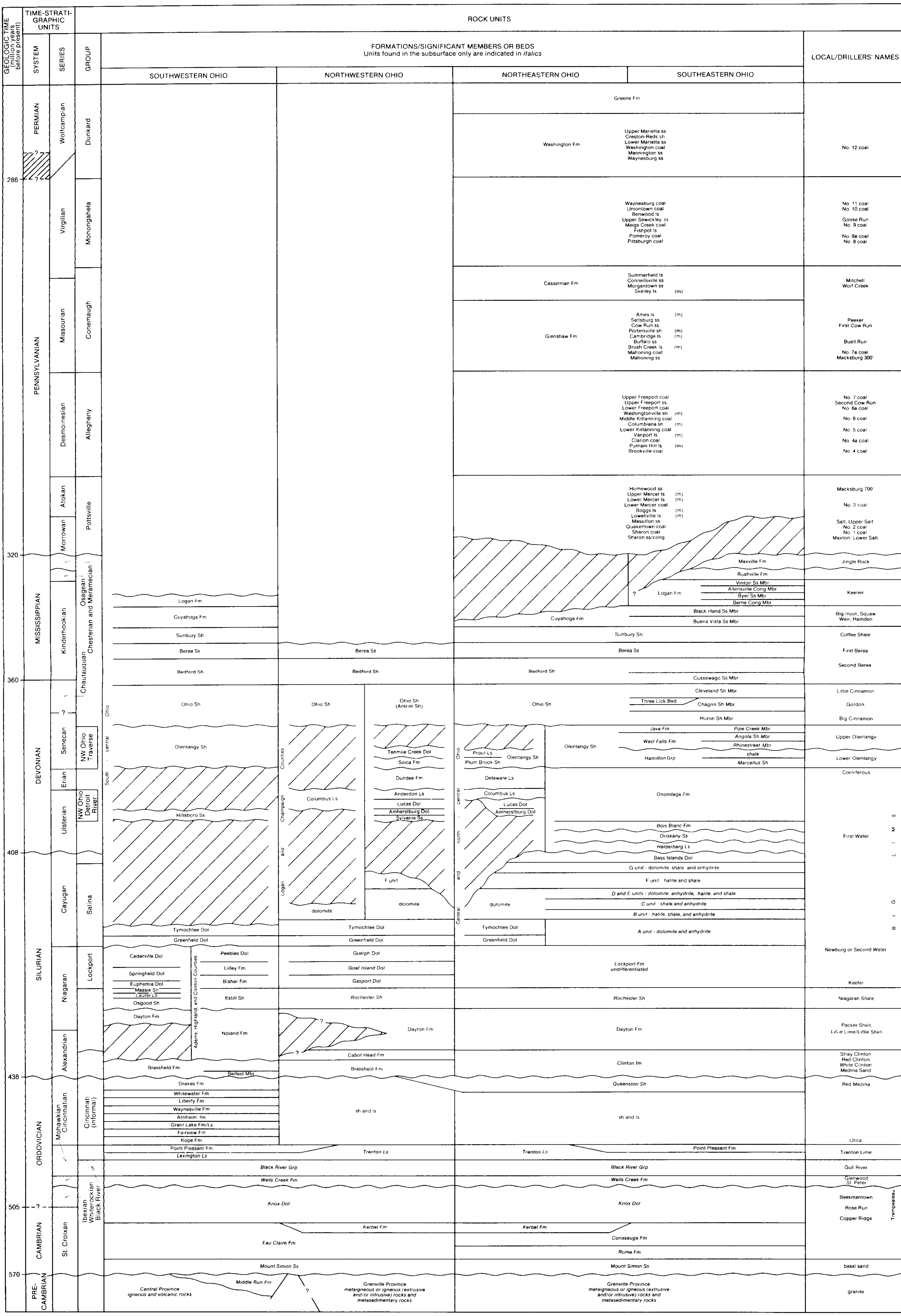
Undifferentiated morainic drift

ODNR
OHIO DEPARTMENT OF NATURAL RESOURCES

STATE [illegible]
Richard F. C[illegible] [illegible]vernor
DEPARTMENT OF [illegible] RESOURCES
Joseph J. So[illegible] Director
DIVISION OF GEOLOGICAL SURVEY
Thomas M. Berg, Chief

GENERALIZED COLUMN OF BEDROCK UNITS IN OHIO

Dennis N. Hull, chief compiler



Sh, sh	shale	Dol, dol	dolomite	Grp, grp	Group
Ss, ss	sandstone	cong	conglomerate	Fm, fm	Formation
Ls, ls	limestone	(m)	Pennsylvanian marine zone	Mbr	Member

/ / Depositional hiatus or interval removed by erosion

~ unconformity

Note: lower case lithologic or stratigraphic names indicate informal status of unit

Compiled by Dennis N. Hull from numerous published and unpublished sources and through personal communications with the staff of the Division of Geological Survey. Time boundaries from Geological Society of America.

6/90

Total copies printed: 5,000
Unit cost: $.0626
Publication date: 10/90

Naturally OHIO the heart of it all!

OHIO DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY

GLACIAL DEPOSITS OF OHIO

Although difficult to imagine, Ohio has at various times in the recent geologic past (within the last 1.6 million years) had almost three-quarters of its surface area covered by vast sheets of ice perhaps as much as 1 mile thick. This period of geologic history is referred to as the Pleistocene Epoch or, more commonly, the Ice Age, although there is abundant evidence that Earth has experienced numerous other "ice ages" throughout its 4.6 billion years of existence.

Ice Age glaciers invading Ohio formed in central Canada in response to climatic conditions that allowed massive buildups of ice. Because of their great thickness these ice masses flowed under their own weight and ultimately moved south as far as northern Kentucky. Oxygen-isotope analysis of deep-sea sediments indicates that more than a dozen glaciations occurred during the Pleistocene. Portions of Ohio were covered by the last two glaciations, known as the Wisconsinan (the most recent) and the Illinoian (older), and by an undetermined number of pre-Illinoian glaciations.

Because each major advance covered the deposits left by the previous ice sheets, pre-Illinoian deposits (brown area on map) are exposed only in extreme southwestern Ohio in the vicinity of Cincinnati. Although the Illinoian ice sheet covered the largest area of Ohio, its deposits (lavender area on map) are at the surface only in a narrow band from Cincinnati northeast to the Ohio-Pennsylvania border. Most features shown on the map of the glacial deposits of Ohio are the result of the most recent or Wisconsinan-age glaciers.

The material left by the ice sheets consists of mixtures of clay, sand, gravel, and boulders in various types of deposits of different modes of origin. Rock debris carried along by the glacier was deposited in two principal fashions, either directly by the ice or by meltwater from the glacier. Some material reaching the ice front was carried away by streams of meltwater to form outwash deposits (yellow areas on map). These deposits normally consist of sand and gravel. Sand and gravel deposited by water on and under the surface of the glacier itself formed features called kames and eskers (red areas on map), which are recognized by characteristic shapes and composition. The distinctive characteristic of glacial deposits that have been moved by water is that the material was sorted by the water that carried it. The large boulder-size particles were left behind and the smaller clay-size particles were carried far away, leaving the intermediate gravel- and sand-size material along the stream courses.

Clay- to boulder-size material deposited directly from the ice was not sorted. Some of the debris was deposited as ridges parallel to the edge of the glacier, forming terminal or end moraines (dark-green areas on map), which mark the position of the ice when it paused for a period of time, possibly a few hundred years. When the entire ice sheet receded because of melting, much of the ground-up rock material still held in the ice was deposited on the surface as ground moraine (light-green areas on map). The term glacial drift commonly is used to refer to any material deposited directly (*e.g.*, ground moraine) or indirectly (*e.g.*, outwash) by a glacier. Because the ice that invaded Ohio came from Canada, it carried in many rock types not found in Ohio. Pebbles, cobbles, and boulders of these foreign rock types are called erratics. Rock collecting in areas of glacial drift may yield granite, gneiss, trace quantities of gold, and, very rarely, diamonds. Most rocks found in glacial deposits, however, are types native to Ohio.

Many glacial lakes were formed during the time that ice covered Ohio. Lake deposits (blue areas on map) are primarily very fine grained clay- and silt-size sediments. The most extensive area of lake deposits is in northern Ohio bordering Lake Erie. These deposits represent early stages in the development of Lake Erie as it is presently known. Other lake deposits accumulated in stream valleys whose outlets were temporarily dammed by ice or outwash. Many outwash-dammed lake deposits are present in southeastern Ohio far beyond the glacial boundary.

Certain deposits left behind by the ice are of economic importance, particularly sand and gravel, clay, and peat. Sand and gravel that have been sorted by meltwater generally occur as kames or eskers or as outwash along major drainageways. Sand and gravel are vital to Ohio's construction industry. Furthermore, outwash deposits are among the state's most productive sources of ground water.

Glacial clay is used in cement and for common clay products (particularly field tile). The minor quantities of peat produced in the state are used mainly for mulch and soil conditioning.

Total copies printed: 15,000 Unit Cost: $.0370 Publication date: 5/95

KELLEY'S ISLAND

Kelley's Island is located approximately three miles north of the Marblehead Peninsula, and approximately five miles east of South Bass Island (Fig. 1). The bedrock exposed on Kelley's Island is composed of Devonian carbonates, predominantly the Columbus Limestone (Fig. 2). Lesser amounts of older Devonian carbonates, specifically the Lucas Dolostone, are exposed at the base of the active Kellstone Quarry and along the northwest shore of the island.

The Columbus Limestone is a highly fossiliferous tan carbonate composed of varying mixtures of mud-sized carbonate (micrite) and larger carbonate particles (allochems). The fossils present indicate that the Columbus Limestone was deposited in a marine setting, but two lines of evidence suggest that the details of the marine setting varied during deposition of the Columbus Limestone. The first line of evidence is variations in the abundance of micrite and allochems; in a general sense, these abundances reflect the amount of energy that was affecting the environment as the sediments were being deposited (Fig. 3). Small particles, such as the micrite, are easily suspended and washed away (winnowed) by high energy conditions, as would occur in shallow marine environments affected by waves. In somewhat deeper water, however, or in protected areas such as lagoons, the waves have less effect on the sediments and mud-sized grains are deposited. The second line of evidence for environmental variability comes from the thickness of the individual beds in the Columbus Limestone; wave action consistently moves the sediment on the seafloor, so that relatively thin and "lumpy" beds are formed. In quieter settings, thicker beds are formed by less-mobile sediment.

The carbonates on both Kelley's Island and South Bass Island are overlain by Pleistocene glacial deposits, and the effects of glacial movement over these carbonates are expressed dramatically at several localities around the islands. In particular, glacially modified surfaces (glacial grooves) are exposed in the State Park on South Bass Island, on Gibraltar Island, and at the Glacial Grooves State Memorial on Kelley's Island. These surfaces range from glacially polished with small striations to the spectacular giant glacial grooves on Kelley's Island (Fig. 4), and appear to show the combined effects of subglacial erosion, dissolution, and variations in substrate strength.

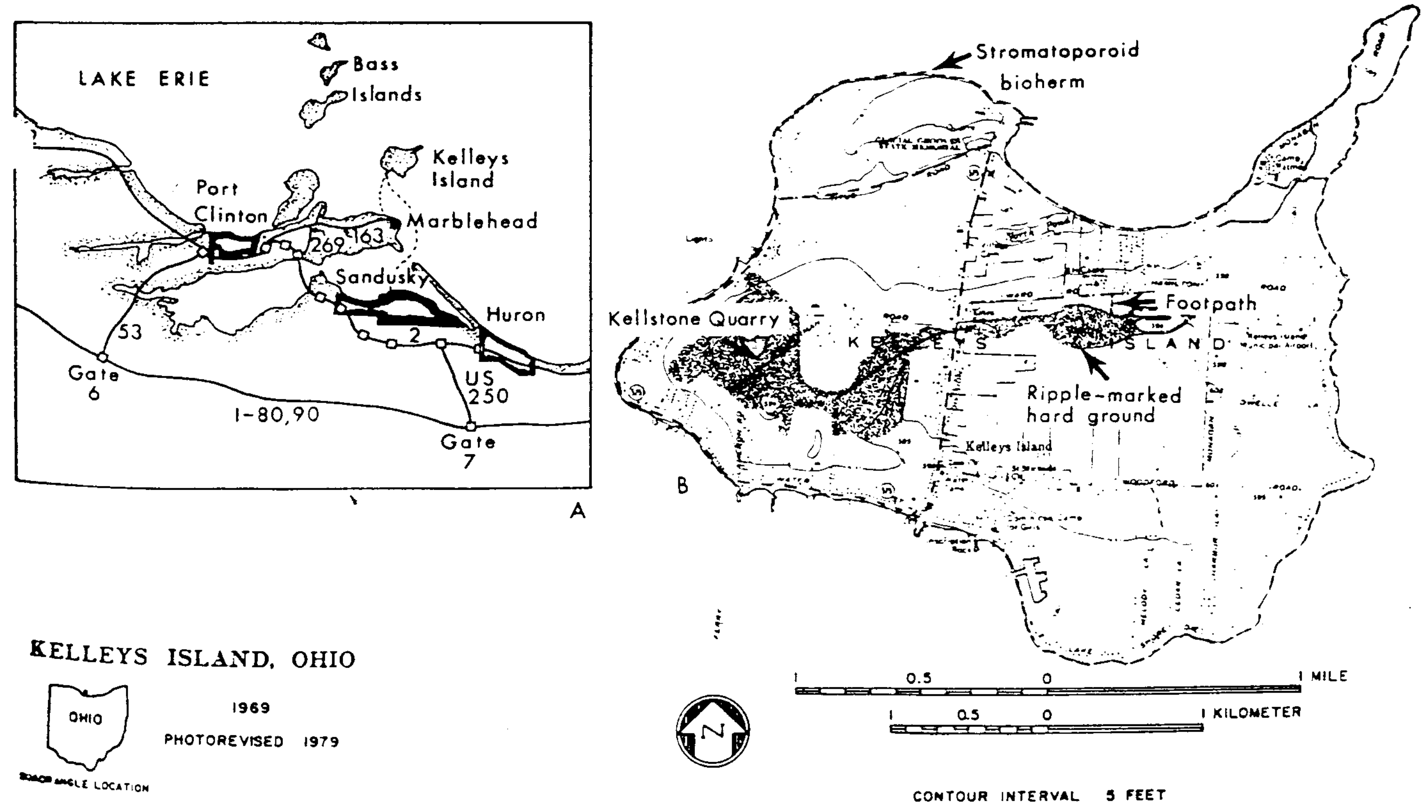


Figure 1. Location map for Kelleys Island (A) and several key geological features on the Island (B).

Feldmann & Bjerstedt, 1987.

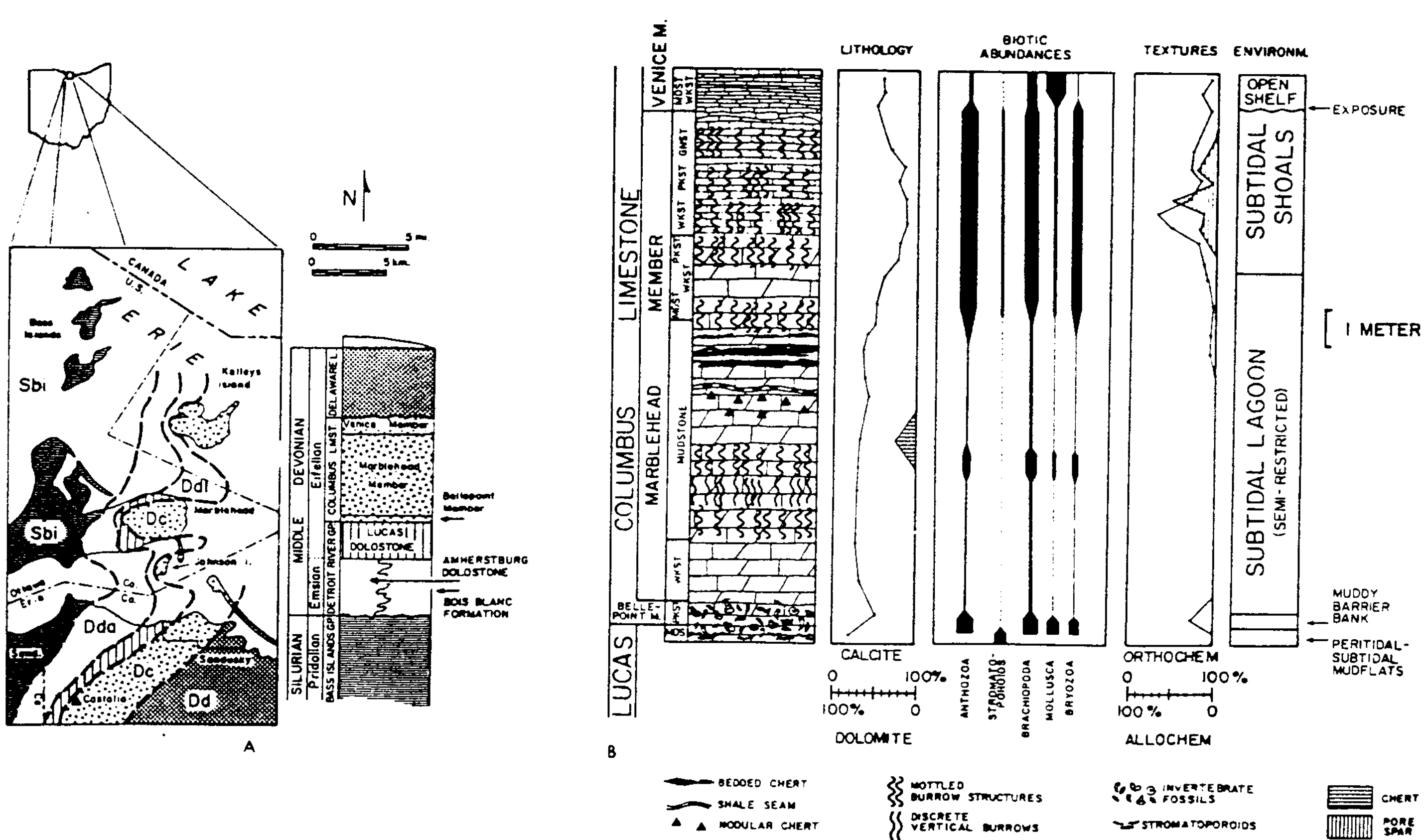


Figure 2. Geological map and generalized stratigraphic column of a portion of northern Ohio (A) showing the distribution of Silurian and Devonian rocks cropping out in the vicinity of Kelleys Island as well as details on the stratigraphy of the Island (B). The units depicted in Figure 4B are exposed at sites described in the text. Summaries of lithologic, biotic, textural, and environmental variation are taken from Bjerstedt and Feldmann (1984) and the generalized geologic map is modified from Forsyth (1971).

