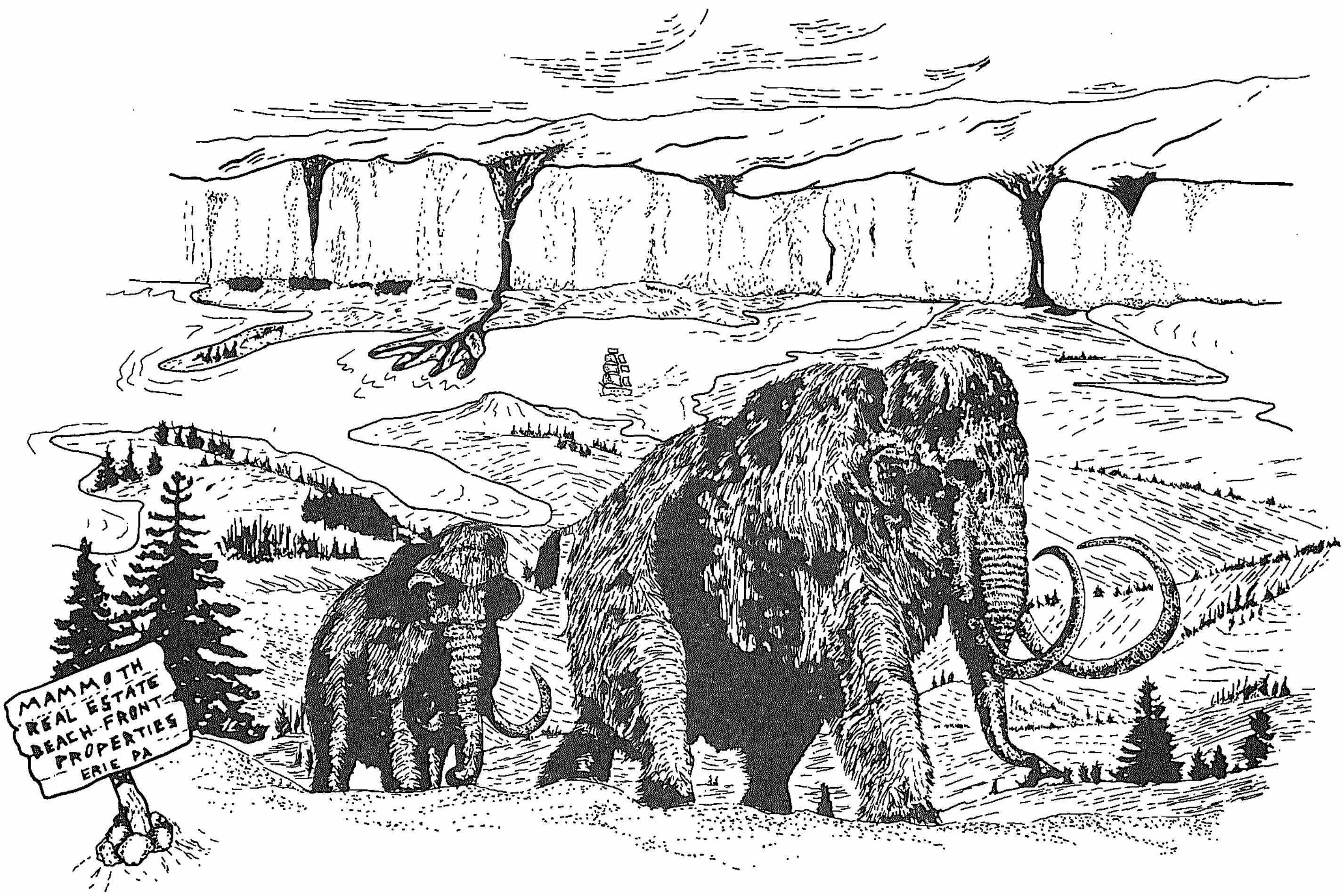
GUIDEBOOK

52 nd. Annual Field Conference Of Pennsylvania Geologists

PLEISTOCENE AND HOLOCENE GEOLOGY ON A DYNAMIC COAST



October 1, 2, and 3, 1987

Erie, Pa.

Hosts: Mercyhurst College
Pennsylvania Geological Survey

Guidebook for the

52nd ANNUAL FIELD CONFERENCE OF PENNSYLVANIA GEOLOGISTS

PLEISTOCENE AND HOLOCENE GEOLOGY OF A DYNAMIC COAST

Authors and Field Trip Leaders:

David J. Thomas, Mercyhurst College
Helen L. Delano, Pennsylvania Geological Survey
M. Raymond Buyce, Mercyhurst College
Charles H. Carter, Akron University

Additional Field Trip Leader:

Kent Taylor, SUNY at Fredonia

October 1-3, 1987

Hosts: Mercyhurst College
Pennsylvania Geological Survey

Cover: Design: William Kochanov
Art work: Jack Kuchinski

Guidebooks distributed by:

Field Conference of Pennsylvania Geologists
c/o Department of Environmental Resources
Bureau of Topographic and Geologic Survey
P. O. Box 2357
Harrisburg, PA 17120

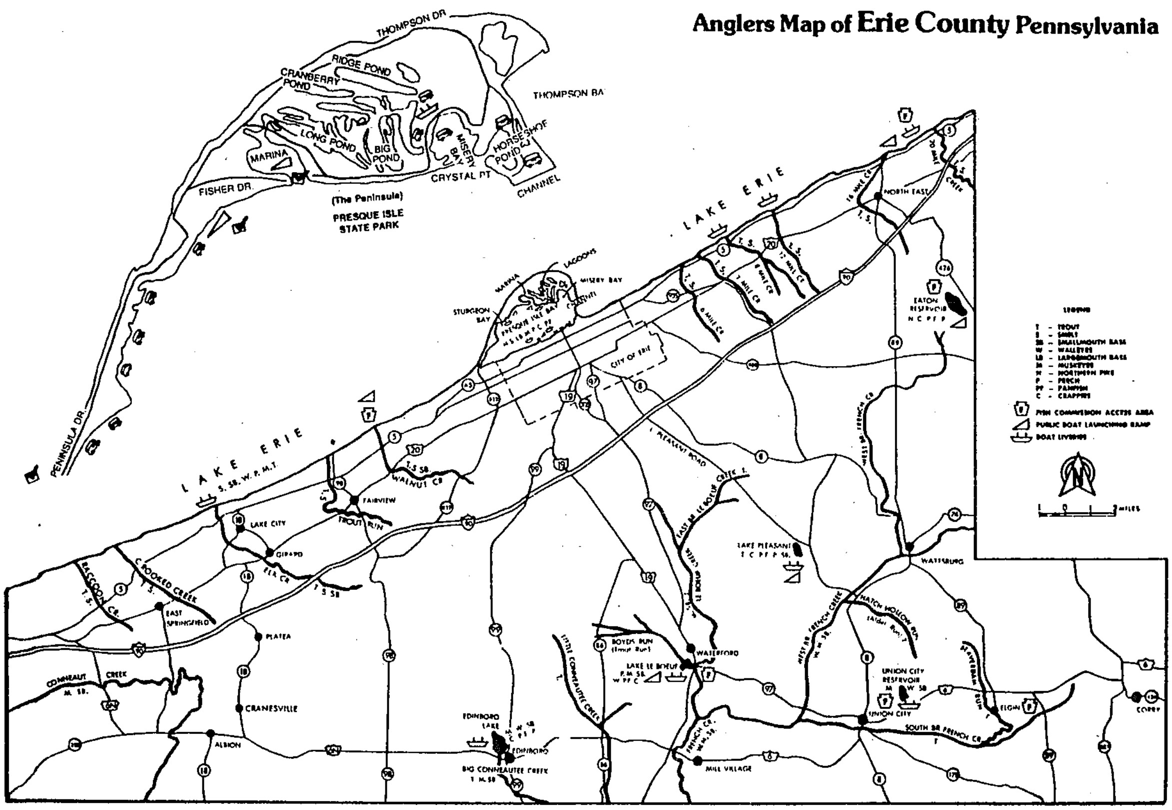
Frontispiece. Vertical aerial photograph of Presque Isle and Erie, Pennsylvania taken May 11, 1983 (U.S. Geological Survey, National High Altitude Photography; photograph 5-11-83, 92-14, 428016, HAP-82).

Table of Contents

List of Illustrations

List of Tables

List of Measured Sections



PLEISTOCENE AND HOLOCENE GEOLOGY OF A DYNAMIC COAST

INTRODUCTION

The 52nd Annual Field Conference of Pennsylvania Geologists will address a small, but important section of Pennsylvania--the shoreline of Lake Erie and its Late Pleistocene ancestors. Our route will be limited to the narrow zone along the lake shore.

We will examine Late Pleistocene glacial and ice-marginal deposits exposed in the modern lake bluffs. These diamicts, gravels, sands, and silts may have a more complicated stratigraphy than previously recognized. Mass-wasting processes and shoreline erosion of these sediments are matters of major environmental geologic concern, especially during the record high lake levels of recent years.

We will look at the topographic and sedimentologic characteristics of the lake terraces, relict wave-cut cliffs, and associated sand and gravel deposits which have been related to various Pleistocene lake levels. These are the "beach ridges" of Leverett (1902) and numerous later workers.

Modern littoral features will include beaches of Presque Isle, a seven-mile long sand spit, its areas of erosion and deposition, and the engineering efforts to control shoreline processes. We will also see beaches at stream mouths and along the base of both bedrock and unconsolidated bluff faces.

We will see examples of efforts to slow down lake erosion to protect buildings and shore access facilities. We will also see evidence that shoreline erosion has been going on for a very long time on the Lake Erie shore.

The northern portion of Erie County is significantly affected by shoreline processes, both modern and ancient. The economic base of the area is greatly dependent on lake transportation, tourism, sand and gravel deposits, and well-drained agricultural soils. All of these are tied to the lake and shoreline processes.

As this trip and guidebook attempt to show, possibly no other people of Pennsylvania are so extensively and intimately involved with the surface and subsurface geology and ongoing dynamic processes of erosion and sediment transport as are the people of the Erie area where all aspects of life truly have a Pleistocene heritage and a Holocene challenge.

PHYSIOGRAPHY

The major physiographic divisions within the field conference area are, from north to south, the Eastern Lake Section of the Central Lowland Province and the Glaciated Section of the Appalachian Plateaus Province (Figure 1).

The Eastern Lake Section of the Central Lowland Province occupies a band 2 to 5 miles wide extending from Lake Erie to the base of an escarpment that rises southward onto the Glaciated Section of the Appalachian Plateau. It consists of three major east-west trending Pleistocene lake terraces delimited by

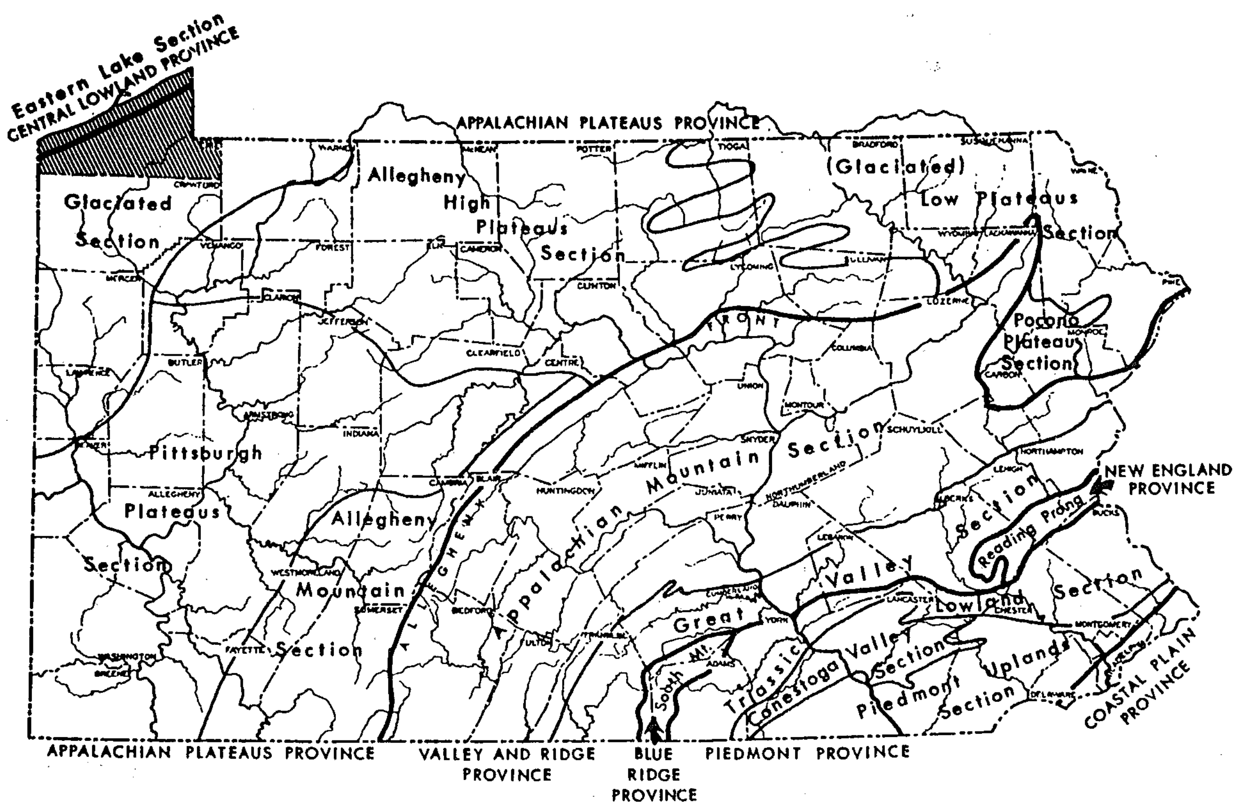


Figure 1. Physiographic provinces of Pennsylvania and location of 52nd Annual Field Conference of Pennsylvania Geologists (Erie County with diagonal pattern).

escarpments including the present Lake Erie bluff. The terraces are dissected by streams that flow northward off the plateau to the lake. Abandoned stream channels with less than 3 m (10 ft) of relief also cut the terraces.

The Glaciated Section of the Appalachian Plateaus Province consists of relatively flat-lying beds of sedimentary rock that have been erosionally truncated to form a north-facing escarpment with up to 60 m (200 ft) of local relief at the northwest margin. The plateau and escarpment are covered by glacigenic deposits of irregular thickness and distribution.

The courses of most major streams draining the Plateau in the conference area begin by flowing westward, then flow northward for a short distance and then westward again until they reach the escarpment. They then flow northward off the escarpment, through the lake terraces and into Lake Erie.

BEDROCK GEOLOGY

The oldest rocks exposed at the surface in northwestern Pennsylvania are those along the Lake Erie shore. The westernmost 2 miles of the shoreline are underlain by the Girard Shale. The Northeast Shale underlies the remainder of the shoreline up to the New York state line (Berg and others, 1980). Both are Upper Devonian in age and correlate with portions of the Chagrin Shale to the west and the Brallier Formation, Bradford Group, and Catskill Formation elsewhere in Pennsylvania (Berg and others, 1986). The regional dip is gentle and to the south.

The Northeast Shale is a series of alternating gray shales and thin layers of gray siltstone and fine-grained sandstone. Fossils are uncommon in this unit in Pennsylvania, but fucoids have been noted (Tomikel and Shepps, 1967). Cone-in-cone structures have also been documented in these rocks. The maximum thickness of the Northeast Shale in eastern Erie County is about 475 feet. The overlying Girard Shale is an ashen gray, flaky shale with rare marine fossils.

The non-resistant nature of the Upper Devonian shales is probably a major factor in determining the locations and extent of the Great Lakes basins (Figures 2 and 3).

Approximately 1830 m (6,000 ft) of Paleozoic rocks lie between the surface and the metamorphosed Precambrian basement in Erie County (Lapham, 1975).

ECONOMIC GEOLOGY

Erie County lays claim to Pennsylvania's only Great Lakes port. It is protected by Presque Isle, a recurved spit which provides a natural harbor in Presque Isle Bay. The port facilities are a large part of the economic base for the city of Erie. We will have an opportunity to view the port facilities from across the harbor at our lunch stop on Day 1 of the trip.

The most valuable mineral product in Erie County is sand and gravel. Numerous pits of various sizes exploit kame, kame terrace, glaciodeltaic, and outwash deposits in the southern two-thirds of the county, and glaciofluvial, glaciodeltaic, and glaciolacustrine sediments at Lake Wittlesey, Arkona, and Warren I and II levels in the northern third. These materials are used for road and building construction, concrete block manufacture, and as nourishment material for the beaches of Presque Isle. In addition, sand is dredged from Lake Erie for concrete and masonary sand. The total production in Erie County exceeds 500,000 tons/year (Tomikel and Shepps, 1967). The field trip will visit two pits at the Lake Whittlesey level.

The well-drained sand and gravel soils along the eastern Lake Section of the Central Lowland Province, which is commonly referred to as the Lake Plain, provide excellent soil for nursery stock, fruit orchards, and fruit and vegetable farms. This soil, plus 15 additional days of growing season in the fall due to the slow release of heat energy by the lake, provides an ideal environment for the cultivation of grapes. There are two major varieties. The fruity native North American grapes, most commonly Concords, produce high quality jelly and juice. Most wines, on the other hand, are the product of vines that have been brought from western Europe. We will be travelling through vineyard areas during Day 2 of the conference.

Lake Erie has a plentiful, high quality water supply for adjacent communities and industries. Where use of lake water is not practical, industries and public water supplies must derive their water from subsurface, primarily from glacigenic sand and gravel aquifers.

Erie County is one of the most active oil and gas producing counties in Pennsylvania. In June 1987, the Pennsylvania Geological Survey had well records on file for 406 shallow wells and 2,191 deep wells in the county. Most are gas wells, but 15,825 barrels of oil were produced from 121 deep wells in 1986 (Harper, 1987). The shallow wells produce from the Upper and Middle Devonian

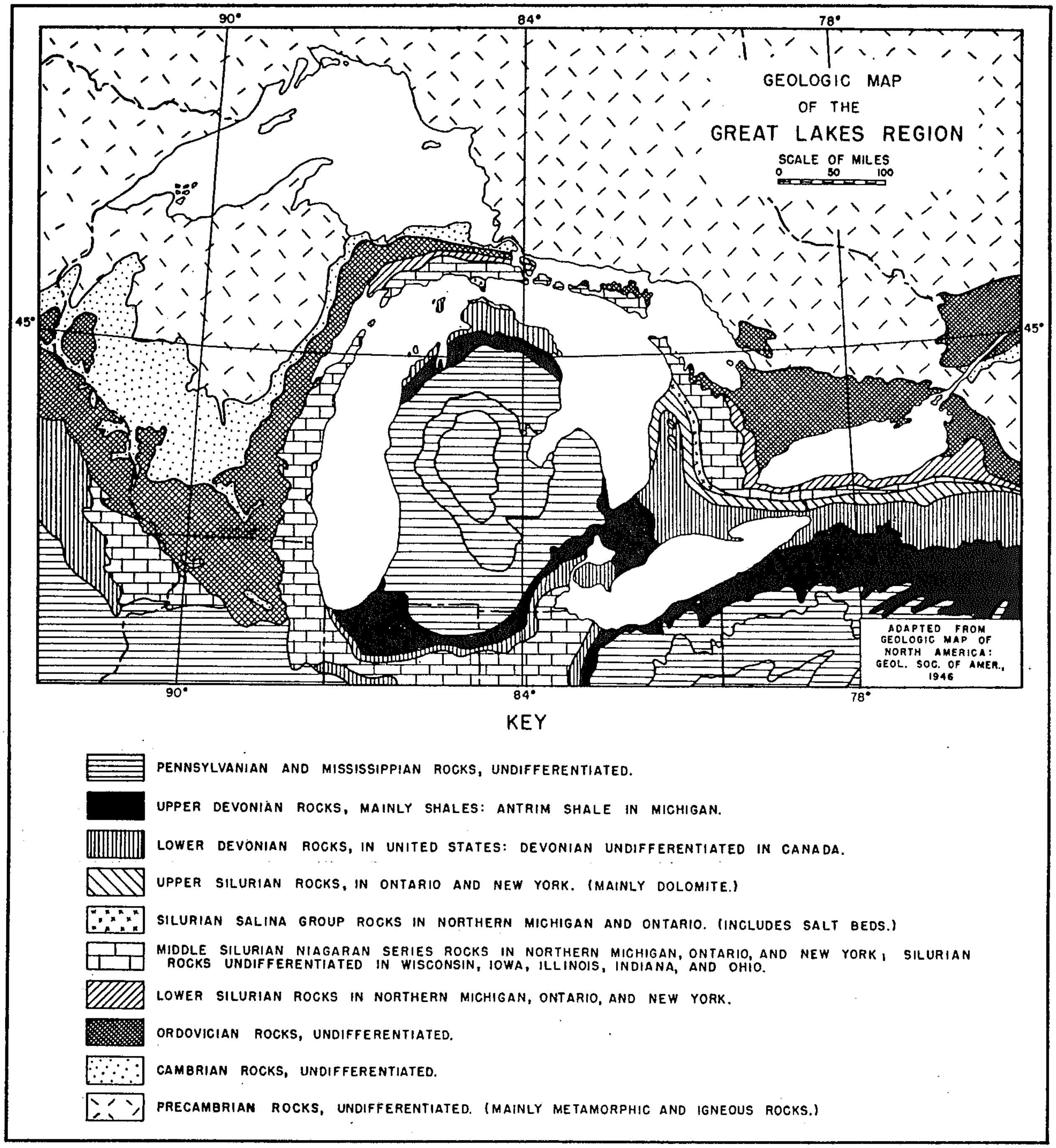


Figure 2. Geologic map of the Great Lakes Region (from Hough, 1958).

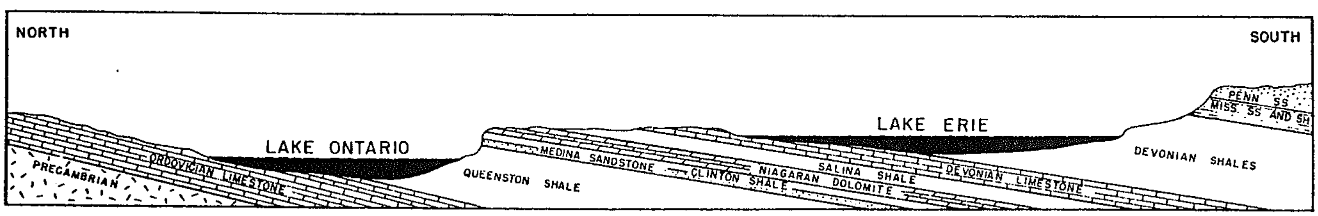


Figure 3. Cross section through the western end of the Ontario basin and the eastern end of the Erie basin, showing relations of the basins to weak shales (from Hough, 1958).

shales and are typically non-commercial, supplying a few local users. Most deep wells in Erie County produce from the Lower Silurian Medina Group, which is about 760 m (2,500 ft) below the surface along the lake shore. The cumulative total deep gas production for Erie County at the end of 1985 was over 118 trillion cubic feet of gas (Harper, 1986).

GLACIAL GEOLOGY OF NORTHWESTERN PENNSYLVANIA

The bedrock of northwestern Pennsylvania is covered with glacigenic deposits transported by continental ice sheets which advanced southward onto the Appalachian Plateau and to the southwest along the Ontario-Erie Basin numerous times during the Pleistocene (White and others, 1969).

The earliest ice sheets advanced farthest to the south and upon melting back left behind the southernmost deposits of till. The term till is used here in a stratigraphic sense referring to all glacial deposits of a specified age and geographic distribution as defined in Shepps and others (1959) and White and others (1969). Each subsequent ice advance was less extensive than the immediately preceeding advance. Each advance deposited till that only partially covers the older deposits, the whole overlapping in a shingle-like fashion. Consequently, each drift till sheet outcrops in an elongate northeast-southeast band roughly parallel to its former ice front. The overlapping of each subsequent deposit conceals the preceeding drifts, but the older deposits frequently occur in the subsurface (White and others, 1969).

The oldest glacial deposit in northwestern Pennsylvania is the Slippery Rock Till of probable pre-Illinoian age. The type section is described from a subsurface occurrence about 3 miles north-northwest of Slippery Rock, Pennsylvania (White and others, 1969). The presumed age is based upon its stratigraphic position below the Mapledale Till.

The next youngest unit, the Mapledale Till, occurs at the surface in a belt 1 to 5 miles wide from Beaver County at the Ohio border, to Warren County near the New York border (Figure 4). The Illinoian age assignment for the Mapledale is based on its stratigraphic position above the Slippery Rock Till and below the Titusville Till, and because of the degree of weathering of a paleosol on its surface.

The Titusville Till is exposed at the surface along a belt 0 to 10 miles wide extending from northern and western Warren County at the New York border to the Ohio border in northwestern Beaver County (Figure 4). Radiocarbon dates obtained from peat deposits in gravel beneath the Titusville Till range from 35,000 to 40,500 yr B.P. (White and others, 1969). This places the Titusville Till within middle Wisconsinan time (Dreimanis and Goldthwait, 1973).

The Kent Till deposits extend along a northeast-southwest band 30 miles wide from the Ohio border in Lawrence County to the New York state border in northern Warren County (Figure 4). Northwest-southeast oriented linear subglacial landforms in southeast Erie County and northern Crawford County (Figure 5) indicate that the movement of the Kent ice was in a southeasterly direction. No organic material for ^{14}C dating has been found in Pennsylvania in association with Kent Till. However, lacustrine material associated with Kent Till near Cleveland, Ohio has yielded a ^{14}C date of 24,000 yr B.P. (White and others 1969).

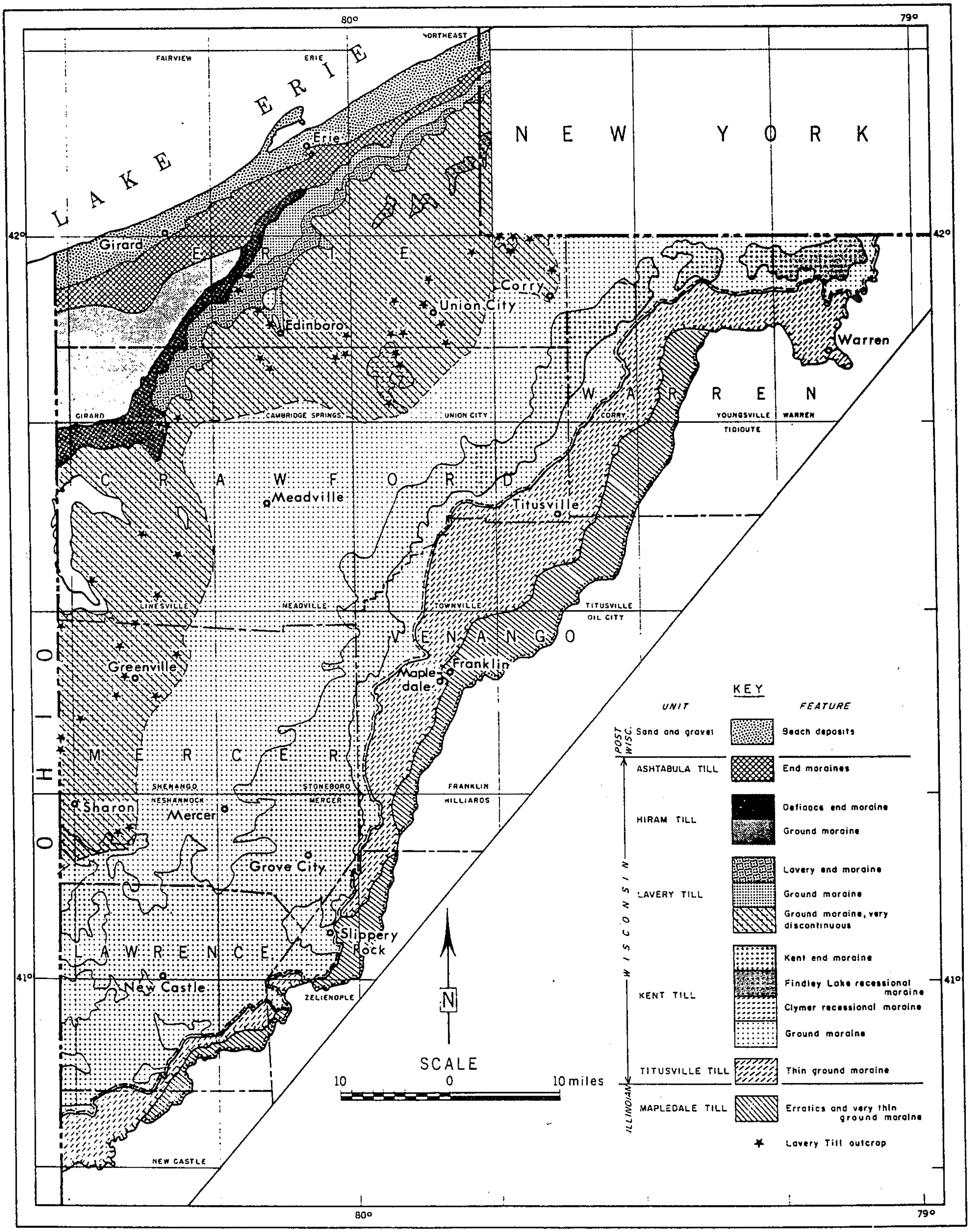


Figure 4. Glacial map of northwestern Pennsylvania showing distribution of Illinoian and Wisconsinan tills, ground moraine, recessional moraine, end moraine, and sand and gravel beach deposits. Neither the Slippery Rock Till nor the Girard moraine are shown on this map (from White and others, 1969).

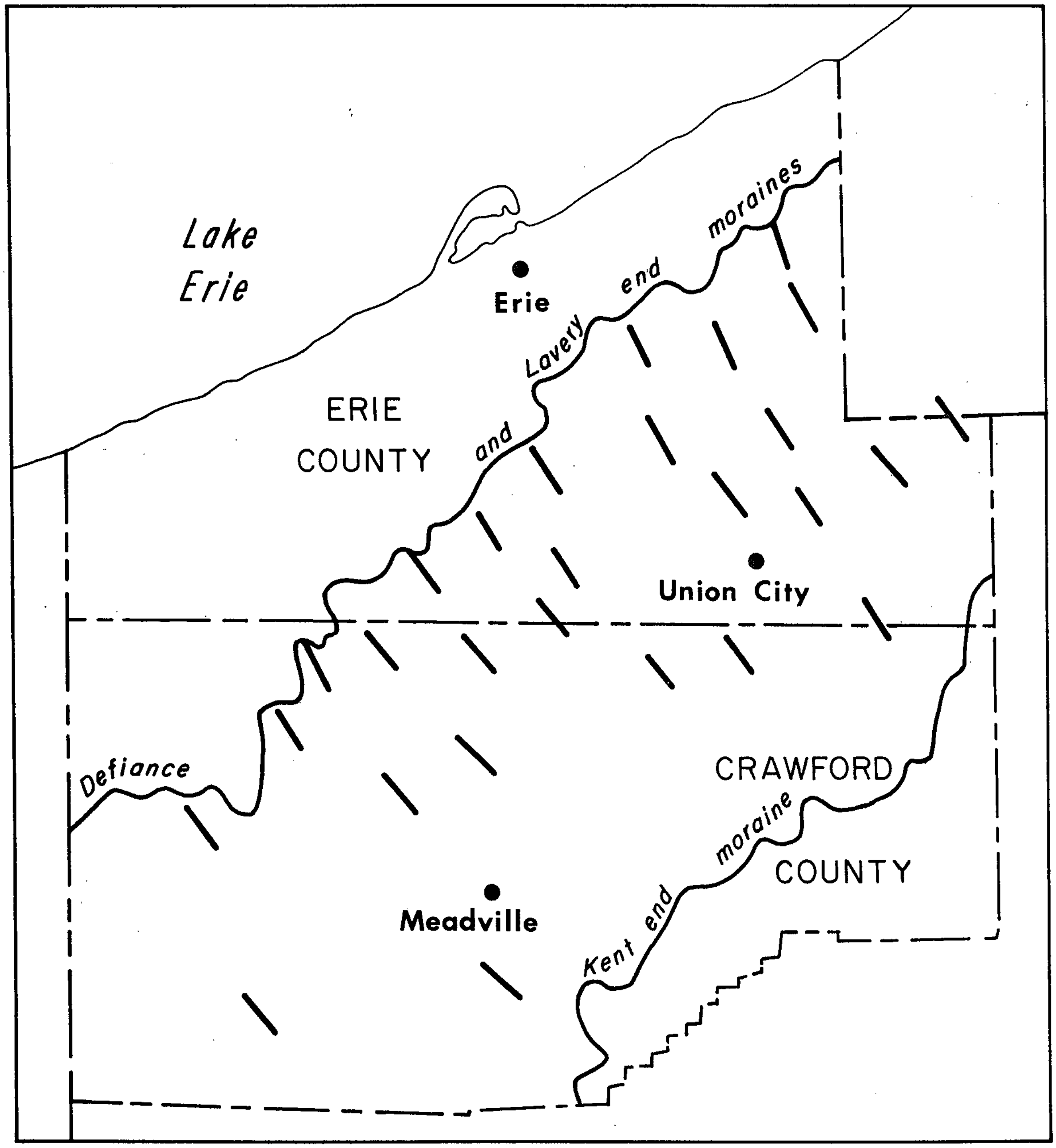


Figure 5. Orientation of linear landforms in northwestern Pennsylvania. Each linear-trend line represents an average of up to 40 orientation measurements. Orientation measured on 1:50,000 scale topographic maps of Erie and Crawford Counties. Only hilltop landforms were measured. Presumably the landforms represent both constructional and erosional features, but no field verification has been done. Note that the linear landforms occur only in a ground moraine area between the Kent and Defiance-Lavery end moraines. Figure prepared by W. D. Sevon, Pennsylvania Geological Survey, 1987.

The Lavery Till is exposed in a northeast-southwest trending belt 1 to 5 miles wide from the western border of New York southeast across Erie County into northwestern Crawford County. Its exposure is terminated about 10 miles east of

Ohio where it is completely overlapped by the Hiram Till (Figure 2). No organic material has been found in direct association with Lavery Till in Pennsylvania. However, a ^{14}C date having a minimum age of 14,000 yr B.P. has been obtained from marl occurring beneath a peat deposit in front of the margin of the Lavery Till at Corry (White and others, 1969). If the marl and peat are proglacial deposits related to ablation of Lavery ice, then the Lavery Till should be older than 14,000 yr B.P.

The Hiram Till is exposed in a triangular-shaped area which narrows from 14 miles wide at the Ohio border to 1 mile wide at its most northeastern extent where it is overlapped by Ashtabula Till. The eastern extent is about 23 miles east of the Ohio line and 5 miles south of the bluff overlooking Presque Isle Bay in Erie (Figure 2).

The Ashtabula Till is exposed across northern Erie County (Figure 2) along a northeast-southwest trending belt between 1/2 and 5 miles wide from the western New York border to the eastern Ohio border.

The westernmost extent of the Girard Till occurs just east of Elk Creek in Lake City, northwest Erie County. It extends eastward as a band 1/2 to 1-1/2 miles wide to about 1 mile south of the Borough of North East where it appears to coalesce with the Astabula Till.

Except for the Titusville, each of the Wisconsinan-age tills has an identified end moraine (Figure 2). The end moraine associated with the Hiram Till is named the Defiance end moraine. Each of the other end moraines takes the same name as the till with which it is associated.

In summary, it appears that there were at least 8 advances and retreats of glacial ice into northwest Pennsylvania within the pre-Illinoian, Illinoian, and Wisconsinan Stages of the Pleistocene. Each left behind till. Each succeeding advance did not encroach as far south as the previous advance although the Hiram ice did completely override part of the Laverly Till and Ashtabula ice moved across part of the Hiram Till. These advances and retreats resulted not only in large-scale alterations of the topography and surface drainage of the region but must have been the major excavators and shapers of the Lake Erie basin.

THE HISTORY OF PLEISTOCENE LAKE LEVELS IN THE LAKE ERIE BASIN

The following discussion of Pleistocene lake levels, associated advances and retreats of glacial ice, drainage outlets, and radiocarbon dates has been summarized from an excellent compilation by Calkin and Feenstra (1985). The version presented here is a simplification and is intended to present only the major points.

The Lake Erie basin has been occupied by a series of major proglacial ice or moraine-dammed lakes and non-glacial lower-level lake phases from the end of the Hiram ice advance until today. The positions and elevations of the lakes have been identified by their associated sediments and topographic features such as beach ridges, terraces, and relic wave-cut cliffs. Among the factors that influenced the various elevations of the lake stands were advances and retreats of ice lobe margins, opening of lower drainage channels during ice retreat, downcutting of outlet channels, and crustal warping due to glacial unloading and reloading.

The geologic history of the lakes of interest here are related to the advances and retreats of three ice lobes in two Great Lake basins. The earlier glacial ice that extended well south of Lake Erie excavated the Huron and Ontario-Erie basins. The basin topography largely controlled the movements of subsequent ice lobes that moved across the area during the time of the glacial and non-glacial lakes. The Huron ice lobe and the Saginaw ice lobe flowed within the Lake Huron basin and the Ontario-Erie lobe flowed within the Lake Ontario-Lake Erie basin. As the ice lobe margins retreated lakes occupied the vacated basins and as the margins readvanced the lakes moved in response.

The lakes have been named Lakes Maumee I (earliest), II, and III; Lake Arkona; Lake Ypsilanti; Lake Whittlesey; Lakes Warren I, II, and III; Early Lake Erie; and present Lake Erie (latest). The sediments and topographic features to be seen during the field conference are those related to Lakes Whittlesey, Warren I, Arkona, and Lake Erie.