	OVER 2/3 LIME MUD MATRIX				SUBEQUAL SPAR & LIME MUD	OVER 2/3 SPAR CEMENT		
Percent Allochems	[illegible]	[illegible]	10-50%	OVER 50%		SORTING POOR	SORTING GOOD	ROUNDED & ABRADED
Representative Rock Terms	MICRITE & DISMICRITE	FOSSILIFEROUS MICRITE	SPARSE BIOMICRITE	PACKED BIOMICRITE	POORLY WASHED BIOSPARITE	UNSORTED BIOSPARITE	SORTED BIOSPARITE	ROUNDED BIOSPARITE
Terminology	Micrite & Dismicrite	Fossiliferous Micrite	Biomicrite			Biosparite		
Terrigenous Analogues	Claystone		Sandy Claystone	Clayey or Immature Sandstone		Submature Sandstone	Mature Sandstone	Supermature Sandstone

LIME MUD MATRIX   SPARRY CALCITE CEMENT

FIGURE 3 Textural classification of carbonate sediments based on relative abundance of lime mud matrix and sparry calcite cement, and on the abundance and sorting of carbonate grains (allochems). (After Folk, R. L., 1962, Spectral subdivision of limestone types, in W. E. Ham (ed.), Classification of carbonate rocks: Am. Assoc. Petroleum Geologists Mem. 1, Fig. 4, p. 76, reprinted by permission of AAPG, Tulsa, Okla.)

FIGURE 4 Westward (down ice flow) view along the megagroove, Stop 2. The cigar-headed ridge in the right foreground shows relatively narrow furrows on either side, and several furrows extending well in front of the head. Scale rod is marked in 10 cm (4 in) increments. A more subtle cigar-headed ridge appears on the left, about 0.5 m (2 ft) from the end of the scale rod. A much larger example of same form is the bulge to Tom Lowell's back. The two smaller ridges are truncated in the down-ice direction by the furrow developed on the right side of the large ridge head.

Snow et al., 1991.

STOP 1: GLACIAL GROOVES STATE MEMORIAL

Access onto the glacial grooves is restricted at this site, but we can still describe and interpret a variety of features from a distance. Be sure to realize that the giant grooves exposed here are only the last surviving remnants of a larger set of grooves that originally were present in this area; the other grooves were removed by quarrying.

1) Describe/sketch the general forms of the features that you see. In your description, you may want to consider the following points:

   a) are all of the features the same size, or do you see features of several different sizes (i.e., a hierarchy of sizes)?

   b) do all features of the same size show the same general orientation, or are features of some sizes more variable than features of other sizes?

   c) can you think of different processes or controls that might give rise to the different types of variation you have observed?

2) Describe/sketch any examples you observe of features that appear to be related to small-scale changes in the bedrock. Do these have a consistent shape? If so, can you interpret this shape as an indicator of ice flow direction?

3) Estimate the general orientation of these grooves, and compare that orientation with the orientation of the grooves

on South Bass Island and Gibraltar Island. How would you explain any differences in these orientations?

STOP 2: EAST QUARRY

Enter the abandoned East Quarry from the trail on Ward Road, and examine the Columbus Limestone exposed along the north quarry wall west of the access trail.

1) List the fossils you observe, and indicate the vertical position of each fossil type within the quarry wall (lower, middle, upper).
2) What is the material, composed of large crystals, that you observe distributed throughout the quarry? How did this material form?
3) Observe the orientation and distribution of fossils within any of the large slabs along the north quarry wall. Are the fossils uniformly distributed, or are they concentrated in layers? Are most of the fossils preserved in the position they held while living, or are they oriented in some other way? What do these observations suggest about the amount of energy in the environment when these sediments were deposited?
4) Observe the unconsolidated material that sits on top of the small hill in the middle of the quarry floor. List the lithologies or characteristics of a collection of 20 pebbles from that location; how important are pieces of the Columbus Limestone in your list? Describe/sketch the general shape of your pebbles, and compare that shape to the shape of most of the Columbus Limestone blocks that you see. How would

you explain any differences in composition and grain shape between the bedrock and the unconsolidated material?

REFERENCES, KELLEY'S ISLAND

Feldmann, R.M., and Bjerstedt, T.W., 1987. Kelleys Island: giant glacial grooves and Devonian shelf carbonates in north-central Ohio. In Biggs, D.L. (ed.), North Central Section of the Geological Society of America, Centennial Field Guide Vol. 3, 395-398.

Mackey, S.D., Fuller, J.A., and Stith, D.A., 1994. Glacial and bedrock geology of Kelleys Island, Ohio. Guidebook, Annual Meeting of the Association of American State Geologists.

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 J. Science, 91: 16-26.

COASTAL PROCESSES AND FEATURES, MARBLEHEAD PENINSULA TO VERMILION

During this trip, we will observe the Lake Erie coastline in two areas: north-central Ohio, between the Marblehead Peninsula and Vermilion, and northeastern Ohio, in Lake and Ashtabula counties. In both areas, we will find that the present-day coastline reflects the local interaction of three controls: the pre-existing framework developed by glacial activity and the post-glacial history of lake development, the modern regime of winds, waves, and lake level changes, and human effects.

1) The presence of large glaciers in the Lake Erie basin directly affected the area by bedrock scouring and sediment deposition; we have observed examples of these effects on Kelley's Island. The large icesheets also affected the area after ice retreat, however, as the ground surface rebounded when the weight of the ice was removed. This rebound effect varied in speed and timing both from east to west and from north to south across the basin, producing a complicated history of lake level changes (Fig. 1). Prior to approximately 12,000 ybp, the lake outlet to the east remained blocked by ice, and Lake Erie drained to the west at an outlet near Fort Wayne, Indiana. The eastern ice dam was removed at approximately 12,000 ybp, and a significant portion of Lake Erie was completely drained by outflow through the still-depressed Niagara outlet. Post-glacial rebound of the Niagara outlet has gradually deepened Lake Erie to its present configuration.

These large-scale fluctuations in lake level have been interpreted from the distributions and elevations of old beaches and wave-cut platforms around the lake. An additional pattern of north-south differences in post-glacial uplift has significantly affected the Ohio shore of Lake Erie; the more recent deglaciation of the Canadian side of the lake, combined with the removal of a thicker ice load on the Canadian side, has produced more rapid uplift on the northern side of the lake than on the southern side. The effect of this difference in uplift rates has been a relative "down-tilting" of the Ohio shore, so that lake level has appeared to rise on the Ohio shore and older coastal features have been flooded. Examples of this flooding include the flooding of the old Sandusky River mouth to form Sandusky Bay, and the drowning of old beach systems to form barrier islands along the east side of the Marblehead Peninsula and along the Cedar Point Spit.

2) The modern regime of wind, waves, and lake level can fluctuate over a variety of time scales to produce the modern shoreline. Lake level fluctuations (Fig. 2) can be

* long term (predominantly caused by variations in precipitation in the Great Lakes Basin),
* annual (caused by seasonal changes in precipitation vs. evaporation), or
* short term (caused by tilting of the lake surface due to wind action).

Superimposed on these lake level changes are the effects of wind-produced waves. The most energetic waves approach the Ohio shore from either the southwest or the northeast; the former are most important along the coast east of Avon Point, and the latter are most important west of Avon Point. This difference creates a change in the regional direction of sand transport along the coast, with sediments east of Avon Point transported to the east and sediments west of Avon Point transported to the west (Fig. 3).

The type and amount of material supplied to the modern Ohio shore is generally controlled by the nature of the material exposed along the coast; rivers generally do not supply much material to the nearshore zone. Sand is supplied by the erosion and winnowing of till from bluffs along the coast (Fig. 3), whereas beaches along rocky parts of the coast are dominated by locally derived rock fragments (shale, sandstone, or carbonate).

During storms, large waves can act high on the beach. Along portions of the shore where the beach is attached to the coast, these large waves can cause significant erosion of the back-beach area, including the lake-facing bluffs. Along portions of the shore where the beach is detached from the coast, forming a barrier complex, these large waves can wash material from the beach front into the back-beach lagoon; in some cases, this wash-over process is sufficient to cut the pre-existing barrier in two (Fig. 4). In such a case, the breach in the barrier island can only be "healed" by the subsequent supply of sand by longshore transport.

3) The major effect of human activities along the Ohio shore of Lake Erie has been the construction of a variety of structures that influence wave interactions with the coast. The

largest of these structures are the harbor jetties, some of which extend 900 to 1800 m into the lake and completely block the regional sand transport. Smaller shore-protection structures are extremely common along the coast, and are especially used to prevent shore erosion. All of these structures interrupt the longshore transport system to some extent, so that the longshore transport is now significantly less than it was prior to the arrival of European settlers. Because of the reduced longshore transport, portions of the shore disturbed during large storms are less likely to be "healed" during fairweather conditions.

A large number of sites along the north-central Ohio coast provide opportunities to examine coastal features and human effects. Depending on the time available, we will visit some subset of the following sites (Fig. 5): East Harbor State Park on the Catawba Peninsula, Cedar Point Spit and its eastern end at Sheldon's Marsh, Huron City Park, the beach at Old Woman's Creek, and Sherod Park, west of Vermilion.

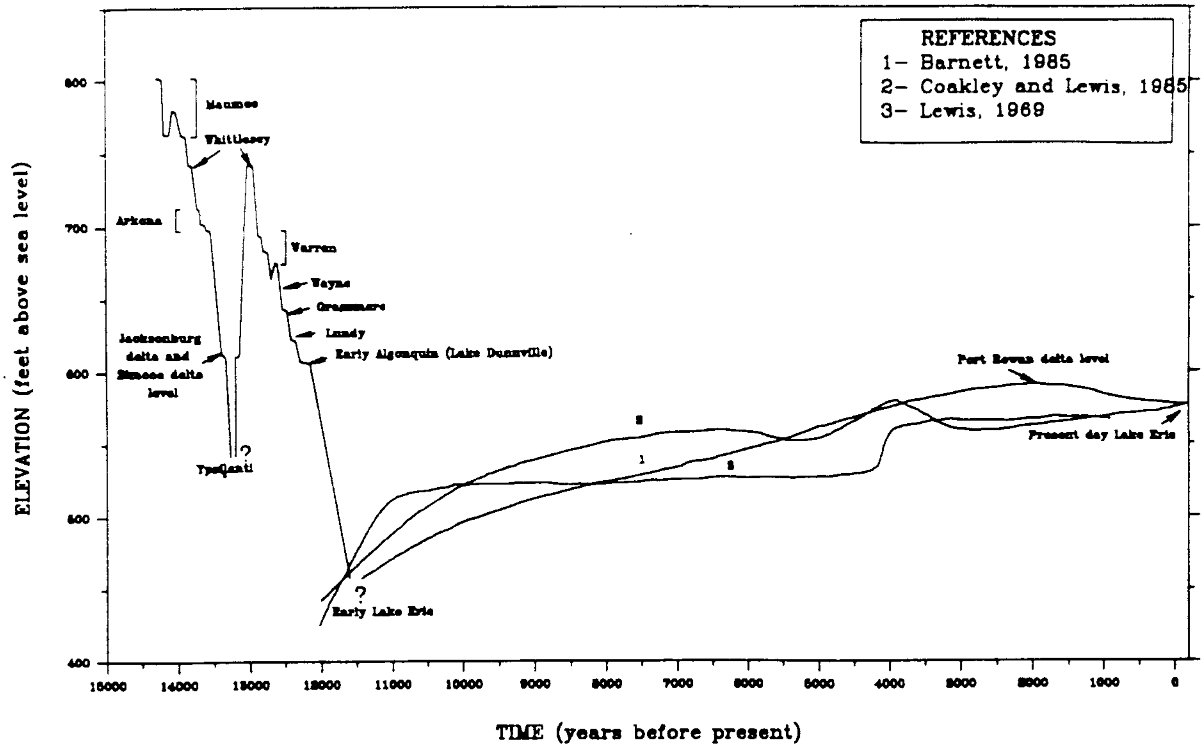


Figure 1 Ancestral lake-level curves for Lake Erie (modified from Lewis, 1969; Coakley and Lewis, 1985; and Barnett, 1985).

FROM MACKEY ET AL., 1994

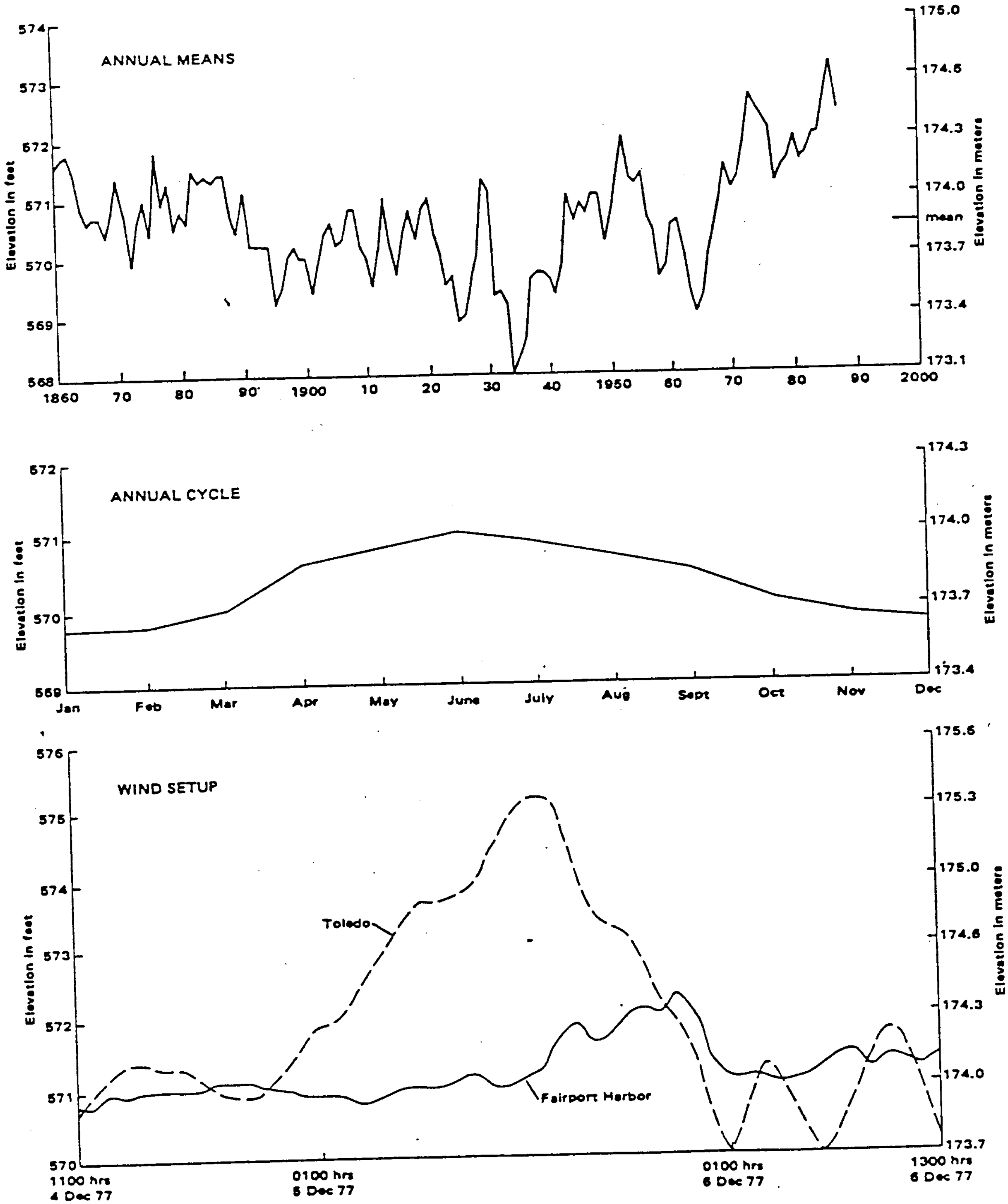


Figure 2.—Lake-level fluctuations.
Guy & Fuller, 1990.