Lake Maumee I

The first of the proglacial Great Lakes in the Lake Erie basin developed in northwestern Ohio and northeastern Indiana following the culmination of the Hiram ice readvance and deposition of the Defiance end moraine during the Late Wisconsinan (Figure 6). Named Lake Maumee I, it stabilized at a present-day elevation of 800 feet and drained into the Wabash River through two outlets

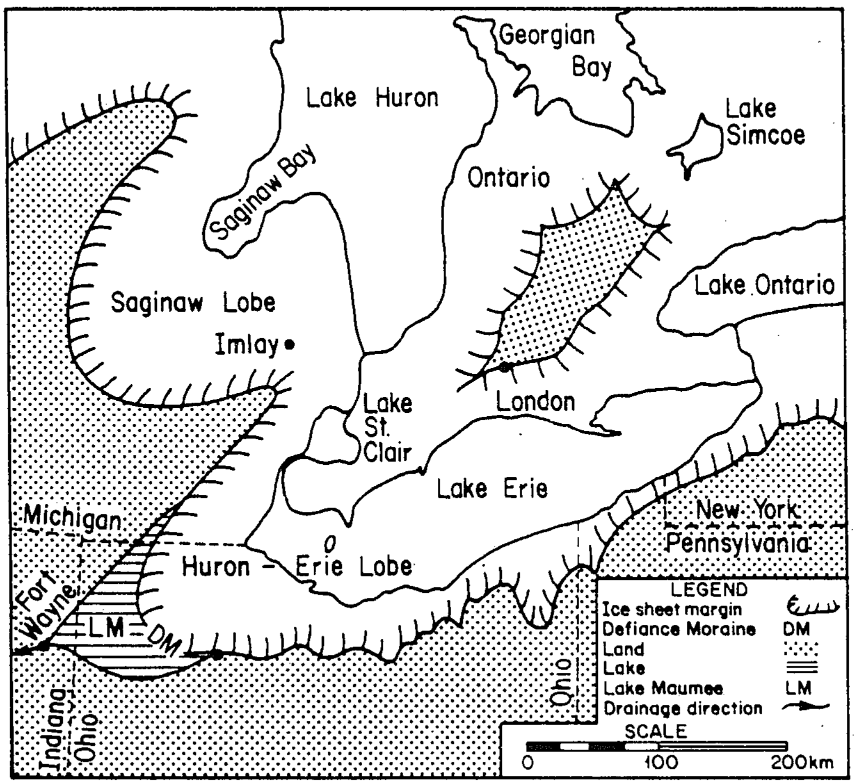


Figure 6. Locations of Maumee I, the western outlet at Fort Wayne, Indiana, and the Defiance End Moraine. Note the positions of Lakes Huron, Erie, and Ontario, and the Huron-Erie Lobes (from Calkin and Feenstra, 1985).

cutting the Fort Wayne Moraine. Maumee I beaches have been traced in northwestern Ohio and southeast Michigan. A ^{14}C date for the minimum age for Hiram ice recession from the Defiance Moraine is 14,500 ± 150 yr B.P. This should serve as a minimum age for Lake Maumee I.

Lakes Maumee II and III

As the ice of the Huron Lobe melted back to the north along the Lake Huron basin and the Ontario-Erie Lobe retreated northeast along the Lake Erie basin from the Defiance Moraine, a lower drainage channel was either uncovered or downcut by escaping water north of Imlay, Michigan causing abandonment of the Maumee I outlet (Figure 7). Consequently, the Maumee II and III phases were stabilized at 780 feet and 760 feet respectively. There is considerable

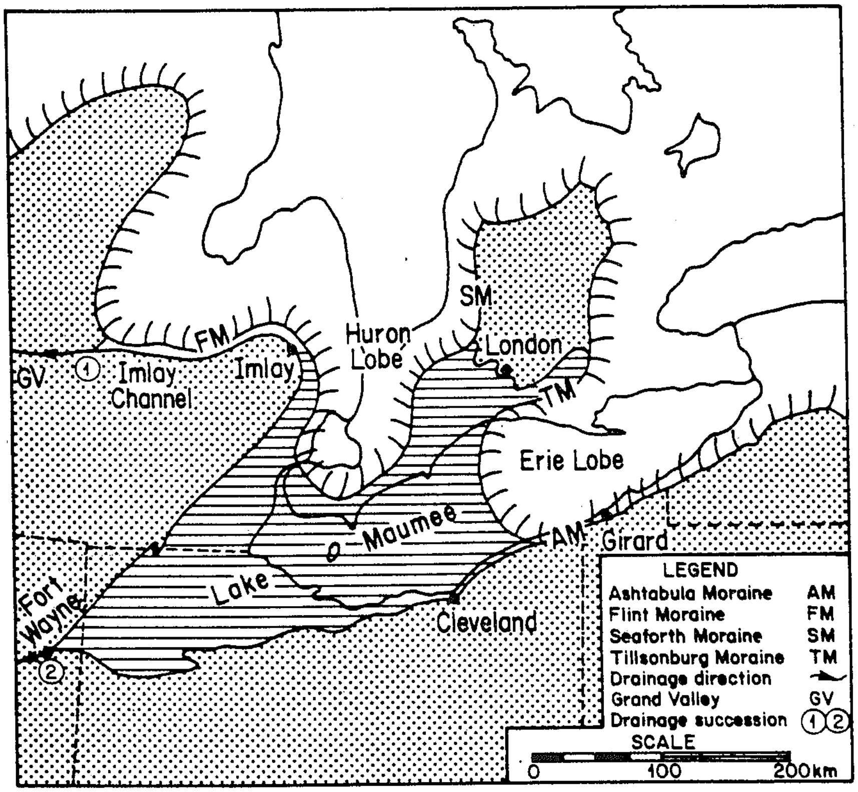


Figure 7. Locations of Lake Maumee III, the western outlet north of Imlay, Michigan, the Grand River valley crossing Michigan, and the Tilsonburg and Ashtabula end moraines. Note the positions of the Saginaw, Huron, and Erie Lobes (from Calkin and Feenstra, 1985).

confusion about the sequence of the two latter Maumee levels and as to the location of the drainage channel for Maumee II. Nevertheless, it appears that Maumee III stabilized, after a readvance or standstill of ice that formed the Tillsonburg Moraine in Ontario, the Ashtabula Moraine in Pennsylvania, and an as yet unlocated moraine below the present Lake Erie. A ^{14}C date for Maumee III is 13,700 ± 220 yr B.P.

Lake Arkona

Subsequent retreat of the Huron and Saginaw ice lobes northward along the Lake Huron basin and the northeast melt back of the Ontario-Erie Lobe in the Lake Erie basin to the Paris Moraine in Ontario and the Girard Moraine in Pennsylvania caused the waters in the Lake Huron and Lake Erie basins to subside and at the same time to join forming an early phase of Lake Arkona (Figure 8). This lake merged with early Lake Saginaw and drained westward via the Saginaw Bay outlet through the Grand River valley to Lake Chicago. Three different Arkona phases have been identifed: Highest Lake Arkona, 710 feet; Middle Lake Arkona, 700 feet; and Lowest Lake Arkona, 695 feet. Beaches of the two higher lakes have been traced to 7.4 miles east of the Ohio-Pennsylvania border by Totten (1982; 1985). A ^{14}C date places Lake Arkona at 13,600 ± 500 yr B.P.

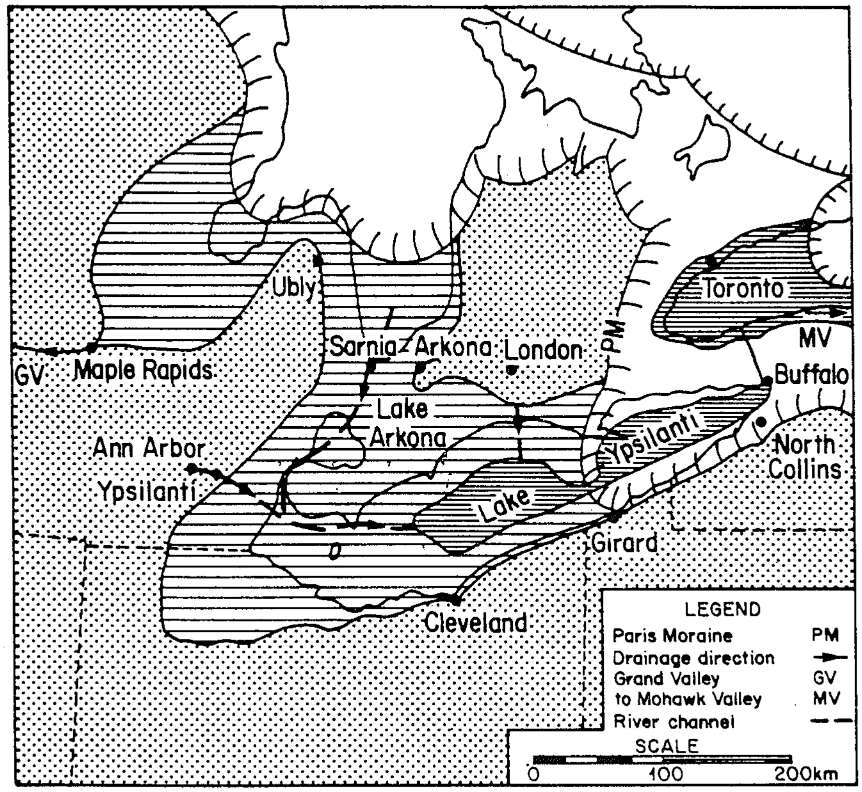


Figure 8. Locations of Lake Arkona, the western outlet through the Grand River valley in Michigan, and the Paris and Girard Moraines. Note the positions of the Saginaw, Huron, and Erie Lobes at the east end of Lake Arkona and the margin of the ice and the eastern outlet through the Mohawk River valley during the existence of Lake Arkona (from Calkin and Feenstra, 1985).

Lake Ypsilanti

The Huron ice lobe continued to retreat to the present location of Georgian Bay while the Ontario-Erie ice lobe melted out of the Erie basin, across the Niagara Escarpment, beyond Toronto to the north, and into the northeast portion of the Lake Ontario basin. This opened an eastward drainage channel from the basins of Lakes Michigan, Huron, and Erie into a lower lake in the Ontario basin which, in turn, drained eastward through the Mohawk River valley and then through the Hudson River valley. The lower lake that developed in the Lake Erie basin was the nonglacial Lake Ypsilanti (Figure 8). Ypsilanti sediments have been found at elevations between 677 feet and 300 feet reflecting a fairly rapid lowering during this time. ^{14}C dates of organic material that relate to Lake Ypsilanti range between 12,600 ± 440 yr B.P. and 13,360 ± 440 yr B.P.

Lake Whittlesey

As the Saginaw and Huron Lobes readvanced south through the Lake Huron basin into Michigan and as the Ontario-Erie Lobe readvanced southwest within the Ontario basin across the Niagara Escarpment and into the northeastern-most part of the Lake Erie basin, waters in the Lake Erie basin rose to form Lake Whittlesey (Figure 9). Westward drainage was re-established through a spillway at Ubley, Michigan to Lake Saginaw which then drained through the Grand River valley to Lake Chicago in the Lake Michigan basin. The farthest extent of the readvance of the ice into the Erie basin is marked by the Hamburg Moraine near Buffalo, New York (Figure 10). Proglacial Lake Whittlesey stabilized against this moraine at the elevation of 740 feet. ^{14}C dates give a maximum age for Lake Whittlesey of 13,000 yr B.P.

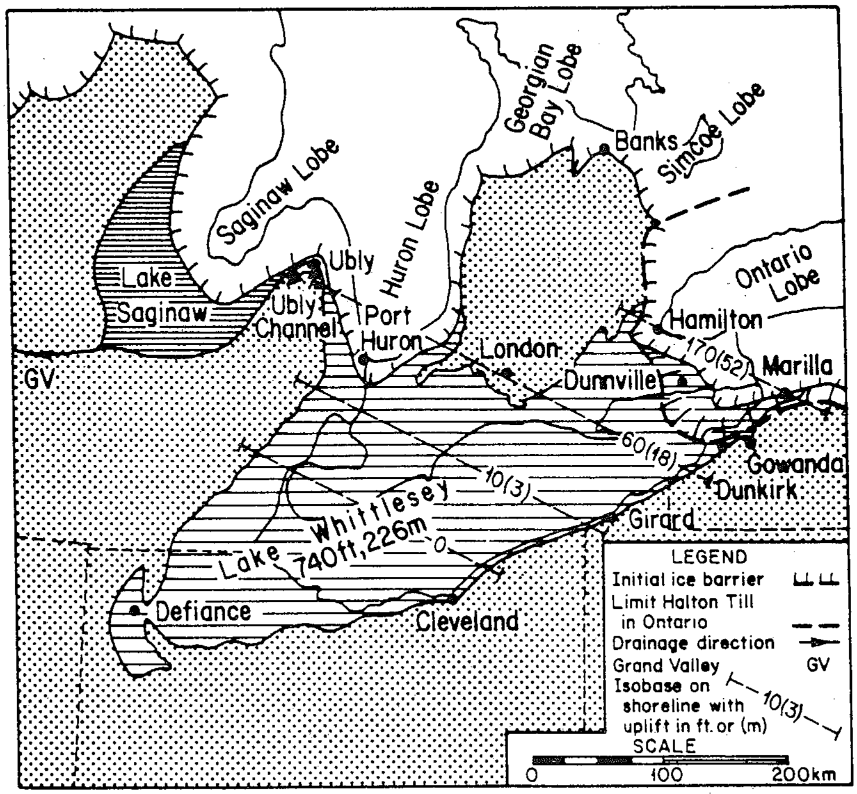


Figure 9. Locations of Lake Whittlesey, the western outlet north of Ubley, the Grand River valley in Michigan, and the Hamburg Moraine in western New York. Note the positions of the Saginaw, Huron, and Ontario Lobes (from Calkin and Feenstra, 1985).

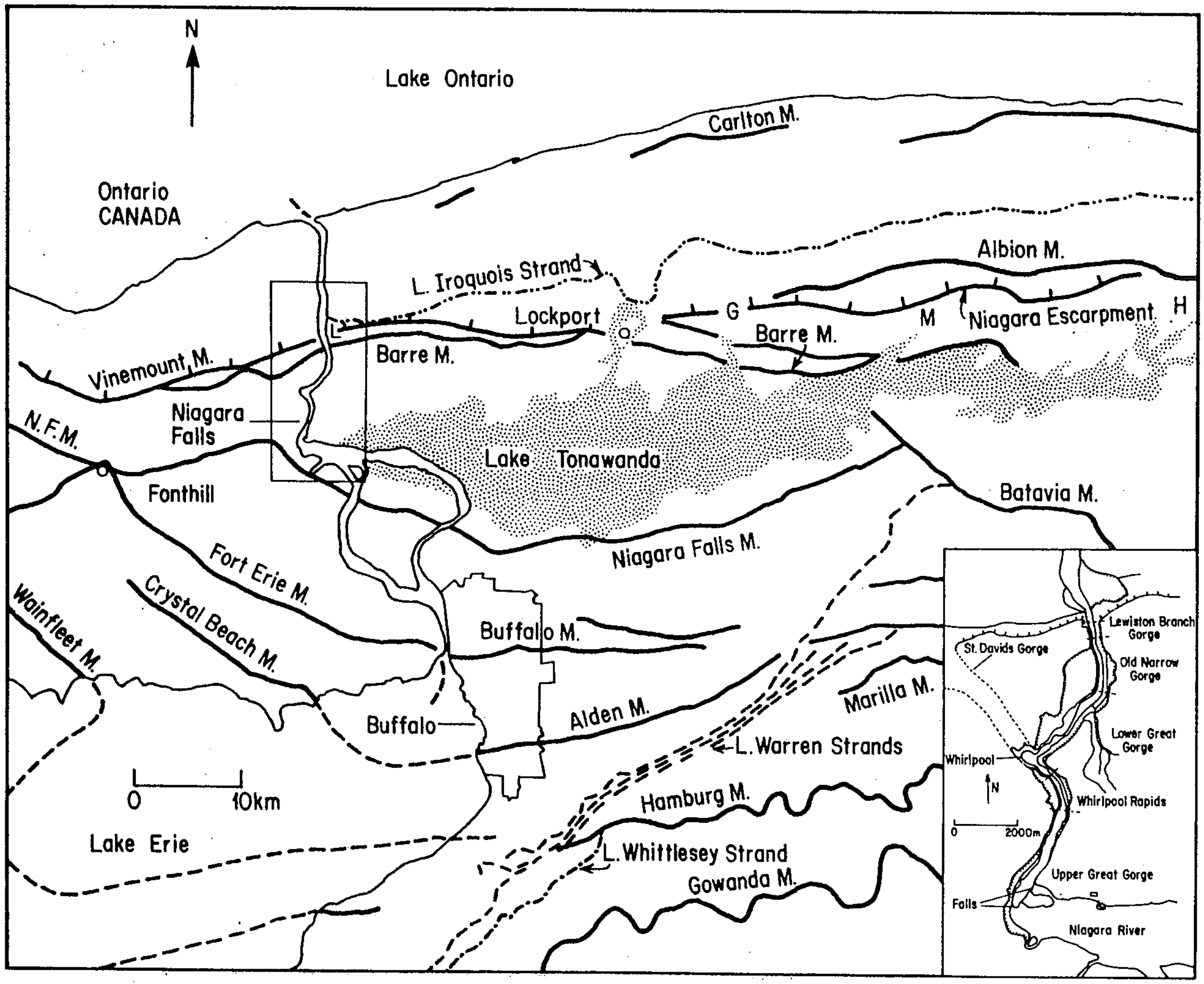


Figure 10. Locations of Lakes Whittlesey and Warren strands and the related Hamburg and Alden Moraines. Note the positions of the Buffalo-Fort Erie and Niagara Falls Moraines that were breached during the formation of Lakes Grassmere and Lundy, and of Lake Tonawanda that formed as a result of the breaching. Also note the northern outlet channels that drained Lake Tonawanda at H, M, O, and L into the Lake Ontario basin (from Calkin and Feenstra, 1985).

Lake Warren

As the ice margin retreated from the Port Huron Moraine north of Ubley, Michigan (Figure 9) and from the Hamburg Moraine to the Alden Moraine south of Buffalo, New York (Figure 10), high discharges into Lake Saginaw and Lake Whittlesey produced downcutting of the western drainage channel through the Grand River valley and into Lake Chicago. This resulted in the lowering of Lake Whittlesey (740 feet) to the highest Lake Warren level (685 feet). As a result of either continued downcutting of the channel in Michigan or retreat of the ice margin in western New York state, three phases of Lake Warren were established: Warren I at 685 feet, Warren II at 675 feet, and Warren III at 670 feet. Warren II has been identified only locally. The various Warren phases were the last and most extensive of the major great glacial lakes to occupy the Erie basin

(Figure 11). ^{14}C dates range from 13,050 yr B.P. on wood beneath Warren I deposits to 12,000 yr B.P. on organic material believed to be post-Warren.

Lakes Grassmere and Lundy

The northward retreat of the ice margin from the Alden Moraine (which had restricted Warren III) was interrupted by brief standstills that are reflected by the Fort Erie-Buffalo Moraine, Niagara Falls Moraine, and the Vinemount-Barre Moraine (Figure 10). The drainage at this time was eastward through the Mohawk Valley which resulted in lower-level lakes named Lake Grassmere at 640 feet and Lake Lundy at 620 feet. These lakes are represented by discontinuous and low relief (less than 2 to 6 feet) shore features.

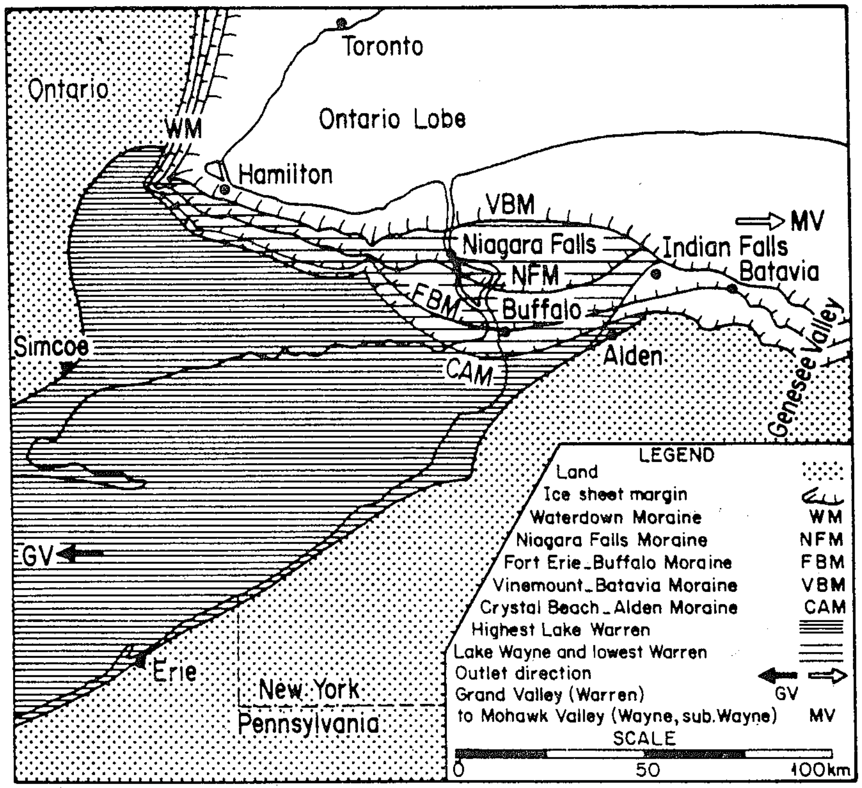


Figure 11. Location of Lake Warren and the position of the Alden Moraine (from Calkin and Feenstra, 1985).

Early Lake Erie

The final ice margin retreat that affected the Lake Erie basin caused the lake surface to fall below the elevation of the Niagara Escarpment. This initiated the first phase of modern Lake Erie known as Early Lake Erie (Figure 12). The final lowering occurred as a channel incised northward across the Fort Erie-Buffalo and Niagara Falls Moraines and down to the underlying Onondaga limestone at Buffalo, New York. This channel became the southern part of the Niagara River. The Onondaga limestone now serves as a threshold for present Lake Erie. Rather than continuing to flow north, the water spilled into the east-west trending Lake Tonawanda which subsequently spilled through drainage channels that opened across the Niagara Escarpment east of Buffalo as the ice retreated farther north into the Ontario Basin. Because of the loading of

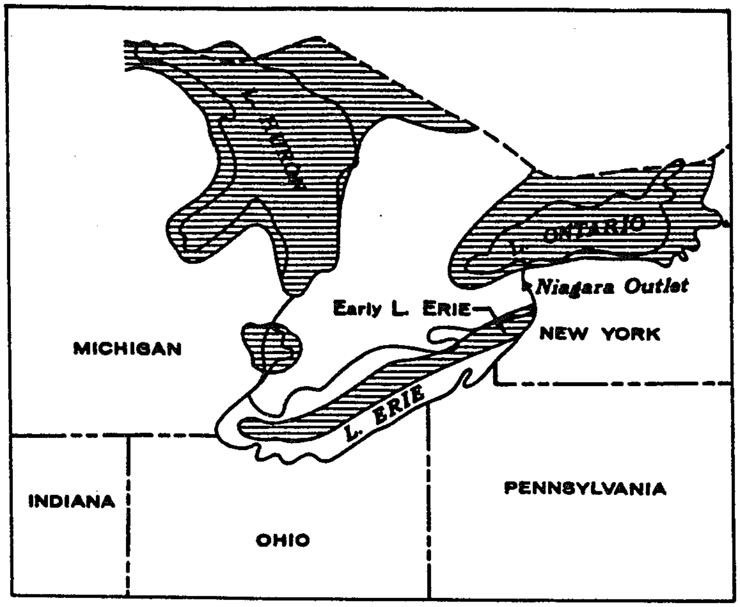


Figure 12. Location of Early Lake Erie. The Niagara River outlet was at least 120 feet lower than today. Note the possible position of the ice margin in Ontario, Canada (from Schooler, 1974).

glacial ice, the Onondaga limestone threshold at that time was 120 feet below its present level and that of the present Lake Erie datum of 570 feet. This places the level of Early Lake Erie over 120 feet below present Lake Erie! ^{14}C dates from organic material found in sediments associated with Early Lake Erie places its age between 12,650 ± 170 yr B.P. and 12,080 ± 300 yr B.P.

Present Lake Erie

Glacio-isostatic uplift of the Onondaga threshold successively raised lake levels to about 12 feet below Lake Erie datum of 570 feet by 3,500 yr B.P. Continuous glacio-isostatic response of that threshold has resulted in the present datum of 570 feet (Figure 13).

Some Points of Controversy in Lake Erie Basin History

1. The eastern margin of Lake Maumee III may have been the Ashtabula Moraine (Fullerton, 1980; Totten, 1982) or the Girard Moraine (Schooler, 1974).

2. Lake Arkona may have occurred before Lake Whittlesey rather than after.

3. Lake Whittlesey strands may have been mapped upon sediments that are not beach deposits.

4. Lake Warren III (lowest) may have drained eastward along the Mohawk Valley rather than westward through the Grand River Valley in Michigan.

5. Some evidence suggests that Lake Erie may have been higher than its present level within the last few thousand years (Coakley and Lewis, 1985; Barnett, 1985; Larsen, 1985).

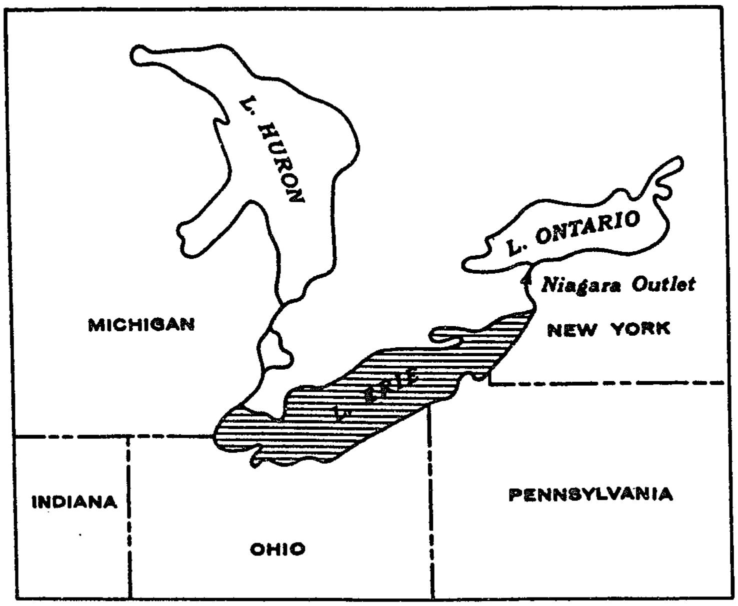


Figure 13. Present Lake Erie. Datum approximately 570 feet (from Schooler, 1974).

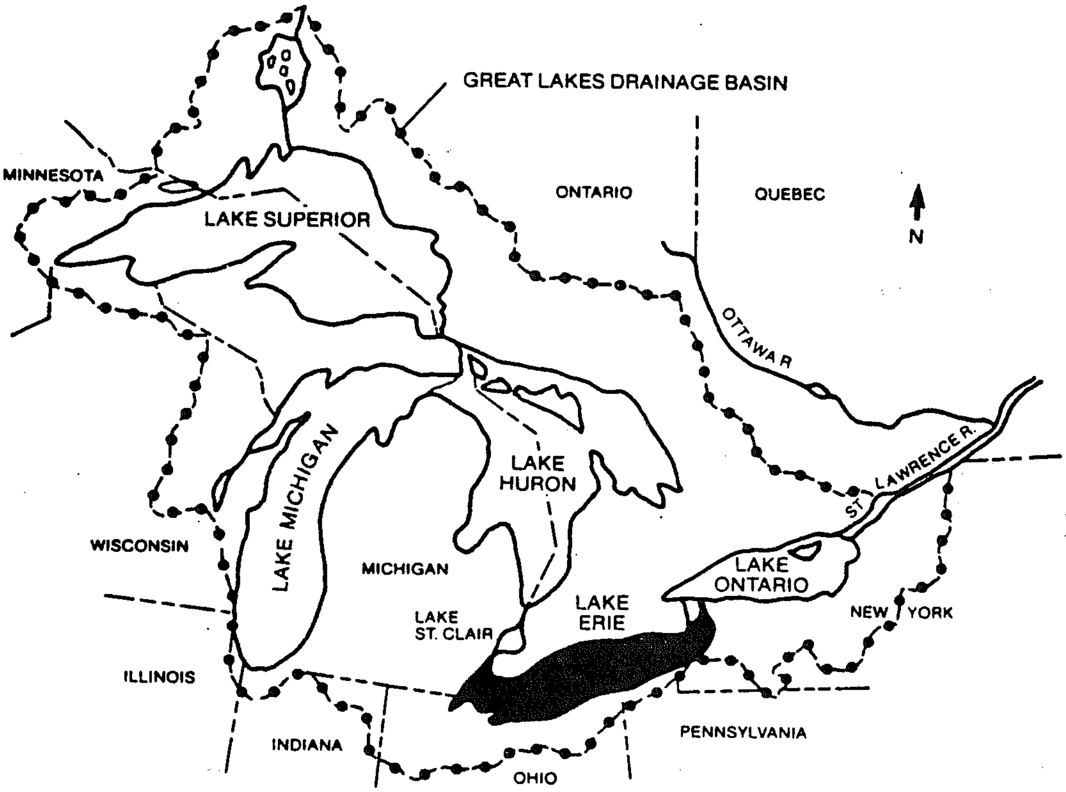
CURRENT LEVELS OF LAKE ERIE

The five lake system of the Great Lakes Basin, with almost 100,000 square miles of water surface, and twice that amount of land draining to it, extends some 2000 miles from the western end of Lake Superior to the Gulf of St. Lawrence on the Atlantic Ocean (Figure 14). These lakes are connected by rivers and channels in a stair-case fashion falling some 600 feet to sea level (Figure 15).

Two of the five lakes, Lakes Superior and Ontario, are regulated. The term "regulated" means that man-made structures control the outflows from these two lakes (Figure 15). Operation of the structures is for the purpose of providing adequate channel depths and velocities for commercial navigation. Lakes Michigan, Huron, and Erie are not affected to any great degree by the regulation of the waterway draining Lake Superior (U.S. Army Corps of Engineers, 1987).

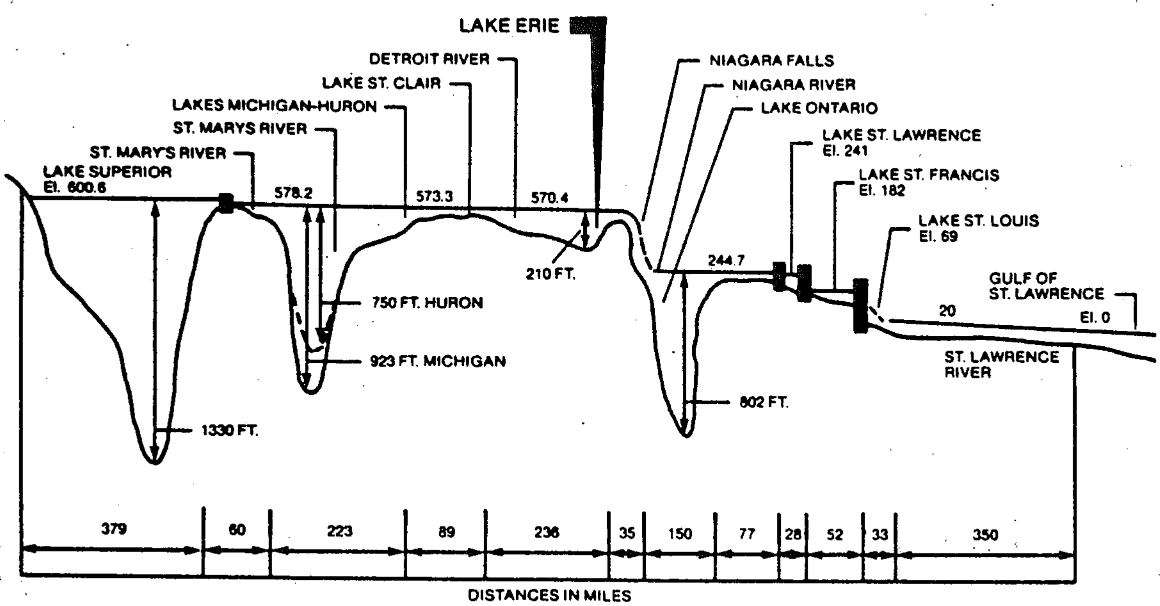
Lake Erie is the shallowest of the Great Lakes and has the second smallest surface area (Figure 16). The factors that control the level of Lake Erie are precipitation, evapotranspiration, and runoff within the basin. Other controlling factors are water flowing into Lake Erie through the Detroit River from Lakes Superior, Huron and Michigan; the outflowing discharge through the Niagara River, and the amount diverted through the Welland Canal system connecting Lakes Erie and Ontario. The outflow through the Niagara River channel is controlled by its natural width and the elevation of the Onondaga limestone that serves as a threshold near the Peace Bridge at Buffalo, New York (Figure 17). The lake's northeast-southwest orientation, coupled with similar prevailing wind patterns, results in frequent movement of water from one end to the other. During severe storms the difference in level between Toledo and Buffalo has been greater than 10 feet (U.S. Army Corps of Engineers, 1987).

Hydrographs have recorded natural lake-level changes since 1860. These changes can be divided into three types: short term, a few days or less; medium



GREAT LAKES — ST. LAWRENCE RIVER DRAINAGE BASIN

Figure 14. Great Lakes-St. Lawrence drainage basin (from U.S. Army Corps of Engineers, 1987).



PROFILE OF THE GREAT LAKES
ST. LAWRENCE RIVER SYSTEM

Figure 15. Profile of the Great Lakes-St. Lawrence River system (from U.S. Army Corps of Engineers, 1987). Black rectangles along the profile indicate the location of man-made control structures.

LAKE ERIE FACTS

Water surface area (about 1/4 of the size of Ohio)	9,910 sq. miles
Land drainage area (parts of Ohio, New York, Michigan, Pennsylvania, Indiana and Ontario)	23,600 sq. miles
Average depth	62 feet
Maximum depth	210 feet
Maximum monthly mean level	573.7 feet
Minimum monthly mean level	567.5 feet
Shoreline (U.S.)	431 miles
Shoreline (Canada)	368 miles
Width (North-South)	57 miles
Length (East-West)	241 miles

Water levels are based on International Great Lakes Datum (1955)

Figure 16. Lake Erie facts and figures.

term, within a year; and long term, over a few years or more (Carter and Guy, 1983). Short term changes result from wind setup, barometric pressure, and seiche activity and are most pronounced at the extreme ends of the lake. Medium term changes are seasonal and lakewide caused by varying rates of runoff and evapotranspiration. Lake Erie shows a high lake level during June and July and a low during January and February. The mean difference in water elevation between these two periods is 1.2 feet. Long term changes are caused by changes in weather patterns over long durations of time. Among the related factors affected by those changing patterns are precipitation, temperature, cloud cover, evapotranspiration, and runoff. Data collected by the Great Lakes Basin Commission in 1975 indicate that diversion structures in Lakes Superior, Michigan, and the Welland Canal system have had the net effect of lowering the level of Lake Erie by 3 inches (Carter and Guy, 1983).

Hydrographs indicate that the lake level has fluctuated between high and low episodes that are in no way periodic or predictable (Figure 18). Most recently, there has been a net rise since 1967 from the mean of 570.5 feet to a record high of 573.70 in June of 1986 (Figure 19). This has resulted in increased rates of shore and lake bluff erosion. The value of land and structures either lost or damaged runs to many millions of dollars. As of June, 1987 the level has lowered to 572.8, a drop of nearly 1 foot since June, 1986. This is the result of less winter and spring precipitation in the Great Lakes basin to the west of Lake Ontario.

WIND AND WAVE CLIMATE

The location of Erie just south of the convergence zone of several major North American cyclone tracks is such that most high winds in the area blow from the west-southwest (Nummedal, 1983). The maximum fetch, or distance across open

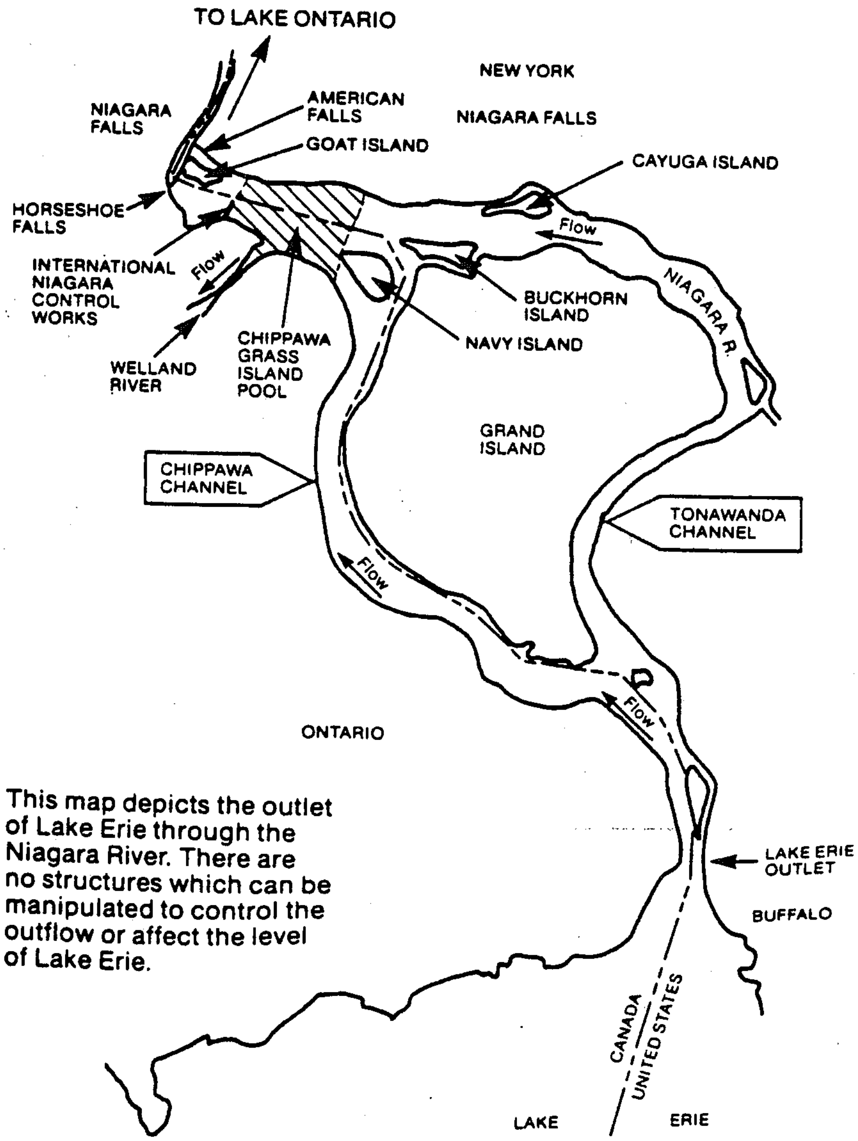


Figure 17. Lake Erie outlet near Peace Bridge at Buffalo. The elevation of the Onondaga limestone threshold controls the level of the lake here (from U.S. Army Corps of Engineers, 1987).

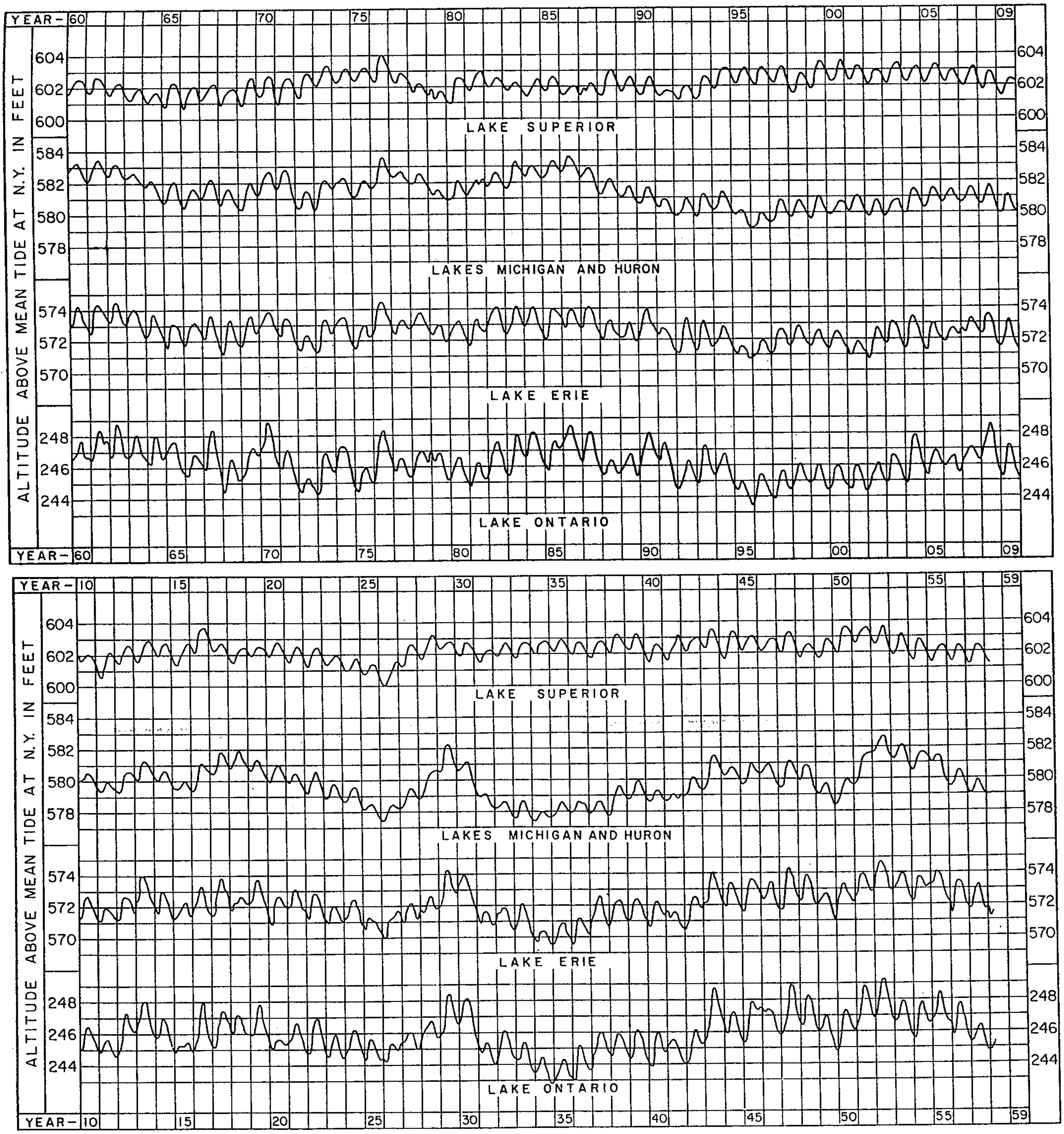


Figure 18. Charts of monthly mean water levels in the Great Lakes: 1860 to 1958 (from Hough, 1958).

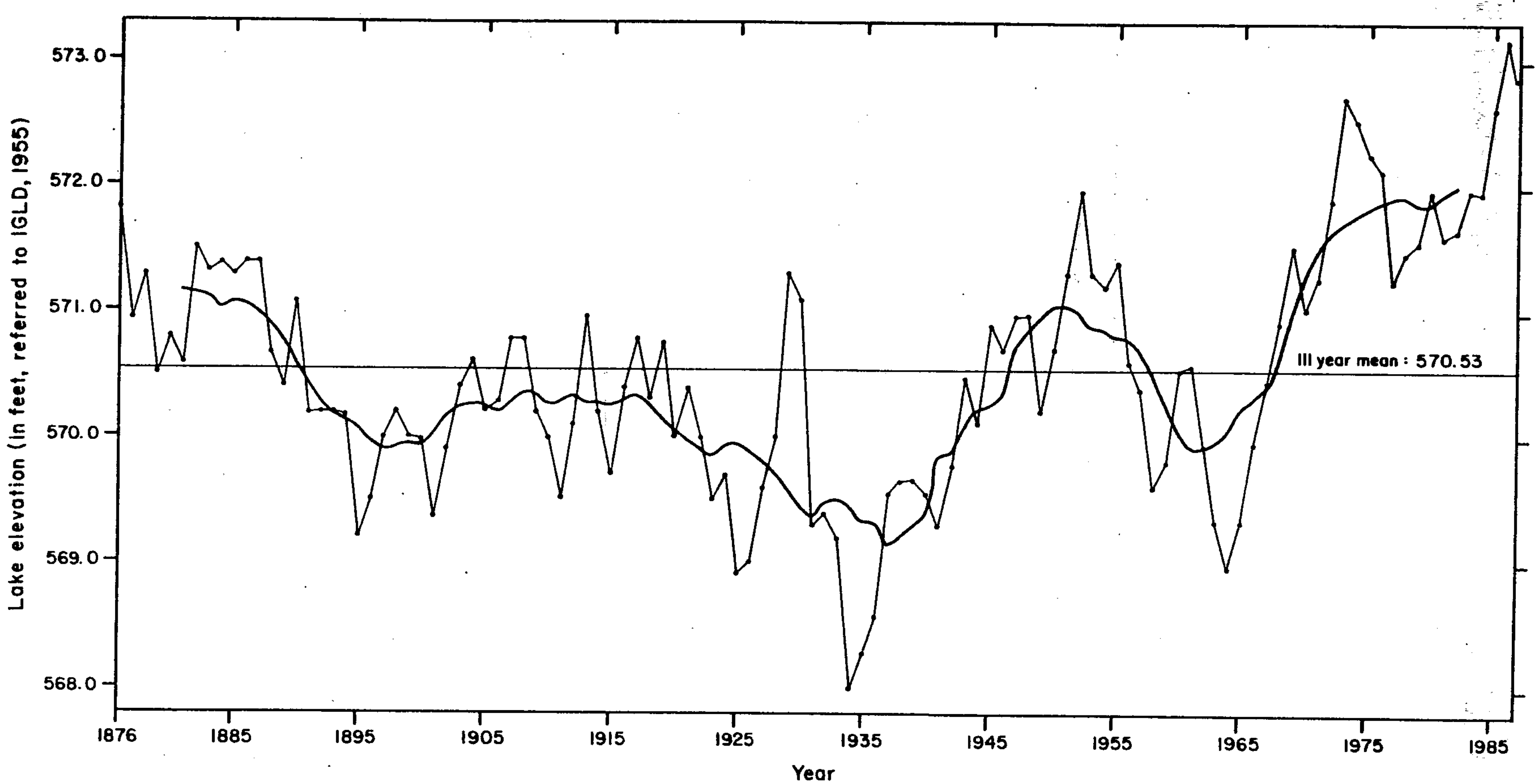


Figure 19. Average water level for Lake Erie, 1876-July 1987. Mean lake level is 570.53 feet. The record low was in 1934 at 568 feet. The record high was 573.19 feet in June, 1986. Data for 1876-1959 is interpolated from Carter and Guy (1983) and may be up to 0.1 foot in error at each point. Data from 1960-1987 is from U.S. Dept. of Commerce, NOAH-NOS, Rockville, MD and is for Cleveland, OH. Zero datum for Lake Erie is 568.86. Smooth curve is drawn from 11 year moving mean lake height calculated for each year.

water, for the Presque Isle shore is also west-southwest (Figure 20), so the dominant waves and maximum wave power impinge on Presque Isle from the west. This is consistent with the observed net eastward transport of sediment along the shore, as determined from the morphology of Presque Isle and features along the "mainland" shore. Less common north and northeast winds, occurring when low pressure areas pass south of the lake, are also an important factor, especially for their effects on the eastern end of Presque Isle.

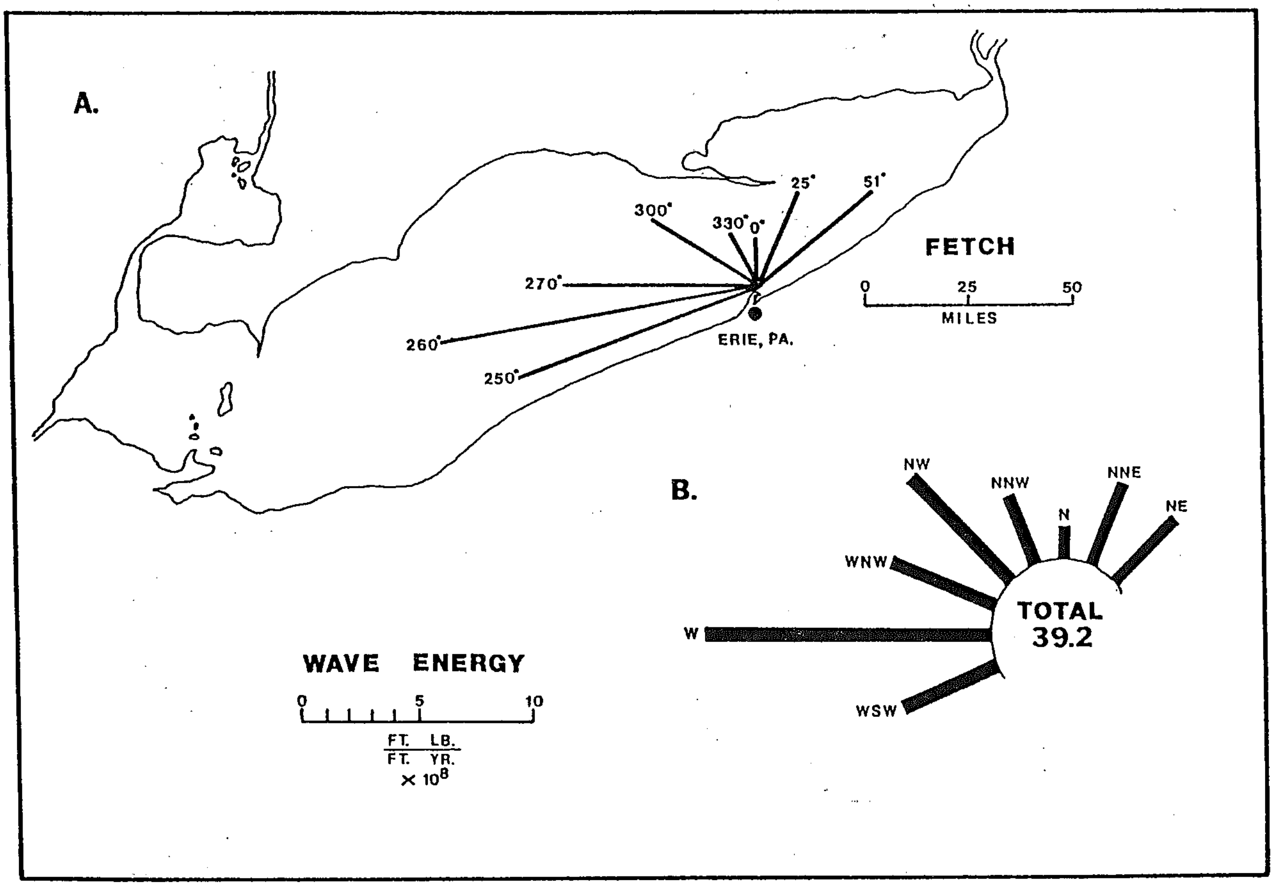


Figure 20. Relationship between fetch and wave energy flux for Erie, Pennsylvania (from Walton, 1978).
(A) Fetch diagram for Lake Erie with respect to Erie, Pennsylvania. Bar lengths are proportional to the fetch along each azimuth.
(B) Summary of the annual wave energy flux for Erie, Pennsylvania. The principal direction of wave energy flux is from the west. Note the close correlation between the directions of maximum fetch and maximum wave power.

No long-term wave-gauge records exist for eastern Lake Erie. All available wave climate information for the Presque Isle area has been hindcast from meteorological records (Saville, 1953) (Figure 21), or is based on discontinuous observations. The wave conditions on Lake Erie are storm dominated. The lake is calm, waves less than 0.15 m (0.5 ft), approximately 62 percent of the time. The calm is interrupted by higher energy events of short duration. The wave climate is also strongly seasonal, with most storms occurring in late fall, winter, and early spring.

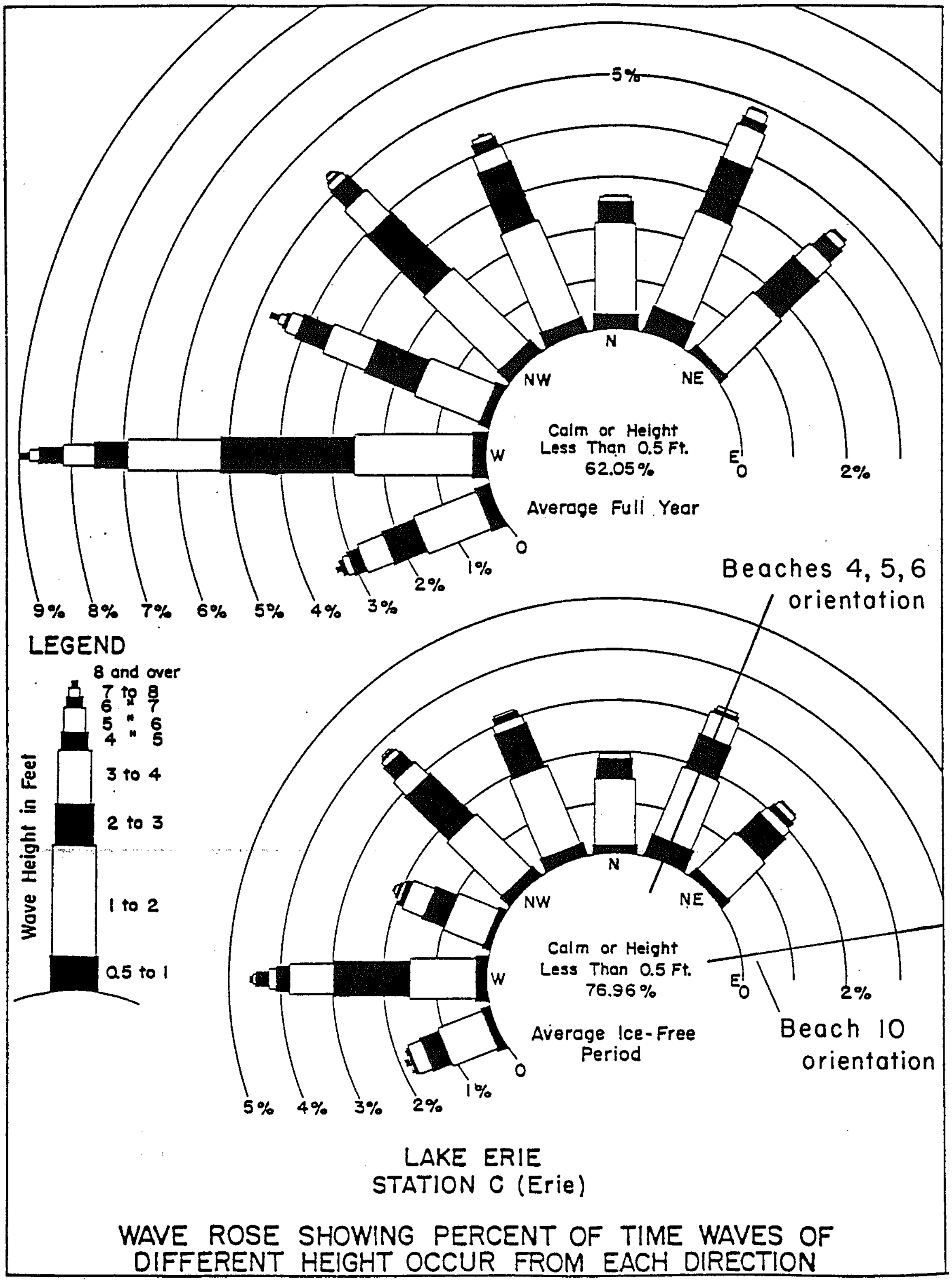


Figure 21. Wave roses showing percent of time waves of different height occur from each direction at Erie, Pennsylvania. Compare the full year conditions to the ice-free period (from Saville, 1953, with Presque Isle beach orientations added).

Existing observations and hindcast data agree that the largest waves along the shore in eastern Lake Erie are 3.7 to 4 m (12 to 13 ft) high (Nummedal, 1983). All waves larger than 2 m (7 ft) come from directions between west-southwest and west-northwest.

Winter conditions on Presque Isle typically include ice cover on the lake and along the shore from December to March. Ice cover formed from spray and lake ice pushed into ridges along the beach and offshore bars protect the beaches during much of the stormy part of the year. The limited time when storms and ice-free conditions occur together combines with normal seasonal high lake levels to concentrate high energy waves on the beaches in November, April, and May.

Summer wave conditions are typically calm, but waves of up to about 0.9 m (3 ft) can occur during "non-storm" weather. These waves can have a significant effect on the beaches, especially if southwest or northeast winds persist for several days.

Weather also affects the short term fluctuations of lake level. Onshore winds and low atmospheric pressure commonly lead to lake levels several feet above normal. The position of Presque Isle on the lake shore is such that high wind set-up levels and high energy waves usually occur together.

PRESQUE ISLE

Presque Isle is the only major depositional sedimentary feature on the south shore of Lake Erie. It is a compound recurved spit which forms the protective barrier for Erie Harbor. The name is French for "almost an island" - equivalent to the Latin derived "peninsula". In local usage, Presque Isle is commonly referred to as "the peninsula". Presque Isle extends roughly parallel to the northeast trending mainland shore about 6.25 miles into the lake from a narrow connection with the mainland just west of the city of Erie. The lakeward perimeter is about 9 miles, to where the recurved end is separated from the mainland by a dredged navigation channel. Across the lake, Presque Isle is mirrored by the similar, but larger sand spit at Long Point, Ontario (Figure 22).

The neck which connects the main body of the spit to the mainland is about 229 m (750 ft) wide, and nearly 3 miles long (Figure 23). The peninsula widens eastward to a maximum width of about 1.3 miles. The main body of the spit is made up of a series of dune ridges and interdune ponds and marshes, which overlie spit platform and beach sands. Elevations are generally less than 2.4 m (8 ft) above lake level except on the four major dune ridges where relief exceeds 6 m (20 ft).

The harbor sheltered by Presque Isle has allowed the development of the city of Erie as a port and manufacturing center, and is the only natural harbor on the Pennsylvania shore of Lake Erie. Oliver Hazard Perry built his fleet in the protected harbor, and returned to it after his victory in the Battle of Lake Erie in 1813. Presque Isle's more recent fame is as a recreational facility. It has been a state park since 1922, and offers year-round activities, although the beaches and boat launching facilities are the major features for most visitors. Presque Isle is the most heavily visited state park in Pennsylvania, and annual visitor numbers exceed those of any U.S. National Park except Great

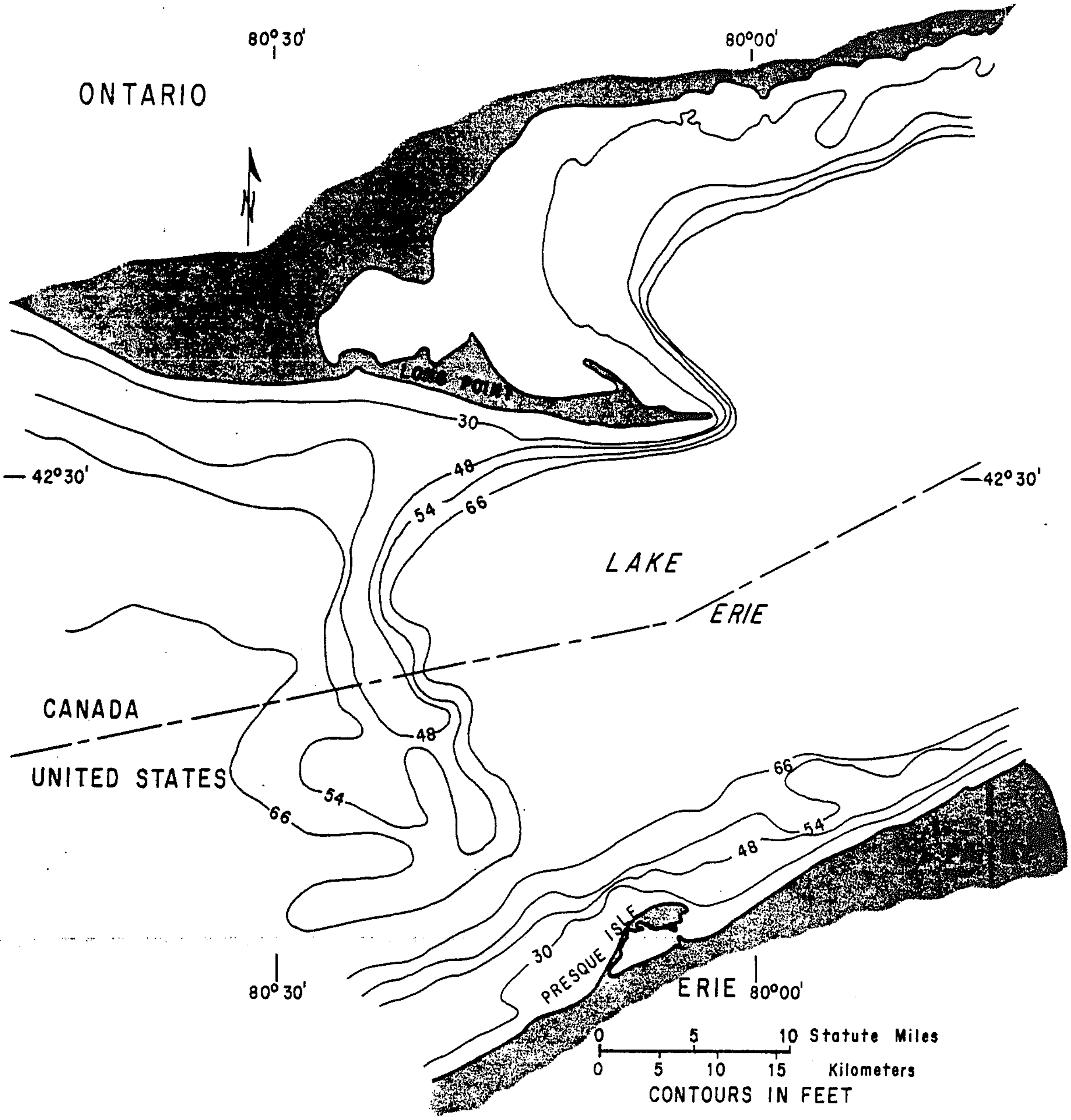


Figure 22. Map of the central Lake Erie basin showing the traverse ridge that connects with Long Point and projects toward Presque Isle. (from Williams and Meisburger, 1982).

Smoky Mountains. The location in the "backyard" of a major city is a contributing factor, but more than half of the park's 4 to 5 million annual visitors come from outside Erie County (Masteller and Baxter, 1985).

The unusual geological conditions support an equally unusual biological community. The park contains a large number of rare and endangered plant species and a diverse fauna. It is noted as a place to observe biological succession across changing environments. Many varieties of shore birds and other migratory birds make use of the park area. The wide variety of aquatic environments of the lake, harbor, and inland ponds are important parts of the fish and bird habitats.

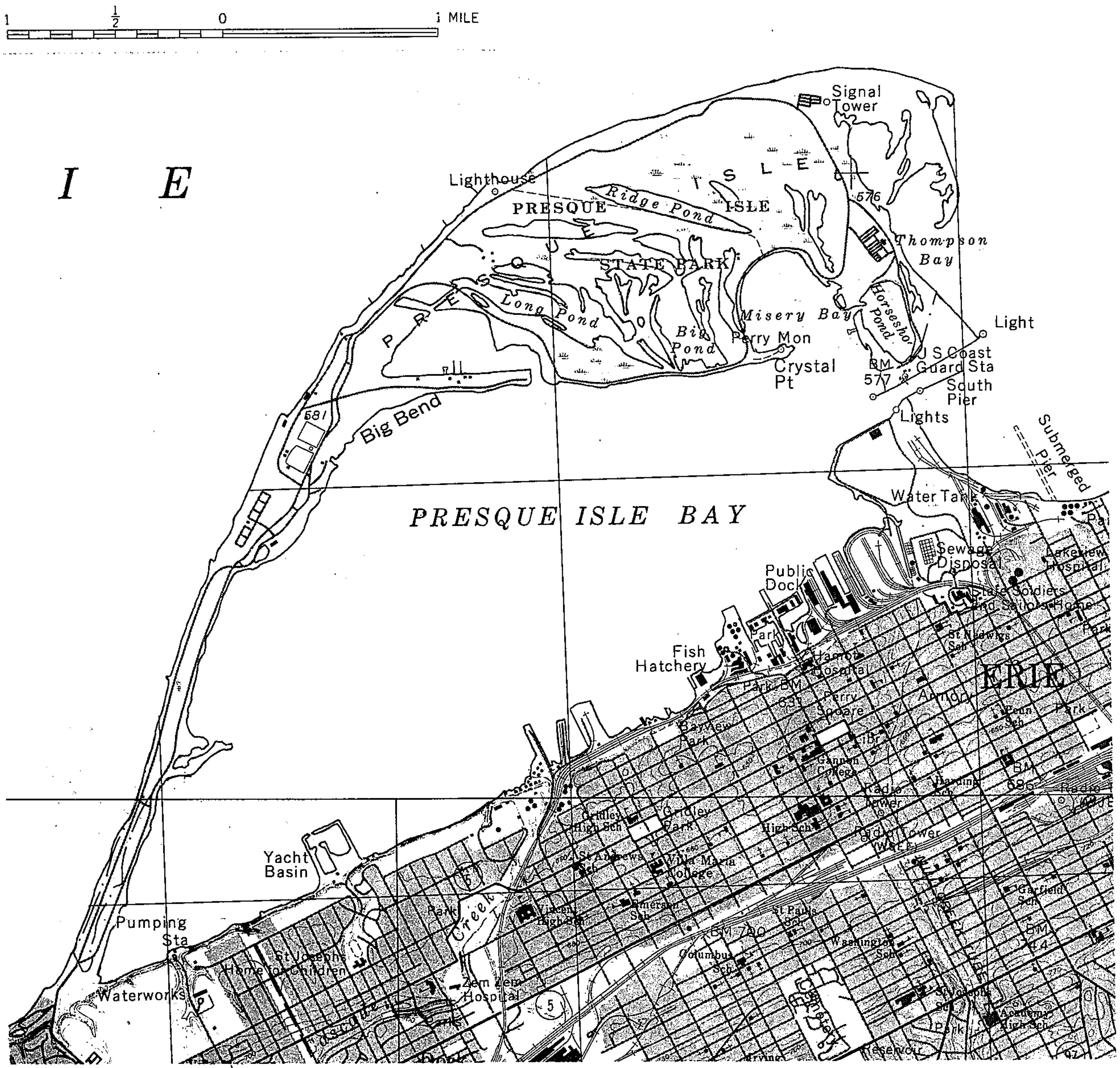


Figure 23. Topographic map of Presque Isle and vicinity (from Erie County, PA 1:50,000 scale map series).

The exact origin of the peninsula is unknown, but is probably related to the existence of a 12 mile long platform about 9 m (30 ft) below modern lake level (Figure 24). The platform is probably related to the transverse ridge, which separates the central and eastern basins of the lake (Figure 22). This ridge consists of morainal sediments mantled by wave and wind sorted sand and gravels (Williams and Meisburger, 1982). One plausible explanation is that Presque Isle developed as rising lake level caused the shoreline to migrate across the platform. Waves reworked available loose sediment which may have been (1) remnant from earlier higher lakes, (2) brought down from uplands by streams, or (3) original glacial material from the platform.

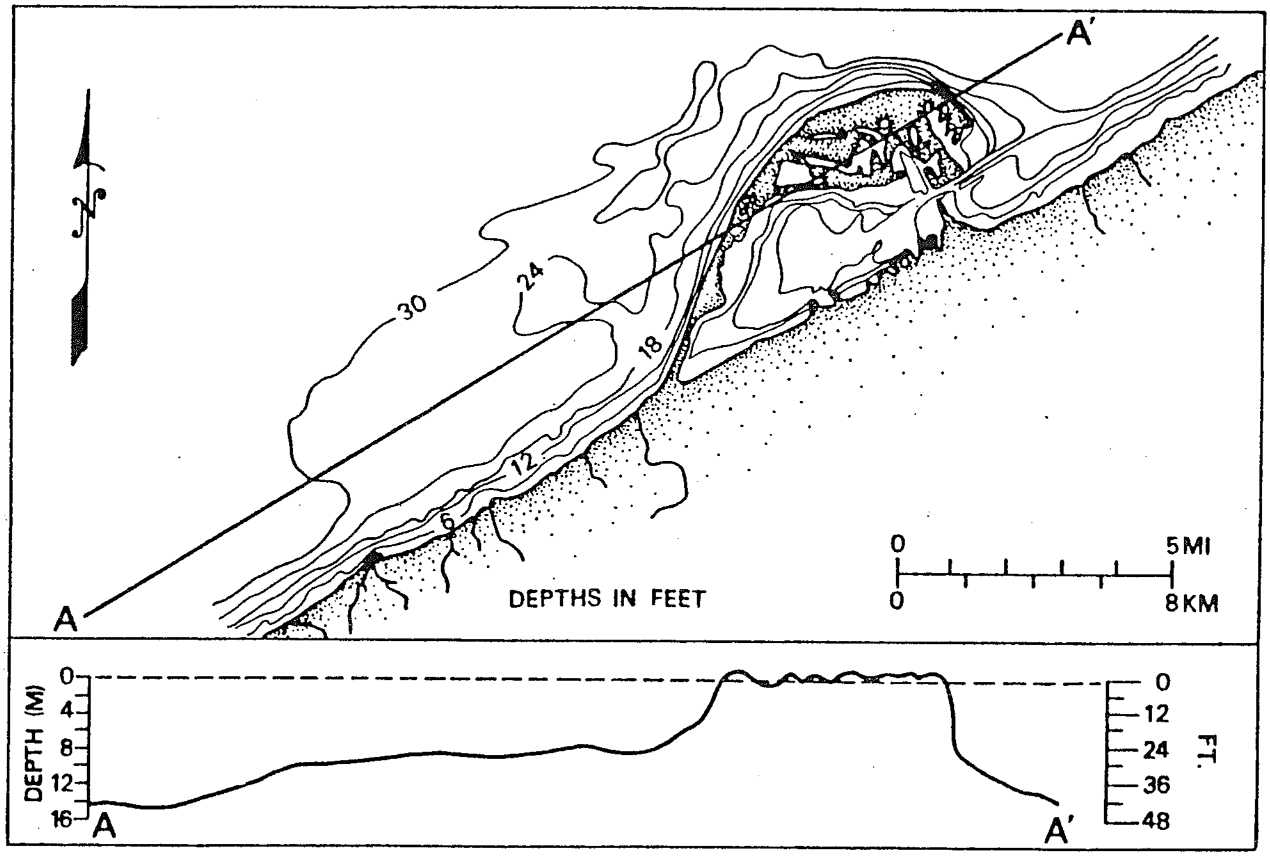


Figure 24. Bathymetry of the lake area surrounding Presque Isle, showing the platform on which the spit is built (from Nummedal, 1983).

Whatever its origin, Presque Isle is known to have a history of migration. The pattern of beach ridges and ponds suggests that the peninsula has moved northeastward by repeated development and accretion of beach ridges at the eastern end, and erosion of earlier deposits along the western edge. Jennings (1930 and 1960) calculated growth rates for the peninsula from historical records (Figure 25) and botanical evidence. He dated the area near the waterworks at 600 years and calculated an average growth rate of 0.5 mile/100 years. Further evidence for the migration of the spit is that there is no apparent difference in the shoreline trend inside Erie Harbor compared to that to the east and west. If Presque Isle had been a static feature for a significant period of time, the harbor bluffs should show evidence of having been protected from erosion and bluff retreat. Migration rates have probably varied with lake level and sediment supply, and are affected by the need for the spit to build the platform into relatively deep water as it migrates (Figure 24).

The bedrock surface is very close to lake level all along the Pennsylvania shore of Lake Erie, and slopes gently offshore under the lake. Logs of two gas wells on the peninsula indicate bedrock under Presque Isle at depths of 34.7 and 35.7 m (114 and 117 ft). Figure 26 shows the topography on the bedrock surface in the vicinity of Presque Isle. The gas well logs also indicate "fire clay" or "gray clay" over the shale at depths of 11.3 and 18.9 m (37 and 62 ft). This presumably is the diamict making up the platform on which the spit is developed.

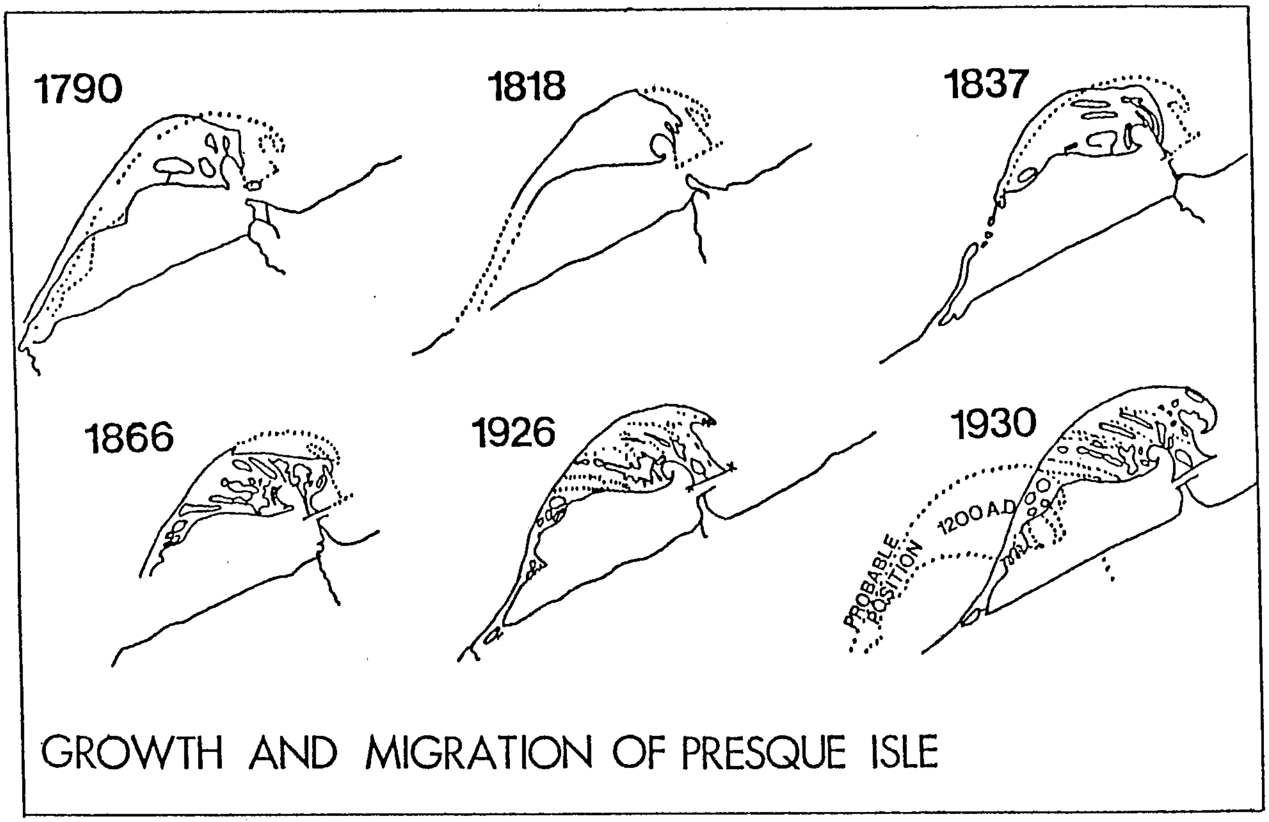


Figure 25. Growth and migration history of Presque Isle, determined from historic maps (from Jennings, 1930).

The bulk of the material on the beaches of Presque Isle at present reflects the long and complex history of beach nourishment rather than the natural sediment supply. This history is discussed later in this section. Personal recollections of long-term Erie residents indicates that the beaches normally had a storm or winter berm (littoral zone terminology is illustrated in Figure 27) composed of shingle above the sandy summer berm. Monitoring wells drilled around the new septic systems at several of the bathhouses found mostly well sorted fine sand, with minor amounts of fine gravel, cobbles up to 15 cm (6 in.), and a few layers of highly organic silt and clay.

The modern sediment transport system at Presque Isle is a very dynamic one. A few recent geological studies have begun to determine the major features of this system, but the details are still poorly known. Most of the following discussion of sediment transport and offshore morphology is derived from the work of Dag Nummedal, Kent Taylor, and David Sonnenfeld.