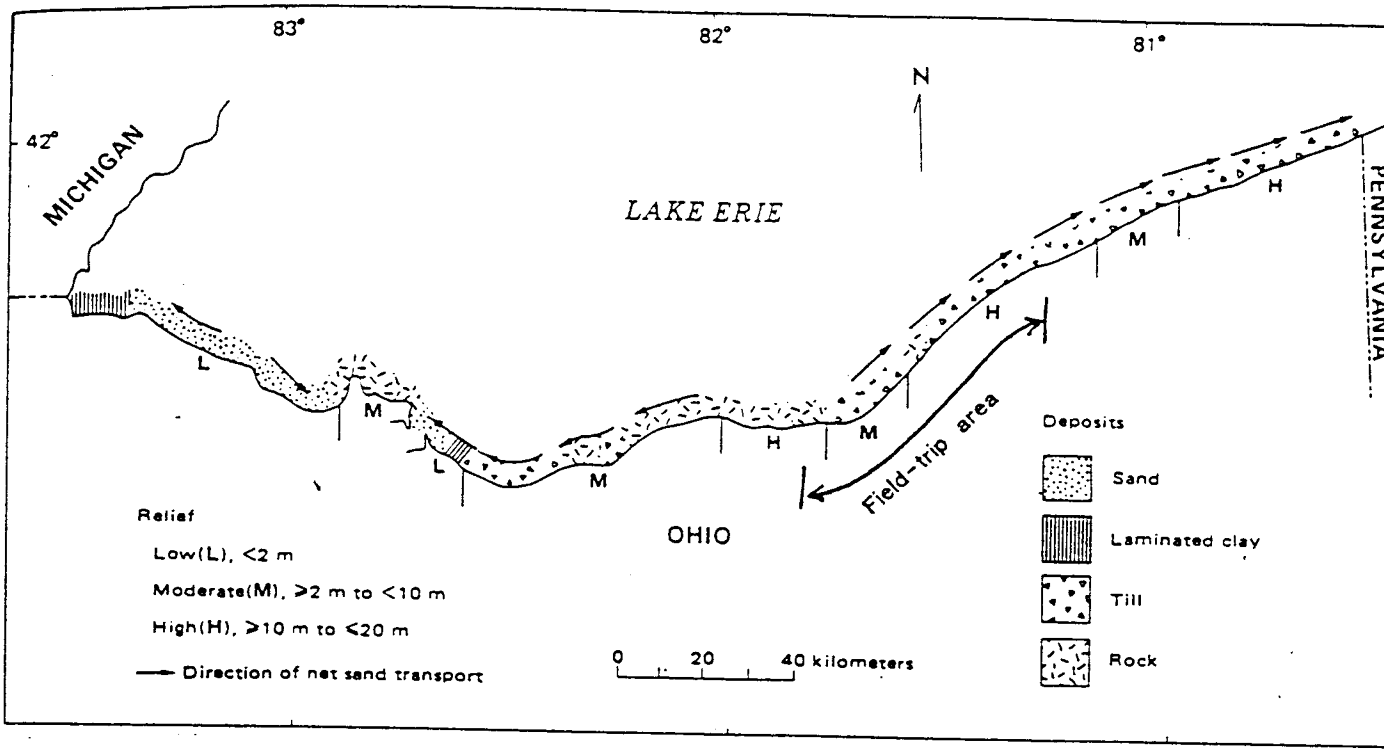


Figure 3.—Generalized map of shore deposits in the wave erosion zone, relief, and net sand transport directions (from Carter, Guy, and Fuller, 1981).

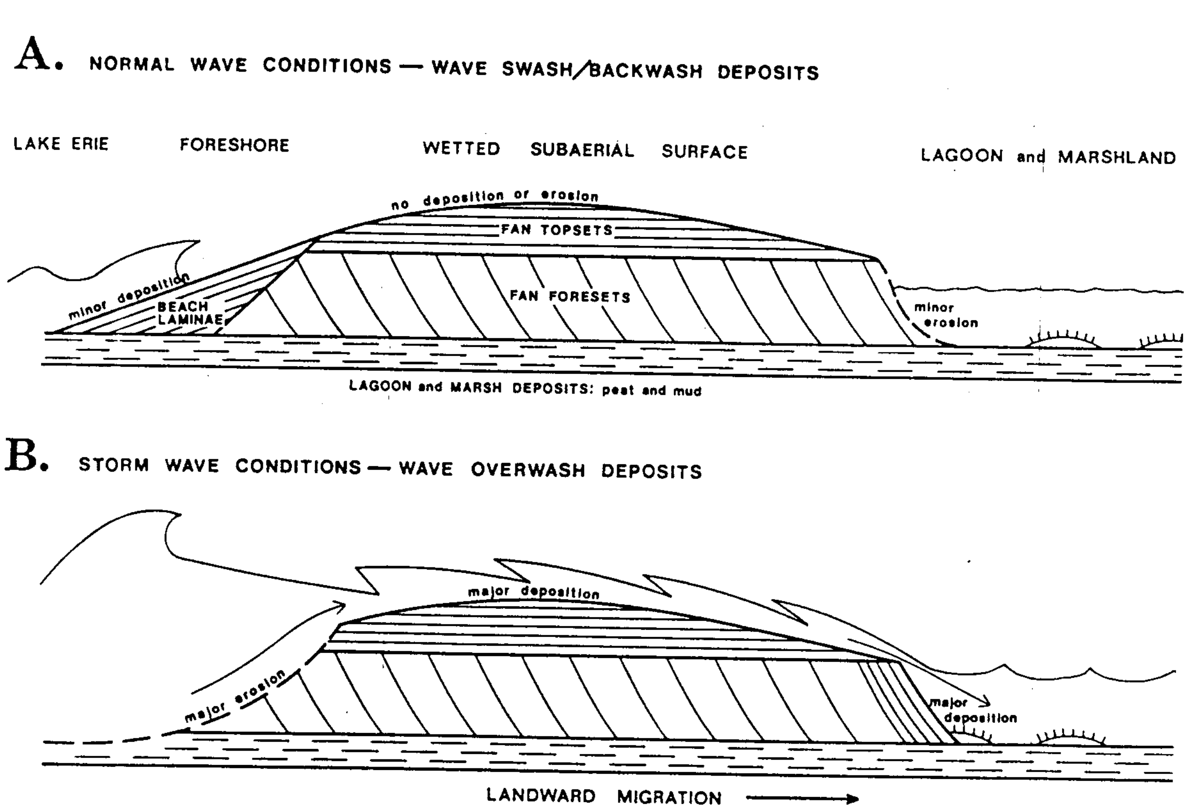


FIG. 4. CROSS-SECTION THROUGH CEDAR POINT SPIT.
ANDERHALT ET AL., 1983

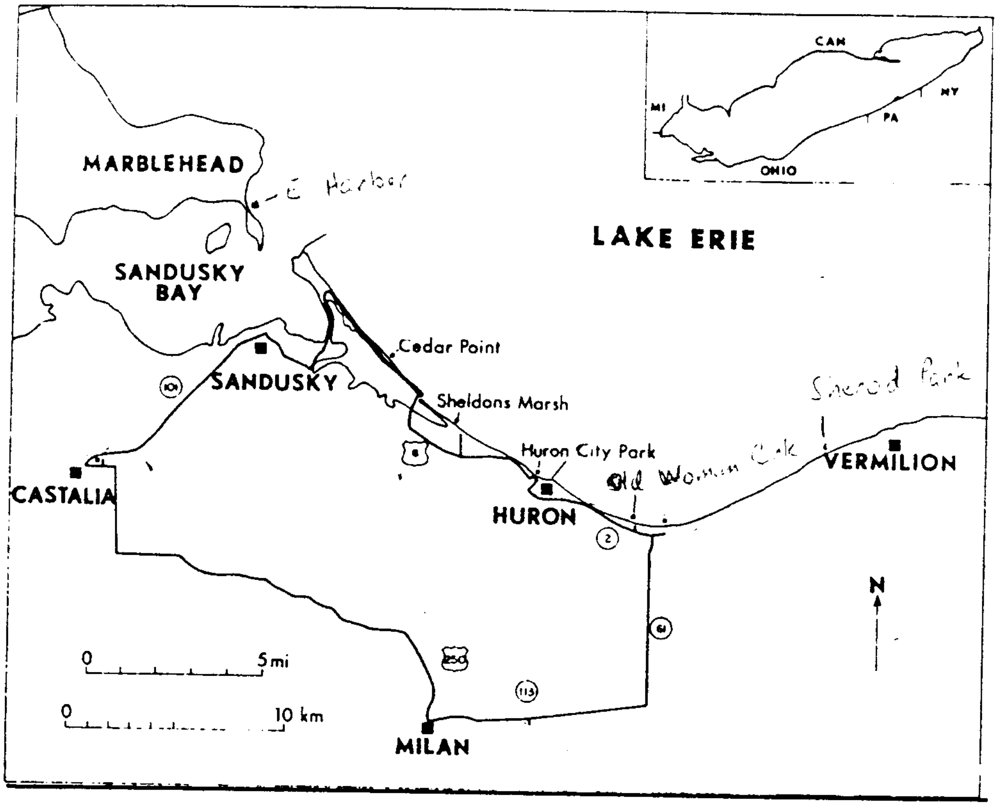


FIG. 5. POTENTIAL STOPS.

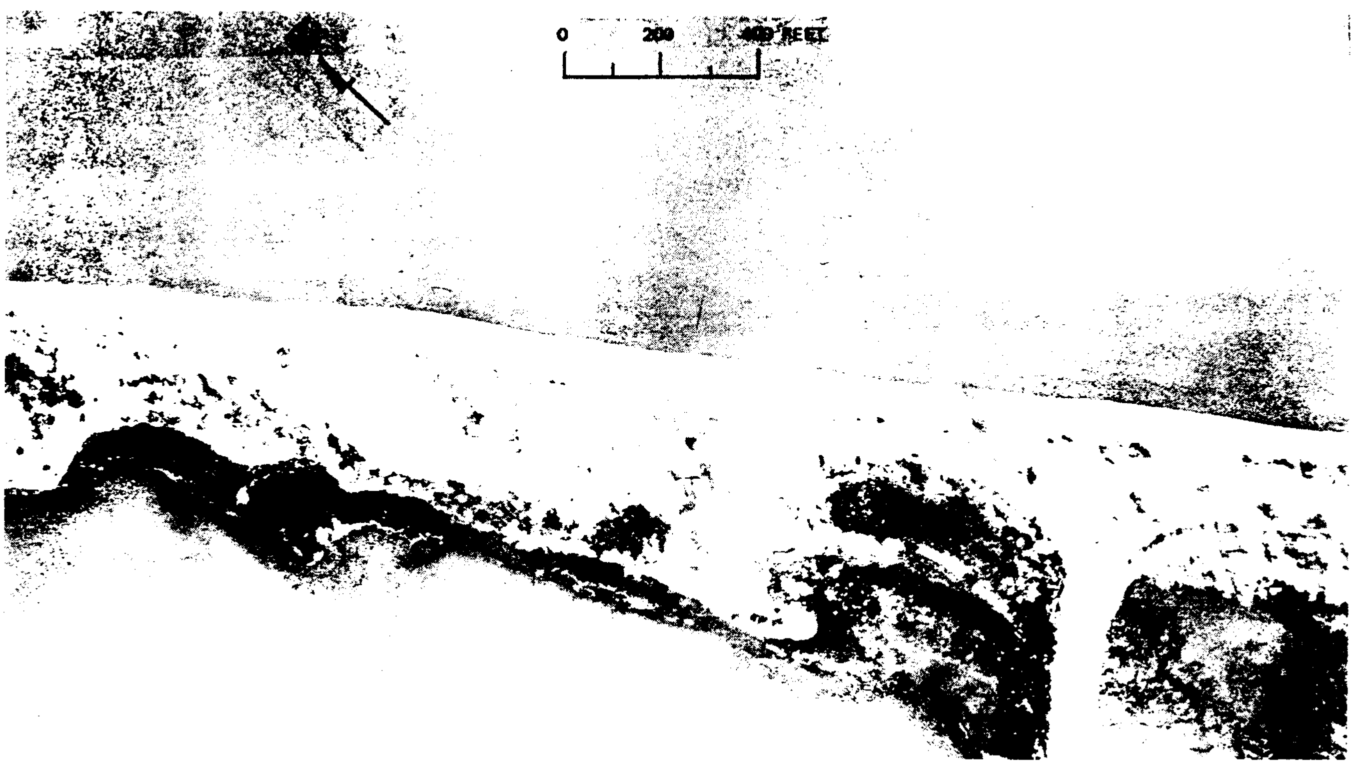


FIGURE 6—STOP 1. East Harbor State Park. Barrier beach and adjoining marsh.

STOP 1: EAST HARBOR STATE PARK

East Harbor State Park (Fig. 6) is located on a barrier-beach complex that extends from the Marblehead Peninsula to Catawba Island. The older beach was separated from the adjacent mainland when rising lake levels drowned the gently sloping back-beach area. Much of the area is presently protected by a seawall, which was badly damaged by storms during the 1970s and has been reinforced with large blocks of limestone (riprap). Four offshore breakwaters have been constructed in an attempt to protect the remaining beach, and sand dredged from adjacent harbors and navigational channels is used to artificially supply the beach.

1.) Describe the direction of wave approach onto the beach. What direction would sand move under this direction of wave approach?

2.) Describe and compare substrates and vegetation on the top of the barrier complex and in the back-barrier lagoons. Do you see any evidence for wash-over of beach material into the lagoons?

3.) Using the attached graph paper, construct a beach profile from the waterline to a distance 150 ft. offshore. Collect a water depth measurement every 5 ft. of horizontal distance. What is the importance of the offshore highs that you have encountered within the beach system?

STOP 2: CEDAR POINT SPIT AND SHELDON'S MARSH

Because essentially all of Cedar Point Spit is private property, we will not be able to work on the beach. However, be sure to note the following features as we drive along the Spit:

1.) the general north-to-south profile of a beach crest and gently sloping back-beach region (now drowned to form a lagoon)

2.) the relative abundance of shore protection features to protect the beach crest from erosion

3.) the gap in the Spit at the east end of the Cedar Point Chaussee, and the extent to which the spit east of the breach has retreated (Fig. 7). Why has the breach in the spit not been sealed off by the longshore transport of sand?