Nummedal (1983) presents sediment budget figures for Presque Isle based on observed and calculated total sediment inputs, accretion at Gull Point, and dredging at the harbor mouth. The relative potential sediment transport rates for five segments of the shoreline were calculated from wave power figures hindcast from meteorological data, and supplemented by some direct wave observations. Combining these two sets of figures yielded the sediment budget summarized in Figure 28. The shore-parallel arrows and accompanying figures indicate net longshore transport between sections; the on and off shore arrows indicate net erosion (off shore arrow) or net accretion (on shore arrow) within

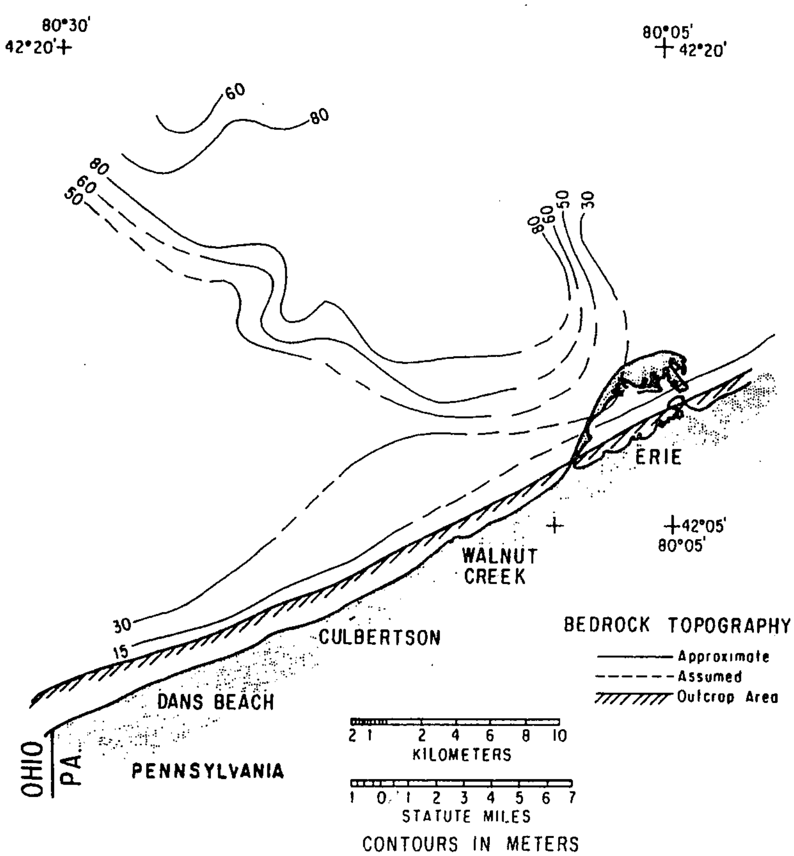


Figure 26. Bathymetry of the bedrock surface under Lake Erie near Presque Isle (from Williams and Meisburger, 1982).

a section. The sediment budget figures indicate net erosion increasing eastward in a zone from the west end of the neck to the vicinity of the lighthouse (areas I, II, and III in Figure 28); a transition zone from near the lighthouse to about Beach 10 (area IV), where transport greatly exceeds net deposition; and a zone of net deposition in the area east of Beach 10 (area V). These three zones, based on sediment budget, are consistent with observable geomorphic changes along the shore of the peninsula.

The active sediment transport area includes the nearshore zone out to a depth of at least 3.7 m (12 ft) as well as the beach face and backshore up to the vegetation line.

The zone of net shore erosion includes the neck of the peninsula and the area of eroding older beach and dune ridges about as far east as the lighthouse. The above-water section of the beach in this area is largely artificial, due to the large amount of beach nourishment material that has been placed here in recent years. Large summer storm waves cut into the nourishment material, leaving steep scarps near the water's edge. The width and steepness of the beach face is generally a factor of wind and wave conditions since the annual

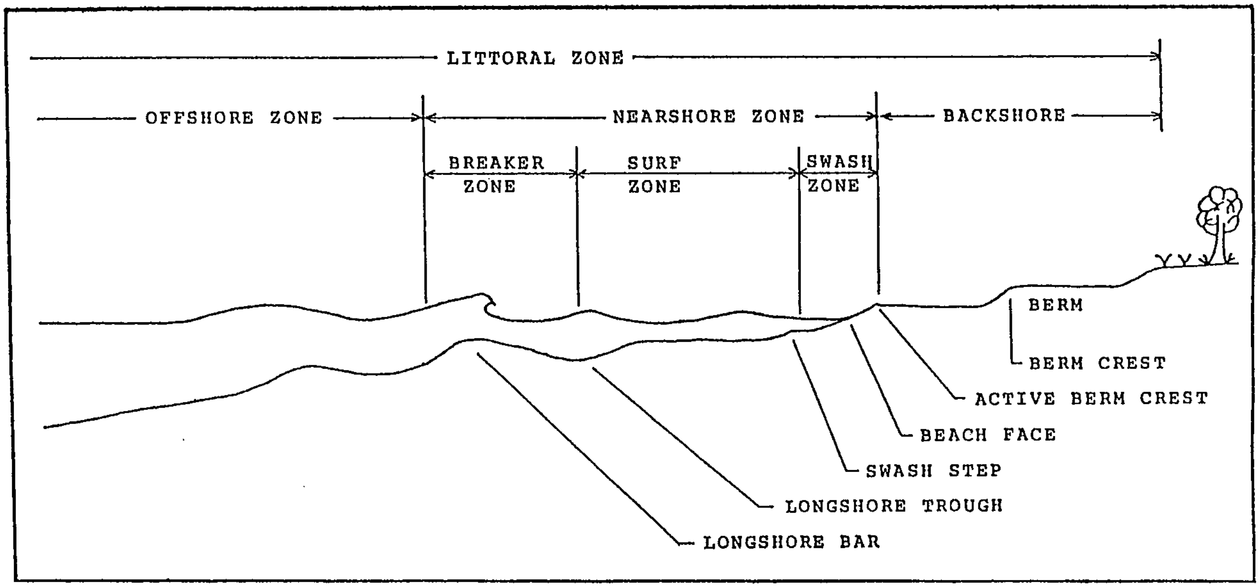


Figure 27. Littoral zone terminology (from Walton, 1978).

spring nourishment. A series of 11 groins have been built along the neck up to Beach No. 6, and a variety of groins and other structures affect the shore eastward from there. The shoreline is typically offset at each groin, sometimes by 15 m (50 ft) or more.

The backshore rarely changes much after the spring placement of sand until fall and winter, when storm waves frequently wash over the normal berm and cause the beach to migrate back into the low dune area. The shore road along the northwest edge of the peninsula is almost completely blocked by sand every winter. Remnants of the winter washovers can usually be seen partly burying the trees along both sides of the shore road. Normal "summer" waves move some sediment along the beachface by swash processes, but most of the longshore sediment transport occurs in the nearshore zone, in a complex system of nearshore bars. Nummedal, Sonnenfeld, and Taylor (1984) describe two sets of bars along the zone of net erosion. The inner bars are highly variable, and less than 91 m (300 ft) from shore. Within the groin field, the inner bars are deflected lakeward at each groin. Plan form of the bars is linear or crescentic. The crests of these bars are at depths of 0.9 to 1.4 m (3 to 4.6 ft), and bar relief may be as much as 0.9 m (3 ft). East of Beach No. 6 and the groin field, the inner bar system is generally straight and fairly continuous. Nummedal and Sonnenfeld (1983) determined that sediment on the inner bars moves lakeward into the trough during moderate wave conditions, and that the inner bars are removed by storm waves.

The outer bar system, from the neck to the lighthouse area, is one continuous, permanent outer bar. The inner and outer bar systems merge near the point where the neck connects to the mainland shore, and a single bar occurs along the mainland shore. (Nummedal and others, 1984). Along the peninsula the outer bar is from 152 to 204 m (500 to 670 ft) offshore. The depth at the bar crest is typically 3 to 3.9 m (10 to 13 ft). The trough landward of the bar is about 4 to 4.9 m (13 to 16 ft) deep. Bathymetric profiling suggests that sand moves between the beach and the offshore bars seasonally and in response to storms (Nummedal and Sonnenfeld, 1983). During storms, net sediment movement is

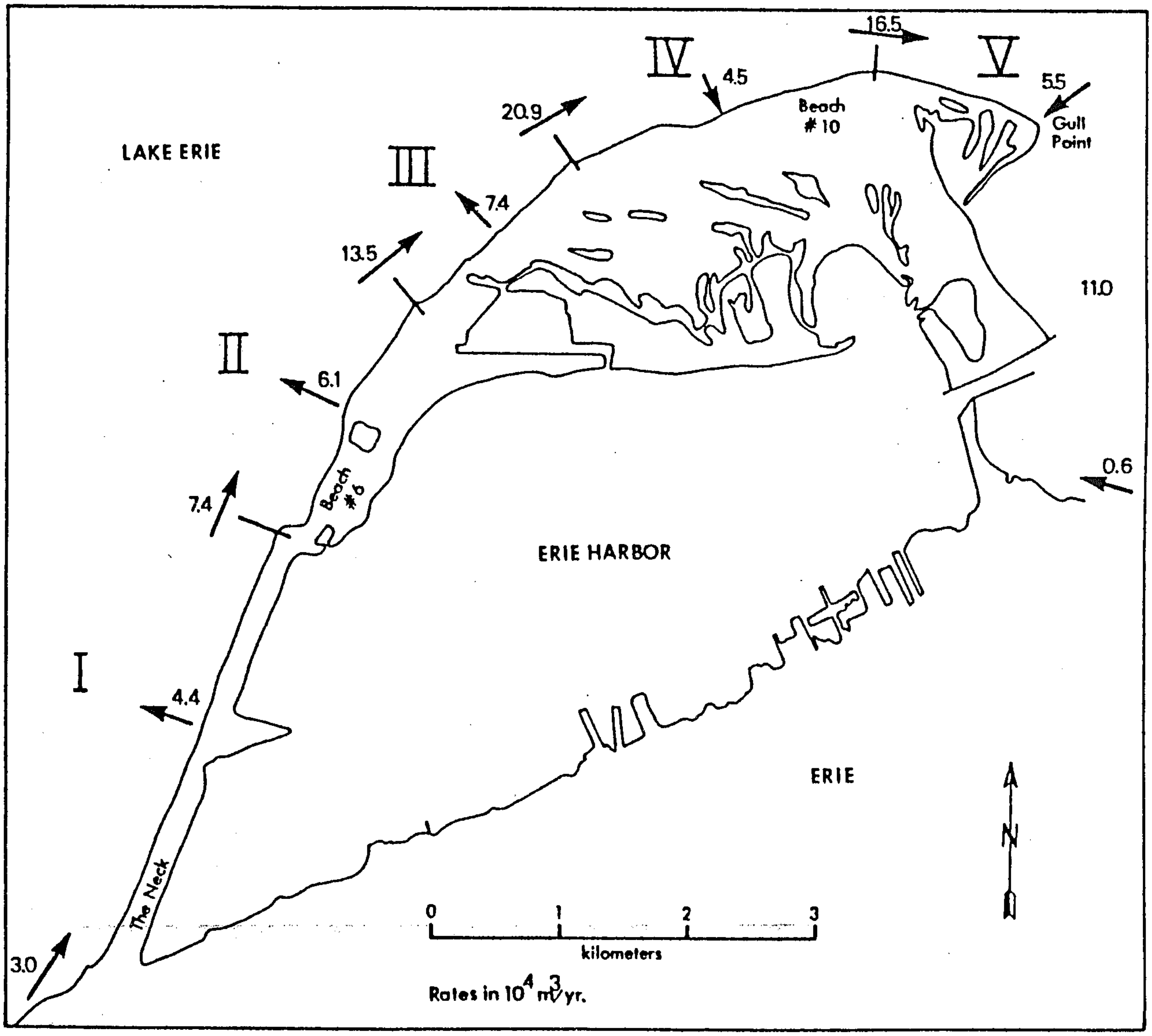


Figure 28. Calculated rates of sediment transport, erosion, and accretion along the Lake Erie shore of Presque Isle. The budget was derived from the distribution of wave power, historical accretion rates at Gull Point, and Erie Harbor dredging records.

offshore. During fair weather, sand moves landward from the crest of the outer bar into the adjacent trough. Most of the sediment transport probably occurs primarily through a combination of inner and outer bar migration and longshore current transport in the troughs along the outer bar.

The sediment transport conditions in the bars and troughs along the neck produce a net offshore and downdrift movement. The bulk of sand movement occurs from the beach to the system of bars and troughs, and little if any sediment returns to the shore in this area.

East of the lighthouse, the bar system is more complex, reflecting the supply of sediment from the neck area, and also the relatively rapid transport of the material through this area to the accretionary Gull Point Complex at the east end of the peninsula. Between the lighthouse and Beach No. 10, the nearshore slope is gentle, and has multiple parallel longshore bars and transverse bar components. The typical shoreline pattern in this area is one of eastward migrating depositional "megacusps", with local erosion in the embayments between the megacusps. The processes described above supply a large volume of sediment to the shoreface here, and wave energies are generally lower, because of the orientation of the shore.

East of Beach No. 10, net deposition of sediment is the dominant factor in shaping the shoreline. Much of the deposition occurs as the subaqueous platform grows eastward into the lake. The steep offshore slope east of Gull Point indicates that the platform is migrating into deep water ahead of the subaerial portion of the spit (Figure 24). Spit growth occurs largely because of bars forming on the platform and migrating eastward across it. One theory of spit growth postulates that the occasional northeast storm winds drive the offshore bars back toward the shore. As a bar nears shore, the northwestern end typically attaches to the shore, and a new beach ridge may be formed. If it is not destroyed, the new ridge may be stabilized by development of grasses and other vegetation, and later small trees. These help to trap windblown sand, building a dune ridge on top of the beach ridge. This process can be observed at the east end of the spit (Messinger, 1977), and is presumably responsible for the development of the series of older beach and dune ridges evident on the peninsula today.

At present there are three natural sources of sediment to the peninsula: (1) input from streams, (2) erosion of bluffs updrift of the peninsula, and (3) migration of sediment from offshore. The harbor protection structure at Conneaut, Ohio extends into the lake far enough to effectively cut off any significant longshore sediment migration from Ohio into Pennsylvania. Six streams enter the Pennsylvania portion of the lake west of Presque Isle. These have all eroded down through the glacial deposits, and flow on bedrock floors. Mass wasting of valley walls and erosion by tributary streams supply glacial sediment to the streams. The stream mouths have been drowned by the rise in lake level, and at normal flow they probably contribute only suspended load. Most have well developed gravel and cobble beaches and bars at the mouth, and transport locally derived cobbles during periods of high discharge. Although movement of the bedload is sporadic, it is believed to supply a significant volume of sediment to the shore. No information is available on quantities of suspended and bedload sediment supplied to the lake by the streams.

Erosion of the unconsolidated bluffs is the other source of sediment to the longshore drift. Carter (1977) measured long term bluff recession rates of 0.15 to 0.6 m/yr (0.5 to 2 ft/yr). The U.S. Army Corps of Engineers (1980) used Carter's figures and measured bluff heights for various reaches to calculate sediment supplied to Presque Isle from the bluffs. They assumed an average figure of 29 percent of the bluff sediment coarser than a 200 mesh sieve (very fine sand size) as the proportion of bluff material available as beach sediment. A further assumption that 20 percent of the sediment in transport is lost to offshore yielded an estimate of 30,582 m^3 (40,000 yds^3) naturally supplied to Presque Isle from updrift bluff erosion.

There are no known offshore sources of sediment input to the Presque Isle system, and most of the offshore lake bottom is well below active wave base, thereby limiting possible onshore movement of sand and gravel.

Walton (1978) examined the gravel lithology of point bars in the streams, at stream mouth beaches, and along the shore to Presque Isle and found a decrease in the proportion of siltstone and shale. Shale was almost entirely lost in transport and siltstone decreased from 90-95 percent in the streams to 66 percent on Presque Isle.

On Presque Isle, occurrences of highly concentrated (up to 99 percent pure) heavy mineral sands are fairly common. Heavy minerals, dominantly magnetite and garnet, make up 10 percent of glacial deposits, and are sorted and concentrated by the transporting processes. Lowright (1973) and Lowright and others (1972) analyze some of the hydraulic and source area factors of heavy mineral distribution on Presque Isle. The heavy mineral concentrations occur as lag deposits on the backshore and concentrations in the swash zone.

Walton (1978) examined sediment on Presque Isle, including an analysis of gravel lithology and particle shapes. He found a general decrease to northeast in the gravel content of beaches, but this is locally interrupted by concentrations downdrift of groins. The gravel distribution is heavily influenced by storm activity. Crystalline cobbles tend to be spherical and concentrate offshore at the foot of the swash zone. Discoidal siltstone cobbles and pebbles are observed to accumulate at the landward edge of the swash zone, and appear to move downdrift more rapidly than the more spherical crystallines. After a storm, beach progradation accompanies a return of a (normal) uneven gravel distribution.

A series of studies on grain size and settling velocities (Lowright and others, 1972) determined that the sand generally became coarser eastward along the peninsula. This suggests that much of the finer grained sediment may be carried in suspension and lost to deeper water, but further work would be needed to confirm this idea.

The existing research on the sediment erosion, transport, and deposition along Presque Isle is a good beginning, but does not answer many of the important questions. Studies of seasonal changes, changes due to storms, and under fall, winter, and early spring conditions would add greatly to understanding the dynamics of this system. Times of high lake levels have been associated with increased erosion (Berg, 1966; Berg and Duane, 1968), but the long term effects of lake level fluctuations on the growth and migration of the spit are not known. All existing work has studied the system under artificial conditions, with the addition of beach nourishment sand and effects of shore protection structures.

The history of shore protection efforts on Presque Isle is summarized in Table 1. Over the 168 year history of engineering efforts to stabilize the peninsula, most of the types of structures and strategies ever devised have been tried. Seawalls, groins and jetties, stone filled cribbing, sheet pile walls, brush weighted with stones, breakwaters, "perched beaches", and tree plantings have been used to slow down the sand movement and maintain the harbor protection and land access to the beaches. In the early years, maintenance of the harbor for navigation was the justification for the expenditures of public money. Since the institution of the state park, recreational and environmental concerns have provided much of the impetus to protect the peninsula.

Table 1. History of shore protection efforts at Presque Isle. Compiled from various U.S. Army Corps of Engineers, Commonwealth of Pennsylvania, and individual sources (much from Pope and Gorecki, 1982).

1819 and 1823	Beach Erosion Studies by U.S. Army Corps of Engineers for improvement of harbor and harbor entrance.
1828-9	First recorded breach of peninsula, closed at cost of $7,390.
1832	Neck breached again, widened to 1 mile by 1835, efforts to close it failed. Plans were developed to maintain a 400-foot wide navigation channel. Cribwork, reinforced with piling and stone, was installed between 1836 and 1839.
1844	Breach reported as 3,000 feet wide. Four hundred seventy feet of cribwork built.
1853-6	Brush weighted with stone placed as shore protection.
1864	Opening closed by natural siltation. The new barrier was very low and subject to frequent washover. Tree trunks and brush were piled on the low area in 1865.
1871-3	Trees planted to stabilize neck. Pilings and brush weighted with stone were placed along neck.
1874	Third breach of peninsula. Closed in 1875 with pile and plank fence reinforced with rip-rap.
1876-79	Fence extended to total length of 6,547 feet. Fence was badly damaged in 1879 storms.
1880-83	Eight jetties were built 200 feet apart to lake depth of 6 feet. Two thousand feet of brush and stone shore protection built. Repairs, reinforcement and extension of earlier piling and plank fence. Total expenditures 1829-1883, approximately $220,000.
1887-89	All earlier construction reported rotten and broken down. Six thousand foot long sheet pile and timber pile breakwater 100 feet offshore was authorized. Forty five hundred feet had been built when a September, 1889 storm wrecked most of it, and project was abandoned.
1896-98	Trees planted along neck.
1900-03	Two timber crib and stone jetties built near waterworks area.
1916-17	Trees planted on neck.
1917	Neck breached in October storm, efforts to close breach were washed out by storm in December. The breach remained open and was large enough for small boat traffic at various times until closing in 1922 or 23.
1919-23	Sandfill, rubble mound, tree planting and rip-rap construction to close breach at cost of approximately $282,000.
1922	River and Harbor Act of 28 November transferred Presque Isle to the Commonwealth of Pennsylvania for park purposes.
1927-29	Six sand traps, 7 sheet pile groins, and 5,300 feet of sheet pile bulkhead built along lakeshore between the neck and the lighthouse.
1930-31	US government built over 5,000 feet of steel sheet pile bulkhead with stone facing, along the neck.
1931-37	State extended sheet pile bulkhead by about 3,500 feet and built 3 sheet pile groins.
1939	State built sheet pile bulkhead and repaired federally built jetties at cost of $44,000.
1943-44	Federal government repaired earlier works, added rubblemound facing to steel bulkheads, and constructed 2,750 feet of rubblemound protection at the root of the peninsula and 2 experimental rubblemound groins. Total cost was $1,041,700.

1946	Road in front of the lighthouse destroyed by erosion.
1947-52	Federal spending on repairs to protection works on Presque Isle totaled $443,100.
1948	The road was relocated shoreward of the lighthouse. A move to establish permanent protection for the peninsula was initiated. Estimated spending by Commonwealth of Pennsylvania from 1924 to 1948 was approximately $3,500,000.
1952	Storm waves washed over peninsula bringing sand into the bay. The neck was not actually breached. A 3,000-foot stone seawall was built along the neck.
1954	Establishment of cooperative beach protection program between the Federal government and the Commonwealth of Pennsylvania. The program continued until 1971.
1955-56	A total of 4,150,000 yd^3 of fine sand (0.20 mm median) were pumped onto the beaches from two areas along the bay shore. Ten new steel sheet pile groins were built, two existing groins were altered, and a damaged bulkhead section near the lighthouse was removed. Total cost (includes 1952 seawall) was $2,451,270. These sheet pile groins are still in place along the neck. The fine sand was finer than the natural beach material (0.35 mm median) and was quickly eroded.
1957-58	Three miles of snowfence placed along neck to stabilize windblown sand.
1958	Two thousand yd^3 of sand replenishment.
1959	Emergency sand replenishment at a cost of $24,000.
1960	Cooperative Federal-State agreement to participate in periodic nourishment for 10 years.
1960-61	A total of 681,467 yd^3 of sand pumped onto beaches at a cost of $500,000.
1963-64	Groins 4 and 11 repaired by placement of rock armor.
1964-65	Replenishment with 402,265 yd^3 of medium sand (0.75 mm median) pumped onto beach near Beach 6.
1966	Six groins modified with rock armor and 45,000 tons coarse sand placed between Groins 2 and 3.
1967-69	Severe erosion at Groin 8, downdrift of Groin 11, and at lighthouse groin. Placement of 102,700 tons of coarse sand.
1968	December storm with waves of 15 feet washed over the peninsula, carrying a large amount of sand into the bay area.
1971	Erosion threatened Beach 6 parking lot and bathhouse. Experimental 1,200-foot long barrier consisting of nylon bags filled with sand and cement was built. Placement of 118,000 yd^3 of sand.
1971-72	Winter storm destroyed 300 feet of road at Sunset Point. Road was reconstructed farther inland, concrete filled nylon bags were placed offshore from Sunset Point. Cement filled bags at Beach 6 replaced sand filled ones, sand replenished.
1973	Erosion and repair of road at Sunset Point. Emergency placement of 100,000 tons of sand along the neck. Rock rip-rap placed along the bayshore road between Marina Lake and Perry Monument.
1974	High lake levels and storms led to emergency placement of 45,000 tons of sand at Beach 6, construction of: 500 feet of stone revetment at Sunset Point and 3,600 feet of rock protection along bay shore of neck. State-Federal cooperative nourishment program was reinstated for 5 years.

1975	Nourishment: 187,000 tons of medium to coarse sand from offshore borrow area.
1976	Nourishment: 183,000 tons from offshore borrow area.
1977	Nourishment: 287,000 tons from land sources.
1978	Nourishment: 173,000 tons sand. Construction of three experimental rubble mound breakwaters at Budny Beach (Beach 10).
1979	Nourishment: 216,000 tons sand.
1980	Nourishment: 216,000 tons sand.
1981	Nourishment: 236,000 tons sand.
1982	Nourishment: 284,000 tons sand.
1983	Nourishment: 194,000 tons sand.
1984	Nourishment: 222,000 tons sand.
1985	Nourishment: 283,000 tons sand and 29,000 tons gravel for experimental gravel beach at Beach 5.
1986	Nourishment: 258,000 tons sand.
1987	Nourishment: 228,000 tons sand (173,000 tons from land sources, 10,000 tons fine sand from offshore sources, and 45,000 tons coarse sand from offshore). Experimental use of coarse offshore sand at Beach 8.

Total sand and gravel placed from 1955 to 1987: 11,383,646 tons or 7,528,866 yd^3.

The success of the various efforts is difficult to assess, without clearly defining the goals. If the goal is to permanently stabilize the spit, the existing work has not been very successful. However, the harbor remains open for shipping and recreational boating, and 5 million people a year visit the park to use its beaches and other facilities, which have been available and open.

Since 1955, the primary focus of shore protection efforts on Presque Isle has been beach nourishment. The first efforts used local fine sand pumped from inside the harbor to the beaches. This was finer than the natural sand existing on the beaches at the time (0.20 mm versus 0.33 mm median diameter), and initial losses of material were much higher than expected (Berg, 1965). Coarser material dredged from offshore was tested in 1965 and found to remain on the beaches better than the finer sand (Berg and Duane, 1968). Since that time coarse material has been specified for the periodic nourishment (Table 2).

Table 2. Gradation limits for Presque Isle beach nourishment material (U.S. Army Corps of Engineers, Contract Specifications, March 1987).

U.S. Standard Sieve Size	Opening size in mm	Gradation - Percent Finer by Weight
3/4 inch	190	100
3/8 inch	85	60-100
No. 4	4.75	40-100
No. 8	2.38	20-85
No. 16	1.19	8-65
No. 30	0.59	2-40
No. 50	0.29	0-15
No. 100	0.15	0-6
No. 200	0.07	0-4

Since 1977, cost factors have caused the nourishment materials to be obtained from onshore sources rather than from lake dredging. The dredged material is also in demand as high quality aggregate (Berkheiser, 1987) and is approximately twice as expensive as sand and gravel from land sources.

Nourishment material is obtained from any of several approved sand and gravel pits. In recent years, the primary supplier has been West Ridge Sand and Gravel Co. This field trip will visit their Girard Pit (Stop 1).

The nourishment material is delivered by truck, dumped on the beach, and reshaped by bulldozer. The design installation is a sand berm extending 15 m (50 ft) lakeward of the existing berm, or of the sheet pile bulkhead along the neck (which is normally covered by sand), with a crest elevation 3 m (10 ft) above Lake Erie low water datum. Actual placement may vary from the design depending on field conditions and amount of material available. The annual proposals specify maximum costs and the volume of material supplied is therefore a function of the price.

The purchased material is supplemented with the material which has washed over the back berm during the winter, and must be removed from the roadway before the trucks can gain access to the beaches. In recent years the specifications call for this washed sand to be used as "top dressing" for the "imported" material.

The land-source nourishment material has not been popular with the general public. The material contains a large proportion of small flat pebbles, which do not match the public perception of "beach sand". The more severe factor is that the material tends to cement shortly after placement. A 0.3 to 0.6 m (1 to 2 ft) thick layer in the upper part of the beach becomes strongly cemented by interstitial carbonate and clay. This leads to several conditions atypical of most beaches. The cemented material holds a steep lakeward scarp after storm erosion events. These scarps may be up to 1.8 m (6 ft) high, are a potential hazard for park visitors, and make swimming access difficult. The steep faces of the scarps are subject to piping, the development of tubular voids due to groundwater sapping of fine material, and the beach tends to collapse over the tubes. Rain water does not penetrate the cemented beaches quickly, and either runs off, eroding gullies in the beach face, or ponds on the flat surface. The cementing characteristics detract from the recreational desirability of the beach, but may actually help in slowing the erosion processes.

The Corps of Engineers has spent considerable effort to address the cementing problems. Grain size and petrologic and mineralogical studies of the beaches and fill sources have provided an explanation, although finding a cost-effective solution will be a larger problem.

The nourishment material as delivered to the beaches meets the design specifications for grain size and lack of extraneous material (Table 2). After it is placed on the beach, the percentage of fines (passing the No. 200 sieve) increases to 16-21 percent in the upper 0.3 to 0.6 m (1 to 2 ft) of the beach (Brian H. Greene, personal communication). The carbonate content of the minus 200 fraction was 11.5-13.8 percent. This is believed to be enough to combine with the clay minerals and produce the observed cement. The higher proportion of fines is believed to be derived from abrasion of siltstone and sandstone particles in the gravel, due to the effects of large tractor trailer trucks driving over the beachfill material during placement of the fill.

The only known source of nourishment material in the Erie area which is likely to avoid the cementing problems is the offshore dredged sand and gravel (Berkheiser, 1987). In 1987, a test section near Beach No. 8 was nourished with offshore sand. Large quantities of appropriate material exist in the lake (Williams and Meisburger, 1982). At present, however, costs are too high and available production capability too small to make this a feasible long-term solution.

The U.S. Army Corps of Engineers has been the agency responsible for most of the design and implementation of shore protection efforts on Presque Isle. Most projects are now jointly funded by state and federal government, with the Corps as the administering agency. The Buffalo District of the Corps of Engineers has prepared a recommended design for a "permanent" structural solution to the erosion problems of Presque Isle (U.S. Army Corps of Engineers, 1980). This would involve construction of 58 segmented rubblemound breakwaters along the shoreline from the "mainland" to Beach No. 10. The three existing breakwaters at Beach No. 10 are prototypes built in 1978. The proposed plan also calls for an initial placement of 382,278 m^3 (500,000 yd^3) of beach fill and annual replenishment of 29,053 m^3 (38,000 yd^3). This plan is presently under consideration by the various agencies involved. The 1986 cost estimate for the project was $34,800,000.

The continuing nourishment program for the last several years is seen as a temporary stop-gap until a more "permanent" solution can be found. The word "permanent" is in quotation marks because it is realized that there can be no truly permanent structural solution to shore erosion problems. The continuing nourishment program provides reasonable beaches, and harbor protection, but the costs are increasing rapidly. The 1986-87 nourishment program costs were $1.5 million.

The total volume of beach nourishment material placed on Presque Isle from 1955 to 1987 is 10.8 million metric tons (11.4 million tons) or 5.73 million m^3 (7.5 million yd^3). If this volume of material were distributed evenly over the 3200 acres of the park, it would form a layer 0.58 m (1.46 ft) thick.

REFERENCES CITED

Barnett, P. J., 1985, Glacial retreat and lake levels, north central Lake Erie basin, Ontario, in Karrow, P. F., and Calkin, P. E., eds., Quaternary evolution of the Great Lakes: Geological Associates of Canada Special Paper 30, p. 185-194.

Berg, D. W., 1965, Factors affecting beach nourishment requirements at Presque Isle Peninsula, Erie, Pennsylvania: Proceedings of the Eighth Conference on Great Lakes Research, Publication No. 13, Great Lakes Research Division, University of Michigan, p. 214-221.

Berg, D. W., and Duane, D. B., 1968, Effect of particle size and distribution on stability of artificially filled beach, Presque Isle Peninsula, Pennsylvania: Proceedings of the Eleventh Conference on Great Lakes Research, International Association for Great Lakes Research, p. 161-178.

Berg, T. M., and others, 1980, Geologic map of Pennsylvania: Pennsylvania Geologic Survey, 4th ser., Map No. 1.

Berg, T. M., and others, 1986, Stratigraphic correlation chart of Pennsylvania, revised edition: Pennsylvania Geological Survey, 4th ser., General Geology Report 75.

Berkheiser, S. W., Jr., 1987, Erie Sand and Gravel Company - suction hopper dredging on Lake Erie: Pennsylvania Geology, v. 18, no. 3, p. 2-6.

Calkin, P. E., 1970, Strandlines of glacial great lakes in northwestern New York: Ohio Jour. Science, v. 70, p. 78-96.

Calkin, P. E., and Feenstra, B. H., 1985, Evolution of the Erie-Basin Great Lakes in Karrow, P. F., and Calkin, P. E., eds., Quaternary evolution of the Great Lakes: Geological Association of Canada Special Paper 30, p. 149-170.

Carter, C. H., 1977, Sediment load measurements along the United States shore of Lake Erie: State of Ohio, Department of Natural Resources, Report of Investigations No. 102, 24 p.

Carter, C. H., and Guy, D. E., Jr., 1983, Erosion in the Lake Erie wave erosion zone near Vermilion, Ohio: Burlington, Ontario, Workshop on Great Lakes Coastal Erosion and Sedimentation Proceedings, p. 21-23.

Coakley, J. P. and Lewis, C. F. M., 1985, Postglacial lake levels in the Erie basin, in Karrow, P. F., and Calkin, P. E., eds., Quaternary evolution of the Great Lakes: Geological Association of Canada Special Paper 30, p. 195-212.

Dreimanis, A., and Goldthwait, R. P., 1973, Wisconsin glaciation in the Huron, Erie, and Ontario Lobes, in Black, R. F., Goldthwait, R. P., and Willman, H. B., eds., The Wisconsinan Stage: Geological Society of America Memoir 136, p. 71-106.

Fullerton, D. S., 1980, Preliminary correlation of post-Erie Interstadial events (16,000-10,000 radiocarbon years before present), central and eastern Great Lakes region, and Hudson, Champlain, and St. Lawrence lowlands, United States and Canada: U.S. Geological Survey Professional Paper 1089, 52 p.

Great Lakes Research Institute, 1975, Shoreline erosion and flooding, Erie County: Commonwealth of Pennsylvania, Department of Environmental Resources, Office of Resources Management, 172 p.

Harper, J. A., 1986, Oil and gas developments in Pennsylvania in 1985: Pennsylvania Geological Survey, 4th ser., Progress Report 199, 112 p.

__________, (in press), Oil and gas developments in Pennsylvania in 1986: Pennsylvania Geological Survey, 4th ser., Progress Report 200.

Hough, J. L., 1958, Geology of the Great Lakes: University of Illinois Press, Urbana, 313 p.

Jennings, O. E., 1930, Perigrinating Presque Isle: Carnegie Magazine, v. 4, p. 171-175.

________, 1960, Presque Isle's last stand: Water, Land, and Life, Spring 1960, p. 1-5.
Lapham, D. M., 1975, Interpretation of K-Ar and Rb-Sr isotopic dates from a Precambrian basement core, Erie County: Pennsylvania Geological Survey, 4th ser., Information Circular 79, 26 p.
Larsen, C. E., 1985, A stratigraphic study of beach features on the southwestern shore of Lake Michigan: new evidence of Holocene lake level fluctuation: Illinois Geological Survey, Environmental Geology Notes 112, 31 p.
Lowright, R. H., 1973, Environmental determination using hydraulic equivalence studies: Journal of Sedimentary Petrology, v. 43, p. 1143-1147.
Lowright, R.H., Williams, E.G., and Dachille, F., 1972, An analysis of factors controlling deviations in hydraulic equivalence in some modern sands: Journal of Sedimentary Petrology, v. 42, p. 203-211.
Masteller, E. C., and Baxter, C., co-chairmen, 1985, Tomorrow's oasis today: Proceedings of the Conference on Presque Isle and the Erie Bayfront, 127 p.
Messinger, D. J., 1977, Form and change of a recurved sandspit, Presque Isle, Pa.: unpublished M.S. thesis, State University of New York College at Fredonia, 121 p.
Nemec, W., and Steel, R. J., 1984, Alluvial and coastal conglomerates: their significant features and some comments on gravelly mass-flow deposits, in Koster, E. H., and Steel, R. J., eds., Sedimentology of gravels and conglomerates: Canadian Society of Petroleum Geologists Memoir 10, p. 1-31.
Nummedal, D., 1983, Sediment transport and morphodynamics of the Presque Isle shoreface: Louisiana State University, Department of Geology, Coastal Research Group, Technical Report 83-1, 33 p.
Nummedal, D., and Sonnenfeld, D., 1983, A tracer study of sediment movement in the bar system at Presque Isle, Pennsylvania: Report to the U.S. Army Corps of Engineers, Buffalo, for contract DACW49-81-C-0019, 80 p.
Nummedal, D., Sonnenfeld, D. L., and Taylor, K., 1984, Sediment transport and morphology at the surf zone of Presque Isle, Lake Erie, Pennsylvania, in Greenwood, B., and Davis, R. A., Jr., eds., Hydrodynamics and sedimentation in wave-dominated coastal environments: Marine Geology, v. 60, p. 99-122.
Pincus, H. J., 1962, Recession of Great Lakes shorelines, in Pincus, H. J., ed., Great Lakes basin: American Association for the Advancement of Science Publication 71, p. 123-137.
Pope, J., and Gorecki, R. J., 1982, Geologic and engineering history of Presque Isle Peninsula, PA, in Buehler, E. J., and Calkin, P. E., eds., Geology of the Northern Appalachian Basin, Western New York: Guidebook, New York State Geological Association 54th Annual Meeting, Amherst, New York, p. 183-216.
Saville, T., 1953, Wave and lake level statistics for Lake Erie: Beach Erosion Board, Technical Memo No. 37, 24 p.
Schooler, E. E., 1974, Pleistocene beach ridges of northwestern Pennsylvania: Pennsylvania Geological Survey, 4th ser., General Geology Report 64, 38 p.
Shepps, V. C., White, G. W., Droste, J. B., and Stitler, R. F., 1959, Glacial geology of northwestern Pennsylvania: Pennsylvania Geological Survey, 4th ser., Bulletin G 32, 54 p.
Tomikel, J. C., and Shepps, V. C., 1967, The geography and geology of Erie County, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Information Circular 56, 64 p.
Totten, S. M., 1982, Pleistocene beaches and strandlines bordering Lake Erie: in White G. W., ed., Glacial geology of northeastern Ohio: Ohio Geological Survey Bulletin 68, p. 52-60.

__________, 1985, Chronology and nature of the Pleistocene beaches and wave-cut cliffs and terraces, northeastern Ohio, in Karrow, P. F., and Calkin, P. E., eds., Quaternary evolution of the Great Lakes: Geological Association of Canada Special Paper 30, p. 171-184.

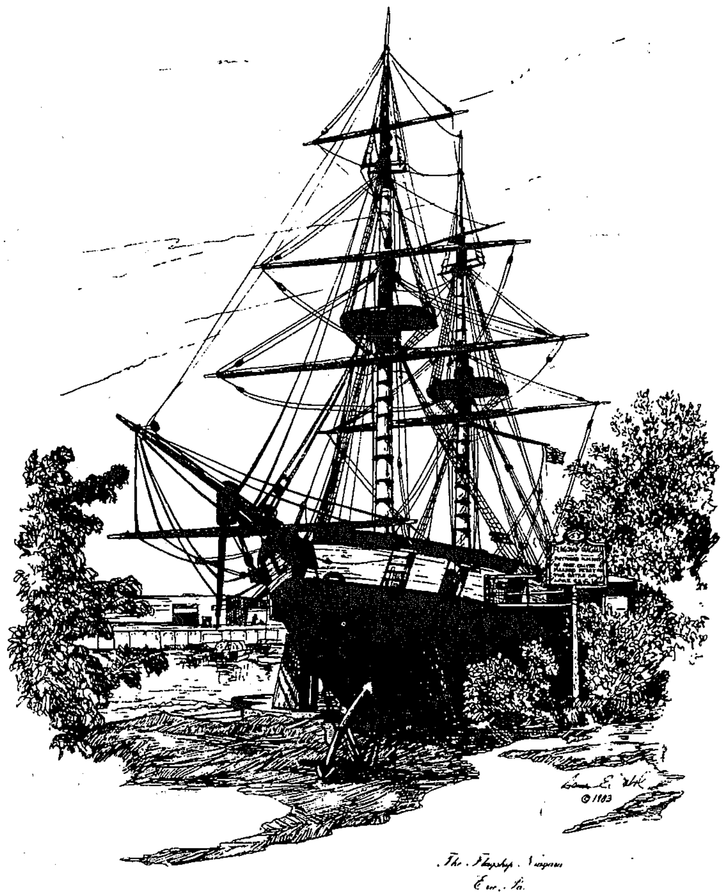
U.S. Army Corps of Engineers, 1980, Final phase 1 general design memorandum for Presque Isle Peninsula, Erie, Pennsylvania: Buffalo District Corps of Engineers, Buffalo, New York.