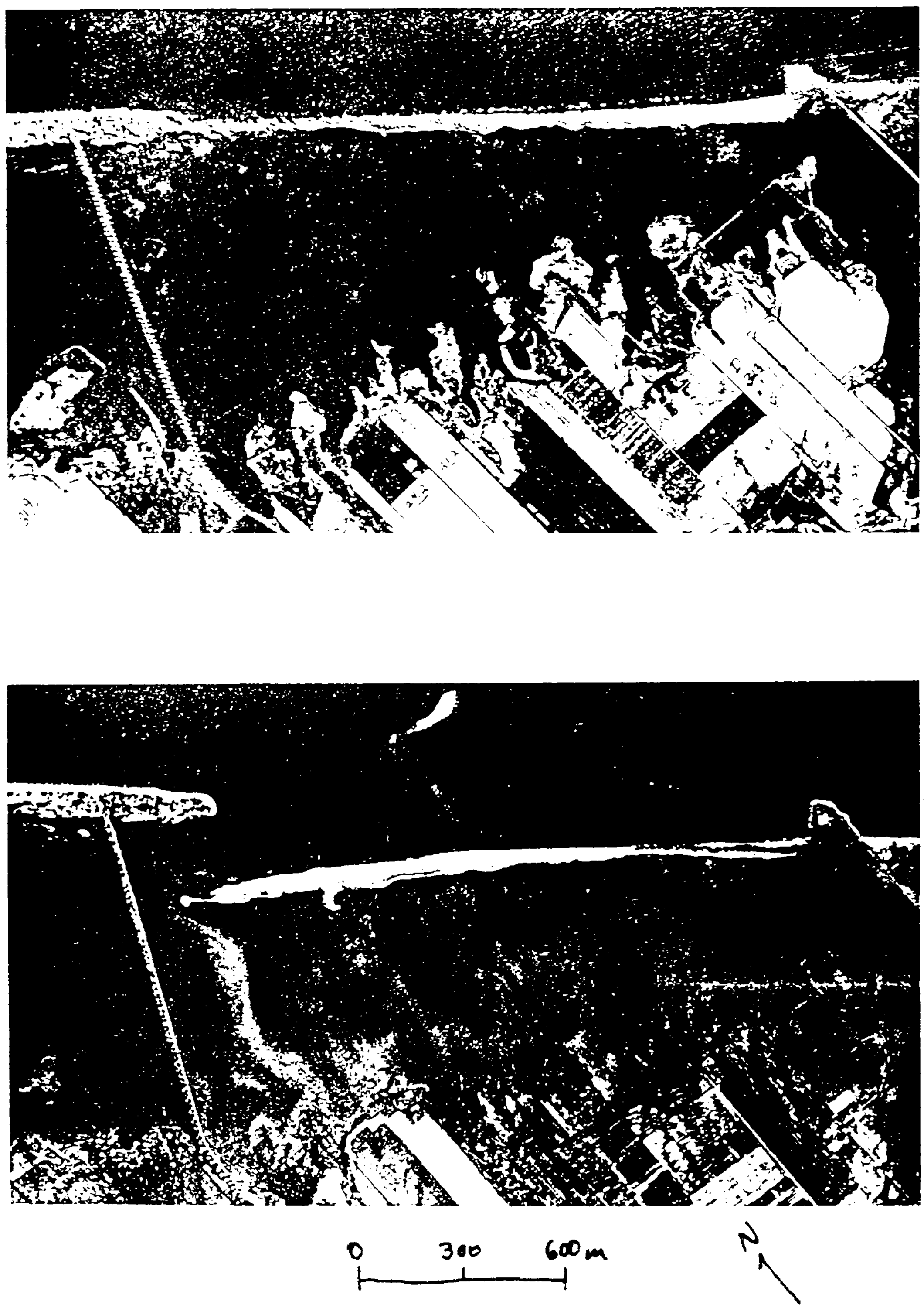


Figure [illegible], [illegible] and the 1979 spit of [illegible].

STOP 3: HURON CITY PARK

Huron City Park (Fig. 8) is located on the western side of the jetties that provide safe entry into the port of Huron. Construction of the jetties began in 1827, and the jetties now extend more than 900 m into the lake. The short, construction-stone breakwater was built in 1929 to protect the lakeward edge of the park; by that time, at least one city block of property had been eroded from the unprotected portions of the coast west of the park. The circular area attached to the west jetty is a diked disposal area, used to contain polluted sediment dredged from the navigation channel at Huron. Proposed uses for the land formed within the diked disposal area have included a city park and a condominium complex.

1.) What is the direction of longshore sand transport along this part of the coast? What evidence can you see indicating this direction of transport?

2.) What is the material that forms the ground in the Huron City Park? How effective was the attached breakwater as a shore-protection feature? How might the construction of the harbor jetties have affected shoreline behavior at this site?

3.) What are the advantages and disadvantages of using a diked disposal area for dredge spoils? What hazards might exist during the human uses of this area mentioned above?

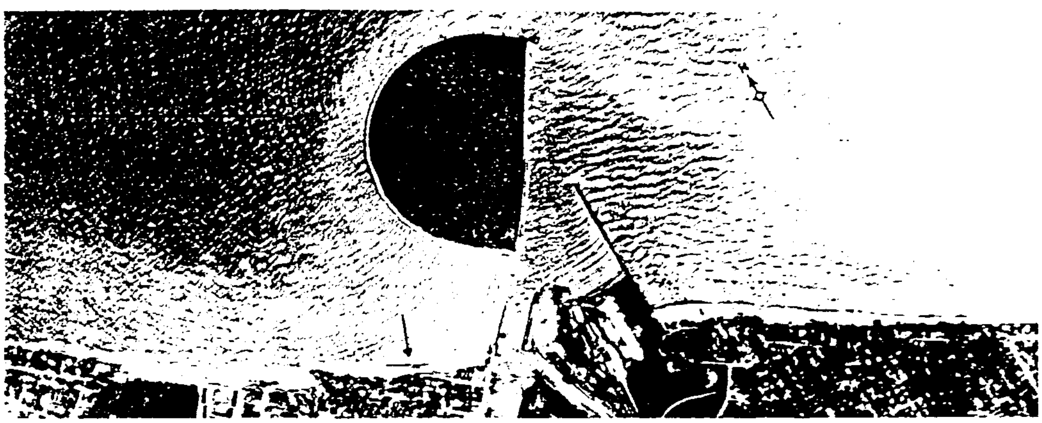


Figure 8. Huron harbor area with associated jetties and diked disposal area.

STOP 3: OLD WOMAN'S CREEK BEACH

This beach is a portion of the Old Woman's Creek National Estuarine Research Center; the Visitor's Center for Old Woman's Creek is located on the south side of Rte. 6 and approximately 0.3 miles east of the bridge over Old Woman's Creek. The opening of Old Woman's Creek is quite dynamic, and migrates noticeably over periods of months to years. During high discharge of the creek, the opening is well-developed; during low-discharge periods, the opening can be completely closed by sand carried in the longshore drift.

1.) Using the attached graph paper, construct an elevation profile across the beach, from the southern vegetated side to the waterline. Collect an elevation measurement every 3 ft. horizontally.
2.) Describe the elevation profile you have constructed. Is there a regular pattern of features that you see repeated in your profile? If so, how do you explain the formation of these features at different levels?
3.) Examine the vertical sides of a shallow trench (approx. 12-18 inches deep) dug into the beach. Sketch the pattern of layering that you observe, and describe the characteristics that make the layering visible. Explain the origin of this layering as the result of processes acting on a beach (look around you for the present-day example of this process).
4.) Name the lithology (or describe the characteristics) of 20

pebbles that you find on the beach. Are there any rock types present here that we have not observed previously, such as at the East Quarry on Kelley's Island? If so, what might be the source of the pebbles?

STOP 4: SHEROD PARK

Unlike the stops farther west, where the adjacent land had little relief above lake level, the beach at Sherod Park is developed at the base of a bluff composed of glacial till and bedrock. As a result, the back-beach area is affected by slumping of the bluff, rather than being dominated by wave wash-over effects. This type of lakeshore relief, and the accompanying importance of shore retreat by mass wasting, is much more important east of Vermilion than to the west.

1.) What evidence can you see indicating that this slope is unstable and susceptible to mass wasting? Is there a change in slope from the top to the bottom of the bluff? What happens to material after it is deposited at the base of the bluff?

2.) Look closely at the particles forming the beach. What differences do you see between this material and the material on the beach at Old Woman's Creek? What might cause this difference?

3.) Look carefully at the elevation changes across the beach. Does this profile resemble the profile you measured at Old Woman's Creek? If not, describe the differences between the profiles, and try to explain the differences.

REFERENCES: NORTH-CENTRAL SHORE OF LAKE ERIE

Anderhalt, R., Guy, D., Jr., and Harrell, J., 1983. Aspects of the sedimentary geology along the southwestern shore of Lake Erie. Guidebook, Fifth Annual Ohio Sedimentary Geology Field Excursion.

Carter, C.H., 1973. Natural and manmade features affecting the Ohio shore of Lake Erie. Guidebook No. 1, Division of Geological Survey, Ohio Dept. of Natural Resources.

Carter, C.H., and Guy, D.E., Jr., 1984. Field Guidebook to the geomorphology and sedimentology of Late Quaternary lake deposits, southwestern Lake Erie. Guidebook, 14th Annual Field Conference of the Great Lakes Section, SEPM.

Feldmann, R.M., Coogan, A.H., and Heimlich, R.A., 1977. Field Guide: Southern Great Lakes. Kendall-Hunt Publishing Co., Dubuque, IA.

Guy, D.E., Jr., and Fuller, J.A., 1988. Geologic setting and coastal processes along the shore of Lake Erie, north-central Ohio. Guidebook, Field Trip 8, SEPM Fifth Midyear Meeting.

Mackey, S.D., Guy, D.E., Jr., Haines, J., and Stith, D.A., 1994. Geology of Ohio's Lake Erie coast. Guidebook, Annual Meeting of the Association of American State Geologists. Division of Geologic Survey, Ohio Dept. of Natural Resources.

DEVONIAN/MISSISSIPPIAN OUTCROPS IN THE ROCKY RIVER GORGE

Bedrock exposures in the Rocky River Gorge contain a record of land-derived sediments deposited in a marine basin during the Devonian and Missssissippian. The characteristics of the sediments are controlled by (1) the physical conditions within the basin (water depth, water chemistry, etc.) at the time of deposition, (2) the physical processes responsible for depositing the sediments (submarine mass movements, settling through the water column, wave action, etc.), and (3) the characteristics of the sediments supplied from the Appalachian Mountains, which were rising to the east at that time.

The sequence to be examined at a series of stops in the Rocky River Gorge (Fig. 1) includes the Chagrin and Cleveland Members of the Ohio Shale, the Bedford Formation, the Berea Formation, and the Sunbury Shale of the Cuyahoga Formation (Fig. 2). Depending on the time available, much of this sequence, together with the overlying Sharon Conglomerate, will be observed later at exposures in the Cuyahoga Valley National Recreation Area (Fig. 3). In general, the sequence of the Ohio Shale through the Berea Sandstone records an infilling of this portion of the basin, so that water depths gradually decreased (a regression). The shift from the Berea Sandstone to the Sunbury Shale appears to record a deepening of the water in this area (a transgression), perhaps accompanied by a decrease in the supply of sand to the area.

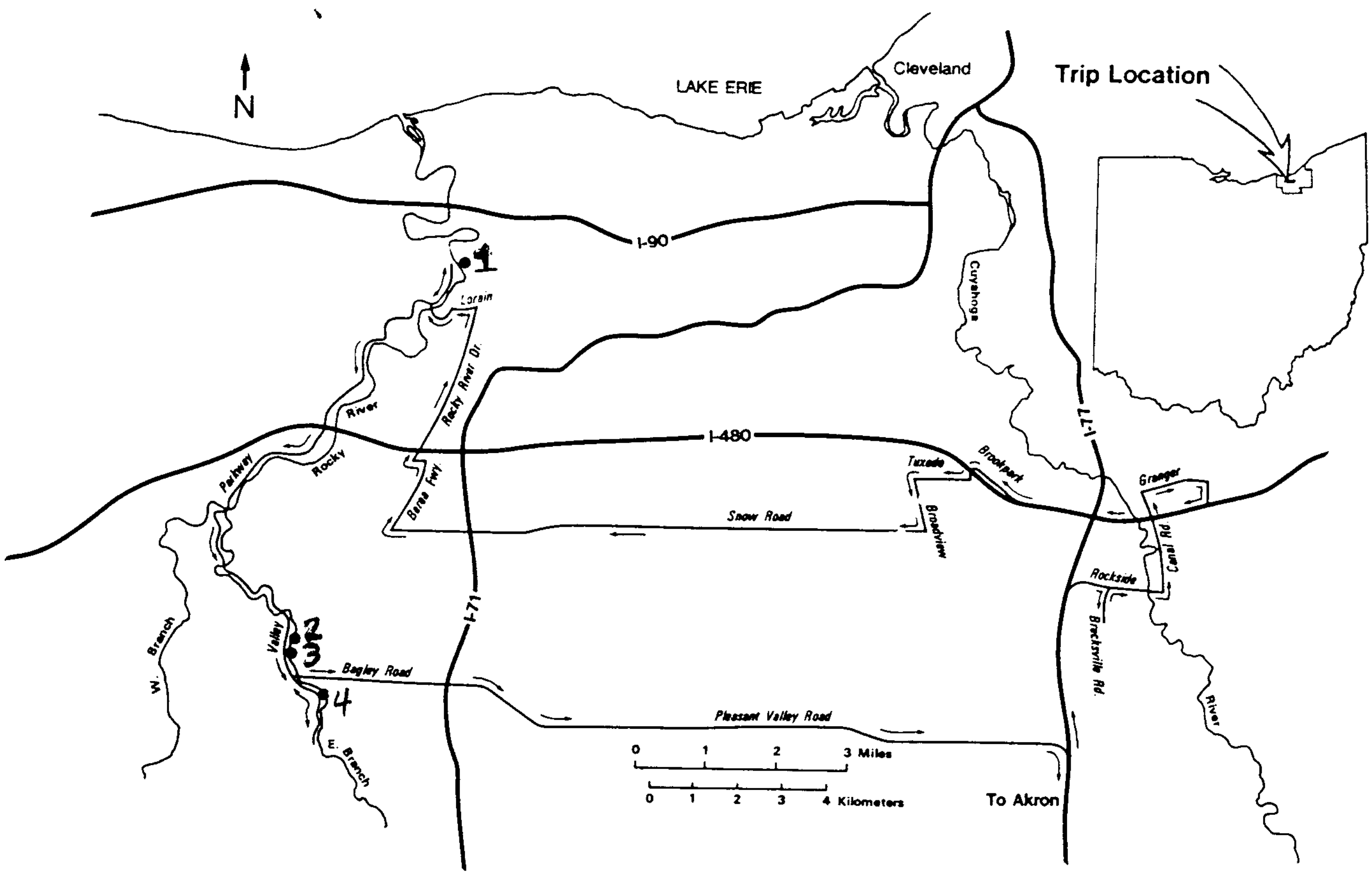


FIGURE 1. Field trip route map and stop locations.

LEWIS, 1988.

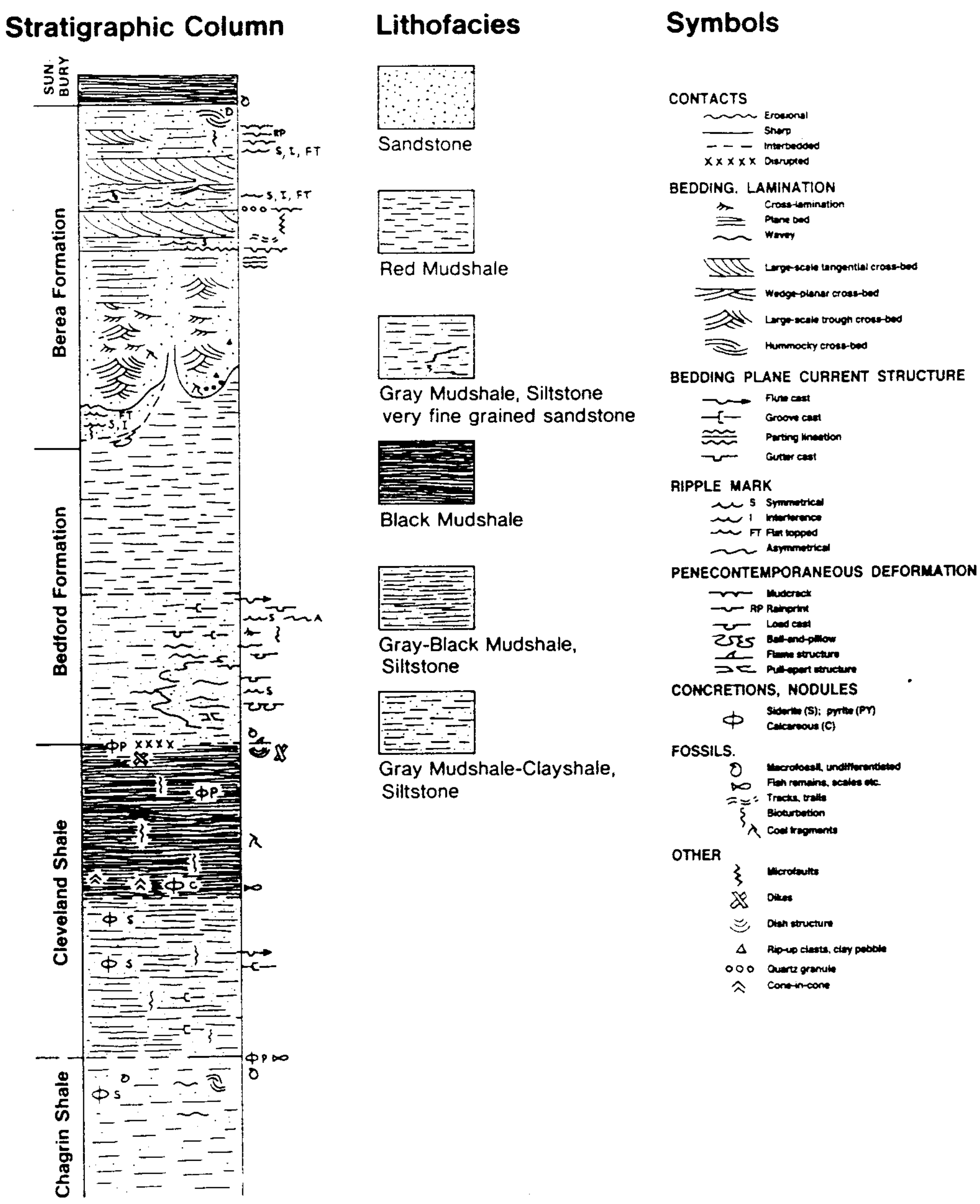


FIGURE 2 Generalized columnar section of part of the Ohio Shale Formation (Chagrin Shale and Cleveland Shale), Bedford Formation, Berea Formation, and the lower Cuyahoga Formation showing lithofacies subdivisions, contacts, fossil horizons, and sedimentary structures.

LEWIS, 1988.

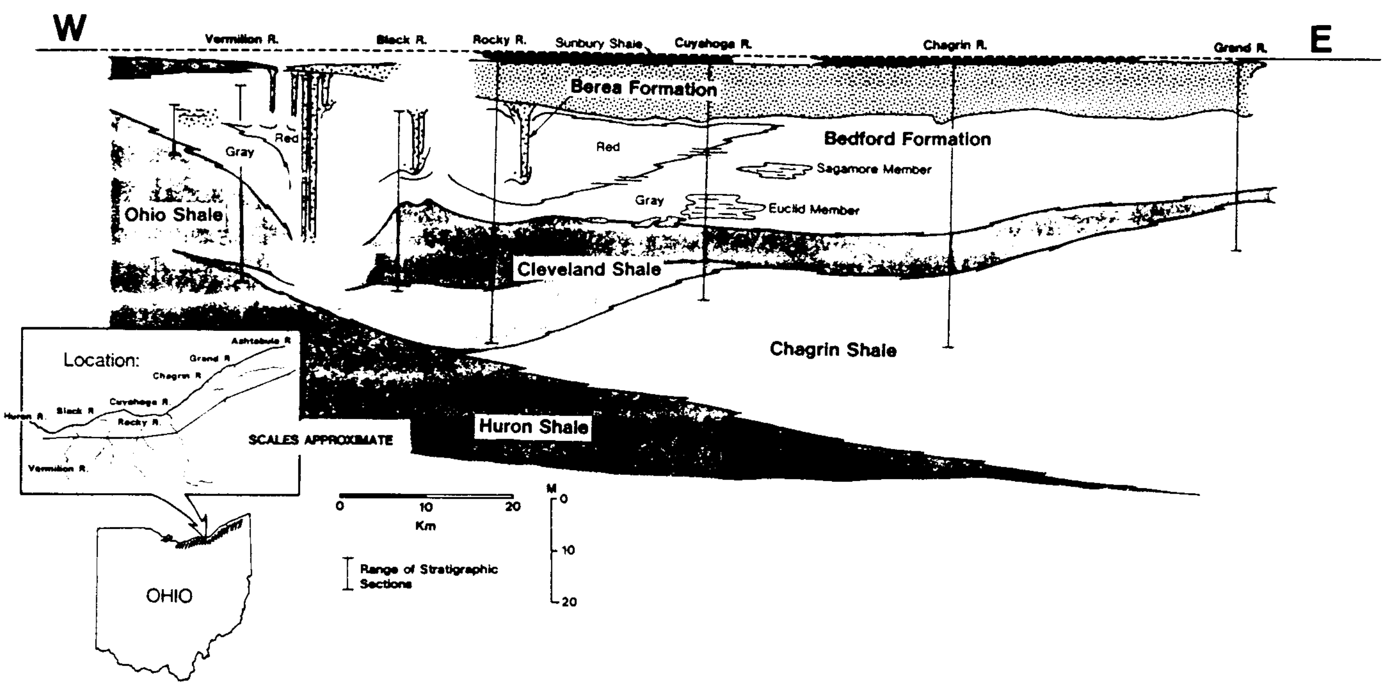


FIGURE 3. Generalized east-west cross-section of the Upper Devonian and Lower Mississippian rocks units, Huron River to Grand River, northern Ohio, showing the two-dimensional geometry of the formations and general lithofacies units.

LEWIS, 1988.

STOP 1: CLEVELAND SHALE

Stop 1 is located approximately 0.8 - 1 mile north of the Little Met. Golf Course. Park on the west side of the Gorge Parkway just north of a small bridge; cross to the east side of the Parkway and follow a dirt trail south along the Rocky River to a large exposure. Close-up examination of the entire section is not possible.

This stop exposes approximately 26 m of the Cleveland Shale, which includes a variety of siltstones and shales.

1.) Sketch the general patterns of layering that you can observe in the complete exposure. Does the distribution of resistant ledges, color, etc. change vertically through the exposure? If so, can you interpret these variations in terms of vertical changes in the rock types present?

2.) If you feel adventurous, climb to the base of the steep face downstream from the complete exposure, and describe the detailed patterns of layering you observe. If you don't feel adventurous, examine the rock chips present on the gentler slope at the base of the hill, and describe those chips.

3.) Examine and describe the rock types and physical features present in the rock slabs that have collected near river level. What do these characteristics indicate about the conditions when these sediments were being deposited?

STOP 2: "SLIDE HILL"

This stop is located approximately 8.5 miles south of Stop 1, and is located in the banks of the Rocky River at the first turnout north of the Berea Falls Scenic Overlook. The name of this stop is derived from the use of the hillside for sledding. After parking, proceed down the hill and through the trees to the Rocky River.

This stop exposes the upper portion of the Cleveland Shale, the contact between the Cleveland Shale and the Bedford Formation, and the lower portion of the Bedford Formation. Close-up examination of the outcrop depends on water level in the stream.

1.) If possible, cross the stream and examine the rock types that form the Cleveland Shale and the Bedford Formation. How are they similar? How are they different? If it is not possible to cross the stream, examine chips of these materials in the sediments on the west bank and make your descriptions from those materials.

2.) Examine the patterns of layering within the Bedford Formation, and sketch one example of layering that is different from the pattern observed at Stop 1. What physical process might this pattern record? What conditions might have existed at the time of deposition to cause such events?

3.) Do you see any evidence of faulting in this section? If so, when did the faulting occur relative to the timing of sediment disturbance? How much movement appears to have taken place along these faults?

STOP 3: BEREA FALLS SCENIC OVERLOOK

This stop is located approximately 0.3 miles south of Stop 2. Park at the turnout for the scenic overlook, and descend on the narrow trail immediately north of the overlook platform. WARNING: THIS TRAIL IS NARROW, STEEP, AND ROUGH -- DO NOT DESCEND IF YOU ARE UNCOMFORTABLE IN SUCH SURROUNDINGS. The upper part of the section is also accessible by descending a wider and less steep trail that begins at the north end of the parking lot.

This stop exposes the top of the Bedford Formation and approximately the lower half of the Berea Sandstone in this area. The Bedford/Berea complex is widely recognized in the western Appalachian Basin. Its outcrop belt extends from the Cleveland area, through Columbus (where it forms the "ripple rocks" on the Ripple Rock Trail in Blendon Woods Metro Park), to Portsmouth, and southward into northern and central Kentucky. The Berea Sandstone, in particular, has been widely quarried for use as building stone and paving stone, and is well known for a variety of sedimentary structures that it contains.

1.) Observe and describe the contact between the Bedford Formation and the overlying Berea Sandstone. Does the nature of this contact suggest a slow and quiet transition from one type of deposition to the next, or a more dynamic transition? What possible explanations can you advance for the nature of this contact?

2.) Describe and sketch the patterns of layering that you can observe in the Berea Sandstone. How do these patterns of layering differ from those observed in the Ohio Shale and the Bedford Formation? Do the patterns of layering change from the bottom of the Berea Sandstone to the top? If so, how?

3.) Summarize the changes in rock types, grain size, and layering that you have observed in moving from the Ohio Shale, through the Bedford Formation, and into the Berea Sandstone. What sequence of depositional conditions do you interpret from these changes?

STOP 4: EXPOSURES SOUTH OF MILL STREAM RUN RESERVATION

This stop is located approximately 1 mile south of Stop 3. Park at the North Quarry Picnic Area of the Mill Stream Run Reservation, and walk north along Barrett Road to exposures between the first two bridges north of the picnic area.

This stop exposes the upper half of the Berea Sandstone in this area, as well as the overlying Sunbury Shale. The Berea Sandstone exhibits some of the same features observed at Stop 3, and the contact between the Berea Sandstone and the Sunbury Shale contains some interesting sedimentological and geochemical features.

1.) Describe/sketch any vertical changes you observe in the composition and the layering patterns of the Berea Sandstone. What aspects of the layering patterns are similar to features you observed at Stop 3?
2.) For each package of distinctive layering type you have identified, trace that package laterally along the outcrop, and describe the lateral continuity of that style of layering. Are certain layers or types of layering more laterally disrupted than others? Do any disruption features resemble features you have observed earlier? What type of disturbance process might these features record?
3.) Examine and describe the boundary between the Berea Sandstone and the Sunbury Shale. Are there any particularly unusual features that occur along this contact? If so, how

far do these features extend into the Berea Sandstone, and what does this pattern imply for the migration of distinctive fluid types?

REFERENCES: BEDROCK GEOLOGY OF THE CLEVELAND AREA

Coogan, A.H., Heimlich, R.A., Malcuit, R.J., Bork, K.B., and Lewis, T.L., 1981. Early Mississippian deltaic sedimentation in central and northeastern Ohio. In Roberts, T.G. (ed.), Geol. Soc. America '81 Cincinnati Field Trip, 13: 113-152.

Coogan, A.H., Babcock, L.E., Hannibal, J.T., Martin, D.W., Taylor, K.S., and Wehn, D.C., 1986. Late Devonian and Early Mississippian strata at Stebbins Gulch, Geauga County, and Quarry Rock, Cuyahoga County, Ohio. Guidebook, Geol. Soc. America North Central Section Meeting.

Corbett, R.G., and Manner, B.M., 1988. Geology and habitats of the Cuyahoga Valley National Recreation Area, Ohio. Ohio J. Science, 88: 40-47.

Feldmann, R.M., Coogan, A.H., and Heimlich, R.A., 1977. Field Guide: Southern Great Lakes. Kendall/Hunt Publishing Co., Dubuque, IA.

Hoover, K.V., 1960. Devonian-Mississippian shale sequence in Ohio. Ohio Geol. Survey Inform. Circular No. 27.

Kohout, D.L., and Malcuit, R.L., 1969. Environmental analysis of the Bedford Formation and associated strata in the vicinity of Cleveland, Ohio. Compass, 46: 192-206.

Lewis, T.L., 1988. Late Devonian and Early Mississippian distal basin-margin sedimentation of northern Ohio. Ohio J. Science, 88: 23-39.

Pashin, J.C., and Ettensohn, F.R., 1995. Reevaluation of the

Bedford-Berea sequence in Ohio and adjacent states: forced regression in a foreland basin. Geol. Soc. America Special Paper 298.

Pepper, J.F., DeWitt, W., and Demarest, D.F., 1954. Geology of the Bedford Shale and Berea Sandstone in the Appalachian Basin. U.S. Geol. Survey Prof. Paper 259.

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. Prepared for the Dept. of Energy, Eastern Gas Shales Project.

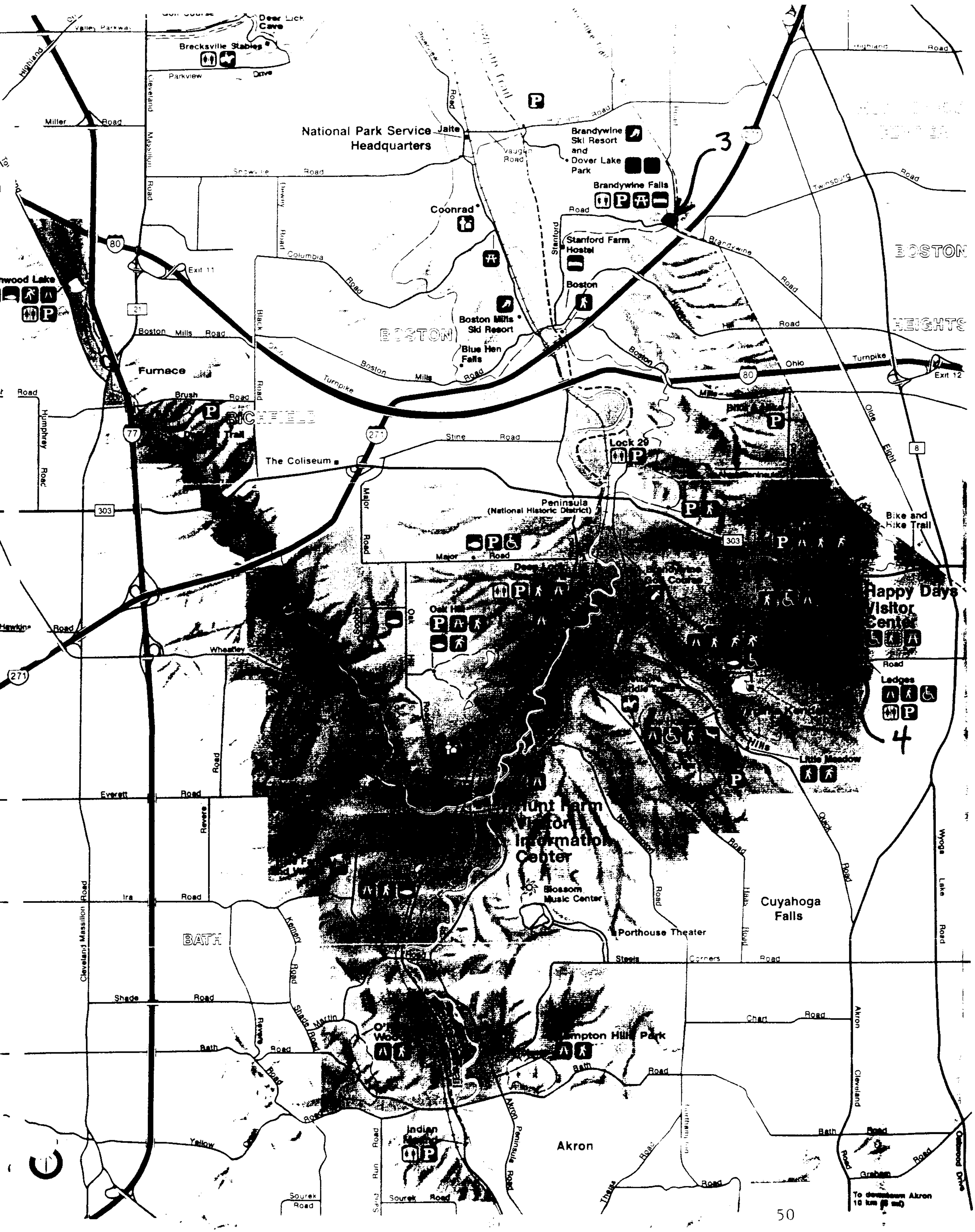
Potter, P.E., DeReamer, J.H., Jackson, D.S., and Maynard, J.B., 1983. Lithologic and environmental atlas of Berea Sandstone (Mississippian) in the Appalachian Basin. Appalachian Basin Geol. Society Special Publication 1.

DEVONIAN THROUGH PENNSYLVANIAN ROCKS OF THE CUYAHOGA VALLEY NATIONAL RECREATION AREA

Bedrock exposures in the Cuyahoga Valley National Recreation Area (CVNRA) contain a record of sediment deposition that is generally comparable to the record observed in the Rocky River Gorge. As such, the sequence records the effects of changes in basin conditions, transport processes, and sediment supply. The sequence in the CVNRA also contains rocks younger than those exposed in the Rocky River Gorge, thereby providing evidence of events after the initial marine basin was completely filled with sediment and deposition was dominated by river processes.

The sequence to be examined at a series of stops in the CVNRA (Fig. 1) includes the Chagrin Member of the Ohio Shale, the Bedford Formation, the Berea Sandstone, and the Sharon Conglomerate of the Pottsville Formation. Neither the Chagrin Member of the Ohio Shale nor the Sharon Conglomerate were observed in the Rocky River Gorge stops; the characteristics of the Bedford Formation and the Berea Sandstone can be compared between the two areas.

FIG. 1. CVNRA STOPS 1, 2, AND 3.



0 1 2 Kilometers
0 1 2 Miles

FIG 1 (CONT.). CUNRA STOPS 2, 3, & 4.

STOP 1: PINERY NARROWS

This stop is located along the railroad right-of-way on the west side of the Cuyahoga River, beneath and immediately south of the Chippewa Rd. (Rte. 82) bridge. To reach the stop from Rte. 82, turn south on Riverview Road, and proceed approximately 0.3 miles to the bottom of the hill. Turn east into the access road for "Station Bridge", and park in the parking lot just east of the railroad tracks.

This stop exposes the Chagrin Member of the Ohio Shale, which underlies the Cleveland Member seen in the Rocky River Gorge.

1.) Examine and describe a relatively unweathered exposure of the Chagrin Shale. In its unweathered state, how does the Chagrin Shale compare with the unweathered Cleveland Shale that we observed in the Rocky River Gorge?

2.) Examine and describe the weathered Chagrin Shale. What characteristics of the Chagrin Shale change during weathering? What has been the effect of some of these changes?

3.) What evidence do you see for slumping in this area? Does vegetation change across the slumped region? If so, what controls might be affecting the distribution of vegetation?