U.S. Army Corps of Engineers, 1987, Fact sheet: Water levels of Lake Erie: Revised, 1987, 6 p.

Walton, J. C., 1978, Sediment characteristics and processes of beaches and bars, Presque Isle, Erie, Pennsylvania (6/22/74-8/10-74): unpublished M.S. thesis, State University of New York College at Fredonia, 157 p.

White, G. W., Totten, S. M., and Gross, D. L., 1969, Pleistocene stratigraphy of northwestern Pennsylvania: Pennsylvania Geological Survey, 4th ser., General Geology Report G 55, 88 p.

Williams, S. J., and Meisburger, E. P., 1982, Geological character and mineral resources of south central Lake Erie: U.S. Army Corps of Engineers, CERC Miscellaneous Report 82-9, 62 p.



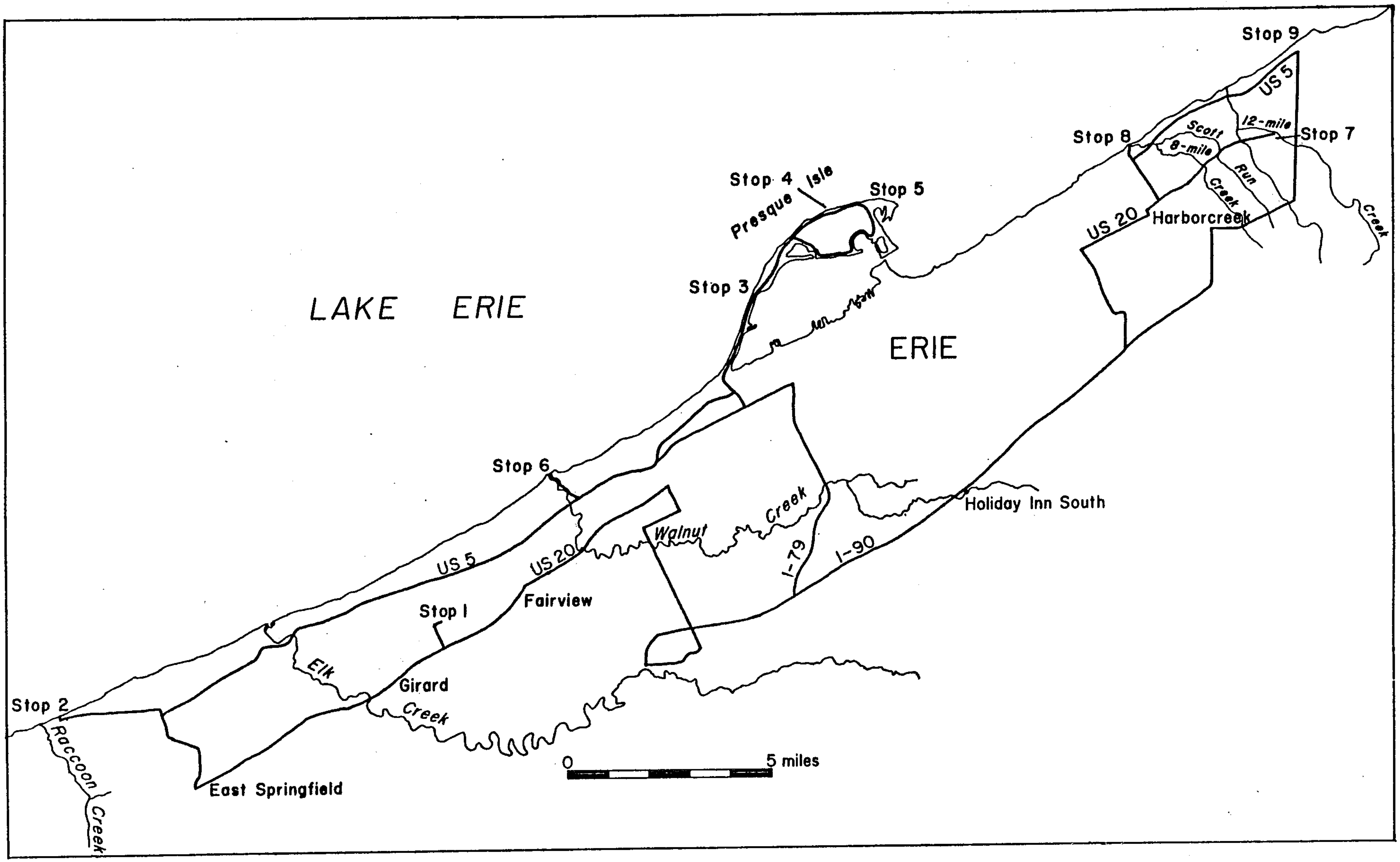


Figure 29. Route map for field trip.

ROAD LOG - DAY 1

Mileage Inc	Mileage Cum	
0.0	0.0	START. Leave parking lot of Holiday Inn South. **TURN LEFT** (north) onto PA Route 97. The Holiday Inn is situated on the Ashtabula Moraine, which is about 2 miles wide (north to south) in this area. The stream to the south of the parking lot is a tributary to Walnut Creek. The mouth of Walnut Creek will be the site of the first stop on Day 2 of the trip.
0.1	0.1	Ramp to I-90 West/Cleveland. **TURN LEFT** onto the entrance ramp and proceed west on I-90.
2.1	2.3	Exit for US Route 19. Peach Street/Waterford interchange **CONTINUE** west on I-90. We are travelling over the typically hummocky topography left by the Ashtabula ice.
1.5	3.8	Hamot Road Bridge
0.7	4.5	PA Route 99/Edinboro Road Bridge
0.1	4.6	Exit for I-79 North/Erie. **CONTINUE** on I-90.
0.4	5.0	Exit for I-79 South/Pittsburgh. **CONTINUE** west on I-90.
0.6	5.6	Bargain Road Bridge
2.1	7.7	Millfair Road Bridge. We are crossing the boundary between the Ashtabula and Defiance Moraines. At this location the Ashtabula ice overrode the Defiance deposits. This is indicated by the total absence of surface exposures of Defiance sediments east of this location. From this area west, we will be travelling over the Defiance Moraine.
0.5	8.2	**TURN RIGHT** onto Exit for PA Route 832, Presque Isle State Park/Sterrettania Road.
0.4	8.6	Intersection of exit ramp with PA Route 832. **TURN LEFT** (south) onto PA Route 832.
0.1	8.7	The hummocky topography of the Defiance End Moraine is to the right. The ridge to the left is the Lavery End Moraine.
0.7	9.4	Intersection of PA Route 832 and unnamed road. PA Route 832 curves sharply to right (large arrow pointing to the right). **TURN LEFT** with caution onto unnamed road.
1.0	10.4	Intersection. **TURN LEFT** onto Buman Road (unpaved).
0.5	10.9	Intersection of Buman Road and Millfair Road (on left). Stop bus here for narrative by bus leaders. Do not leave bus. To the right (south) is the summit of the Defiance End Moraine (elevation 1100 feet). This marks the southern margin of the Defiance ice at about 14,000 yr B.P. The ridge to the north is the summit of the Ashtabula Moraine (elevation 910 feet). We will travel north down the north-facing slope of the Defiance Moraine. **TURN LEFT** and proceed north on Millfair Road.
0.4	11.3	We have completed the descent of the Defiance Moraine and are ascending the south-facing slope of the Ashtabula Moraine. The Ashtabula is dated at 13,700 ± 220 yr B.P.
0.2	11.5	Bridge over I-90.
0.6	12.1	Stop sign at intersection of Millfair Road and Sterrettania Road. **CONTINUE** north on Millfair road.

0.2	12.3	Intersection of Millfair Road and Bridlewood Drive on the left. The hilltop a short distance ahead is the highest point of the Ashtabula Moraine on Millfair Road. The elevation is 960 feet. Beyond it to the north you can see the distinct summit of the Girard Moraine. The boulders used as decorations by local property owners are erratics of Precambrian crystalline rocks.
0.2	12.5	Intersection of Millfair Road and Bridlewood Drive (south end) on left. **CONTINUE** north on Millfair Road.
0.4	12.9	Stop sign at intersection of Millfair Road and Heidler Road. The cemetery on the left is on glacial outwash. **CONTINUE** north on Millfair Road.
0.5	13.4	Intersection of Millfair Road and Sunrise Circle. We are descending the north slope of the Ashtabula Moraine.
0.4	13.8	Bridge over Walnut Creek. We have come off of the Ashtabula Moraine and are about to start climbing the south side of the Girard Moraine. Walnut Creek's westward course is controlled here by the relative positions of the two moraines.
0.4	14.2	**STOP SIGN. TURN RIGHT** onto West 38th Street. This is one of the best locations for viewing the Ashtabula Moraine from the summit of the Girard Moraine. This marks the southernmost advance of the Girard ice at 13,000 ± 500 yr B.P. Elevation is 850 feet. We are now travelling east along the crest of the Girard Moraine.
1.0	15.2	**STOP SIGN. TURN LEFT** onto Asbury Road. We are descending the north slope of the Girard Moraine. The terraces and cliffs of Lake Whittlesey and Lakes Warren I and Warren III are north of the base of this slope.
0.7	15.9	Traffic light at intersection of Asbury Road and US Route 20. **TURN LEFT** onto US Route 20. We are now travelling on the Lake Whittelsey terrace level at an elevation of 760 feet. The Girard Moraine is to the left (south). To the right (north), about 30 feet below the Lake Whittlesey terrace lies the broad, flat terrace representing the Lake Warren I level (730 feet). The east-west trending scarp, probably a wave cut cliff, can be seen a few hundred feet from the highway. Deposits associated with Lake Whittlesey have been radiocarbon dated at 12,920 ± 400 yr B.P. Lake Warren I has been similarly dated at 13,050 ± 100 yr B.P. A historical marker in front of the cemetery on the south side of Route 20 (left) reads: "Erie Extension Canal. A section of the Canal linking New Castle and Erie lies at the foot of the slope to the right side of the road...... Begun by State, 1838, finished by Company headed by R. S. Reed of Erie, 1843-44."
1.0	16.9	Intersection of US Route 20 and Millfair Road. Boundary between Millcreek and Fairview Townships. The gravel pits in this area have been worked as excellent sources of relatively clean, well-sorted pebbly gravel used for concrete building blocks.
1.1	18.0	Intersection with Manchester Road on right. **CONTINUE** west on US Route 20.
0.5	18.5	Walnut Creek valley. One quarter mile south of this point, the creek makes a 90° turn from its westward course to flow north toward Lake Erie. It enters the lake about 1.5 miles north of here.
2.1	20.6	Traffic light at intersection of PA Route 98, in the borough of Fairview. **CONTINUE** west on US Route 20.
0.3	20.9	Bridge over Trout Run.

1.2	22.1	Intersection with Blair Road on right. **CONTINUE** on US Route 20.
0.2	22.3	Boundary between Fairview and Girard Townships.
0.4	22.7	**TURN RIGHT** onto Fairplain Road (unpaved) and proceed north. Radio beacon in field to left.
0.7	23.4	**TURN RIGHT** into West Ridge Sand and Gravel Company's Girard Pit. Proceed with caution.

STOP 1. WEST RIDGE SAND AND GRAVEL COMPANY PIT.
Leaders: Ray Buyce and Dave Thomas.

The entrance to the West Ridge Sand and Gravel Company pit is located 0.6 mile north of US 20 on Fairplain Road in Girard Township, in the northeast section of the Fairview, PA 7.5-minute quadrangle (Figure 30). The property is owned by Mr. Arendash. We will be examining an unworked portion in the northeastern-most part of the busily worked pit. Because of the heavy truck and equipment traffic, be certain to stay in the designated area.

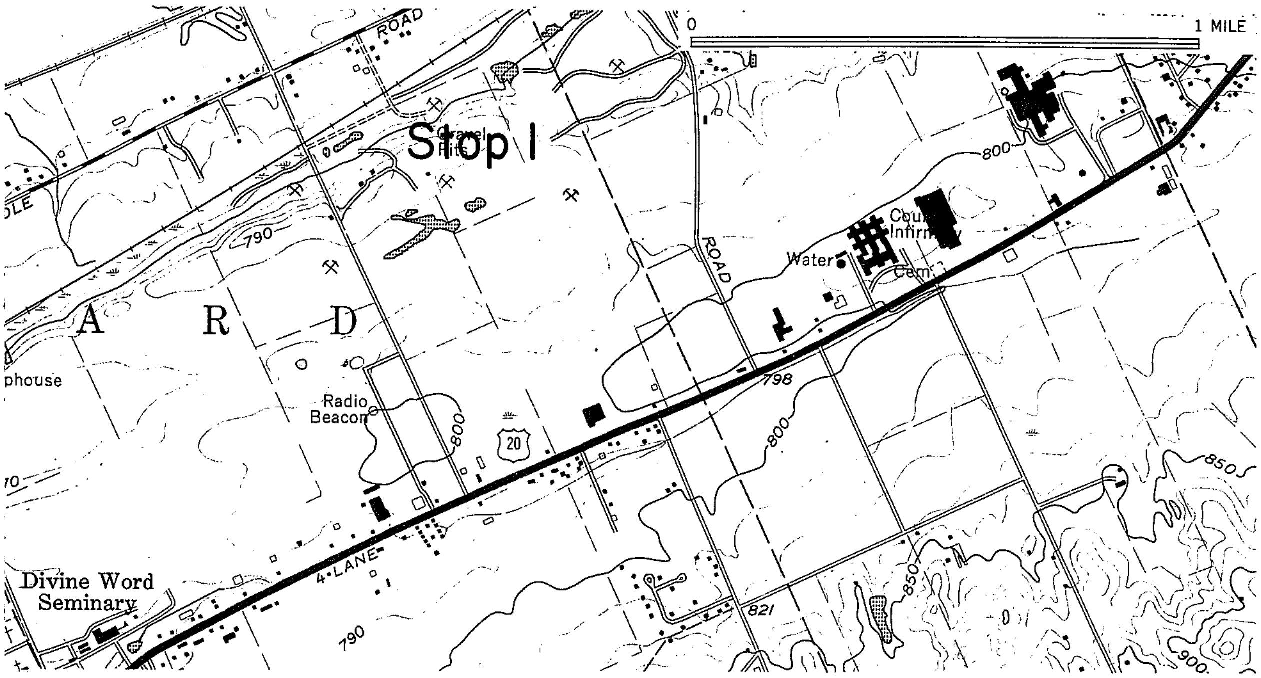


Figure 30. Location map for Stop 1 (from the Fairview, PA 7.5-minute topographic map).

Landform

The elevation of the uppermost surface at the pit area is 790 feet and is within the elevation range of Lake Whittlesey. Schooler (1974) identified the surface as a part of a Lake Whittlesey beach ridge. The part of the pit that we will observe is located at its northern boundary. This location overlooks (to the north) the Lake Warren I terrace at about 730 feet and beyond, the Lake Warren III terrace at an elevation of about 670 feet extending to the present wave-cut cliff of Lake Erie whose present mean elevation is 570 feet. Scarps that separate the terraces of Lakes Whittlesey, Warren I, and Warren III are assumed to be relic wave-cut cliffs formed by waters of the respective lakes. Lake Whittlesey stabilized against the Hamburg Moraine which extended across the eastern extremity of the Lake Erie basin near Buffalo, New York. Its waters spilled westward into Lake Saginaw in Michigan and then into Lake Chicago via the Grand River valley and, finally, through the Mississippi River drainageway to the Gulf of Mexico. ^{14}C dates place the time at about 13,000 yr B.P.

Stratigraphy

Exposed at the bottom of one face is a gray, gravelly, clay-silt diamict which has an undulatory surface with a relief of at least 3 m (10 ft). It is this very coherent unit underlying the economically valuable sand and gravel that has limited the depth of this part of the pit.

Overlying the basal diamict is a series of sand and gravel units which are laterally discontinuous. Some units have channel forms, cross cut lower units, and display distinct planar cross bedding. Some of the sandy units are massive; some are horizontally laminated, some are ripple laminated, and some comprise climbing ripple sets. Only one minor clay drape was seen. In the location of one of the measured sections the sandy/gravelly units are overlain by a stack of two silt and gravel diamicts which are also laterally discontinuous.

Features and Possible Interpretations

You are invited to observe the lithologies and the primary and secondary features preserved in the section exposed at this locality and to interpret the most probable environment(s) that could have formed what you see. The graphic log and description of the measured section below (Figure 31 and Measured Section 1) will assist your observation. The lateral relationships of the discontinuous sediment packages have not been worked out and our interpretations will remain incomplete.

A number of suggestions are given below.

Feature:

Color versus facies. The lower units exposed are gray and the overlying units are yellow brown. The change from the underlying diamict to overlying sandy/gravelly units is within the underlying gray sequence not at the color boundary.

Possibilities:

1. The color is a secondary feature controlled by oxidation subsequent to deposition.
2. Another explanation?

Feature:

A diamict underlies the section exposed and other diamicts occur within the overlying sandy/gravelly units.

Possibilities:

1. The basal diamict and the upper diamict are both subglacial meltout tills. The upper diamict represents a readvance of glacial ice.
2. The basal diamict is a subglacial meltout till and the upper diamict is a supraglacial debris flow.
3. Both the basal diamict and the upper diamict are supraglacial debris flows and no meltout tills are exposed here.

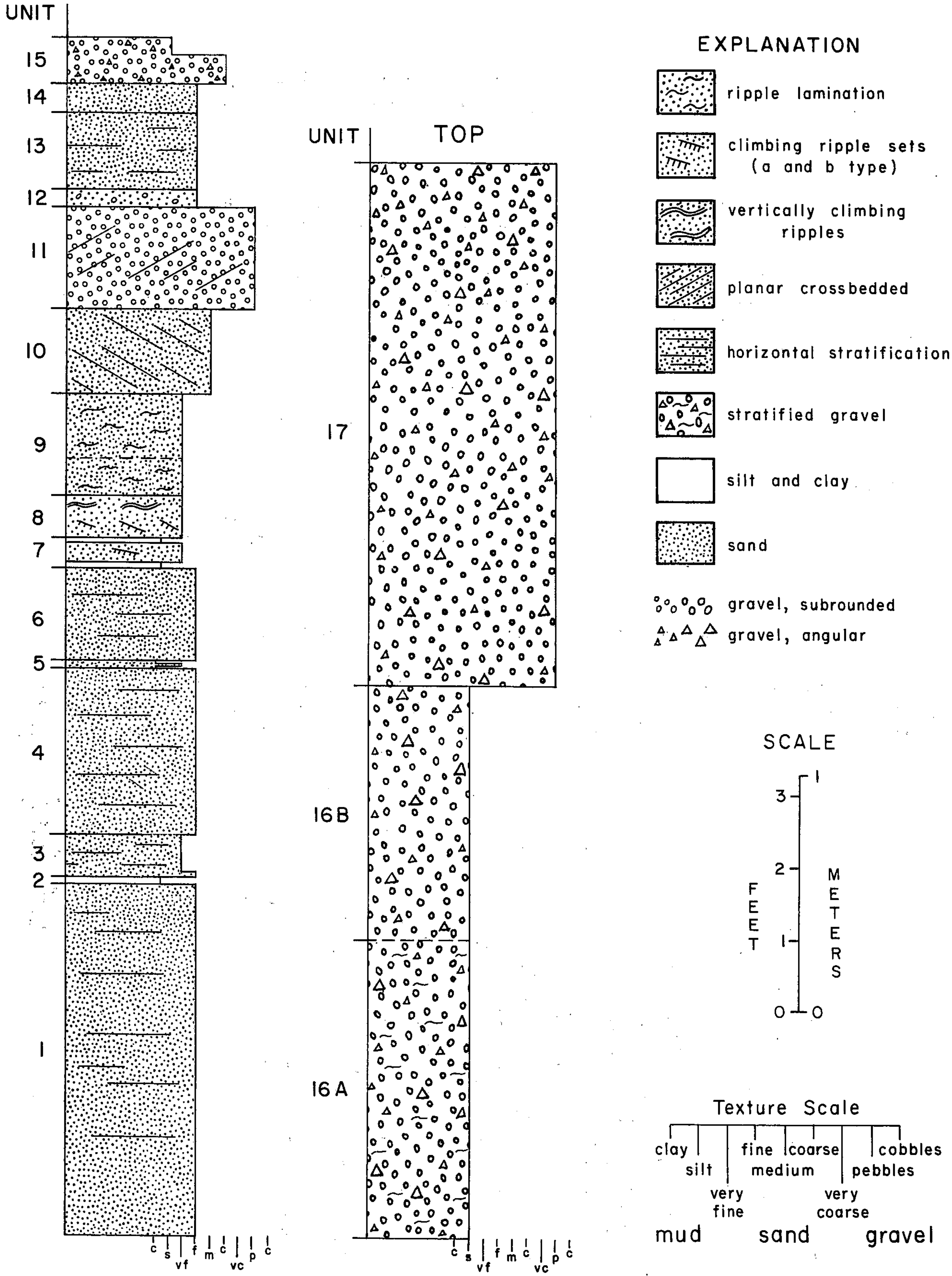


Figure 31. Graphic log of sediments occurring in West Ridge Sand and Gravel Company Pit. See Measured Section 1 for description.

Feature:

Some sandy units are massive, some are horizontally laminated, some are ripple laminated, and some are composed of climbing ripple sets, but show only one minor clay drape.

Possibilities:

1. Deposition was not interrupted by any periods of low energy.
2. Fairly rapid deposition occurred in a constantly moderate-energy environment.
3. Clay and silt were not available for deposition.
4. These deposits originated in a (1) lacustrine, (2) proximal delta, or (3) fluvial environment.
5. Another explanation?

Feature:

Different planar crossbedding sets indicate different transport directions.

Possibilities:

1. They are cross-channel bars in a sinuous braided stream (sandar).
2. They represent various current directions on a proximal delta or subaquous fan.
3. Another explanation?

Measured Section 1. West Ridge Sand and Gravel Pit

Stratigraphic section measured at west end of pit on west-facing cliff, approximately 2/3 distance across the face to the north. The base was dug out to the level of the top of the diamict which, at this point, is about equal to the maximum depth of the cut to the west.

Unit	Description	Thickness Meters (feet)
17	Diamict, silty gravel, very abundant pebbles and cobbles; mostly sharp, angular, flat, hard siltstones with lesser amounts of various shaped igneous, metamorphic, and sedimentary rock clasts; a few subrounded boulders; clast supported; faintly stratified; imbricated in part; well-developed soil at top.	2.21 (7.25)
16	Diamict, pebble to cobble silt, massive, matrix supported. Upper 1.07 m (3.5 ft)--cobble silt, yellow brown; cobbles sharp, angular, flat, hard, siltstones; some rounded pebbles. Lower 1.27 m (4.17 ft)--alternating discontinuous irregular bodies, olive gray and moderate yellow brown. This unit and overlying Unit 17 described from slope position approximately 2 m (6 ft) to the north of the rest of the section.	2.34 (7.67)
15	Diamict, gravelly sand and silt; light olive brown; maximum clast size 0.1 m (4 in.). Upper 0.1 m (0.33 ft) silt with pebbles; lower 0.1 m (0.33 ft) gravelly sand.	0.20 (0.67)

14	Sand, fine, massive except for discontinuous cemented concretions arranged horizontally; some roll-up deformation folds present.	0.12 (0.4)
13	Sand, fine, horizontally laminated, moderate yellow brown with iron oxide staining at base.	0.28 (0.9)
12	Sand, fine, pebbly with maximum 5 mm (0.2 in.), moderate yellow brown.	0.08 (0.25)
11	Sandy gravel to gravelly sand; average pebble size 2 cm (0.75 in.), maximum, 10 cm (4 in.), erosional base; tabular shape; planar crossbedded with dip 16° S30W.	0.43 (1.4)
10	Sand, medium, rare pebbles up to 7 mm (0.25 in.); dark yellow brown; channel-fill shape, planar crossbedded with dip to N40W.	0-0.73 (0-2.4)
9	Sand, very fine, pebbles up to 8 mm (0.3 in.); channel form. Upper 0.25 m (0.83 ft) with large scale ripple laminations; ripple wave lengths approximately 0.23 m (0.75 ft); moderate yellow brown. Lower 0.15 m (0.5 ft) with small scale ripple laminations; ripple wave lengths approximately 0.15 m (0.5 ft).	0.43 (1.42)
8	Sand, very fine, light yellow brown. Upper 6.5 cm (2.5 in.) with vertical climbing ripples. Lower 11.5 cm (4.5 in.) ripple laminated with crossbed dip to the south.	0.18 (0.58)
7	Clay-sand-clay sandwich, dark yellow brown. Upper silty clay to clayey silt with 3 mm silty clay at base going up into silt. Middle fine sand crossbedded but not ripple laminated; crossbeds dip south; some coarse sand. Lower silty clay with rare pebbles and dark red brown rip-up clasts up to 5 mm (0.2 in.).	0.04-0.08 (0.13-0.25)
6	Sand, fine, moderate yellow brown; horizontally laminated; extensively stained with iron oxide along anastomosing Y-shaped nearly vertical fractures.	0.4 (1.3)
5	Clay-very fine sand-clay sandwich; faulted with vertical upthrow of 5 cm (2 in.) to north. Upper 1-19 mm (0.06-0.75 in.) clay in drapes over ripples. Middle 0-2.5 cm (0-1 in.) with mostly north-dipping cross laminations and ripple laminations. Lower 6-19 mm (0.25-0.75 in.) clay with abundant coarse sand-size grains at base.	0.01-0.06 (0.04-0.16)
4	Sand, fine; horizontally laminated with laminae up to 5 mm (0.2 in.); moderate yellow brown stained to dark red brown and partially cemented with iron oxide at top and bottom 5 mm (0.2 in.); upper and lower contacts offset by vertical faults with 1.9 cm (0.75 in.) displacement.	0.7 (2.3)
3	Sand; wedge-shaped, flat-topped, thickens to the south. Upper part, very fine sand, horizontally laminated, olive gray. Lower 0.02 m (0.75 in.) fine sand, horizontally laminated with laminations up to 3 mm (0.1 in.) thick, olive gray.	0.05-0.28 (0.16-0.91)

2	Silt, clayey, dark yellow brown with rare sand grains; layer displaced by nearly vertical faults which trend approximately east-west; upthrown to the north with maximum displacement of 25 mm (1 in.).	0.025 (0.83)
1	Sand; upper 1.2 m (3.9 ft) fine sand, faint horizontal laminations, brown gray mottled to dark red brown. Lower 0.3 m (1.02 ft) fine sand, faint horizontal laminations, olive gray. Base of section.	1.5 (4.92)

		LEAVE GRAVEL PIT. TURN LEFT onto Fairplain Road and go south to US Route 20.
0.6	24.0	**TURN RIGHT** onto US Route 20 and proceed west.
1.0	25.0	Boundary for Girard Borough, for which the Girard Moraine is named.
0.4	25.4	**STAY IN LEFT LANE** at traffic light. Intersection of US Route 20 and Church Street. **CONTINUE WEST** on US Route 20.
0.2	25.6	Traffic light at Olin Ave. **CONTINUE** west on US Route 20.
0.3	25.9	Traffic light at Rice Ave. **CONTINUE** west on US Route 20.
0.2	26.1	Bridge across north-flowing Elk Creek. Elk Creek displays the same flow pattern as Walnut Creek. From its headwaters to the southeast, through 3/4 of its course, it flows generally westward, then abruptly changes direction and flows north into Lake Erie.
0.8	26.9	Intersection with PA Route 18 on left. **CONTINUE** west on US Route 20.
2.9	29.8	Intersection with Townline Road. Boundary between Girard and East Springfield Townships. **CONTINUE** west on US Route 20.
1.2	31.0	**TURN RIGHT** (north) onto PA Route 215 in East Springfield. Elevation 730 feet.
1.1	32.1	Railroad crossing with blinker lights and **NO GATE. CONTINUE** north on PA Route 215 to North Springfield.
1.2	33.3	Stop sign at junction of PA Route 215 and US Route 5. **PROCEED** through intersection with caution.
0.2	33.5	Railroad crossing with gate and blinker lights. Cross tracks and be ready to turn left.
0.1	33.6	**TURN LEFT** onto Lake Road. PA Route 215 ends. Elevation 660 feet.
1.2	34.8	Entrance to Camp Lambec, a family camp operated by the Presbyterian Church. **CONTINUE** west on Lake Road.
0.4	35.2	Intersection with Eagley Road on left. **CONTINUE** on Lake Road. The moderate relief in this area is due to dissection of the generally flat lake plain by short, north-flowing streams.
0.3	35.5	Intersection with Ellis Road on the left. **CONTINUE** on Lake Road.
0.4	35.9	Participants will offload bus here. The bus will continue west 0.6 miles to Elmwood Road and turn around. Parking is available at Raccoon Creek County Park. Bus will return to pick up participants in 1 hour.

STOP 2. RACCOON CREEK.
Leaders: Ray Buyce and Dave Thomas.

Stop 2 is at a bluff along Lake Erie north of Lake Road about 0.4 mile west of Ellis Road and about 0.4 mile east of the entrance to Raccoon Creek County

Park in the northwest section of the East Springfield, PA 7.5-minute quadrangle (Figure 32). The lake cliff sediments will be observed from the beach. We will proceed to the beach by way of stairs that are behind a home to the west of the open field. Please respect the property of the generous landowner who permitted use of the stairway. Because we will be examining exposures provided by 1987 vintage mass wasting, we urge extreme caution when walking or climbing along these very steep, unstable slopes.

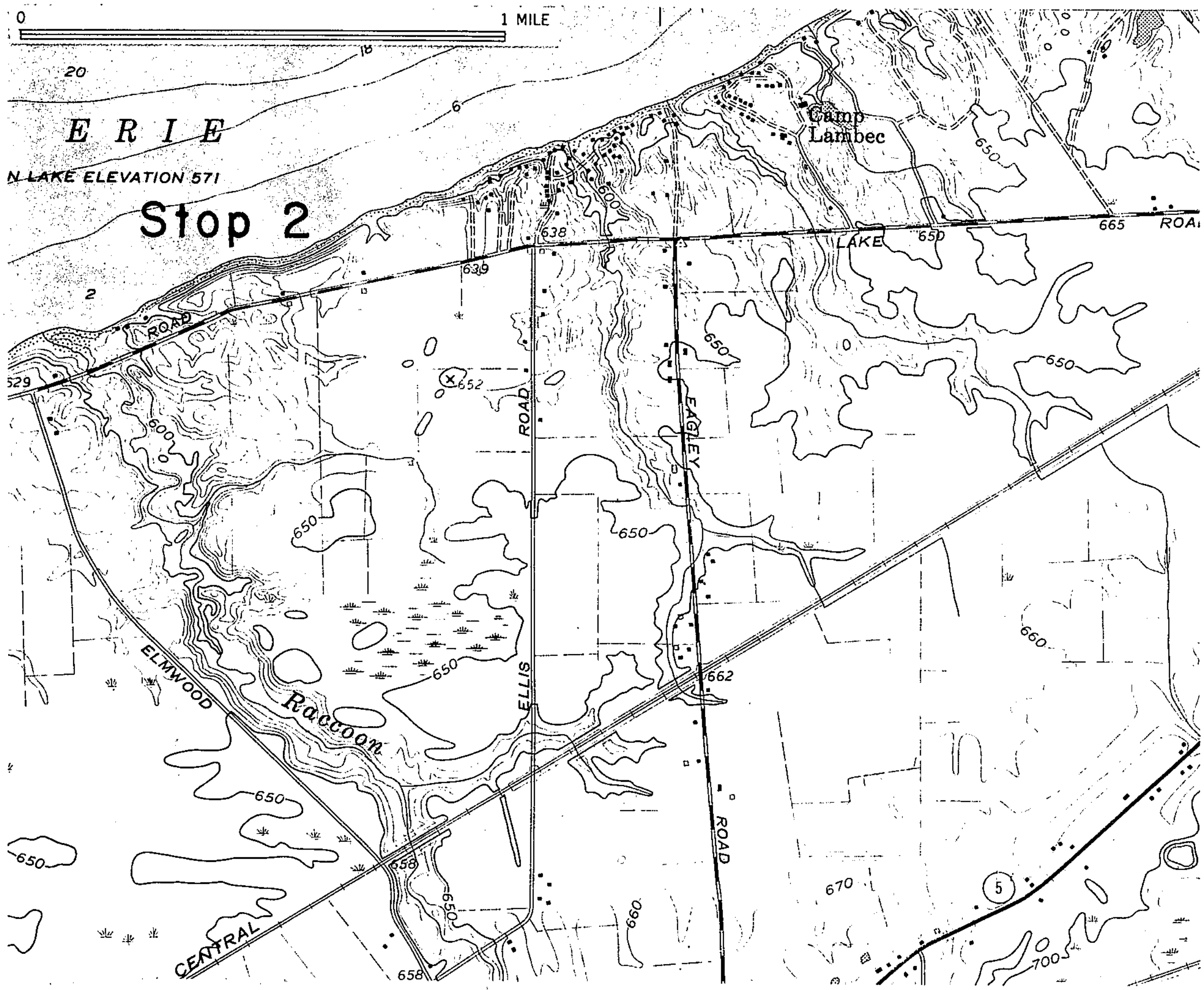


Figure 32. Location map for Stop 2 (from East Springfield, PA 7.5-minute topographic map).

Landform

The summit of the bluff at this location is at an elevation of about 640 feet. It is the northwest margin of an atypical sloping band of landscape that begins at an elevation of 680 feet 1.9 miles to the south at US Route 5 and slopes gently toward the 640 feet bluff elevation (Figure 32). The 690-foot terrace edge that runs roughly east-west along US Route 5 is Schooler's (1974) Lake Warren I beach ridge which was visible to the north of Stop 1 (Figure 30).

Could this band of landscape, 1.9 miles wide and sloping from 680 feet to 640 feet at this location, represent a terrace of Lake Grassmere (640 feet)? Could it be a Lake Warren III terrace (670 feet) that underwent extensive erosion by streams flowing into Early Lake Erie (450 feet)? Is this an erosional surface left by a slowly retreating Lake Warren III? One thing is certain. This 1.9 mile band from the bluff to US Route 5 is not typical of the Warren III terraces to the east of this area. The north-flowing drainage density is much greater and the area occupied by swampland is much more extensive than in areas to the east. These features suggest that the underlying strata are not the typical sand and gravel facies that are common on the eastern Warren III terraces. It also may be that the sand and gravel facies overlying the diamict is much thinner here. Erosional removal of some of the upper part of the sand and gravel in this area would fit this interpretation.

Stratigraphy

Waves of Lake Erie and mass wasting have cut this cliff near the mouth of Raccoon Creek exposing approximately 18 m (59 ft) of glacigenic sediments. They are comprised of subequal thicknesses of two facies: a lower 7.3 m (24 ft) section of olive gray cobble/pebble clay-silt diamicts overlain by 10.7 m (35 ft) of pebbly very fine sand units, olive gray at the bottom changing upward to yellow brown.

The lower units are predominantly olive gray massive diamicts consisting of a clay-silt matrix supporting angular to subrounded pebbles and cobbles. Four distinct diamict units are present ranging in thickness from 0.76 m (2.5 ft) to 2.59 m (8.5 ft). Within the section dominated by diamicts are olive gray very fine sands, some as thin interbeds within the massive diamict units and one as a thick bed overlying the lowest exposed diamict unit.

About half of the total thickness of the sediments exposed in the upper part of the bluff is composed of very fine sand beds with relatively thin interlayers of silty clay. Some silty clays occur as drapes in stacks of ripple-laminated sand/silty-clay couplets which alternate with horizontally-laminated, well sorted, very fine sand beds. In other units the silty clays are interbedded with massive, very fine, sands.

Several of the interbedded sand and silty clay units are now so contorted by soft sediment deformation that few if any primary sedimentary structures have been preserved. There are at least two different styles of deformation present. One style of deformation is represented by complexly folded and dismembered clay layers possibly formed by drag of overlying sediment movement. A second style is displayed most dramatically in a 0.46 m (1.5 ft) interlayered bed approximately 1.8 m (6 ft) down from the top of the bluff: the entire unit is periodically upwarped and ruptured, presumably by dewatering.

The well sorted sand units which make up the other half of the total thickness of the upper bluff lack any silty clay interbeds and are either massive in beds up to 0.9 m (3 ft) or horizontally laminated in units up to 0.23 m (9 in.).

A graphic log of one measured stratigraphic section is presented in Figure 33. Considerable lateral discontinuity of the units described makes this of limited use as a guide to the entire exposure, but it will help focus your observations. You are invited to participate in the interpretation of the features described. Some of the features open to interpretation are listed below.

Observations Open To Interpretations

Observation: Several diamict units are present. What process(es) formed them? Subglacial meltout? Supraglacial debris flow? Others?

Observation: A 0.7 m (2.3 ft) thick sand unit occurs above the lowermost diamict. What processes formed this layer? Where they subglacial? Supraglacial? Proglacial?

Observation: There is a lower diamict facies and an upper sandy facies. What depositional environments where responsible for each facies and how are they related? Subglacial meltout followed by lake delta deposition? Subglacial lodgement of till followed by sandar (alluvial plain braided stream) deposition? Other?

Observation: The olive gray color extends above the top of the diamict facies up into the overlying sandy facies. What controls the color change if a change in environment of deposition and facies does not? Is the color a secondary effect resulting from the ponding of groundwater on top of the relatively impermeable diamict? Another explanation?