STOP 2: TINKERS CREEK GORGE

This stop is located approximately 3 miles northeast of Stop 1, and is located in the banks of Tinkers Creek east of the picnic grounds at the east end of Button Road. The outcrop is reached by following a trail east from the parking area, and walking approximately 0.5 miles upstream along Tinkers Creek.

This stop exposes the Bedford Formation, both in several large cut-banks of the creek and in bedding plane exposures along the creek bed. Close-up examination of both types of exposures depends on the water level.

1.) Examine and describe the Bedford Formation, including color, grain size, and bedding thickness/style. How does this example of the Bedford Formation compare with the Bedford Formation seen at "Slide Hill" in the Rocky River Gorge? What compositional differences might explain these changes?
2.) Spend approximately 5 minutes looking for evidence of biological activity at the time these sediments were deposited. Describe/sketch any body fossils or trace fossils you find. What physical/environmental conditions could explain why fossils are significantly less abundant in these rocks than in the Columbus Limestone?
3.) Examine the fracture sets in the Bedford Formation, as they are exposed on a bedding surface in the stream bed. Describe any regularity in orientation or spacing of the fractures. From the appearance of the fractures on the cut-

bank exposure, how much movement appears to have taken place on these fractures?

STOP 3: BRANDYWINE FALLS

This stop is located at Brandywine Falls, approximately 5 miles south of Stop 2. Access is via Brandywine Road; turn west on Stanford Road (just north of the Brandywine Road overpass over I-271) and park in the Brandywine Falls parking lot. Follow the trail to the "Lower Observation Deck".

This stop exposes the Bedford Formation and the lower part of the Berea Sandstone.

1.) Describe the contact between the Bedford Formation and the overlying Berea Sandstone. How does the contact at this location compare with the contact in the Rocky River Gorge? What might cause these differences?
2.) Sketch the vertical sequence of general layering patterns within the Berea Sandstone. Do some intervals contain layering that is less continuous laterally than other intervals? How does the pattern of layering and disturbance compare with the patterns we observed at the last stop in the Rocky River Gorge?
3.) Sketch any medium- to small-scale structures that you can observe in the Berea Sandstone. What information do any of these provide about environmental energy or direction of water flow during deposition of the Berea Sandstone?

STOP 4: THE LEDGES AT VIRGINIA KENDALL PARK

This stop is located in Virginia Kendall Park, approximately 4 miles south of Stop 3. From Akron-Cleveland Road, turn west on Truxell Road (Virginia Kendall Park Road), and proceed approximately 1 mile west to the entrance to the "Ledges". Park in the parking lot, and follow the trail that continues north from the north end of the entrance road. At the first directional sign on the trail, turn east, and follow the trail as it descends and curves to the left. Return to the parking lot by following the trail to a set of steps, ascending through the ledges, and returning south along the trail.

This stop exposes the Pennsylvanian Sharon Conglomerate of the Pottsville Group; the slope below the Ledges is composed of Mississippian shales of the Cuyahoga Group.

1.) If possible, examine the base of the Sharon Conglomerate and trace its elevation along the outcrop. How would you describe the base of the Sharon Conglomerate? Do you see any evidence that this is an erosional surface, and that a considerable amount of time is not represented by rocks along this surface? If so, summarize this evidence.
2.) Examine and describe the coarse grains in the Sharon Conglomerate. What is their composition? Shape? Is this a rock type we have seen much before? If not, what might have been the source of these grains?
3.) Examine the near-vertical wall of the Ledges, and sketch the

lateral distribution of the larger grains across an area approximately 20 feet wide. Do these distributions resemble the general forms of other features you have seen before (Hint: think about the Berea Sandstone)? How do these examples differ from those you have seen earlier? Try to identify a zone of larger grains that looks like a bank-to-bank cross-section through a channel.

4.) Describe differences between the vegetation on top of the Ledges and the vegetation on the protected slopes below the Ledges. What environmental differences do these vegetation changes reflect?

COASTAL PROCESSES AND FEATURES, NORTHEASTERN OHIO

Our examination of coastal features along the shores of Lake and Ashtabula counties will be led by Frank Lichtkoppler, the Ohio Seagrant extension agent for Lake County. Our exact itinerary is unknown, but may include Headlands Beach State Park in Mentor and Painesville Township Park (Fig. 1).

HEADLANDS BEACH STATE PARK

The beach at Headlands Beach State Park has formed as a result of sediment in the longshore transport being trapped on the "upstream" (west) side of the jetties at Fairport Harbor (Fig. 2). The first jetties at Fairport Harbor were constructed in the mid-1820s, and these structures have been modified since that time to maintain blockage of the longshore transport. Observe the beach profile in this area, together with the distribution of vegetation on the landward side of the beach. Also observe the composition of the material on the beach.

PAINESVILLE TOWNSHIP PARK

Painesville Township Park is located "downstream" from the jetties at Fairport Harbor, so the transport of material into this area by longshore drift has been interrupted. As a result,

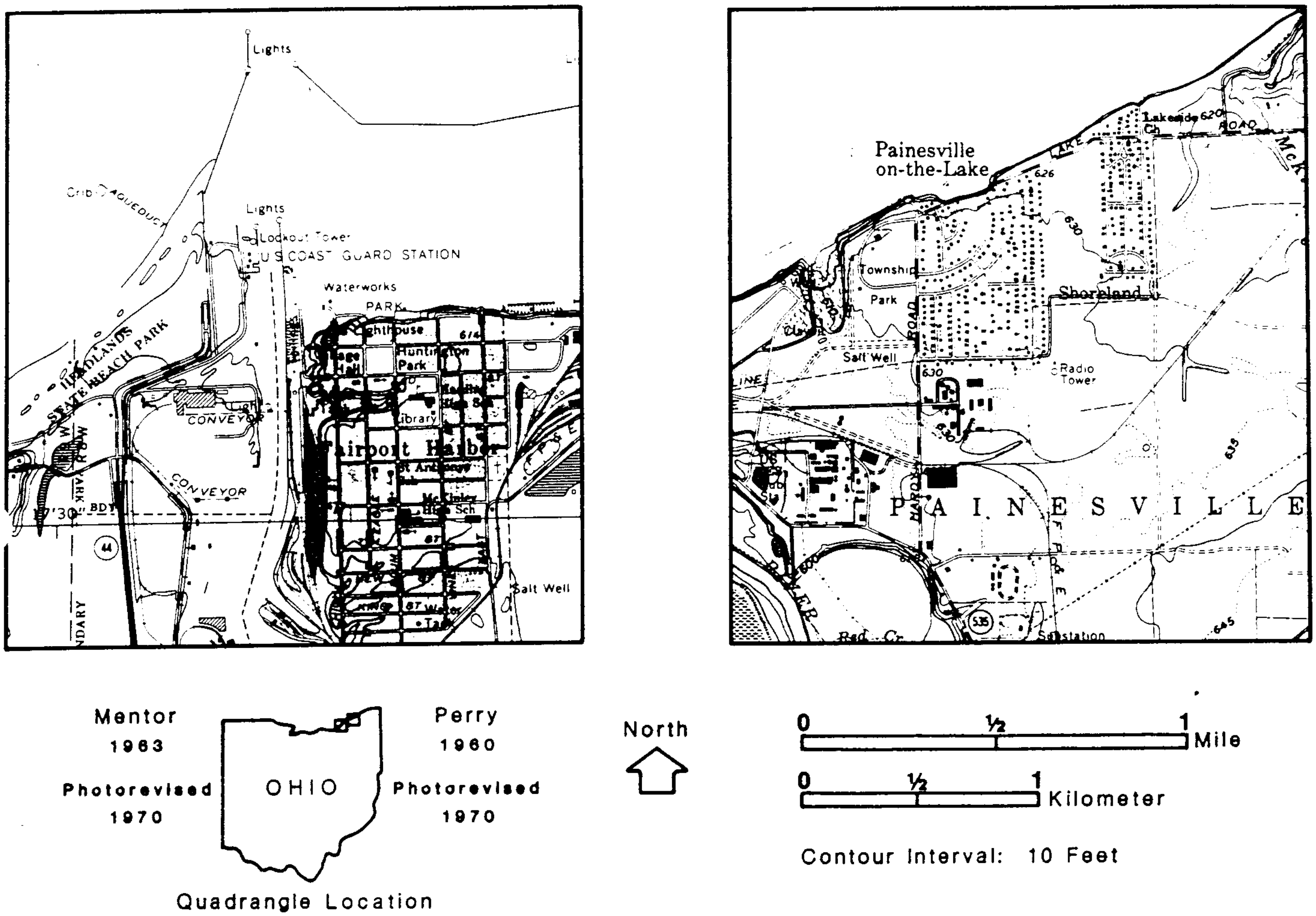


Figure 1. Location maps of Headlands Beach State Park (Mentor, Ohio 7½-minute quadrangle) and Painesville Township Park (Perry, Ohio 7½-minute quadrangle).

CARTER, 1987.

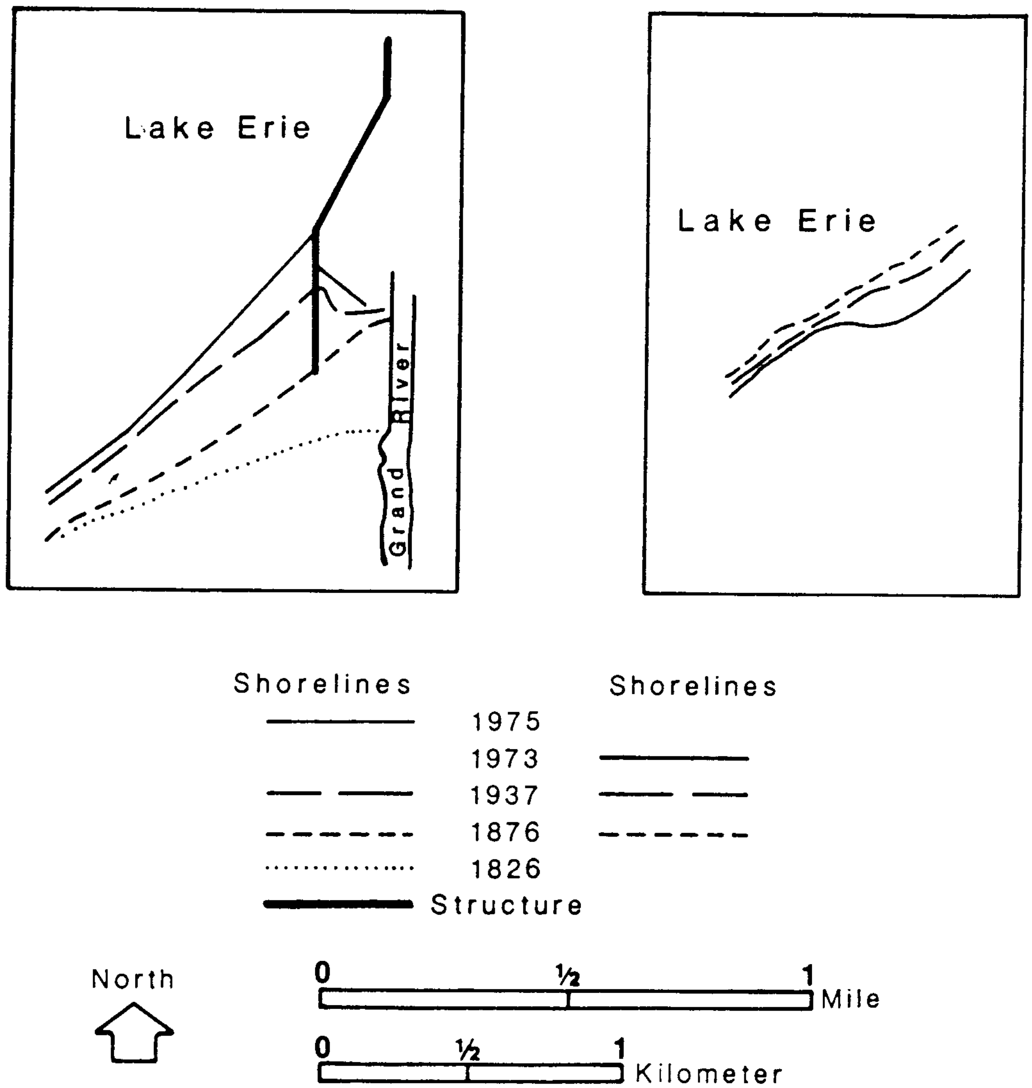


Figure 2. Headlands Beach State Park stretch with harbor structures and historic shorelines, and Painesville Township Park with historic recession (bluff) lines.

CARTER, 1987.

the coast near the park has undergone erosion, and the lake bluffs are failing by mass wasting (especially block falls and rotational slumps; Figs. 2 and 3). Observe the elevation profile from the top of the bluff to the waterline, and interpret the style of mass wasting at different positions along the shore. What evidence do you see for bluff erosion impacting on human activities?

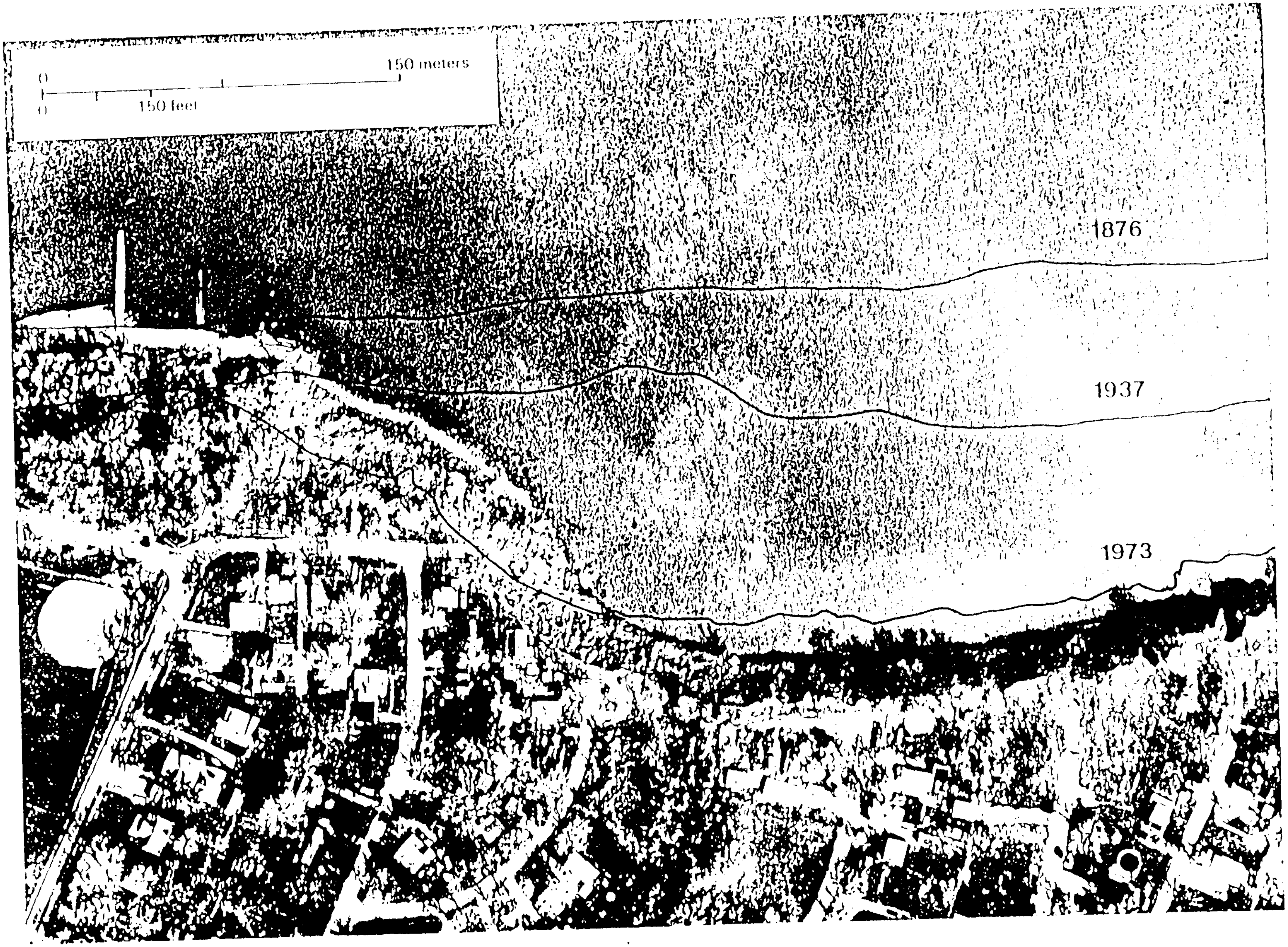


Figure 3.—Recession line map for Painesville-on-the-Lake;
drawn on a 1990 photograph.
GUY & FULLER, 1990.