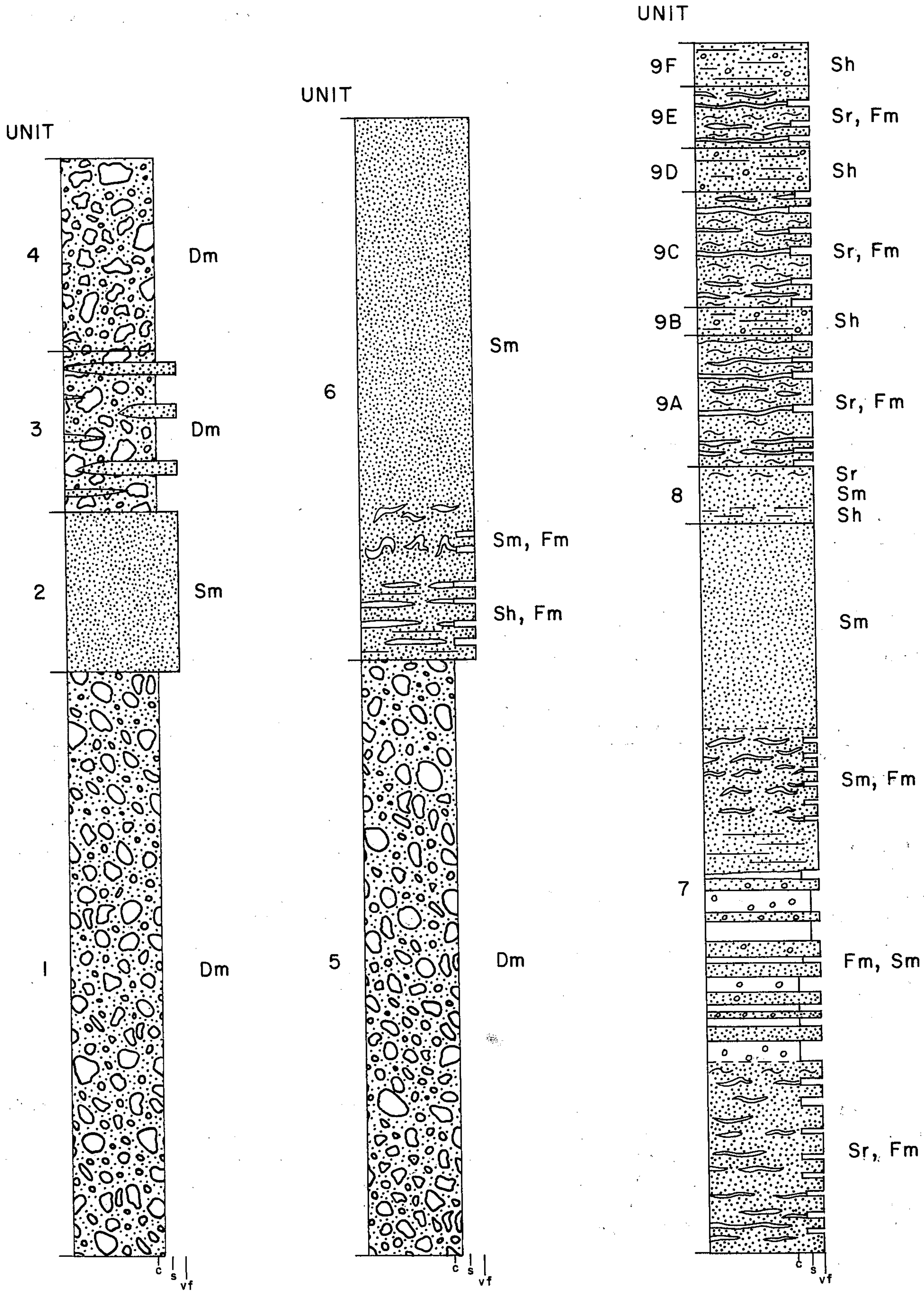
Observation: Cyclic sedimentation is indicated by the stacked couplets of ripple-laminated sand and clay drapes. What environment and processes are responsible? Distal turbidites on a sublacustrine fan? Current ripples and slack water deposits in a braided stream? Another explanation?

Observation: Convoluted sand and clay interbeds with complex folds and dismembered clay layers suggest soft sediment deformation. Were they formed by drag of sediment moving over them? By debris flow on primary depositional sublacustrine slope? Another explanation?

Observation: Regular periodic upward ruptures of several sets of sand and clay interbeds in some units seem to be dewatering structures. Are they really the result of dewatering? If so, what processes caused the rapid deposition of overlying sediments which resulted in the increase of overburden at rates which exceeded the normal dewatering rates? Did the interlayering of clays in the disturbed units play a role in the buildup of the pore water pressures of the units below? What environment is consistent with the processes suggested? Fluvial? Fan in a glacial lake with periodic rapid dumping of sediment? Distal delta environment?

Bluff Recession

The height of the bluff is about 18 m (60 ft). This location is classified as a critical hazard area. The bluff recession rate from 1938 to 1975 has been calculated to be 0.5 m (1.7 ft) per year (Great Lakes Research Institute, 1975). This translates to 26.4 m (86.7 ft) from 1938 to 1987. However, record high lake levels in 1976 and again in 1986 have probably caused the overall total of bluff recession to be greater.


UNIT
4
Dm
3
Dm
2
Sm
1
Dm
c
s
vf
UNIT
6
Sm
Sm, Fm
Sh, Fm
5
Dm
c
s
vf
UNIT
9F
Sh
9E
Sr, Fm
9D
Sh
9C
Sr, Fm
9B
Sh
9A
Sr, Fm
8
Sr
Sm
Sh
Sm
Sm, Fm
7
Fm, Sm
Sr, Fm
c
s
vf

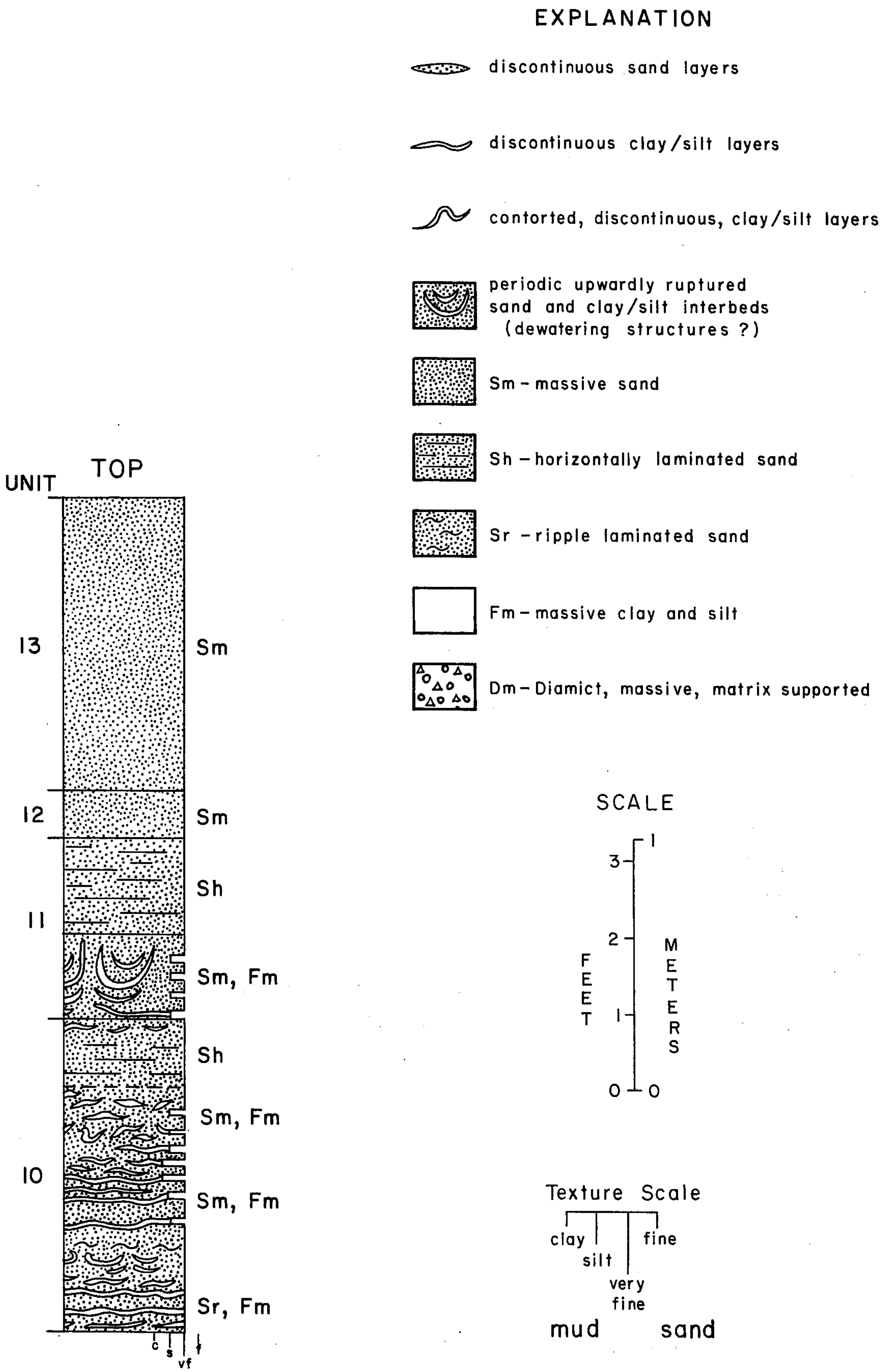


Figure 33. Graphic log of section at Raccoon Creek.

The contact between the basal diamict and the unit below is covered by a very low sloping beach about 2.4 m (8 ft) wide (measured June 10, 1987) consisting of well rounded to subrounded cobbles, pebbles, and sand. The narrow beach is nourished by locally eroded bluff material. No significant amount of sediment is provided by the short streams to the west. It is doubtful that any coarse sediment has been transported from the bluffs or littoral zone in Ohio since the construction of jetties and breakwaters along the coast to the west at Conneaut, Ohio. One large jetty can be seen from here. The jetties and breakwalls were constructed from the late 1800's through the 1930's to provide harbor and dock facilities for iron ore boats that transported the ore from the Masabi Range and Duluth harbor in Lake Superior.

The lower, steep 41 percent of the bluff that is composed of diamicts is topped by a gentler sloping bench or berm composed of colluvium which extends upward to a steep slope composed of sand with interbeds of finer material. Because the diamicts and sand have different lithologic and geotechnical characteristics and are positioned at different heights, they do not completely undergo the same erosional processes.

Types of mass wasting evidenced in the diamicts are (1) undercutting by moderate and high wave energy where the base of the slope meets beach material; (2) development of stress-release fractures due to lateral unloading followed by outward rotation of cohesive diamicts along the stress-release fractures; (3) slumping; and (4) debris flow due to rainfall and melting snow and ice. Other types of erosional processes that occur on and within the diamicts, some of which are not apparent, are sheet wash, raindrop impact, shrink/swell due to wetting and drying, frost heaving within the material, and frost wedging in the fractures.

Mass wasting processes that occur in the upper sandy 59 percent of the bluff are (1) spring sapping of sand along the spring line at both the contact between sand and diamict and at the fine-grain drapes and sand beds produces sand flow or sand fall; (2) extrusion (Pincus, 1962) (may be referred to as large-scale spring sapping) of fine sand overlying much lower permeability diamict due to saturation of the sand unit during spring thaw and after high intensity rainfall; (3) slumping due to removal of underlying diamict or sand removal during spring sapping or extrusion; and (4) sand or debris flow as a result of spring sapping, extrusion, snow melt, and rainfall. Other erosional processes include raindrop impact, wind, and the removal and weakening of sand by swallows.

		LEAVE STOP 2, PROCEED EAST on Lake Road.
2.4	38.3	Intersection of Lake Road and PA Route 215. **TURN RIGHT** onto PA Route 215. Railroad crossing with gates and blinker lights.
0.2	38.5	**STOP SIGN. TURN LEFT** and proceed east on US Route 5.
0.3	38.8	Bridge over Crooked Creek.
0.7	39.5	Historical Marker: "Old State Line. The Northern boundary of Pennsylvania, before the purchase of the Erie Triangle in 1792, crossed the highway at this point. The State paid $151,640.25 for the Erie tract and its port on the Lakes."
1.1	40.6	Intersection with Townline Road on the right. **CONTINUE** east on US Route 5.
0.6	41.2	Bridge over railroad tracks.
1.0	42.2	Bridge over Elk Creek.

0.4	42.6	Intersection with Old Lake Road on left. Old Lake Road leads to the mouth of Elk Creek. CONTINUE east on US Route 5.
0.5	43.1	Intersection with Cherry Street on right, entrance to Lake Erie Community Park on left. CONTINUE on US Route 5.
0.1	43.2	Intersection with PA Route 18 on right. CONTINUE on US Route 5.
0.8	44.0	Intersection with Nursery Road. CONTINUE east on US Route 5. The Fairview Evergreen Nursery is the largest of its type east of the Mississippi River. The well drained sand and gravel provide a perfect locale for the raising of decorative trees and shrubs, fruit trees and vineyards.
1.6	45.6	Intersection with Fairplain Road. CONTINUE east on US Route 5. The gravel pit at Stop 1 on the Whittlesey level can be seen to the right (south).
0.5	46.1	Fairview Township boundary.
1.2	47.3	Traffic light at intersection of PA Route 98. CONTINUE east on US Route 5. We are travelling along the north edge of the Lake Warren terrace. Elevation 680 feet. The scarp is visible to the left. This is a wave-cut cliff eroded by Lake Warren III. The Warren terrace is at 670 feet elevation.
2.4	49.7	Intersection with Dutch Road. CONTINUE east on US Route 5.
0.2	49.9	Bridge over Walnut Creek.
0.3	50.2	Intersection with Manchester Road. CONTINUE east on US Route 5.
1.2	51.4	Traffic light at intersection with Garloch Road. CONTINUE east on US Route 5.
0.8	52.2	TRAFFIC LIGHT. BEAR LEFT at intersection onto US Alternate Route 5 (West Lake Road). Erie International Airport visible to right.
0.7	52.9	West Lake Middle School rests on the very edge of a wave-cut cliff formed while the waves of Lake Warren III were eroding the Warren I terrace. West Lake Road persistantly follows the wave-cut cliff which can be seen by looking left (north) down the side streets leading to Lake Erie.
1.2	53.7	Traffic light at junction with PA Route 299 (Powell Avenue). CONTINUE east on US Alternate Route 5.
0.7	54.4	Entrance to Calvary Cemetery on right.
0.3	54.7	BEAR LEFT onto West 6th Street.
0.3	55.0	TRAFFIC LIGHT at West 6th Street and Peninsula Drive (PA Route 832). TURN LEFT and proceed north on Peninsula Drive to Presque Isle State Park.
0.6	55.6	New condominium construction on left. Pile of large sandstone blocks is remains of 1948 vintage seawall, which was removed during condo construction.
0.1	55.7	Entrance to Presque Isle State Park. Bike path leaves road on right.
0.1	55.8	View of Presque Isle Bay (Erie Harbor) to right.
0.2	56.0	Entrance to Beach No. 1 parking lot and bathhouse on left.
0.1	56.1	Parking lot entrance on right.
0.3.	56.4	Parking lot on right, Erie Yacht Club boat dock area visible across the bay.
0.1.	56.5	Parking lot on right, Park Nature Center on left.
0.2	56.7	Extensive swampy land area to right is related to efforts to close openings in the neck in the early and mid-1800's. There has probably been additional deposition of material by overwash in later years. The bay area between here and Swan Cove was one of the 2 source areas for dredged sand for the first beach nourishment project in 1956. At that time there was a more extensive area of barely submerged to barely emergent land.

0.7	57.4	Parking lot entrance on right.
0.3	57.7	Road curves to the right.
0.1	57.8	Swan Cove parking area on right.
0.1	57.9	Park headquarters building on right.
0.3	58.2	Niagara boat launch area on right.
0.2	58.4	**TURN RIGHT** into parking area for Cookhouse Pavilion. **LUNCH STOP.** The rectangular ponds across Peninsula Drive are the settling ponds for the original Erie City waterworks. The tower-like structure on the bay shore houses control valves for the pipeline which crosses the bay. The present city water system relies on an intake several miles out into the lake, but the old system is still workable and available as an emergency backup. The present intake line crosses the neck of the peninsula near Beach 1.
0.1	58.5	Leave parking lot. Cross median strip and **TURN LEFT** onto Peninsula Drive.
0.1	58.6	Waterworks ponds on right.
0.4	59.0	**TURN RIGHT** into entrance to Beach No. 6 parking lot.
0.1	59.1	**STOP SIGN.** Experimental electric generating windmill on right. **TURN LEFT.** Go past bathhouse into west parking lot. Proceed to far end of parking lot.
0.1	59.2	This stop and the other two stops in the park may be moved depending on changes in conditions between guidebook writing and the time of the trip.

STOP 3. PRESQUE ISLE: EROSIONAL BEACH AREA.
Leaders: Helen Delano and Kent Taylor.

This stop will be in the erosional section of the Peninsula, probably near Beach 6 at the northeastern end of the "neck" (Figure 34). This is the section of the peninsula where the set of 11 groins were built as part of the cooperative shore protection program beginning in 1954. The older steel sheetpile bulkhead is usually covered by sand, but the groins are very evident. The annual beach nourishment program supplies sand to this area every spring. Most of the material in the last few years has come from the West Ridge Sand and Gravel Company's Girard Pit (Stop 1). We should be able to observe the effects of the summer wave activity on the nourished beach. Typical effects are the cutting of a beach scarp, movement of some material offshore to the bar system, and deposition of sand updrift of the groins. A variety of small scale sedimentary structures such as ripples and swashmarks are common.

During times of extreme high water levels due to storms, (usually in winter) waves may wash over the neck, blocking road access and depositing sand in the bay. Less extreme events lead to washovers of the dune line and the shore road, which is now used primarily for access by maintenance vehicles and sand trucks.

Things to look for at this stop include the "old" shore road, which is generally covered by sand every winter; the forested dune area behind the backshore; the effects of the groins on the conformation of the beach; and the character of the sediment in the nourished beach, in the dunes, and on the active beachface. If we are fortunate, the weather will be right for us to observe the northeastward transport of sediment by waves.

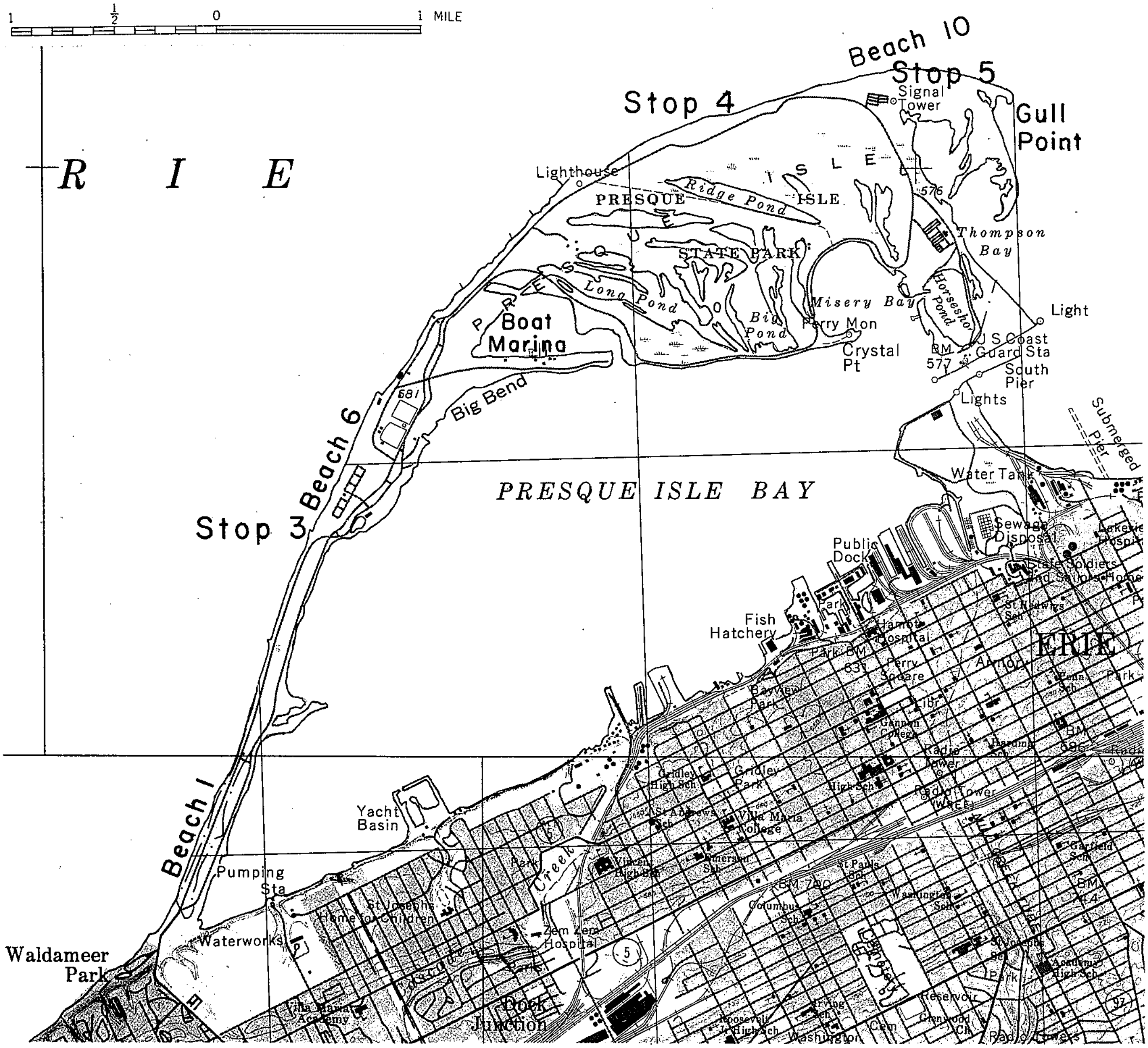


Figure 34. Location map for Presque Isle (from Erie County, PA 1:50,000 scale map series).

Some questions to think about: Has the coarse grain size of the nourishment material affected growth and maintenance of the dunes? What would happen to the peninsula and harbor if the neck were breached? How would a different configuration of groins (shorter? lower?) change the conditions? What will this section of beach be like when/if the proposed system of breakwaters is built? Does the nourished beach with its sand-derived sediment meet your expectations for a recreational beach?

LEAVE STOP 3. RETRACE ROUTE through parking lot, **TURN RIGHT** at windmill and bathhouse.

0.3	59.5	**STOP SIGN** at main park road. **CROSS** median and **TURN LEFT.** Park office is straight ahead.
0.5	60.0	Cookhouse pavilion entrance on right.
0.2	60.2	Swampy area on right, large number of dead trees due to high lake levels during the last several years.
0.1	60.3	Road to Marina and West Pier on right runs along an old dune ridge. It was the old park perimeter road before the 1956 dredging of nourishment material opened the Marina area.
0.3	60.6	Dunes and beach visible to left.
0.3	60.9	**GET IN LEFT LANE, TURN LEFT** at stop sign.
0.1	61.0	**STOP SIGN, TURN RIGHT** onto Pine Tree road. Dunes and beaches visible on left, old dune ridges on right.
0.2	61.2	Entrance to park maintenance area on right.
0.3	61.5	Lighthouse (built in 1871) on left, Sidewalk Trail trailhead on right. This concrete paved trail runs along the base of a dune ridge from the lighthouse to the bay shore near the East Boat Livery. It is shown on the 1900 15-minute topographic map, and was originally used as an access route for the lighthouse keepers, who crossed from Erie by boat. It was paved in 1913. The park road originally ran in front of the lighthouse, but was damaged by erosion in 1946, and relocated to its present position in 1948.
0.4	61.9	**STOP SIGN.** Road curves right, **GO STRAIGHT AHEAD INTO PARKING LOT** for Beach No. 9.
0.1	62.0	Park in parking lot.

STOP 4. PRESQUE ISLE: BEACH NO. 9 AREA.
Leaders: Helen Delano and Kent Taylor.

This stop will be within the section of the peninsula where sediment transport rates begin to decrease eastward. There is some net deposition, but most sediment is carried through this section. The nodal point between net erosion and net deposition has migrated eastward from 150 m (500 ft) west of the lighthouse (Figure 34) in 1877 to near Beach 10 in recent years.

The offshore bar system changes here, and material transported in the trough between bars along the neck may return to shore in this area. The bar system is complicated, with transverse bars migrating across a gently sloping nearshore platform. A large amount of sand moves along the beach face here as migrating "megacusps" or sand waves.

The wide flat beach here in 1987 has built out since the major nourishment program was instituted and the abundant sediment supply to this area was reestablished. From 1946 into the 1970's, parts of this area experienced significant erosion. The road was relocated, a rock revetment built at Sunset Point, and emergency nourishment material placed several times.

Most of the beach sediment here is transported nourishment material. Notice the lines of low vegetation which are beginning to establish dune ridges on the backshore.

0.1	62.1	**LEAVE** parking lot, **TURN LEFT** at stop sign.
0.7	62.8	Sunset Point area, Beach and lake visible to left.
0.2	63.0	Parking lot entrance on left.

0.1 63.1 West end of Budny Beach parking lot, bathhouse on left.
0.1 63.2 TURN LEFT into east section of Budny Beach (Beach No. 10) parking lot. Proceed to far east end of lot.
0.1 63.3 Park in parking lot.

STOP 5. PRESQUE ISLE: BEACH NO. 10 AND GULL POINT AREA.
Leaders: Helen Delano and Kent Taylor.

This stop, at Budny Beach (Beach 10) and Gull Point, is in the accretionary part of the peninsula. We will look at the beach area at Budny Beach and walk eastward onto Gull Point far enough to see the extensive sand plain and series of accretionary ridges. We will not have enough time to walk around the point to look at the newest area of spit growth and inlet closure, but hope to get a sense of the accretion processes in our shorter walk. The area east of the parking lot is a nature preserve set aside to protect nesting areas and other fragile habitats for shore birds.

Budny Beach is the site of the three "test models" of breakwaters. These are similar to the breakwaters which are proposed for the lakeward shoreline of the peninsula from here west to the mainland. The sand trapping efficiency of the structures is usually quite evident. The beach has built out since their installation, and is normally built out farther in the lee of each breakwater.

East of Budny Beach, the beach and dune ridges have experienced considerable erosion in the last few years. The relative importance of high lake levels and limited sand supply from updrift as causative factors is unknown. In the early summer of 1987, lower lake levels allowed the beach in this area to become wider. The offshore profile off the east end of the peninsula is the steepest that was measured along Presque Isle. This causes the surf zone to be narrow, and allows a large proportion of the wave energy to reach the shore. The orientation of the shore is such that it is sheltered from the major storm waves, and is most affected by the less common northeast storms.

The primary processes responsible for growth at the east end of Presque Isle are (1) eastward progradation of the spit platform into deep water; (2) formation of small spits and bars on the platform followed by migration of these onshore, forming beach ridges enclosing lagoons and ponds; and (3) overwash during storms, building up the ridges and filling the ponds.

Gull Point, the center for most of the modern growth of Presque Isle is a fairly new feature. The 1900 topographic map (Figure 35) shows the end of the spit as a smooth curve to the harbor area. Gull Point began to develop in the 1930's, possibly in response to the sudden increase in available sand supply from the breached neck in 1917-23. Lake levels were unusually low in the 1930's as well.

We can expect to see washovers, concentrations of heavy mineral sands, and evidence of the vegetative succession on developing dune ridges in this area. Notice the character of the sediment. There seems to be less influence from the nourishment material, but it is not known whether some of the sand here is still "natural" or if the nourishment material is sufficiently sorted by transporting processes to have different characteristics.

Figure 35. Part of the 1900, 1:62:500 scale Erie topographic map.

		LEAVE STOP 5. RETRACE ROUTE out of parking lot.
0.2	63.5	**LEAVE** parking lot. **TURN LEFT** at stop sign onto Thompson Drive.
0.4	63.9	Thompson Circle loop road on right.
0.1	64.0	Road to Coast Guard Station on left.
0.1	64.1	Entrance to Beach No. 11 on left.
0.3	64.4	Misery Bay on left. Admiral Perry's fleet returned here after the battle of Lake Erie to spend the winter. The Perry Monument is visible on the point across the bay. Niagara Pond is on the right.
0.1	64.5	Lawrence Boat Launch on left.
0.3	64.8	South end of Sidewalk Trail on right.
0.1	64.9	Entrance to East Boat Livery (Park franchised boat rental area).
0.1	65.0	Grave Yard Pond on right.
0.2	65.2	**CROSS** Misery Bay Bridge.
0.1	65.3	Parking area for Perry Monument on left.

0.5	65.8	Bike trail crosses road. Stone rip-rap along bay shore on left. View to left across Erie Harbor to city of Erie.
0.4	66.2	Entrance to East Pier area parking on left, **CONTINUE** straight.
0.3	66.5	Dredged harbor area on left is location of the park Marina. This area supplied much of the initial beach nourishment material in the 1950's. Range lights on left and right are navigational aids for marking the marina entrance.
0.3	66.8	Bridge over inlet to Long Pond.
0.2	67.0	Bike trail crosses road. Road divides, **BEAR RIGHT**.
0.1	67.1	**STOP SIGN, TURN LEFT** onto Peninsula Drive. This is an area of frequent winter washovers and dune migration across road.
0.3	67.4	Junction with old shore road on right.
0.3	67.7	Pettinato Beach entrance on right.
0.3	68.0	Waterworks lagoons on right, picnic area on left.
0.5	68.5	Beach No. 6 entrance on right.
1.0	69.5	Modern restrooms on right (Barracks Beach access).
0.4	69.9	Nature Center on right.
0.6	70.5	Beach No. 1 entrance on right.
0.1	70.6	**LEAVE** park.
0.9	71.5	Peninsula Drive and 6th St. traffic light. **GO STRAIGHT.**
0.1	71.6	Peninsula Drive and 8th St. traffic light. **GO STRAIGHT.**
0.3	71.9	Peninsula Drive and 12th St. (PA Route 5) traffic light. **GET IN LEFT LANE and TURN LEFT.**
0.6	72.5	Villa Maria College on left. **GET INTO RIGHT LANE.**
0.2	72.7	Traffic light at shopping center entrance. **GO STRAIGHT.**
0.05	72.75	Traffic Light at Pittsburgh Ave. **GO STRAIGHT.**
0.25	73.0	**BEAR RIGHT** onto entrance ramp for I-79 South.
5.3	78.8	Junction I-79 and I-90 West. **STAY** on I-79.
0.4	79.2	Junction I-79 South and I-90 East. **TURN RIGHT** onto I-90 East.
2.6	81.8	Exit 6. **CONTINUE** on I-90.
2.5	84.3	Exit 7. **BEAR RIGHT** onto exit ramp.
0.2	84.5	**STOP SIGN** at end of ramp. **TURN RIGHT** onto PA Route 97.
0.1	84.6	**TURN RIGHT** into parking lot of Holiday Inn. **END OF DAY 1 TRIP. SEE YOU AT THE BANQUET!**

ROAD LOG - DAY 2

Mileage Int	Mileage Cum	
0.0	0.0	**LEAVE** parking lot of Holiday Inn South. **TURN LEFT** (north) onto PA Route 97.
0.2	0.2	**TURN LEFT** onto I-90 West/Cleveland.
2.1	2.3	Exit to US Route 19, Peach Street/Waterford exchange. **CONTINUE** on I-90 West. We are travelling on the hummocky topography left by the Ashtabula ice.
1.6	3.9	Hamot Road Bridge.
0.6	4.5	PA Route 99, Edinboro Road bridge.
0.1	4.6	**EXIT RIGHT** onto I-79 North, Erie.
2.5	7.1	Exit to Kearsarge and the Millcreek Mall. **CONTINUE** on I-79 North. We will begin to descend the north slope of the Ashtabula morainic system.
0.7	7.8	Bridge over Walnut Creek. The ridge ahead is the crest of the Girard Moraine. Lake Maumee I developed west of this moraine in northwestern Ohio.
0.4	8.2	West Grandview Blvd. bridge.
0.9	9.1	Exit to US Route 20. **CONTINUE** on I-79 North.
1.1	10.2	Exits to US Route 5 East and West. **STAY LEFT AND EXIT** onto US Route 5 West.
0.6	10.8	Exit to I-79 South, Pittsburgh. **CONTINUE** on US Route 5 West.
0.5	11.3	Traffic light at intersection of US Route 5 and Pittsburgh Avenue. **CONTINUE** on US Route 5 West. We will be travelling on the flat topography of the Warren I-II level at about 710 feet.
0.1	11.4	Traffic light at intersection of US Route 5 and West Erie Plaza. **CONTINUE** on US Route 5 West.
0.7	12.1	Traffic light at intersection of US Route 5 and PA Route 832, Peninsula Drive. **CONTINUE** on US Route 5 West.
1.3	13.4	Traffic light at intersection of US Route 5 and PA Route 299, Powell Avenue. **CONTINUE** on US Route 5 West.
1.0	14.4	Entrance to Erie International Airport. The airport is built upon the Warren I-II level. The first raised terrace to the south of the airport along which US Route 20 is built is the Lake Whittlesey level. The ridge on the horizon south of the Whittlesey terrace is the crest of the Girard Moraine.
0.3	14.7	Traffic light at intersection of US Route 5 and Asbury Road. **CONTINUE** on US Route 5 West.
0.9	15.6	Traffic light at intersection of US Route 5 and Garloch Road. **CONTINUE** on US Route 5 West.
0.4	16.0	Entrance to Gate of Heaven Cemetery. Note the very flat topography of the Warren I-II level. We are travelling a few hundred feet south of the scarp that separates the Warren I-II level from the Warren III level. This scarp can be seen by looking north (right) down roads that lead northward from US Route 5.
0.3	16.3	Entrance to Lake Shore Country Club. The southern part of the golf course to the left is on Warren I-II. The northern part to the right is on Warren III.
0.5	16.8	Intersection of US Route 5 and Manchester Road. **TURN RIGHT** onto Manchester Road. We will be descending the east valley

		wall of Walnut Creek. Previous levels of Walnut Creek are reflected in the several terraces along the valley wall. Walnut Creek here has cut through the Warren I, II, and III levels, down through glacial diamict and into the Upper Devonian Girard Shale that is present in the stream channel.
0.6	17.4	Intersection of Manchester Road and Walnut Creek Access. **TURN RIGHT** onto Walnut Creek Access road.
0.2	17.6	STOP SIGN. TURN RIGHT.
0.2	17.8	Intersection of Walnut Creek Access road and parking lot. Buses will be directed to parking area.

STOP 6. WALNUT CREEK ACCESS AREA.
Leader: Helen Delano.

This site is the Pennsylvania Fish Commission's Walnut Creek Access area, and is located at Manchester Beach, at the mouth of Walnut Creek (Figure 36). Early October will probably be peak salmon fishing time, so this area will be crowded with cars, boats, and fishermen. Please be careful of traffic, and avoid interfering with boat launching, etc.

The creek is fairly typical of the streams entering the lake west of Erie. In its upper reaches it flows north, then swings to a westward course between glacial moraines, and then flows north again around the end of the Girard Moraine and into the lake (Figure 36). The lower reaches of the stream flow over bedrock, with several cobble and gravel bars. At normal flow, the creek is shallow and carries very little sediment. Transport of bedload cobbles does occur during high flows, as evidenced by migration of channel bars and the existence of a cobble and gravel beach before dredging of the creek mouth area.

The Fish Commission's major improvements began in 1972 and consisted of construction of a stone jetty on the west side of the creek mouth and dredging the creek mouth to facilitate boat launching. A shorter and lower jetty was built on the east side of the creek. The harbor mouth jetties interrupted the longshore drift, and erosion on the beaches east of the creek increased. Groins were built in 1973 and 1974 in an effort to prevent further erosion. The beach west of the harbor jetty is built up to the level of the jetty, and is a wide, sandy beach. Figure 37 shows shoreline changes between 1955 and 1975, most of which occurred after 1972.

The boat docking basin was dredged later than the initial work on the access area. Annual maintenance dredging of the boat dock area and harbor entrance is necessary to keep the design depth of about 3 m (10 ft). Most of the dredged material is coarse gravel and cobbles. Environmental regulations presently do not allow the dredge spoil to be returned to the lake, and it is piled on the shore. Much of it is used by the township as washed gravel for various purposes. The stream banks are armored with rip-rap along the dredged sections.

East of the public access area, the shoreline and bluffs are experiencing erosion and many of the same bluff recession processes that we observed at the Raccoon Creek bluff exposure at Stop 1. **WE WILL NOT WALK THE SHORE EAST OF THE PARKING LOT**, but can look from the parking lot down drift to extensive cribbing wall and groin installation along the bluffs. Erosion is not a new phenomenon here, as one of the large groins was built before 1950. The concrete cribbing wall was built between 1975 and 1981, and was probably a response to increased erosion due to the combined effects of high lake levels and loss of sediment supply from the Walnut Creek area. This cribbing wall was damaged during the winter of 1986-87.

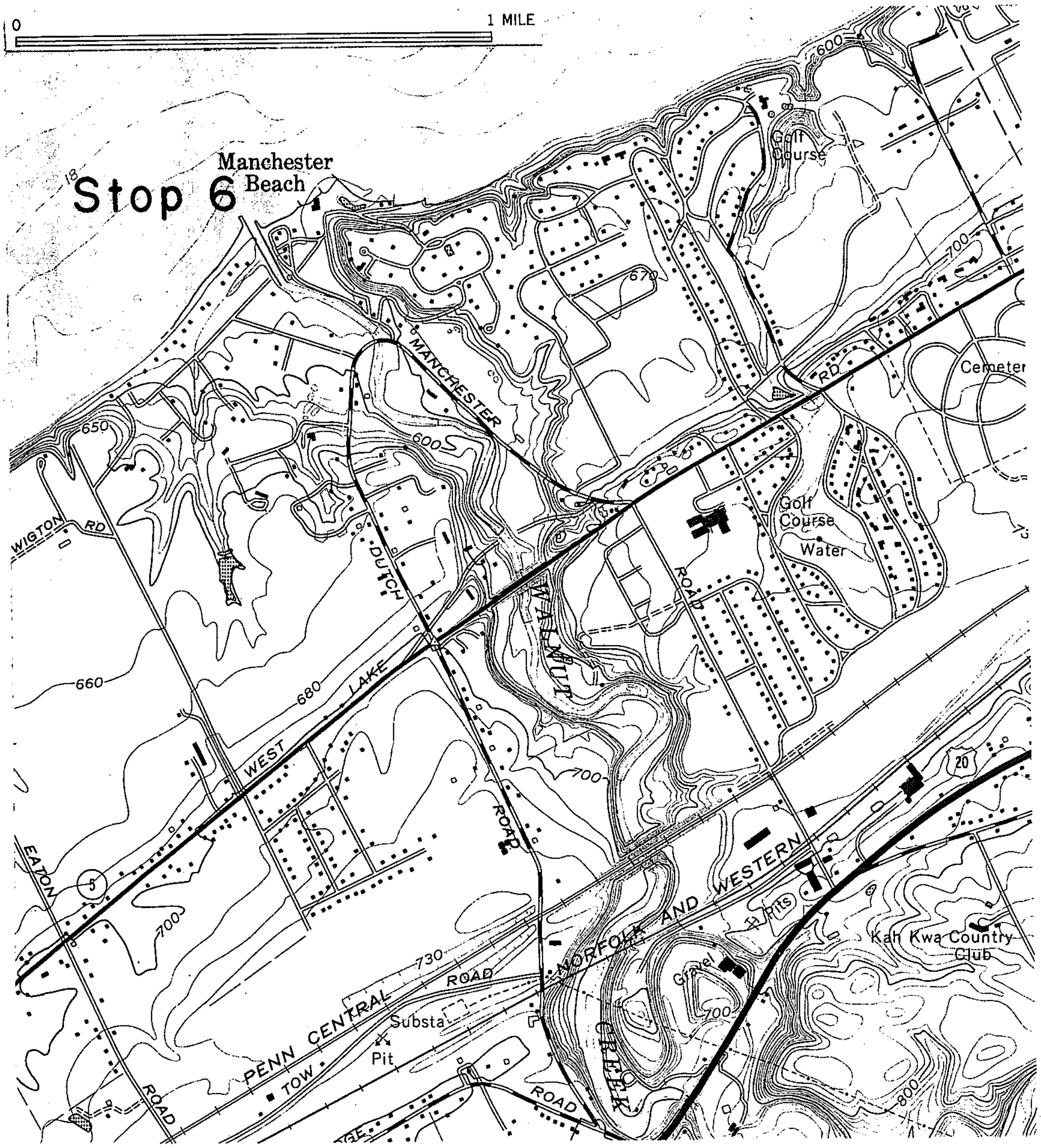


Figure 36. Location map for Stop 6 (from Swanville, PA 7.5-minute topographic map).

		LEAVE Stop 6 and Walnut Creek Access and retrace route to entrance.
0.2	18.0	Intersection. **TURN LEFT.**
0.1	18.1	Intersection. **TURN LEFT** onto Manchester Road.
0.6	18.7	Intersection. **TURN LEFT** onto US Route 5 East.
1.2	19.9	Traffic light at intersection of US Route 5 and Garloch Road. **CONTINUE** on US Route 5 East.

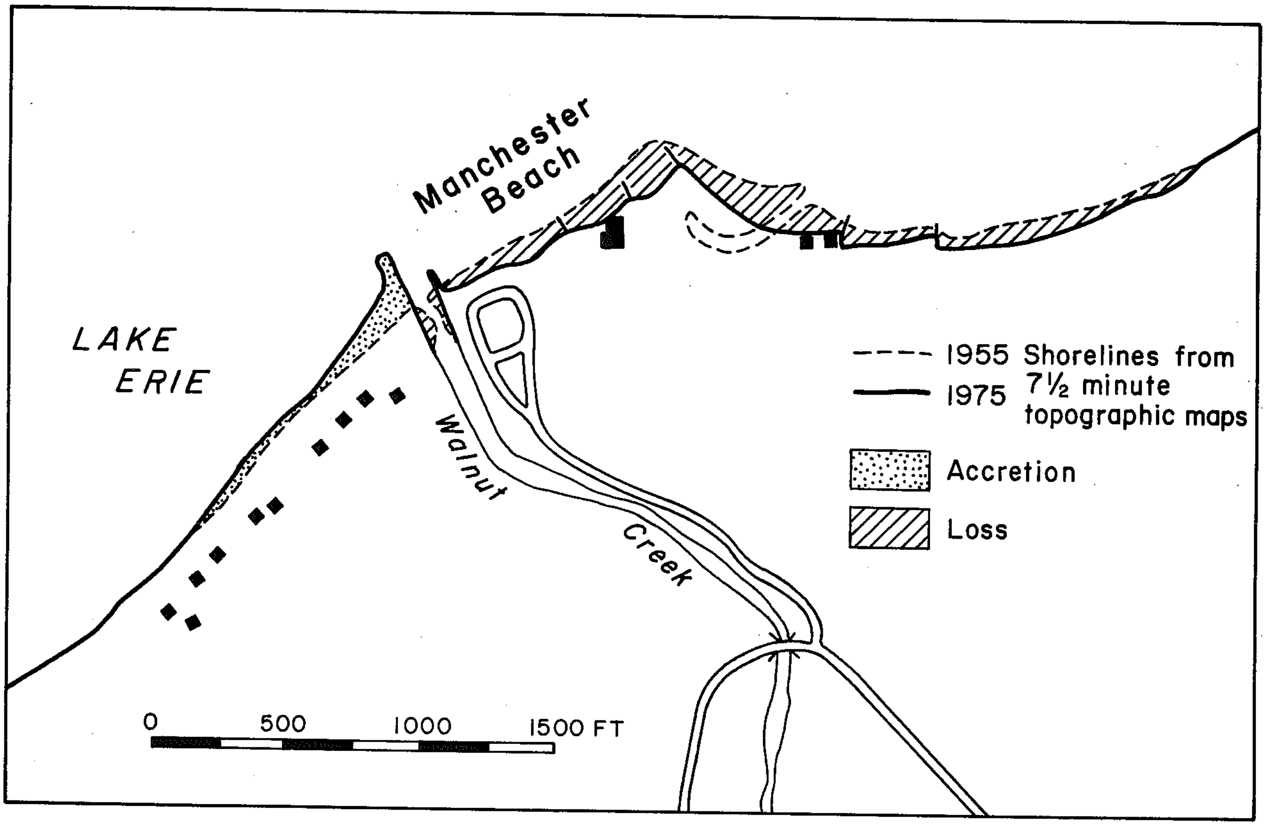


Figure 37. Shoreline changes near the mouth of Walnut Creek (from the 1957 Swanville, PA 7.5-minute topographic map which was based on 1955 aerial photographs, and the 1975 photorevision of the same topographic map).

0.9	20.8	Traffic light at intersection of US Route 5 and Asbury Road. **CONTINUE** on US Route 5 East.
0.3	21.1	Entrance to Erie International Airport.
1.0	22.1	Traffic light at intersection of US Route 5 and PA Route 299, Powell Avenue. **CONTINUE** on US Route 5 East.
1.3	23.4	Traffic light at intersection of US Route 5 and PA Route 832, Peninsula Drive. **CONTINUE** on US Route 5 East.
0.7	24.1	Traffic light at intersection of US Route 5 and entrance to West Erie Plaza. **CONTINUE** on US Route 5 East.
0.1	24.2	Traffic light at intersection of US Route 5 and Pittsburgh Avenue. **KEEP RIGHT** in preparation for ramp onto I-79 South/ Pittsburgh.
0.2	24.4	**BEAR RIGHT** onto entrance ramp to I-79 South/Pittsbugh.
0.7	25.1	Exit 43, US Route 20, 26th Street. **GET IN MIDDLE LANE AND CONTINUE** on I-79 South.
0.4	25.5	US Route 20 (West 26th Street) bridge. We are leaving the Lakes Whittlesey and Warren I, II, and III terraces and ascending the north-facing slope of the Girard Moraine.
0.7	26.2	West 38th Street bridge. We are continuing to ascend the Girard Moraine.
0.6	26.8	West Grandview Boulevard bridge. We are passing over the crest of the Girard Moraine. The ridge to the south (straight ahead) is the Ashtabula Moraine.

0.4	27.2	Bridge over Walnut Creek. The creek flows between the Girard and Ashtabula Moraines.
0.2	27.4	Exit 41, US Route 19 and Kearsarge. **CONTINUE** on I-79 South. We will continue to travel over the hummocky topography of the Ashtabula Moraine.
0.2	27.6	Interchange Road bridge. We continue to travel across the hummock topography of the Ashtabula Moraine.
1.6	29.2	Hershey Road bridge.
0.6	29.8	Exit to I-90 West/Cleveland. **CONTINUE** on I-79 South.
0.4	30.2	**BEAR RIGHT** onto I-90 East/Buffalo.
1.0	31.2	PA Route 99, Edinboro Road bridge.
0.8	32.0	Hamot Road bridge.
0.7	32.7	Exit 6, US Route 19/Peach Street. Holiday Inn South, field conference headquarters. **CONTINUE** on I-90 East.
1.6	36.9	Lake Pleasant Road bridge.
1.9	38.8	Morehouse Road bridge.
0.2	39.0	Crossing Four Mile Creek.
0.7	39.7	Jordan Road Bridge.
0.7	40.4	**EXIT RIGHT** at Exit 9, PA Route 430/Wesleyville.
0.4	40.8	**TURN LEFT** onto PA Route 430. **STAY TO THE RIGHT.**
0.2	41.0	Intersection of PA Route 430 and Hannon Road. **TURN RIGHT** onto Hannon Road. We are travelling down the north slope of the Ashtabula Moraine. The ridge straight ahead (north) is the crest of the Defiance Moraine. The relief separating the Ashtabula and Defiance Moraines is much less here than it is to the west. Apparently the Defiance ice encroached upon the Ashtabula Moraine to a greater extent here than in the western part of the county. Precambrian glacial erratics from the Canadian Shield occur along the road.
1.2	42.2	Intersection of Hannon Road and Reese Road to the left. We are on the crest of the Girard Moraine with a splendid view of its steep north slope overlooking the Pleistocene lake terraces and Lake Erie. **CONTINUE** north on Hannon Road.
1.1	43.3	Intersection of Hannon Road and Markwood Road to the left. Hannon Road cuts through the Lake Whittlesey terrace at this point. Well-sorted, pebble-size gravels overly diamict here, but no primary sedimentary structures have been reported to determine probable facies.
0.6	43.9	**STOP SIGN** at intersection of Hannon Road and US Route 20. **TURN RIGHT** onto US Route 20.
0.4	44.3	Cross Sixmile Creek. The Northeast Shale of the the Upper Devonian Canadaway Formation is exposed along the creek banks. We will be travelling east parallel to the Warren I terrace. It has been dissected by streams both active and inactive.
1.3	45.6	Intersection of US Route 20 and PA Route 531. Harborcreek High School to the left (south). **BEAR LEFT** following US Route 20 and pass beneath railroad bridge. **BEAR RIGHT AND CONTINUE** east on US Route 20 through the village of Harborcreek. The village lies near the scarp separating Warren I and Warren II. Eastward the scarp can be seen clearly. US Route 20 is generally at elevation 720 feet, while Warren I lies at about 680 feet in this area.
2.0	47.6	Intersection of US Route 20 and Highmier Road to the right. **CONTINUE** east on US Route 20. We are travelling along the

		Warren I terrace. The Lake Whittlesey terrace, the Girard Moraine, and the Ashtabula Moraine are to the right (south). The Lake Warren III terrace lies to the left (north).
1.1	48.7	Intersection of US Route 20 and Mooreheadville Road. Cross a tributary to Twelvemile Creek. Twelvemile Creek and its tributaries were routes of the Underground Railroad. Escaped slaves walked along the streambed at night and were hidden by farmers during the day. One of the most active hiding places was a mill about 0.2 mile to the north, just east of Mooreville Road. After hiding in the mill during the day, the escaped slaves would continue after dark down the streambed of Twelvemile Creek, board rowboats at the shore of Lake Erie, and row over 24 miles to Canada.
0.5	49.2	Boundary marker for the Harborcreek and Northeast Townships.
0.3	49.5	Intersection of US Route 20 and Haskel Road. Go Slow. Stop 7 is 0.1 mile east.
0.1	49.6	Entrance to Central Sand and Gravel Company. **TURN RIGHT.**

STOP 7. CENTRAL SAND AND GRAVEL PIT
Leader: Charles Carter.

Introduction

This pit is part of an extensive (several kilometers long and up to a few kilometers wide) sand and gravel deposit that trends southwest-northeast, roughly parallel to the present Lake Erie shore. The existing pit is nearly mined out as are adjacent pits to the west and south. The sand and gravel are used for road construction, the mining is done with front-end loaders, and the processing is accomplished by a hydraulic sorter. The deposit is at least 8 m (26 ft) thick and mining has been done to 5 or 6 m (16 or 20 ft) below the original, prestripped surface. Foreman Scott Weissenk said that the deposit was coarser to the east so that although the sediments exposed along the western face are largely granule- and pebble-sized, the overall grain size for the pit was larger.

A small, about 4 m (13 ft) long, normal, nearly bedding-plane parallel fault (Figure 38) occurs near the center of the face. The apparent fault plane is curved and has a strike of about east-west and an overall dip of about 23°N although siltstone cobbles are oriented nearly 90° from the horizontal at the north end. Whether the origin of the fault is tectonic or isostatic is unknown.

The elevation of the surface of this deposit (about 780 to 790 ft), and the correlation of this surface both to the east and the west, has led to the mapping of this feature and elevation as the Whittlesay strandline (Schooler, 1974, p. 11, 12). The deposits underlying this surface in this area of Pennsylvania have been interpreted as "beach deposits" (most recently by Schooler, 1974, p. 19) mainly on the basis of geomorphic evidence. However, she also recognized a "channel-like feature" at one location that included imbricated gravel that she interpreted as a "delta" (p. 22). Schooler's work is typical of most of the work that has been done on the "beach ridges," in that the interpretations of these deposits have been made largely on topographic expression and texture with little consideration given to the internal characteristics and geometry of the deposits. Because of this, University of Akron students and faculty are doing sedimentologic studies of the ridges in

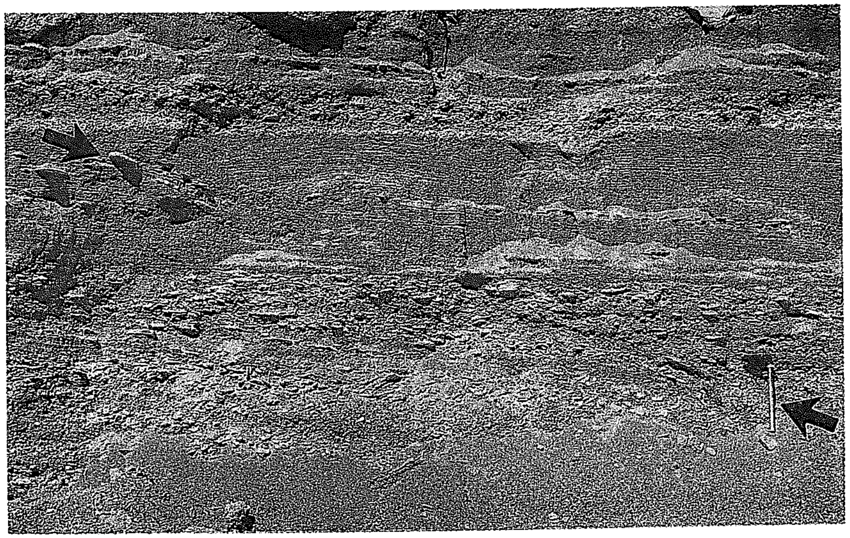


Figure 38. Small fault near center of pit face. Arrows indicate fault trace.

Figure 41. Interbedded granule and pebble/cobble facies along north-south trending pit face (north to right).

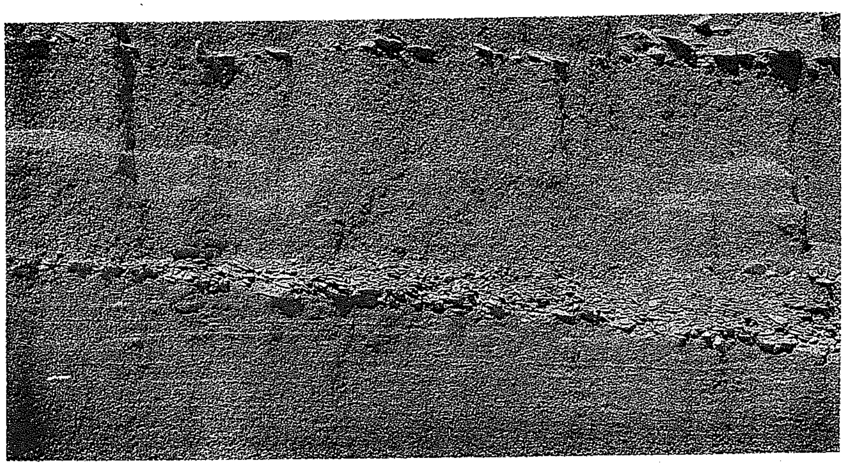


Figure 42. Interbedded granule and pebble/cobble facies. Note erosion of granule bed beneath pebble/cobble lens (pocket knife for scale).

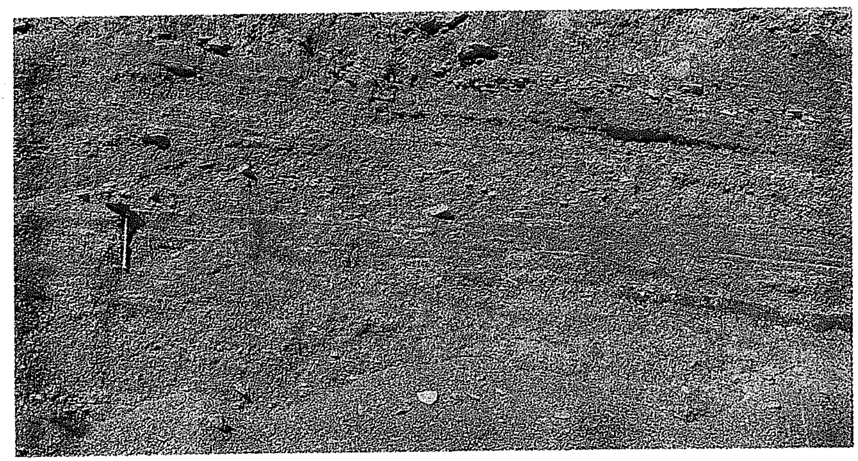


Figure 43. Gravel lens facies. Erosional contact between interbedded granule and pebble/cobble facies and the gravel lens facies at shovel head. Poorly defined lateral accretion surfaces slope to the left in the gravel lens.

order to improve our knowledge of their origin and evolution.

Sedimentology and Paleogeography

The pit lies near the western apex of a triangular-shaped terrace that opens to the east (Figure 39). A north-south face with a length of about 350 m (1148 ft) and a mean height of about 4 m (13 ft) provides an excellent cross section of the deposit. There are three facies exposed in the face: an interbedded granule and pebble/cobble facies (about 80 percent of the face), a gravel lens facies (5 percent), and a turbated clay/gravel facies (15 percent) (Figure 40).

The interbedded granule and pebble/cobble facies consists of thin to thick beds and lenses that dip gently to the north (Figure 41). The particles making up the individual beds or lenses consist almost entirely of well sorted, well rounded, disc-shaped, siltstone clasts. The individual beds and lenses of granule contain laminations and very thin beds that parallel the enclosing bedding planes. The laminations and beds are distinguished on the basis of slight textural differences, although internally they appear to lack grading (Figure 42).

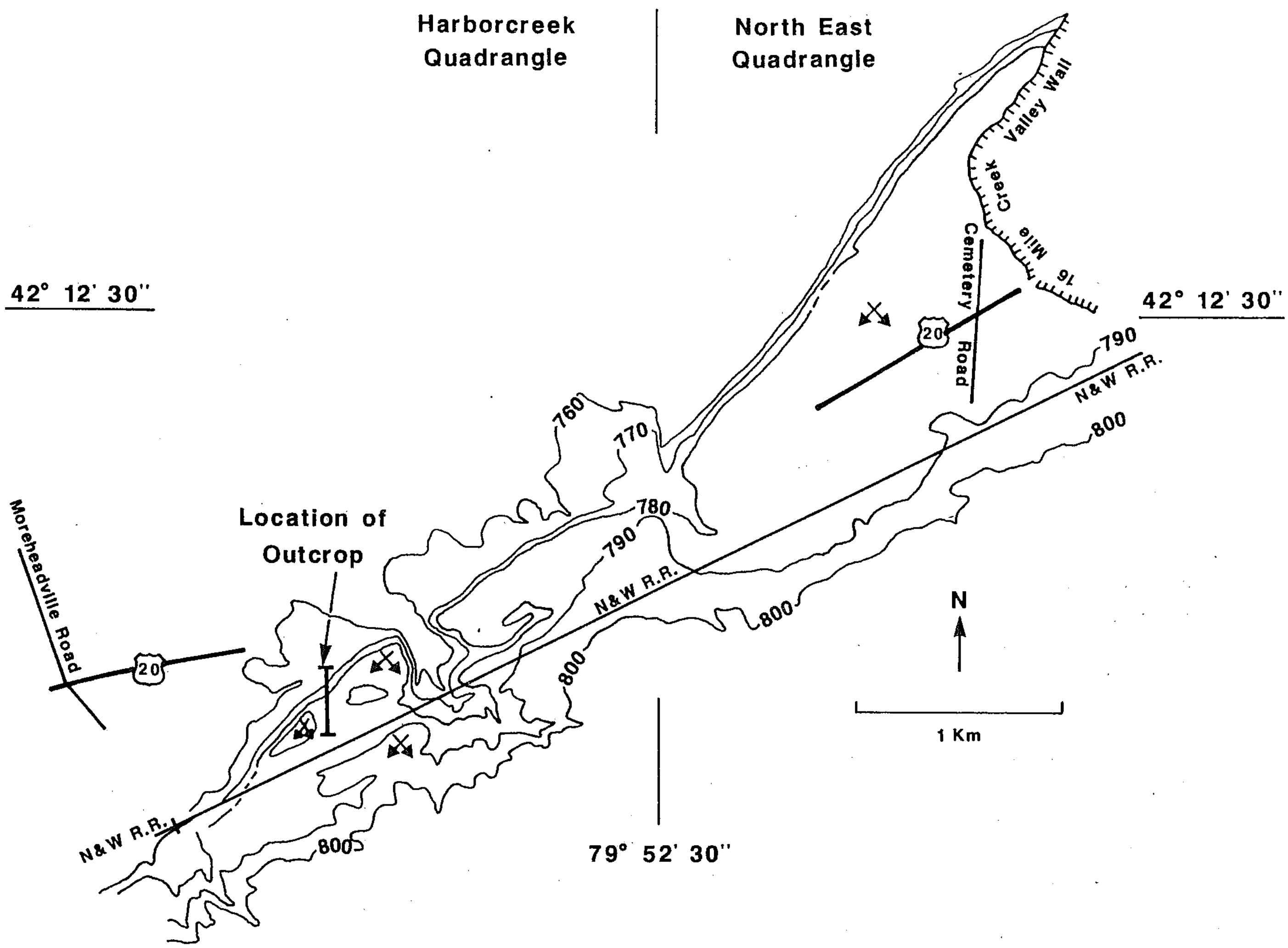


Figure 39. Location map of Central Sand and Gravel pit and plan view of deposit.

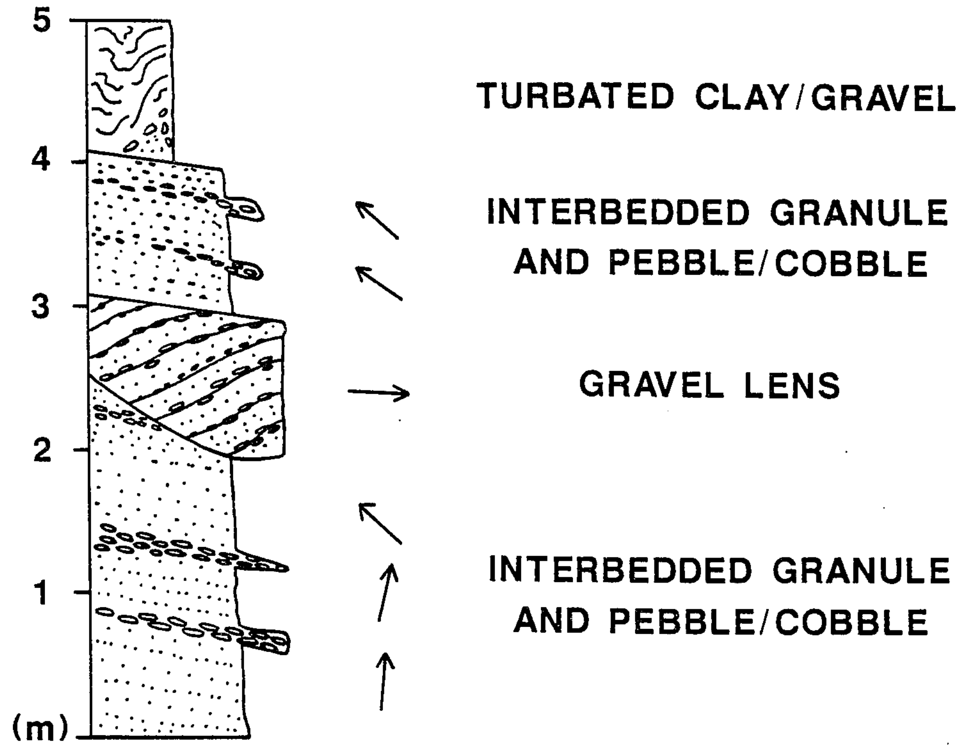


Figure 40. Generalized sequence with facies and paleoflow directions.

The individual lenses of pebble/cobble consist of framework-supported clasts with long axes oriented parallel to the northerly dip of the surrounding beds. The majority of the lenses are made up of siltstone pebbles no more than a few centimeters thick and thin to single pebble thicknesses at the margins.

In general, the beds and lenses can be traced laterally for 10 to 20 m (33 to 66 ft). The granule beds are thickest and most continuous, but the pebble/cobble lenses are up to 25 m (82 ft) and 20 cm (0.6 ft) thick. In places, the pebble/cobble lenses truncate the underlying granule at low angles. Overall, there is little if any lateral change in this facies from north to south, but vertically the facies fine upward in a 2-3 m (6-10 ft) section from fine pebbles to granules. The true dips of the sloping surfaces in both the granule and the pebble/cobble lenses are oriented between 305° (NW) and 15° (NE) with dips from 4° and 17° (the dips of 6 of the 7 readings lie between 4° and 7°). The dip orientations are not scattered. The 2 lowermost orientations are just east of north whereas the 5 uppermost orientations are to the northwest.

The gravel lens facies consists of flat to convex-up lenses that enclose cross-stratified beds of granules, pebbles, and cobbles (Figure 43). In this facies, some of the long axes of the gravels lie parallel to the stratification and others do not. In two flat-topped lenses near the south end of the face, the shape of the cross-stratification resembles lateral accretion surfaces. In a major convex-up lens located about one-third the distance from the southern end of the face, the central part of the lens consists of tightly packed, imbricated gravels. Flanking the central zone are cross-stratified cobbles, pebbles, and granules that fine as well as steepen (11° to 27°) away from the center. There is no apparent change in the texture of the individual cross-stratified layers. A second, much smaller but coarser (mostly cobbles), convex-up lens lies about 30 cm (1 ft) above the larger lens. This lens lacks the cross-stratification of the underlying lens. In both lenses the siltstone cobbles dip uniformly in a westerly direction whereas the stratification flanking the major lens dips to the south.

The gravel-size clasts, as in the interbedded facies, are framework supported, although in both facies there are numerous discrete cobble and even siltstone boulders that occur here and there in the section, parallel to the stratification of the enclosing granules, and commonly in the same planes. The pebbles and cobbles in the lenses are mostly siltstone. However, at three scattered places, well sorted and rounded, more spherically-shaped, gravel-sized clasts of mixed rock types are found. A pebble count of 69 clasts from one of these gravel lenses showed the following: 53 percent siltstone, 23 percent sandstone, 20 percent igneous and metamorphic, and 4 percent carbonate clasts.

The gravel lenses can be traced laterally for 10 m (33 ft) or more with the major convex-up lens having a lateral extent of at least 30 m (98 ft). The lenses dip gently to the north and although there are no vertical changes in the lenses, nearly all of the lenses show an updip (south) decrease in grain size. The true dip orientations of the "cross-stratification" in the lenses lie between 160° (SE) and 190° (SW) with dips from 11° to 27°. The true dip orientation of the cobbles in one imbricated zone is 275° (NW) with a dip of 10°, and the unmeasured orientation of other imbricated zones is also to the west.

The turbated clay/gravel facies consists of pods of clay separated by contorted zones of granule/gravel. Most of the facies has been removed, but before the surface was stripped there was about 15 cm (0.5 ft) of soil underlain by about 75 cm (2.5 ft) of clay (Scott Weissenk, personal communication).

In terms of facies association and order, the interbedded granule and pebble/cobble facies is eroded by the gravel lens facies, with a relief as much as 1 m (3 ft). There are about 6 gravel lenses along the face with the lenses occurring throughout the section in a vertical sense, and along the southern two-thirds of the face. The turbated clay/gravel facies caps the two underlying facies.

Interpretation

The northward-dipping, interbedded granule and pebble/cobble facies is interpreted as proximal Gilbert-type deltaic foresets. The gently dipping lenses represent deposition from grain flow and avalanching on the delta foreset because of flow expansion and deceleration at the river mouth. The coarser gravel lenses may have been segregrated during avalanching and/or may represent higher energy, episodic events. Rapid deposition took place during homopycnal flow mixing (Nemec and Steel, 1984). The incomplete foreset thickness of 3 to 4 m (10 to 13 ft) indicate minimum water depths of 3 to 4 m (10 to 13 ft) at the river mouth. The overall fining-upward sequence in these deposits may be due to decreased flow strengths caused by a gentler gradient.

The cross-cutting, cross-stratified sands are interpreted as channel deposits. Incisions of the delta slope by distributary channels during episodic drops in water level, and subsequent rises in water level, may have caused this scour and fill type of structure.

The northerly paleoflows are consistent with a delta/coastal alluvial fan origin. Northward flowing streams coming off the steep isostatically uplifted glaciated uplands debouched into glacial Lake Whittlesey with little modification by waves. The high rate of bedload coupled with low wave energy allowed the deltas to build directly to the north.

Alternate hypotheses could include sandar or barrier systems. However, the geometry of the deposit and the thickness and lateral extent of the interbedded granule and pebble/cobble facies make these hypotheses unlikely.

		LEAVE Central Sand and Gravel Company pit by the same route entered. **TURN LEFT** onto US Route 20 West.
0.1	49.7	Intersection of US Route 20 and Haskel Road to left. **CONTINUE** west on US Route 20.
0.3	50.0	Boundary marker for Northeast and Harborcreek Townships.
0.5	50.5	Tributary of Twelvemile Creek.
0.3	50.8	Intersection of US Route 20 and Mooreheadville Road.
0.3	51.1	Intersection of US Route 20 and King Road to the left. **CONTINUE** west on US Route 20.
0.5	51.6	Intersection of US Route 20 and Highmyer Road to the right. **CONTINUE** west on US Route 20.
0.8	52.4	Intersection of US Route 20 and Davison Road. **CONTINUE** west on US Route 20.
0.5	52.9	Blinker light at intersection of US Route 20 and Bartlett Road. **TURN RIGHT** and proceed north on Bartlett Road. In the next 0.3 mile we will be moving off the Lake Warren I terrace, down the scarp (possible Warren III wave-cut cliff), off the Warren I terrace at 730 feet, down the scarp (possible Warren III wave-cut cliff), and onto the Lake Warren III terrace. We will remain in the Warren III terrace the remainder of Bartlett Road.
0.6	53.5	Intersection of Bartlett Road and Dutton Road. **CONTINUE** north on Bartlett Road. We remain on the Warren III terrace at 661 feet.
0.2	53.7	Peter's Welding Shop. Dinosaurs and elephants on the Warren III terrace?
0.4	54.1	Stop sign at intersection of Bartlett Road and US Route 5. Entrance to Shades Beach Recreation Area operated by Harborcreek Township is directly across US Route 5. **CONTINUE** across US Route 5 to the entrance road to Shades Beach.
0.2	54.3	**STOP SIGN. TURN RIGHT AND CONTINUE** down narrow unpaved road with caution. Park buses to the left.

STOP 8. SHADES BEACH PARK.
Leader: Helen Delano.

This township park takes advantage of a rare low flat valley with lake access. The reason for the existence of the flat area which the park occupies is evident from the topographic map of the area (Figure 44) and Figure 45. Eightmile Creek, which now enters the lake just east of the access from the park to the lake shore, formerly occupied this valley. Lake erosion and bluff

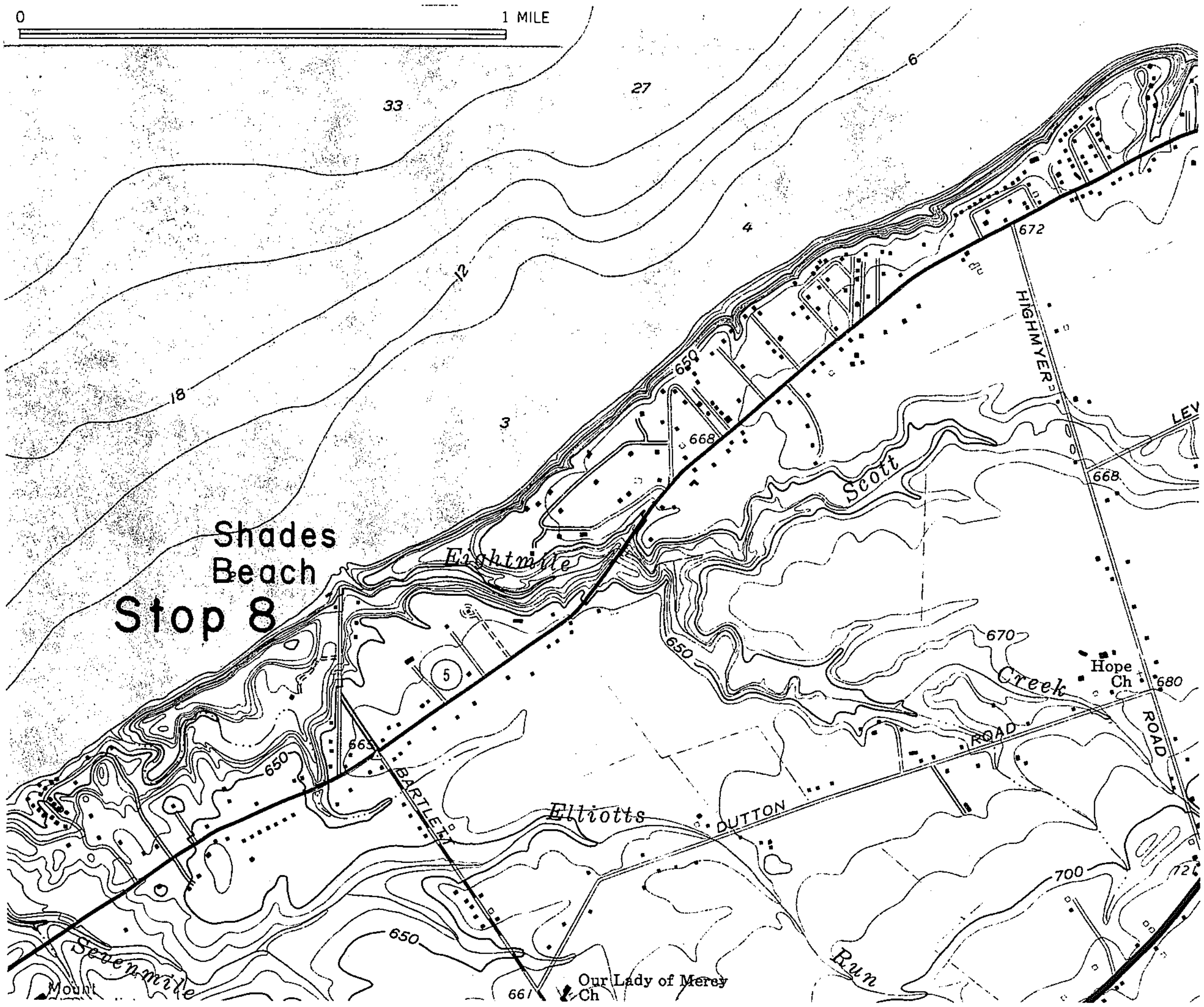


Figure 44. Location map for Stop 8 (from the Harborcreek, PA 7.5-minute topographic map).

recession caused the shore line to retreat until it intersected a northward meander loop in the entrenched stream valley. The lake effectively captured the stream, leaving the lower valley occupied by a severely underfit stream. Eightmile Creek falls approximately 12 m (40 ft) from the abandoned channel elevation to the lake, and has cut a steep, narrow valley for about a half mile upstream of the mouth. This example of piracy is evidence that erosion and bluff recession along the Lake Erie shore are not recent developments. Comparing the profiles of the streams may be a useful approach to quantifying net bluff recession.

The character of the lake shore here is different than at our other stops for two reasons. Bedrock, the Northeast Shale, is exposed at lake level along the shore as well as in the stream bed, and the glacial deposits comprising the bluffs are mantled with colluvium and debris flow deposits. The slopes are active, but are not undergoing the same rapid erosion processes that we have observed east of Raccoon Creek (Stop 2) and (from a distance) east of the Walnut Creek access area (Stop 6). Two possible explanations for this are: (1) the

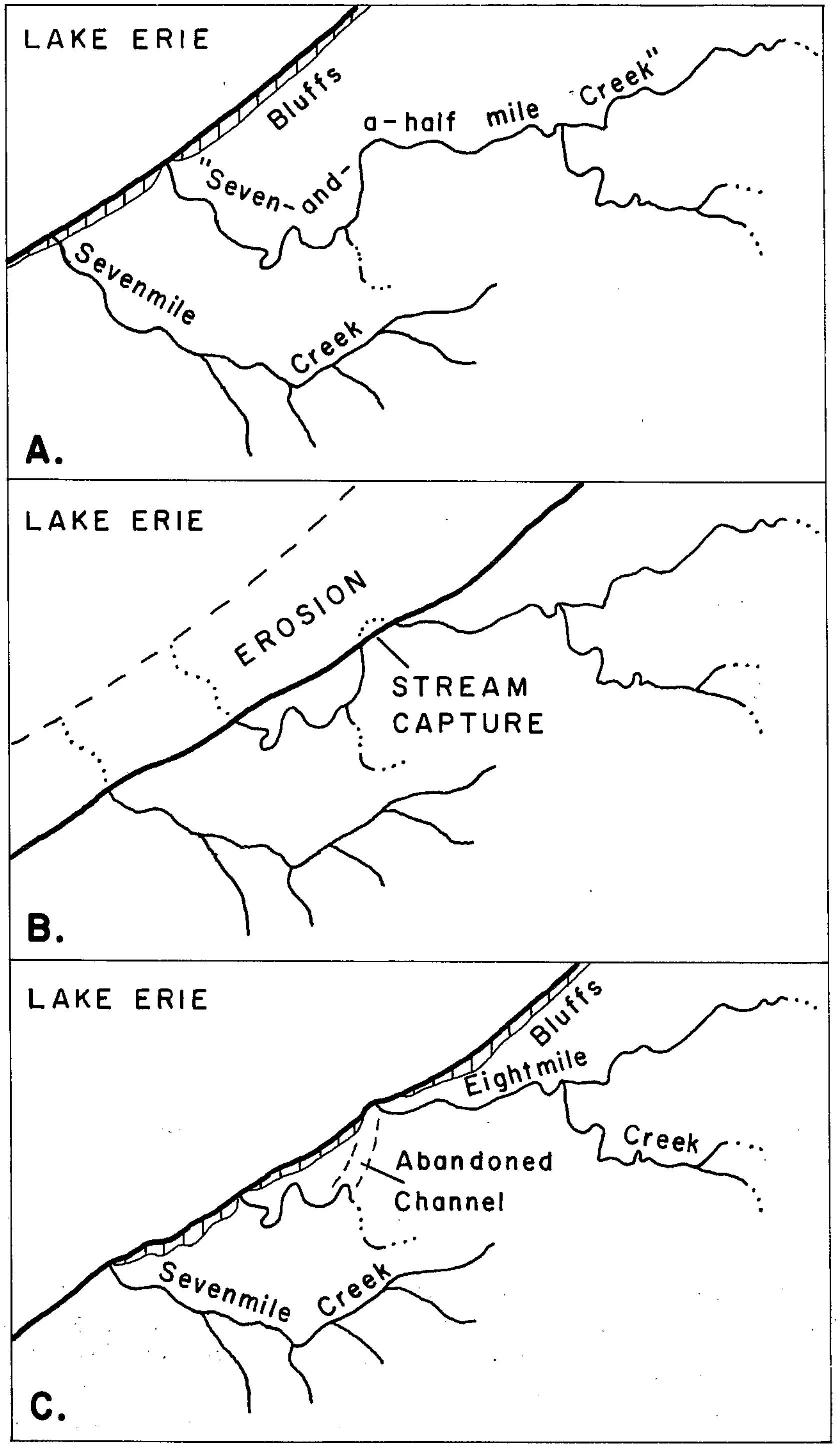


Figure 45. Schematic diagram showing hypothesized origin of the topography at Shades Beach Park. A similar but less detailed diagram is shown by Schooler (1974, Fig. 5, p. 18).