REFERNCES: COASTAL GEOLOGY OF NORTHEASTERN OHIO

Carter, C.H., 1987. Lake Erie: Deposition, erosion, and the effect of harbor structures near Fairport Harbor, Ohio. In Biggs, D.L. (ed.), North Central Section of the Geological Society of America, Centennial Field Guide, 391-394.

Carter, C.H., Guy, D.E., Jr., and Fuller, J.A., 1981. Coastal geomorphology and geology of the Ohio shore of Lake Erie. Geol. Society of America Field Trip Guidebook, 3:433-456.

Guy, D.E., Jr., and Fuller, J.A., 1986. Geomorphology of the Lake Erie shore in northeast Ohio. Field Trip Guidebook 3, Geological Soc. of America North Central Section Meeting.

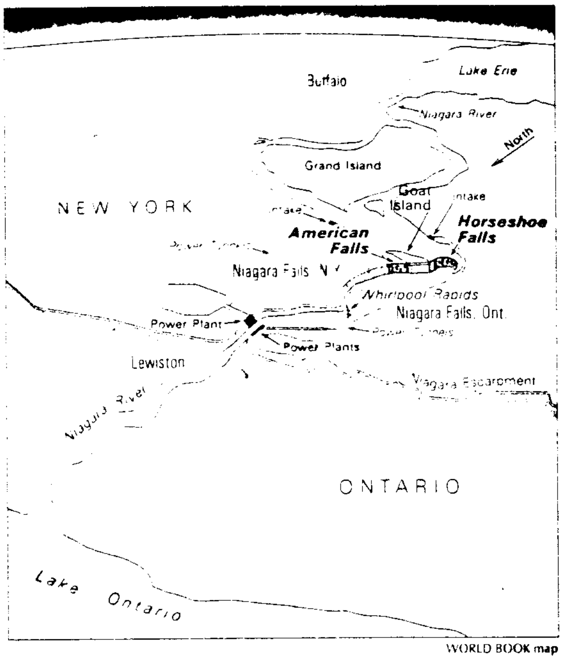
Guy, D.E., Jr., and Fuller, J.A., 1990. Geologic setting and coastal processes along the Ohio shore of Lake Erie, Painesville on-the-Lake to Lakewood. Guidebook, prepared for the International Joint Commission Workshop on Nonstructural Shoreland Management.

NIAGARA FALLS AND NIAGARA GORGE

INTRODUCTION

Although neither the highest nor the widest, Niagara Falls is one of the most spectacular waterfalls in the world, and it attracts more visitors annually than any other waterfall (more than 10 million). During our one-day visit, we will briefly consider the Paleozoic geology, geomorphology, Pleistocene history, and hydrogeology of this important area.

The Niagara River is quite short in overall length (32 mi.; 51 km) and very narrow through the Niagara Gorge. It flows north, connecting Lake Erie to Lake Ontario (Figure 1). The natural average flow rate of the Niagara River is approximately 204,285 ft^3/sec (5,720 m^3/sec). This represents overflow from the capacity of Lakes Superior, Michigan, Huron, and Erie, which eventually drains through Lake Ontario and on through the St. Lawrence Seaway. Rapid water flow of the Niagara River is caused by a considerable elevation fall and the narrow gorge. Elevation at the head of the river (at Lake Erie) is 571 ft (174 m) above mean sea level (msl). From the head to the edge of the falls the elevation drops 75 ft (23 m) in 18.3 mi (31 km) or 4.1 ft/mile (0.74 m/km). The Horseshoe Falls are approximately 173 ft (53 m) high and 2,600 ft (792 m) wide, and the American Falls are approximately 182 ft (53 m) high and 1,000 ft (305 m) wide. From the base of the falls to the Niagara Escarpment, the river drops another 72 ft (22 m) in 6.8 mi (11 km) or 10.6 ft/mi (2.0 m/km) (Figure 2). Beyond the Niagaran Escarpment, the Niagara River widens, and its gradient declines sharply. From the escarpment to Lake Ontario the river length is 5.6 mi (9 km), but it only descends in elevation 3 ft (1 m) (0.5 ft/mi, 0.1 m/km) along the margin of the Lake Ontario basin (Fisher, 1981; Brett and Calkin, 1987).



Niagara Falls lies on the United States-Canadian border. It consists of the American Falls and the Horseshoe Falls on the Niagara River, about halfway between Lakes Erie and Ontario.

Figure 1

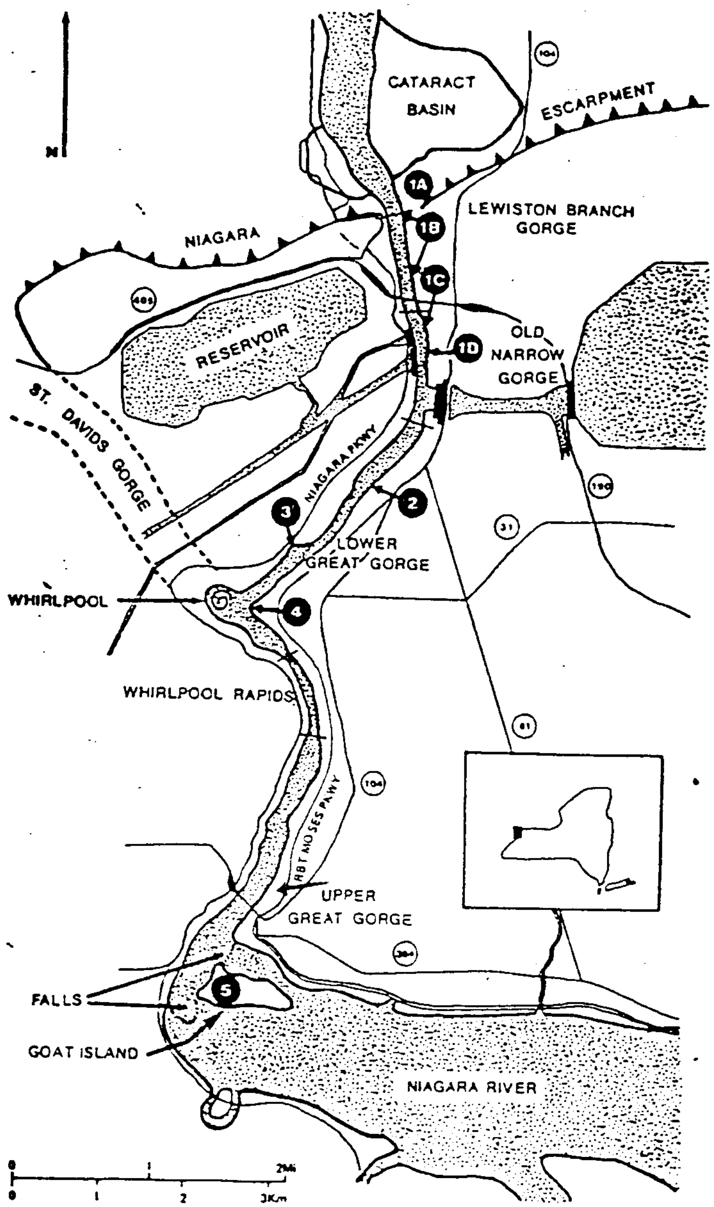


Figure 1. Location map of the Niagara Falls and gorge showing gorge segments and numbered stops described in the text. Data from Kindle and Taylor (1913), Calkin and Feenstra (1985), and Flint and Lalcama (1986).

(Brett + Calkin, 1987)

Figure 2

As spectacular as the river and falls are it is noteworthy that the average flow of the river is only 50% of its natural rate during "tourist times". This decrease has occurred since 1905 due to river capture by hydroelectric power plants (Figure 1). The flow rate is further decreased to 25% of its natural flow during "off times." (Calkin and Brett, 1982).

HISTORY OF STUDY

The first written account of Niagara Falls was in 1683 by Louis Hennepin who visited the falls with the French explorer LaSalle. As outlined in Brett and Calkin (1987), the spectacular nature of both the falls and the exposure of Paleozoic strata in the gorge attracted the attention of some very early geologists. Consequently, the Niagara holds a place of considerable importance for North American geology. Charles Lyell (1837, 1845), the English geologist credited for popularizing "uniformitarianism", provided some of the initial geological discussions of the Niagara area. More comprehensive early studies took place near the turn of the century, and recent investigations are summarized in Calkin and Brett (1978) and Calkin and Feenstra (1985).

Middle Silurian strata throughout North America are generally referred to as the Niagaran Series, based on the sequence of strata in the Niagara Gorge. James Hall, the famous mid-Nineteenth Century paleontologist and geologist, studied these sections and established their importance. More recent studies of these strata include Brett (1982, 1983).

HISTORY OF NIAGARA FALLS

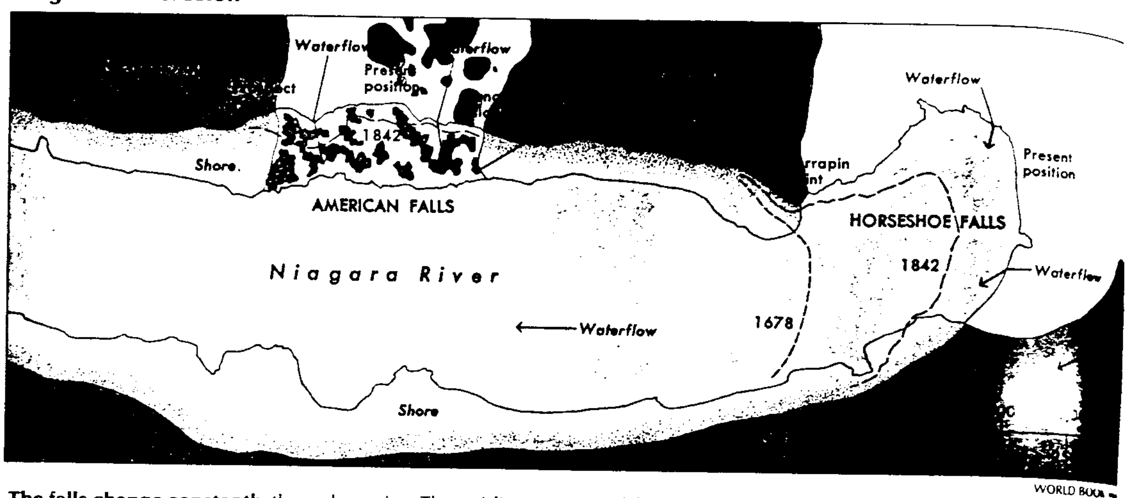
Niagara Falls is a product of the interplay between the Niagara Escarpment, Paleozoic geology, and Pleistocene glacial history. The Niagara Escarpment is a geomorphic feature, termed a cuesta (Figure 1), which is a natural erosional and elevation differential between erosionally resistant strata and subjacent non-resistant strata. The Niagaran Escarpment is a dominant feature across northwestern New York and adjacent Ontario.

Approximately 12,400 years before present (bp), the last glaciers retreated from the Wisconsin continental glaciation, but the previous gorge connection had been filled by glacial sediments. Drainage from the western Great Lakes spilled through several outlets into the Lake Ontario basin. Regional eustatic rebound changed this drainage, and by 10,000 bp the Niagara River was the only drainage. Since approximately 12,400 years bp, the falls have receded from the present day escarpment at Lewiston to the falls present location (Brett and Calkin, 1987). Overall, the recession rates are approximately 2.9 ft/yr (0.89 m/yr). Recession records have been measured since 1842; and during the period from 1842 to 1969, recession rates have been 3.6 ft/yr (1.1 m/yr) (Figure 3) (American Falls International Board, 1974). Considerable international concern is focussed on the preservation of this most unique treasure.

PALEOZOIC STRATIGRAPHY

The Niagara Gorge is synonymous with the Middle Silurian, but Upper Ordovician though Middle Silurian strata are exposed here. In general, the Ordovician and lower half of the Silurian strata are less resistant shales, thin sandstones, and thin carbonates, whereas the upper half of the Silurian is represented by thick-bedded to massive limestone and dolomites. Pleistocene sediments are directly above the Middle Silurian. This stratigraphy -- the Queenston Shale, Whirlpool Formation, Power Glen Formation, Grimsby Formation, Thorold Sandstone, Neahga Shale, Reynales Limestone, Irondequoite Limestone, Rochester Shale,

Niagara Falls erosion



The falls change constantly through erosion. The swirling currents of the Niagara River slowly wear away the walls of the gorge and sometimes cause major rock slides. In the map above, the dotted lines indicate earlier positions of the falls, which are gradually moving upstream.

Figure 3

Lockport Formation (with members Decew, Gasport, Goat Island, Eramosa, Oak Orchard) -- is depicted and described in Figures 4-5.

The Queenston Formation is Upper Ordovician. It is a largely a sequence of non-marine red beds and represents nearshore and terrestrial facies, time equivalent with the fossiliferous Upper Ordovician of the Cincinnati area. Following deposition of the Queenston, epicontinental seas drained from North America causing a regional unconformity with uppermost Ordovician and lower Silurian strata absent. As the first Silurian seas encroached across this area a sand beach facies was deposited, which is represented today by the sandstones of the Whirlpool Formation. The remainder of the Silurian records marine sedimentation (Figure 5).

The brink of the American Falls is in the lower part of the Oak Orchard Member of the Lockport Formation, and the resistant beds that hold up the falls are the Gasport, Goat Island, and Eramosa Members of the Lockport (Figure 5). The rentrant beneath the falls and power plant tunnels are in the Rochester Shale. The river level beneath the American Falls, is at the Neahga Shale. At the Whirlpool, the river is at the base of the Power Glen Formation, and at the mouth of the Niagara Escarpment at Lewiston, the river level is well down within the Queenston Shale (Figure 4).

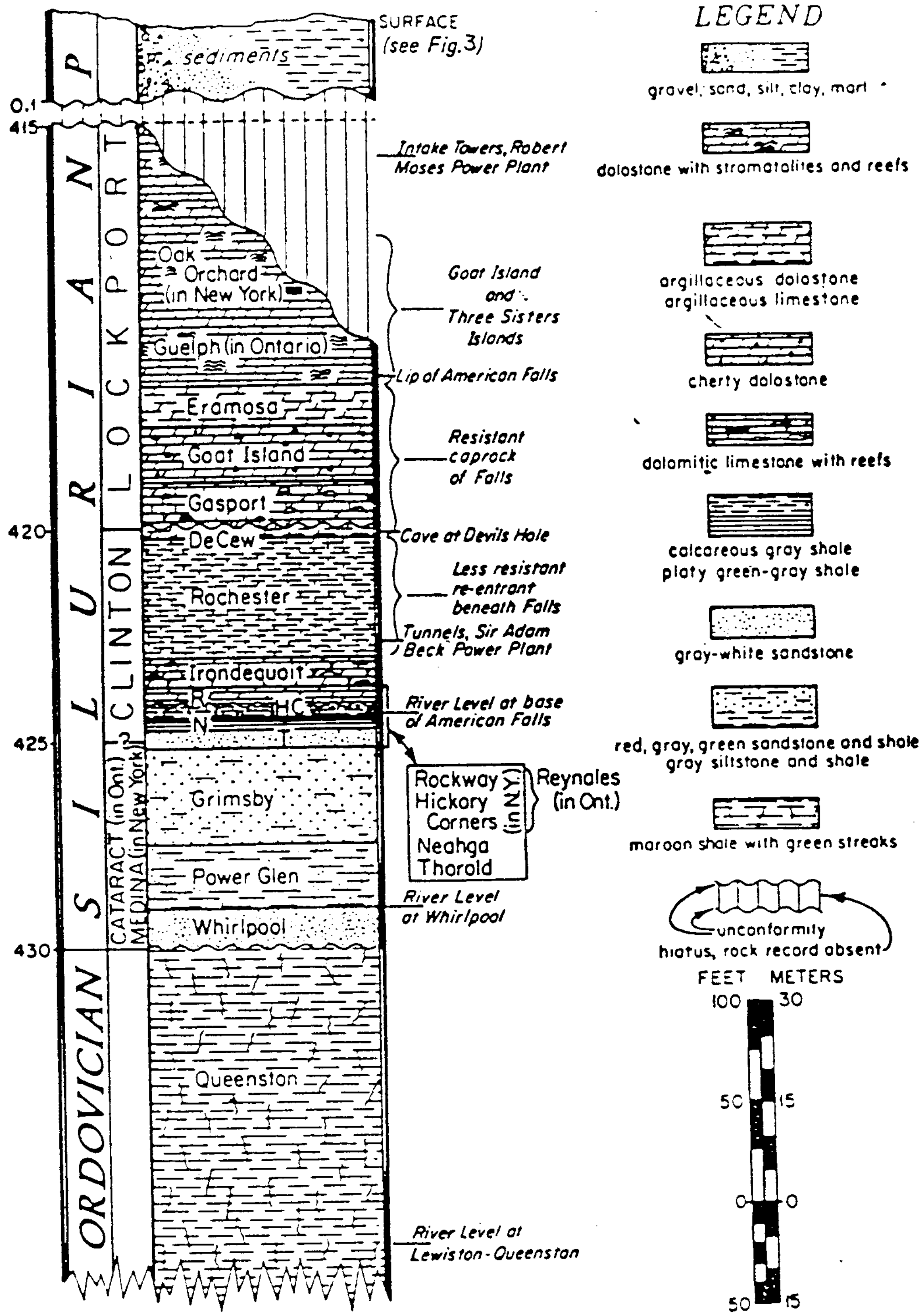


Figure 2. Stratigraphic section of the Upper Ordovician and Silurian bedrock exposed along the Niagara Gorge. Modified after Fisher and Brett (1981).