A. Reconstruction of drainage pattern at a time before extensive bluff erosion.

B. Shoreline erosion led to bluff recession and "stream capture" by the lake.

C. Present drainage pattern and the abandoned channel of "Seven-and-a-half mile Creek."

bedrock ledge protects the bluffs from toe erosion, and (2) the isolation of the bluff section by the abandoned stream channel limits the source area for groundwater, and the resulting small amount of seepage out of the slope face is a factor in the apparent increased stability of the bluff. Both factors are probably important, but the relative importance of each is unknown.

This locality is the only place on this field trip where we will have the opportunity to see a good exposure of the Northeast Shale.

Eightmile Creek is fairly typical of the small, bedrock floored streams in the eastern part of Erie County. Note the gravel bar at the mouth, joint controlled channel development on the rock stream bed, and the nature of the bedload in the shallow basin at the mouth of the stream.

The beach here is generally composed of coarse sediment. Large boulders and cobbles were built up against the boathouse walls in the spring of 1987, and winter storms had badly damaged the boathouse and launching ramp. The groin east of the boathouse has been described as maintaining a beach 15 m (50 ft) wide and protecting the boathouse. Apparently the record high lake levels in 1986 were high enough to overcome this protection.

		LEAVE STOP 8 AND RETURN VIA ENTRY ROUTE.
0.2	54.6	Intersection of park entrance and US Route 5. **TURN LEFT** and proceed east on US Route 5.
1.0	55.6	Passing over Eightmile Creek.
0.7	56.3	Intersection of US Route 5 and Highmyer Road. **CONTINUE** east on US Route 5.
1.2	57.5	Intersection of US Route 5 and Mooreheadville Road. **CONTINUE** east on US Route 5. Cross Twelvemile Creek.
0.3	57.8	Boundary marker between Harborcreek and Northeast Townships.
0.3	58.1	We will leave the Warren III terrace and ascend a scarp that terminates at the Warren I terrace. The scarp and Warren III level can easily be seen to the right (southeast).
1.1	59.2	Intersection of US Route 5 and Catholic Cemetary Road to the right. **CONTINUE** east on US Route 5.
0.3	59.5	Intersection of US Route 5 and Brickyard Road. **TURN RIGHT** and park on the right side of Brickyard Road.

STOP 9. BRICKYARD ROAD SECTION.
Leaders: Dave Thomas and Ray Buyce.

This stop is located at the foot of a private, unpaved road that extends north of US Route 5 from Brickyard Road in the northeast section of the Harborcreek, PA 7.5-minute quadrangle (Figure 46). The property is owned by the McCord family, one of the pioneer vintners in the Pennsylvania-New York section of the grape belt. Permission must be obtained from the McCord family for access to the property. We will be examining the bluff-face exposures.

The summit of the bluff overlooking Lake Erie about 300 m (1000 ft) from US Route 5 is dangerous! It is capped by noncohesive sand that fails under very small additional loads. **DO NOT WALK TO THE BLUFF EDGE!**

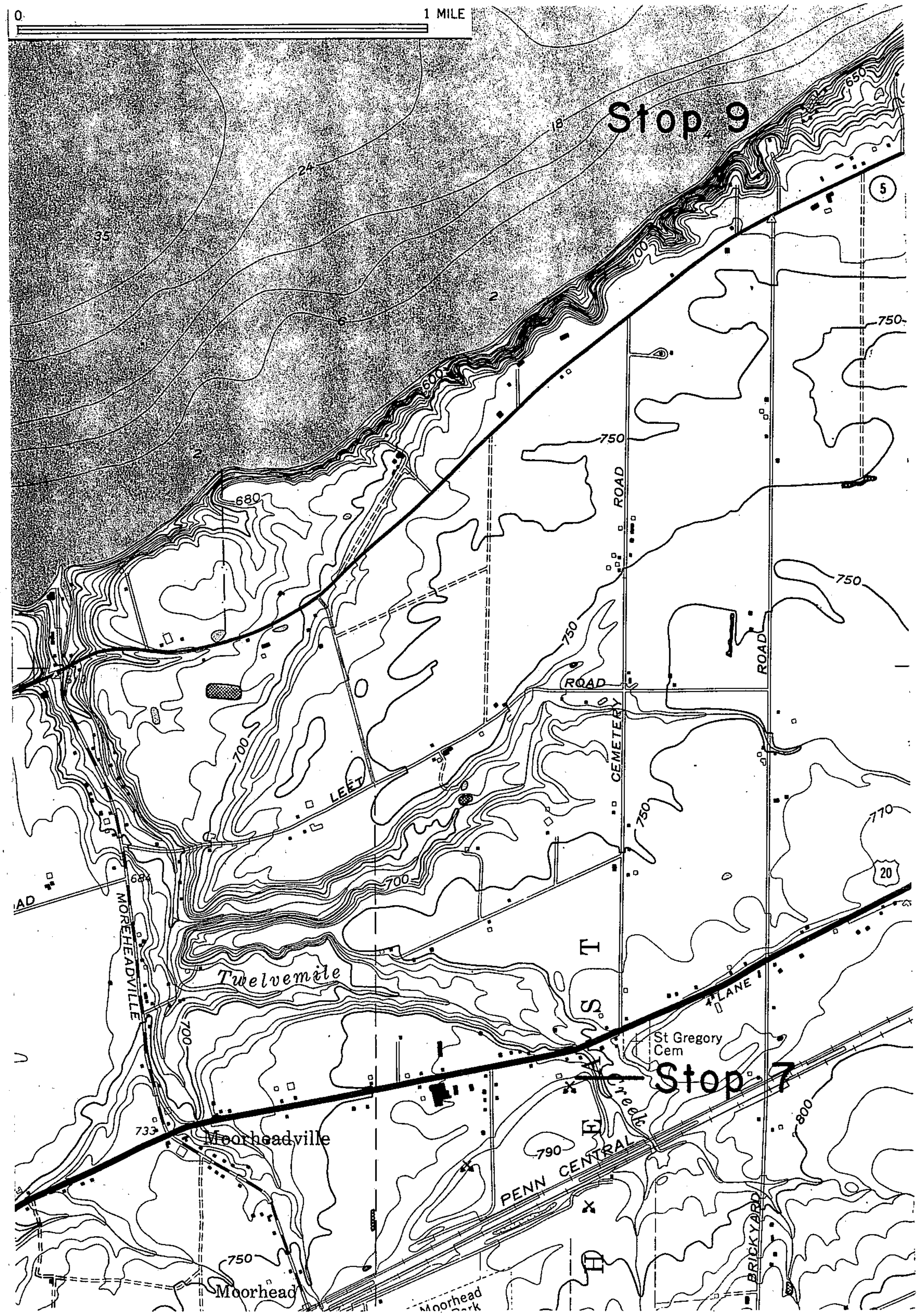


Figure 46. Location map for Stop 9 (from the Harborcreek, PA 7.5-minute topographic map).

Landform

The summit of the bluff at this location is about elevation 700 feet. It is the location of the northern margin of a gently sloping terrace that can be traced south on Brickyard Road from elevation 730 feet at US Route 5 to elevation 770 feet just below US Route 20. South of elevation 770 feet there is a steep 20 foot scarp that rises to elevation 780 feet at US Route 20. We believe that this terrace represents a Lake Warren I level.

Bluff Recession

The height of the bluff from the topographic map is between 48 and 52 m (160 and 170 ft). This location was classified as a critical hazard area (Great Lakes Research Institute, 1975), and with record high lake levels in 1976 and again in 1987 its status has not changed. In places along the beach at the base of the bluff there are deposits of colluvium that have accumulated this spring after high wave activity. This colluvium consists of blocks of diamict that have rotated and toppled as a consequence of moderate wave action upon the toe of the bluff. The colluvium extends to a maximum height of 3 m (10 ft) and is covering a 2.4 m (8 ft) east-west trending band of beach gravel. The colluvium protects the toe of the bluff from further low to moderate wave action. Although this bluff is over twice as high as the 18 m (60 ft) bluff at Stop 2, essentially the same sequence of erosional processes have taken place, all of which have been triggered initially by wave erosion of the diamict at the base of the bluff. Apparently most beach deposits have been derived from bluff erosion to the west. The lower 17.4 m (57 ft) of the bluff is composed of several units of diamict. Mass movement occurs in the following sequence: (1) undercutting at the base by moderate wave action, (2) outward rotation of cohesive diamicts along stress release fractures, (3) slumping, and (4) debris flow during snow melt and rainfall. Other erosional processes within the diamict units are sheet wash, raindrop impact, swell/shrink during wetting and drying, frost heaving, and frost wedging. Mass movement processes that occur in the gravel/sand facies that occupies the upper approximately 33 m (107 ft) of the bluff are: (1) spring sapping and extrusion along sand or gravel and finer-grained beds, (2) slumping due to removal of underlying material, and (3) sand and debris flow. Other erosional processes within the gravel/sand beds include raindrop impact, wind, and the removal and weakening of sand by hundreds of swallows.

Stratigraphy

General.

Wave erosion and a variety of mass wasting processes have exposed approximately 50 m (165 ft) of glacigenic deposits represented by 2 distinct facies. The lower part of the section is a diamict facies which comprises 17.4 m (57 ft) or 35 percent of the total bluff height. The upper 33 m (108 ft) or 65 percent of the total bluff height is composed of a gravel and sand facies. Figure 47 presents a graphic display of Measured Section 2.

Diamict Facies.

This facies may be divided into 2 distinct lithologic types based upon thickness and grain size distribution. The lower segment consists of 11 units

(1 through 11, Measured Section 2) ranging in thickness from 0.06 m (0.2 ft) to 0.6 m (1.75 ft). These 11 units occur as 2 different lithologies. Six of the units are massive, matrix-supported diamicts composed of olive gray, clayey silt to very fine sand supporting angular to subrounded pebbles and rarer gray and reddish gray soft clay clasts. Thicknesses range from 0.07 to 0.53 m (0.25 to 1.75 ft). The other 5 units are laminar-bedded, clayey silt, silt, or very fine sand supporting angular to subrounded pebbles and rarer gray and reddish gray soft pebble-size clay clasts. The thicknesses range from 0.06 to 0.07 m (0.20 to 0.25 ft). These 2 lithologies consistently alternate up through the entire 2.2 m (7.25 ft) of this segment of diamicits. At the lower contact of the uppermost unit (11) are alternating dark and light gray, clayey silt laminae with a roll-up structure and folds overturned westward.

The upper diamict segment is 12.75 m (41.85 ft) thick and consits of 4 units (12 through 15) ranging in thickness from 1.3 to 5.3 m (4.25 to 17.25 ft). These 4 units are composed of olive gray, massive, clayey silt or very fine sand matrixes supporting angular to subrounded pebbles, and fewer cobbles and rare boulders. The angular cobbles are hard siltstones or very fine sandstones whose origins may be found in the Upper Devonian bedrock to the immediate east. The subangular to subrounded cobbles are either Lower Paleozoic sedimentary rocks plucked from the Ontario-Erie basin farther to the east or Precambrian crystalline igneous and metamorphic rocks transported from the Canadian Shield. The lower 2 units (12 and 13) show, at their lower contacts, roll-up structures and folds in laminar clayey silt beds that are overturned toward the west. In addition, there is a normal fault with 6 mm (0.25 in.) displacement in the rolled-up laminar beds near the base of Unit 12.

Gravel/Sand Facies.

The diamict and gravel/sand facies is separated by a 0.15 m (0.5 ft) thick laminar-bedded clay with a thin sand bed at the base and top. The contact between the clay and gravel facies appears erosional. The gravel segment of the gravel/sand facies (Unit 17) is 6.6 m (21.65 ft) thick. It consists of angular to subrounded pebbles and interstitial sand and clayey silt. The lower part of the unit has 2 cut and fill channels. The beds of the lowest channel dip northwest, while the beds of the upper channel truncate those of the lower and dip northeast. Bedding is not apparent in the remaining upper part of the gravelly unit; however, discontinuous fine-grain drapes occur throughout. A continous 2.5 to 5 cm (1 to 2 in.) drape separates the gravel from the sandy units above.

The sandy segment of the gravel/sand facies is about 20 m (66 ft) to the summit of the bluff. The upper 4.6 to 6 m (15 to 20 ft) were not measured because of steepness and instability of the slope. The sand units are composed of very fine, fine, and medium sand with relatively thin interlayers of clayey silt or very fine sand. The clayey silts or very fine sands occur as drapes.

The lowest unit (18) is composed of 0.46 m (1.5 ft) of very fine laminated sand displaying horizontal, trough, wavy, and flaser bedding and beds of horizontally laminated clayey silt.

The overlying unit (19) is 10.6 m (35 ft) thick. The lower 7 m (23 ft) is covered with sandy colluvium; however, exposures east and west of Measured Section 2 indicate lithologies consistent with the measured upper 3.7 m (12 ft) of the unit. The upper 3.7 m (12 ft) is composed of alternating beds of very fine sand and clayey silt beds. The laminar clayey silts are bedded horizontally while the very fine sand units display horizontal, trough, wavy, and flaser bedding. Pebble-size drop stones are sparsely scattered through the unit. The thicker sand beds in the lower part of the unit yield to clayey silt beds upward through the unit. This fining upward sequence is contorted by soft sediment deformation structures with amplitudes of 3 ft or more in its upper part. The remainder of the measured section (Unit 20) which is 20.1 m (66 ft) thick is composed of sand and clayey silt or very fine sand beds. The sand beds display laminar and thin horizontal, wavy, trough, and flaser bedding and climbing ripples. The clayey silt or very fine sand occurs as relatively thin drapes.

Questions.

Questions to be asked at this stop are basically the same as those at Stop 2:

1. What process (es) formed the diamicts?
2. Is there evidence of sublacustrine deposition and if so what mechanisms were involved?
3. Is there more than one age of diamict here? What approach could be utilized to resolve th problem?
4. How many different environments of deposition may be represented by these sediments?

Measured Section 2. Brickyard Road Bluff Face.

Stratigraphic section measured on bluff just east of valley which provides access to the beach. The upper 4.6 to 6 m (15 to 20 ft) were not described because of the steepness and instability of the slope.

Unit	Description	Thickness Meters (feet)
20-N	Sand, light brown, laminar, fine to medium. Trough and horizontal bedding.	1.49 (4.9)
20-M	Sand, light brown, laminar, fine to medium. Horizontal bedding. Ripple cross laminated unit near the top.	3.0 (10)
20-L	Sand, light brown, laminar. Wavy and trough crossbedding.	0.36 (1.2)
20-K	Sand, fine, light brown, very thinly bedded to thinly bedded. Horizontal bedding.	0.24 (0.8)
20-J	Sand, fine, light brown laminar coarsening upward to medium. Horizontal, wavy and trough crossbedding.	1.9 (6.2)
20-I	Clay, gray.	0.15 (0.5)
20-H	Sand, fine, light brown, laminar. Trough crossbedding and climbing ripples. Silt bed at top.	0.18 (0.6)
20-G	Clay, gray, massive.	0.03 (0.1)
20-F	Sand, fine, light brown, laminar. Horizontal and trough crossbedding.	0.34 (1.6)

20-E	Sand, fine, and silt; light brown, laminated. Ripple crossbeds with wave lengths of about 6.5 cm (2.5 in.) and amplitudes of 2.5 cm (1 in.). Some flaser bedding.	0.34 (1.13)
20-D	Clay, silty, gray, laminar.	0.048 (0.16)
20-C	Sand, light brown, laminar to very thin bedded. Trough crossbedding throughout.	0.6 (2.0)
20-B	Clay, silty, gray, laminar.	0.045 (0.15)
20-A	Sand, fine to medium, light brown, laminar. Horizontal and flaser bedding. Climbing ripples with lee and stose sides preserved.	0.09 (0.3)
19	Sand, very fine, light to medium gray, alternating with silt or clay beds in upper 3.7 m (12 ft). Trough, wavy, flaser, and horizontal bedding in the sand units. Clay or silt laminations are horizontally bedded. Rare sub-angular to subrounded dropstones. Silt or clay beds become more apparent upward through the silt. Loading structures become more apparent upward with amplitudes greater than 1.5 m (5 ft) in the uppermost part. Lower 7 m (23 ft) is covered with sandy colluvium.	10.74 (35.25)
18	Sand, laminated, olive gray to light olive gray and yellowish brown, with clayey silt. Trough, wavy, and flaser bedding.	0.46 (1.5)
17	Gravel, light brown angular to subrounded pebble-size with silt and sand in interstices. A 2.5 cm (1 in.) clay drape extends across the top of the unit separating it from Unit 18. Middle bed truncates the lower bed and dips about 30° toward the northeast. A 5 cm (2 in.) clay drape truncates both the lower and middle beds about 0.6-0.9 m (2-3 ft) above the contact with Unit 16. No bedding is evident in the upper 6 m (20 ft) of the unit, but several discontinuous clay drapes occur throughout. Lowest bed dips about 23° to the northwest.	6.6 (21.65)
16	Sand, fine to very fine, laminated, alternating with clay. Some lenses of pebbles. Sand is rippled at top of unit. Five cm (2 in.), laminar, medium gray and dark gray clay near center of unit. Bottom 2.5 cm (1 in.) is fine to medium sand.	0.1-0.15 (0.33-0.5)
15	Diamict, massive, matrix-supported. Olive gray, clayey silt supporting pebble-size, angular, hard siltstones and subangular to subrounded sedimentary, igneous, and metamorphic rock fragments with maximum diameters of 2.5 cm (1 in.). Large number of cobble-size, angular, hard siltstones and subangular to subrounded sedimentary, igneous, and metamorphic rocks. Cobbles become more abundant and smaller upward.	0.38-1.3 (1.25-4.25)
14	Diamict, massive, matrix-supported. Olive gray, clayey silt supporting pebbles of angular, hard siltstone and subangular to subrounded sedimentary, igneous, and metamorphic rock fragments up to 2.5 cm (1 in.) in diameter.	5.26 (17.25)
13	Diamict, massive, matrix-supported. Silt and clay supporting angular to subrounded pebbles with 1.3-5 cm	3.0 (10)

	(0.5-2 in.) in diameter. Rarer angular siltstone and subrounded to rounded sedimentary, igneous, and metamorphic cobbles and one 0.6 m (2 ft) subrounded boulder. Cobbles increase in size and number eastward. Three wavey sand layers, 2, 6, and 25 mm (0.15, 0.25, and 1 in.) thick, with horizontal laminations occur within the unit. Roll-up structure overturned toward the west occurs near the base. Lower contact is not distinct, but probably erosional. Undulating intercalated sand bodies along east end of contact. One 0.6 m (2 ft) cobble and angular, flat siltstone cobbles positioned on Unit 12 at western end.	
12	Diamict, massive, matrix-supported. Olive gray, clayey silt supporting angular, subangular, and subrounded pebbles between 6 mm and 5 cm (0.25 and 2 in.) in diameter with cobble-size angular siltstones showing striations; Subangular to subrounded sedimentary and crystalline igneous and metamorphic rocks with 7-13 cm (3-5 in.) diameters in lesser amounts. One 25 cm (10 in.) subrounded boulder. Sparsely occurring beds of very fine to fine sand between 6 and 25 mm (0.25 and 1 in.) thick and from 0.45 to 1 m (18 to 45 in.) long with light and dark laminae below and above a massive core. A roll-up structure and folds overturned to the west and normal faults with apparent dips of 75° west are diplaced 6 mm (0.25 in.) along the fault plane within part of the roll-up structure 0.8 m (2.6 ft) above the lower contact.	2.97 (9.75)
11	Diamict, massive, matrix-supported. Gray mud with sparse distribution of angular to subrounded pebbles with maximum diameter of 2.5 cm (1 in.). Lower part shows alternating dark and light laminae. Roll-up structures at bottom contact with Unit 10 are deformed from east to west.	0.13-0.4 (0.42-1.33)
10	Diamict, massive, matrix-supported. Olive gray, clayey silt or very fine sand supporting a scattering of angular to subrounded pebbles with a maximum size of 2.5 cm (1 in.) and a few cobbles 8 cm (3 in.) or more in diameter.	0.38 (1.25)
9	Sand, very fine to fine, occurring as 1-2 mm alternating light gray and dark gray laminae. Rip-up clasts from Unit 8 in bottom 6 mm (0.25 in.) of unit. Dark gray layer of mud laminae in upper 1.4 cm (0.5 in.). Rippled very fine sand bodies with amplitudes and lengths of 3 mm (0.1 in.).	0.06 (0.21)
8	Diamict, massive, matrix-supported. Silt with scattering of angular to subrounded pebbles. Wavey laminae 2 mm (0.05 in.) thick of very fine sand occur within one unit.	0.08 (0.25)
7	Gravel, pebble-size. Maximum diameter of 2.5 cm (1 in.) with very fine interstitial sand, silt, and clay. No bedding or imbrication observed.	0.08 (0.27)
6	Diamict, massive, matrix-supported. Brownish gray silt or fine sand matrix supporting a scattering of angular to subrounded pebbles and rare grayish red and medium gray soft clay clasts.	0.15 (0.50)
5	Sand, very fine, thin to medium laminae, light brownish gray alternating with dark gray silt or clay laminae.	0.08 0.25)

4	Diamict, massive matrix-supported. Olive gray to brownish gray silt or fine sand supporting a scattering of angular to subrounded pebbles and rare grayish red soft clay clasts. Bottom 4 cm (1.5 in.) of unit has grayish red soft clay clasts with olive gray interstitial silt or very fine sand.	0.15 (0.5)
3	Silt or fine sand, alternating in thin to medium laminae of pale red and grayish red with dense scattering of grayish red, soft clay clasts between 6 and 25 mm (0.25 and 1 in.) in diameter.	0.08 (0.25)
2	Diamict, massive, matrix-supported. Olive to brownish gray silt or very fine sand supporting a scattering of angular to subrounded pebbles up to 2.5 cm (1 in.) in diameter. Pebbles become more sparse upward. Slight evidence of bedding when dampened with water.	0.53 (1.75)
1	Silt and/or very fine sand in alternating bands of light and darker olive gray, laminar bedded, supporting a sparse scattering of subrounded to rounded pebbles and rare clasts of grayish red clay. Base of section.	0.08 (1.75)

		LEAVE STOP 9. PROCEED SOUTH on Brickyard Road. We will be travelling across the Warren III terrace from elevation 740 feet to elevation 760 feet over the next 1.8 miles, a gradient of about 11 feet per mile.
1.2	60.7	Intersection of Brickyard Road and West Middle Road to the right. **CONTINUE** south on Brickyard Road. US Route 20 is straight ahead (south) running parallel to the Whittlesey terrace just above the Warren III scarp (wave cut?).
0.7	61.4	Stop sign at intersection of Brickyard Road and US Route 20. **PROCEED ACROSS** US Route 20 with caution and **CONTINUE** south on Brickyard Road.
0.3	61.7	Railroad crossing with blinker lights and gates. We will leave the Lake Whittlesey terrace and move onto deposits associated with Girard ice.
0.2	61.9	Bridge crossing Twelvemile Creek.
0.5	62.4	Intersection of Brickyard Road and Law Road. **CONTINUE** south on Brickyard Road. The Girard Moraine rises prominently to the south.
0.9	63.3	Stop sign at intersection of Brickyard Road and Sidehill Road. Brickyard Road ends here. **TURN RIGHT** and proceed west on Sidehill Road. We will be travelling parallel to the north-facing slope of the Girard Moraine.
0.8	64.1	Intersection of Sidehill Road and Mooreheadville Road. **CONTINUE** west on Sidehill Road.
0.3	64.4	Intersection of Sidehill Road and Rohl Road to the left. **CONTINUE** west on Sidehill Road.
1.1	65.5	Intersection of Sidehill Road and Davison Road. **TURN LEFT** and proceed south on Davison Road. We will be ascending the north-facing slope of the Girard Moraine.
0.4	65.9	Intersection of Davison Road and Hoover Heights Road. **CONTINUE** south on Davison Road.
0.3	66.2	Intersection of Davison Road and McGill Road. Within the next 0.5 mile we will be leaving the Girard Moraine and travelling onto the Ashtabula Moraine.

0.6	66.8	Stop sign at intersection of Davison Road and PA Route 531. **TURN LEFT.** The entrance ramp to I-90 West is 0.1 mile ahead.
0.1	66.9	Entrance ramp to I-90 West/Cleveland. **TURN RIGHT** onto I-90 West.
7.4	74.3	Exit 7, US Route 97/State Street. **EXIT** to the right.
0.3	74.6	Stop sign at intersection of exit ramp and US Route 97. **TURN LEFT** and proceed south for 0.1 mile.
0.1	74.7	**TURN RIGHT** into Holiday Inn South parking lot. **END OF TRIP. HAVE A SAFE TRIP HOME!!**

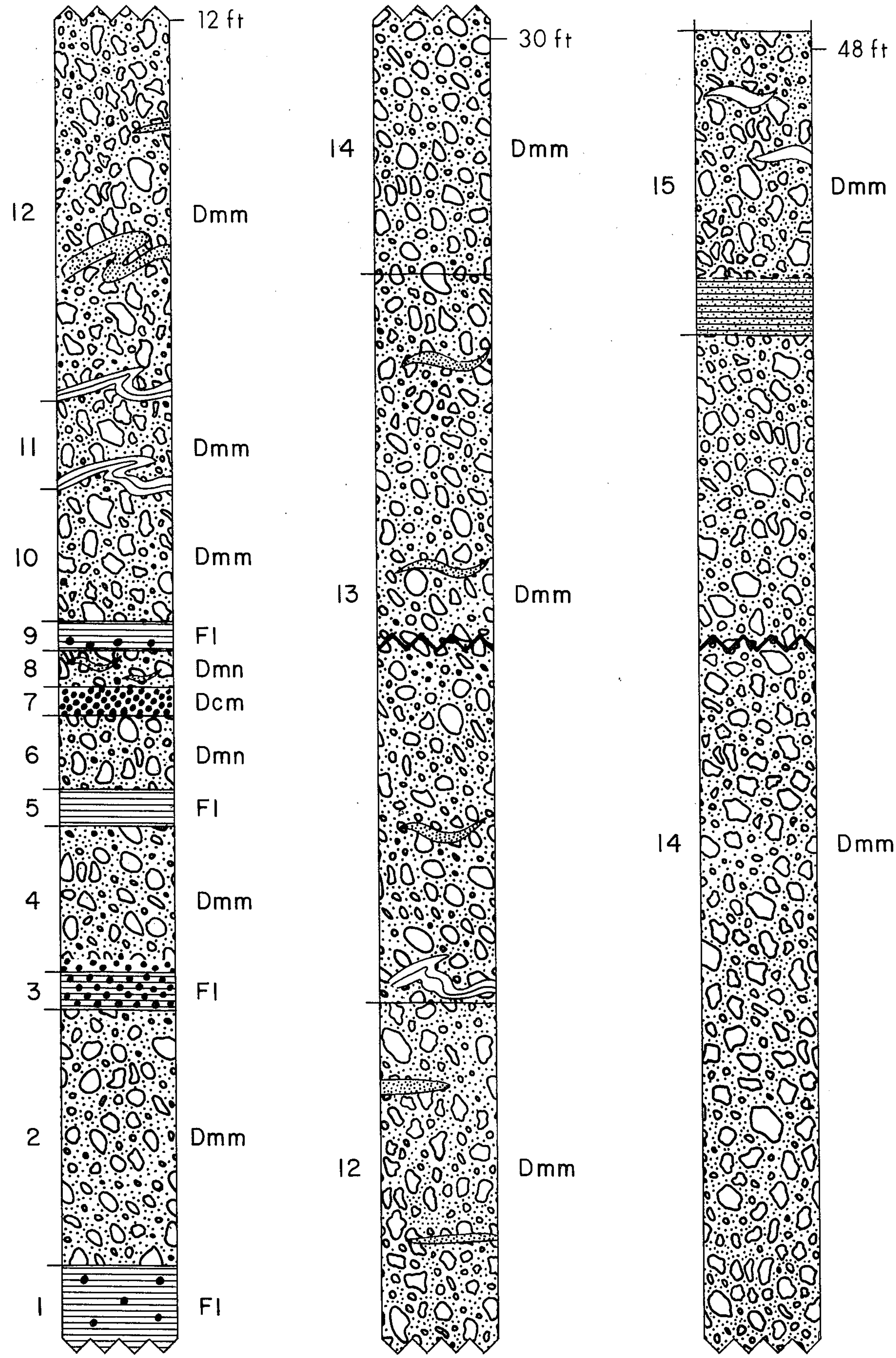
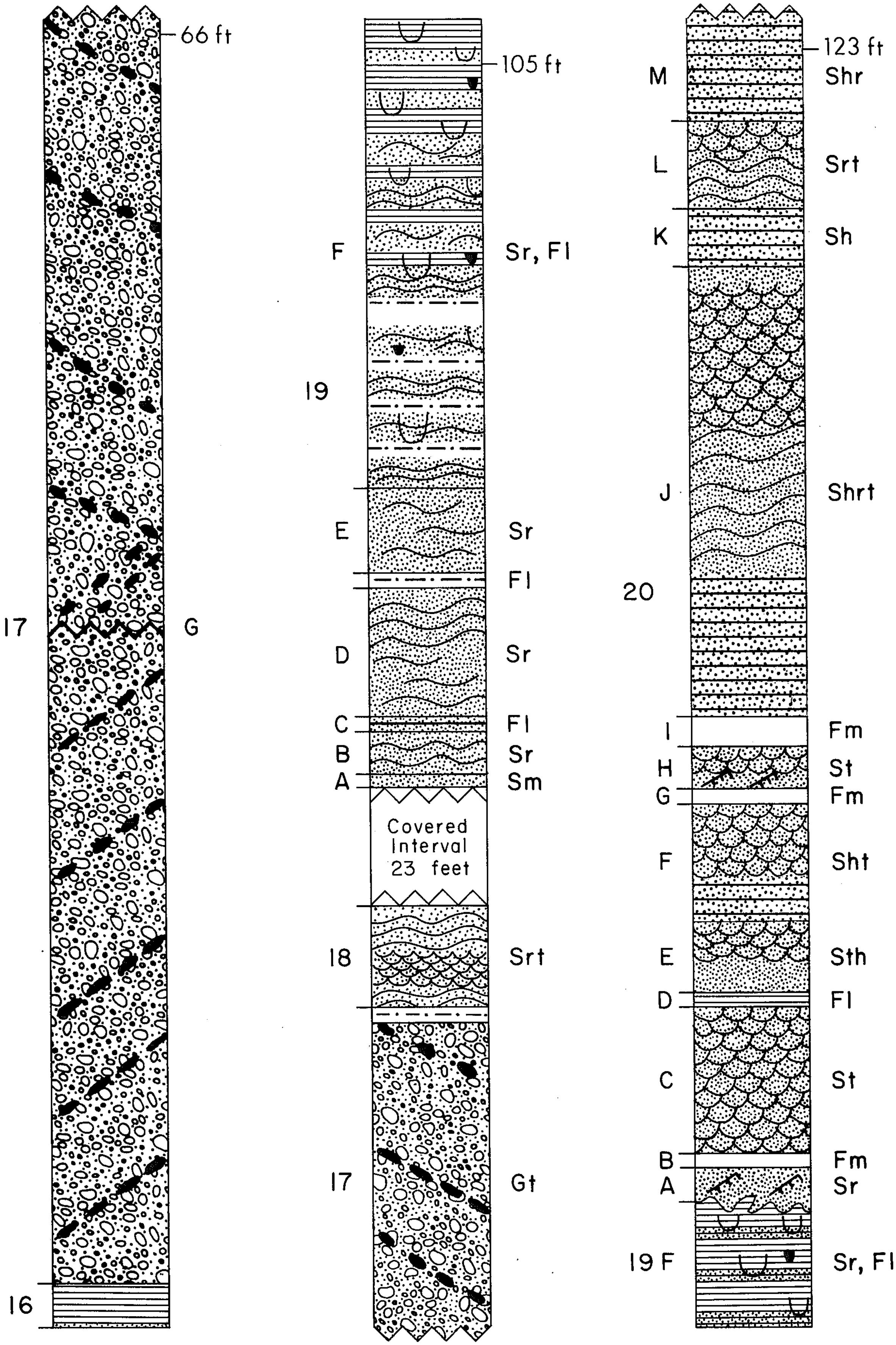
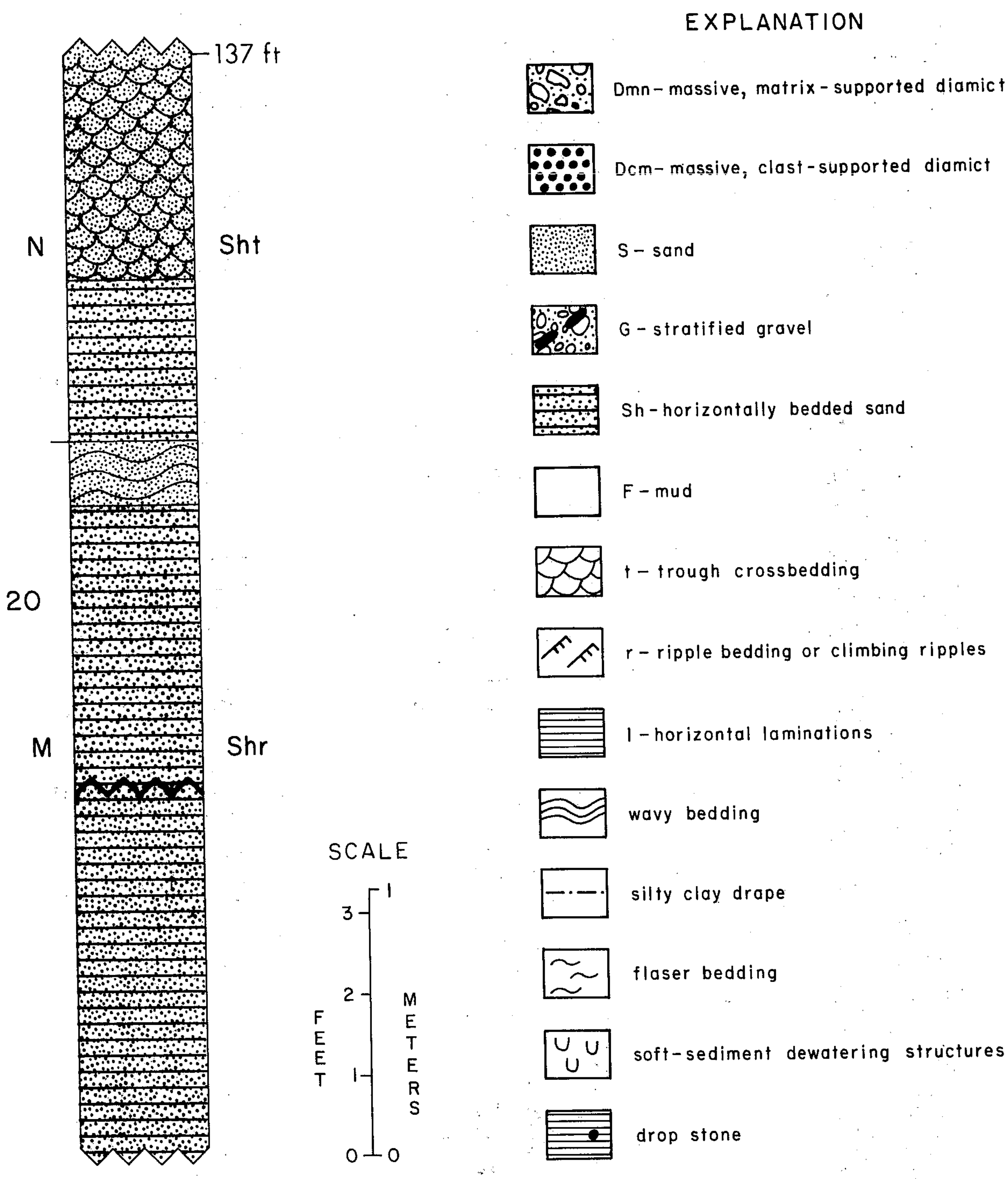


Figure 47. Graphic log of sediments occurring in the Brickyard Road Bluff Face. See Measured Section 2 for description.


66 ft
17
G
16
105 ft
F
Sr, Fl
19
E
Sr
Fl
D
Sr
C
Fl
B
Sr
A
Sm
Covered
Interval
23 feet
18
Srt
17
Gt
123 ft
M
Shr
L
Srt
K
Sh
J
Shrt
20
I
Fm
H
St
G
Fm
F
Sht
E
Sth
D
Fl
C
St
B
Fm
A
Sr
19 F
Sr, Fl


137 ft
N
Sht
20
M
Shr
SCALE
FEET
METERS
3
2
1
0
1
0
EXPLANATION
Dmn- massive, matrix-supported diamict
Dcm- massive, clast-supported diamict
S- sand
G- stratified gravel
Sh- horizontally bedded sand
F- mud
t- trough crossbedding
r- ripple bedding or climbing ripples
l- horizontal laminations
wavy bedding
silty clay drape
flaser bedding
soft-sediment dewatering structures
drop stone