(Brett + Calkin, 1987)

Figure 4

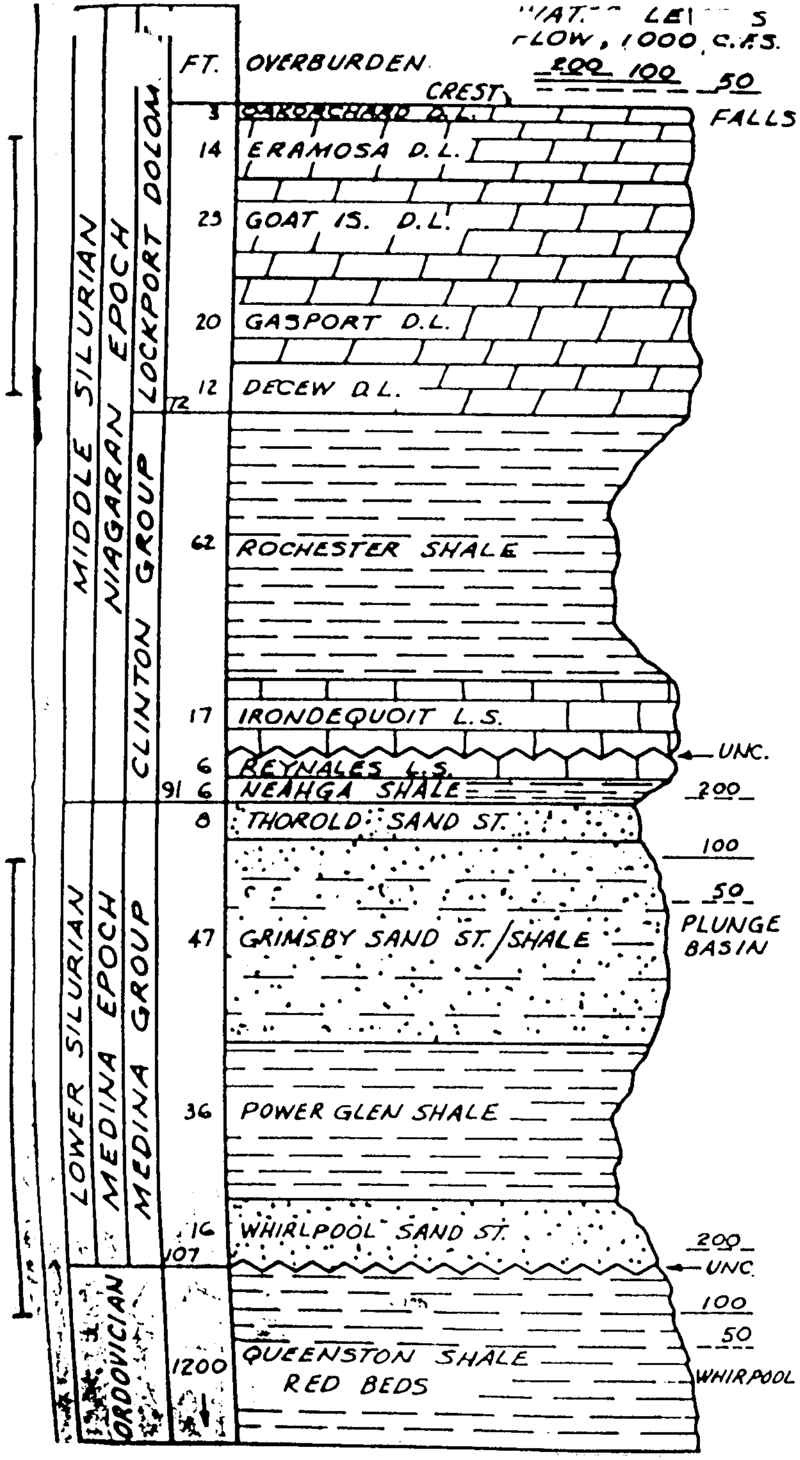


Figure 5

TIGR OF IIAG. ORGE

by Beverly Seyler

LOCKPORT DOLOMITE Massive formation that caps the Falls and gorge. A total 120 ft is exposed if the islands and cascades above Falls are included. The $MgCO_3$ content is less than in a true dolomite. It is quarried and used locally as crushed stone and concrete aggregate. Certain members of this formation are mineralized: specimens of pink dolomite, dog-tooth calcite, selenite and quartz have been collected. The Lockport was deposited in a shallow sea, conducive to the formation of algal and coral reefs. One such reef can be seen on the trail (Tour 1-b) in the ledge that overhangs the path. This formation is also highly fossiliferous, though nearly impossible to extract and not as perfectly preserved as those found in the Rochester shale.

ROCHESTER SHALE A dark gray layer 60 ft thick, the lower portion containing limestone lenses. The lower layers are very fossiliferous, with a tremendous variety of species in excellent preservation. Cystoids, crinoids, bryozoa, brachiopods and cephalopods are abundant. Because it is situated between two resistant limestone formations, the Rochester is inaccessable for most of its extent along the gorge. The Rochester is impervious to water. The groundwater in the area seeps through the overlying Lockport and then runs along the Lockport-Rochester contact, forming a number of springs along the gorge wall.

IRONDEQUOIT LIMESTONE Possibly the most fossiliferous stratum in the gorge. The fossils are mostly fragments of crinoids. Though only 15 ft thick, it is a prominent feature along the gorge walls because of its durability.

REYNALES LIMESTONE Not much thicker than the two layers below it, but much more prominent in the gorge because it is so much harder and more durable. The upper Reynales is somewhat fossiliferous, although the fossils are few in variety and poor in quality.

THOROLD AND NEAHGA STRATA These are two lesser strata in the Niagara Gorge. The Thorold is light sandstone, no more than 8 ft thick. The Neahga is a greenish shale, about 6 ft thick. These layers are very soft and crumble with very little weathering.

GRIMSBY FORMATION A mixture of red and mottled green shale and sandstone about 47 ft thick. Its character is varied: soft, friable layers intermingled with hard resistant layers. The Grimsby is first visible under the railroad bridges at the northern end of the Upper Great Gorge along the trail, Tour 1-b. It is exposed throughout the Whirlpool Rapids section, Tour 2, and is then covered by dirt and talus along most of the Ongiara trail,, Tour 3. The Grimsby can be seen again in the Niagara Escarpment section, Tour 4-a. Its red color comes from small amounts of iron present in the sediments that make up this rock. Weathered portions of the Grimsby also show cross-bedding.

POWER GLEN SHALE This is a crumbly shale about 36 ft thick. It is dark gray, friable and easily eroded when exposed to the river's cutting edge. This action serves to undermine the overlying Grimsbyformation.

WHIRLPOOL SANDSTONE This is a coarse sandstone layer, believed by many to be sub-aeolian, or wind deposited. The formation shows cross-bedding where it has been exposed to weathering. The Whirlpool sandstone forms the flats along the bottom of the gorge where the rapids enter the Whirlpool. In the Whirlpool Rapids section, this hard resistant sandstone is at the base of the gorge, and has protected the gorge walls from erosion and undercutting. The gorge has thus remained narrow since its formation. In time, this base of Whirlpool sandstone will be worn through, and may lead to dramatic changes in this section. The Whirlpool-Queenston contact contains pebbles and rocks from other strata,- absolute proof of an interval (probably lengthy) of erosion. The unconformity is marked on the chart opposite.

QUEENSTON SHALE These red beds are the lowermost strata exposed in the Niagara Gorge. They can best be seen in the Lewiston section. In Canada about 8 ft are visible just under the Whirlpool sandstone in the Whirlpool. From this point north, to the mouth of the Niagara River, this layer forms the base of the Niagara Gorge. The Queenston was laid down in a shallow, torrid sea. Mud cracks and ripple marks indicate periods of dessication when the sea very nearly dried up. Finally the sea disappeared and a period of erosion marks the contact between the Ordovician Queenston shale and the Silurian Whirlpool sandstone. Total thickness of the Queenston, 1200 ft.

(STOP 1) American Falls at Goat Island

Situated in the middle of the Niagara River, Goat Island offers a unique vantage from which to view Niagara Falls. The American Falls, including Bridal Vale Falls, are to the north, and the Canadian Horseshoe Falls are to the south.

The lip of the falls at Goat Island is in the Oak Orchard Member of the Lockport Formation, but the majority of island above river level consists of Pleistocene sediments. Pleistocene sediments are a variety of Wisconsin-age deposits, and the highest strata are Holocene gravels of the Niagara River.

(STOP 2) -- Niagara Sewage Treatment Plant. Dead end gravel road west of Niagara Aquarium (on Whirlpool Street), Niagara, New York.

This stop allows for examination of the Lockport Formation, through the Rochester Shale. We will concentrate on the members of the Lockport that form the resistant cap to the Niagara Escarpment and to Niagara Falls. The Oak Orchard, Eramosa, Goat Island, and Gasport members of the Lockport are present along the road (Figure 6).

Consider the following questions:

- These rocks were originally deposited as limestones, and they are now dolomites. How could this happen; what changes might be expected to occur in the rock besides composition?
- Look carefully at the rocks. What features do you see in the various formations, and what depositional environments deposited these rocks.

Figure 6

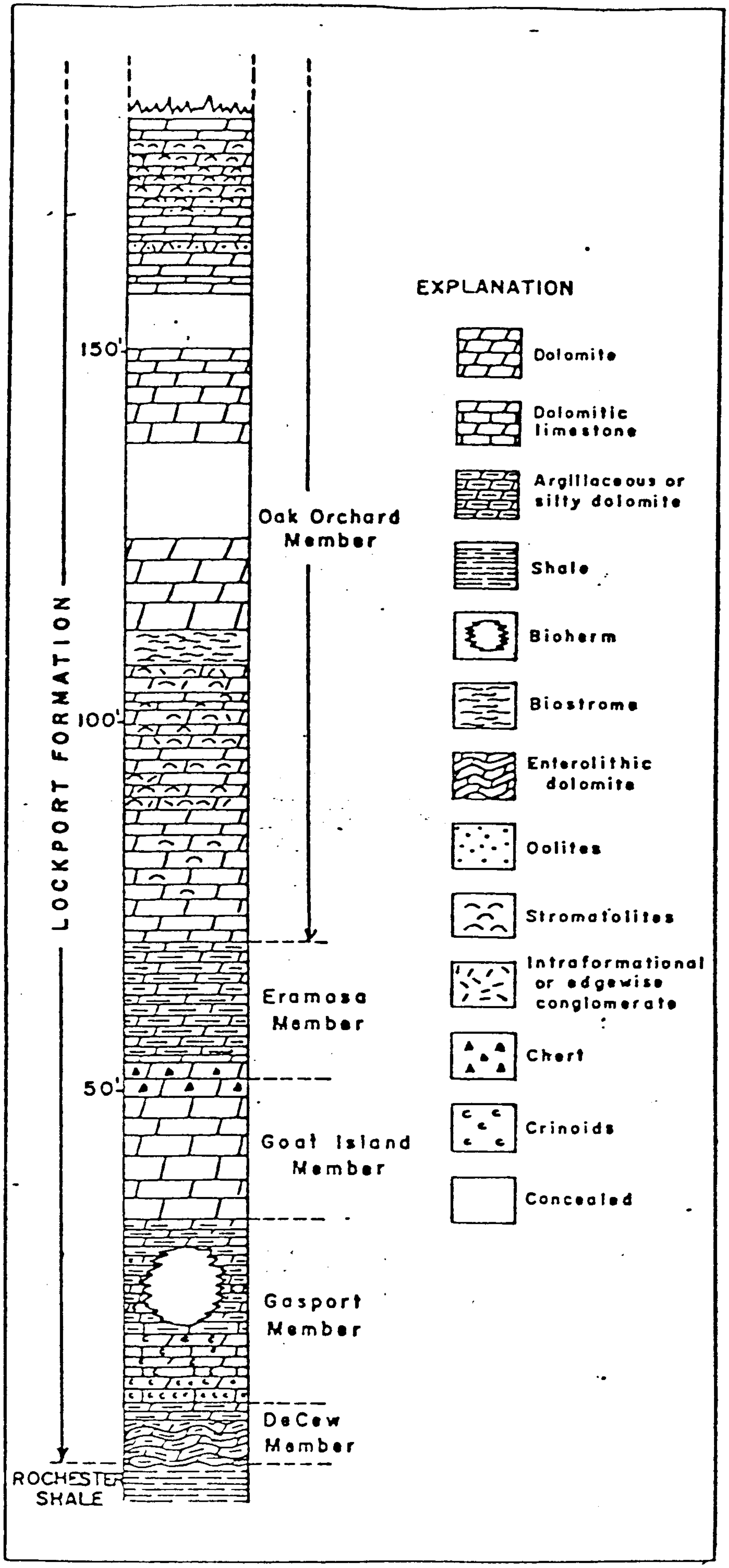


Figure 1.--Columnar section of the Lockport Formation in the Niagara Falls area

(STOP 3a) -- Whirlpool State Park Overlook; along Robert Moses Parkway, Niagara, New York

The Whirlpool Basin is formed where the modern Niagara River intersects the ancient, filled gorge called the St. Davids Gorge. St. Davids Gorge was the interglacial drainage between the Lakes occupying the areas of the present day Lakes Erie and Ontario. It is presently filled by glacial material, but it is less resistant than the surrounding bedrock, so a slight notch has been carved into it by the Niagara River.

At this stop only a gorge overlook is available.

(STOP 3b) -- Devil's Hole State Park; along Robert Moses Parkway, 3.7 mi (5.2 km) south of Lewiston, New York.

At Devil's Hole State Park, another gorge overlook is available, but a stairway provides access to the gorge floor. The upper parts of the exposures are the Lockport Formation. The Decew Member of the Lockport is characterized by penecontemporaneous soft-sediment deformation, and the Gasport Member is a crinoidal limestone with cross bedding.

(STOP 4) -- Mouth of Niagara Gorge at Earl W. Brydges Artpark, Lewiston, New York

The impact of the Niagara Escarpment is just as impressive here as at the brink of the falls. The Lake Ontario plain is to the north with Ordovician Shales as the bedrock, and the top of the escarpment is maintained by the Lockport Formation. These strata are tilted approximately ½° toward the south.

At this stop we will walk into the gorge to examine the stratigraphy of the less resistant units below the Silurian dolomites. The mouth of the gorge is in the Queenston Shale, and we will walk through the gorge to examine blocks of the Rochester Shale (Figures 4 and 5).

Consider the following questions:

- Why is the Queenston Shale red and lack fossils?
- What sedimentary facies is represented by the Whirlpool Sandstone? What evidence supports this hypothesis?
- What sedimentary facies is represented by the Power Glen Formation? What evidence supports this hypothesis? How does it relate to the units below?
- Draw a simple diagram showing relative water depth as a function of the stratigraphy that we examined.

REFERENCES

American Falls International Board. 1974. Preservation and enhancement of the American Falls at Niagara: Final report to the International Joint Commission; Appendix C, Geology and Rock Mechanics, 71 p.

Brett, C.E. 1982. Stratigraphy and facies variation of the Rochester Shale (Silurian: Clinton Group) along Niagara Gorge, p. 217-230. In E.J. Buehler, and P.E. Calkin (eds.), New York State Geological Association Guidebook, 54th Annual Meeting.

Brett, C.E. 1983. Sedimentology, facies, and depositional environments of the Rochester Shale (Silurian; Wenlockion) in western New York and Ontario. Journal of Sedimentary Petrology, 53:947-971.

Brett, C.E., and P.E. Calkin. 1987. Niagara Falls and gorge, New York - Ontario, p. 97-105. In Geological Society of America Centennial Field Guide, Northeastern Section.

Calkin, P.E., and C.E. Brett. 1978. Ancestral Niagara River drainage; stratigraphic and paleontologic setting. Geological Society of America Bulletin, 89:1140-1154.

Calkin, P.E. and B.H. Feenstra. 1985. Evaluation of the Erie-Basin Great Lakes, p. 149-170. In P.F. Karrow, and P.E. Calkin (eds.), Quaternary evolution of the Great Lakes; Geological Association of Canada Special Paper, 30.

Fisher, D.W. 1981. Introduction, p. 1-15. In I.H. Tesmer (ed.) Colossal cataract; The geologic history of Niagara Falls. University of New York Press, Albany.

Lyell, C. 1837. Principles of geology, Volume 1. John Murray, London, 546 p.

Lyell C. 1845. Travels in North America in the years 1841-42, with geological observations on the United States, Canada, and Nova Scotia. Wiley and Putnam, New York, 472 p.