Berea Sandstone escarpment and abandoned quarry north of Berlin Heights, Ohio (Charles E. Herdendorf).

CHAPTER 2. GEOLOGY

Lake Erie and its coastal watersheds are underlain by middle Paleozoic sedimentary bedrock, composed of limestones, dolomites, shales, and sandstone. These rocks were deposited as sediments under tropical to subtropical conditions ranging from barrier reef habitats to those environments of clastic deposition associated with mountain building episodes related to the tectonic plate collisions taking place to the east. After lithification, uplift following these episodes initiated a long period of erosion that resulted in excavation of a major stream system along the longitudinal axis of the present lake. Late Cenozoic (Pleistocene) continental glaciers further sculptured this valley by overriding the Niagara Escarpment and excavating most deeply in the eastern end of the lake, moderately deep in the central portion, and least deeply over the carbonate bedrock at the western end of the lake. This process formed the distinctive three basins that characterize Lake Erie (Figure 2.1).

During the most recent Wisconsinan glacial advance, 18,000 years before the present (YBP), ice extended as far south as the Ohio River. Thereafter, the ice margin receded in pulses with ground and end moraines deposited across of the present lake; prominent end moraines occur at the junctions of the three basins.

As the ice margin retreated northward a series of proglacial Great Lakes formed across the Lake Erie basin between older end moraines and the ice front. With progressive ice retreat, new and lower outlets were uncovered and new lake stages were formed at successively lower elevations except where minor readvances of the ice temporarily reversed this trend. Massive sand ridges and dunes were deposited along these shores and thick glaciolacustrine sediments were deposited in the offshore regions of each of these lakes. When the glacier retreated from the Niagara Escarpment and the Niagara River outlet was finally available—greatly depressed by the weight of the ice—much of the lake drained and smaller lakes were present only in parts of the eastern and central basins. Isostatic rebound eventually raised the outlet, which brought the lake to near its present level. At this time the present shoreline landforms, including embayments, estuaries, bluffs, dunes, spits, and barrier bars began to form. Human construction works along the shore have greatly modified the natural landforms, often resulting in accelerated erosion rates.

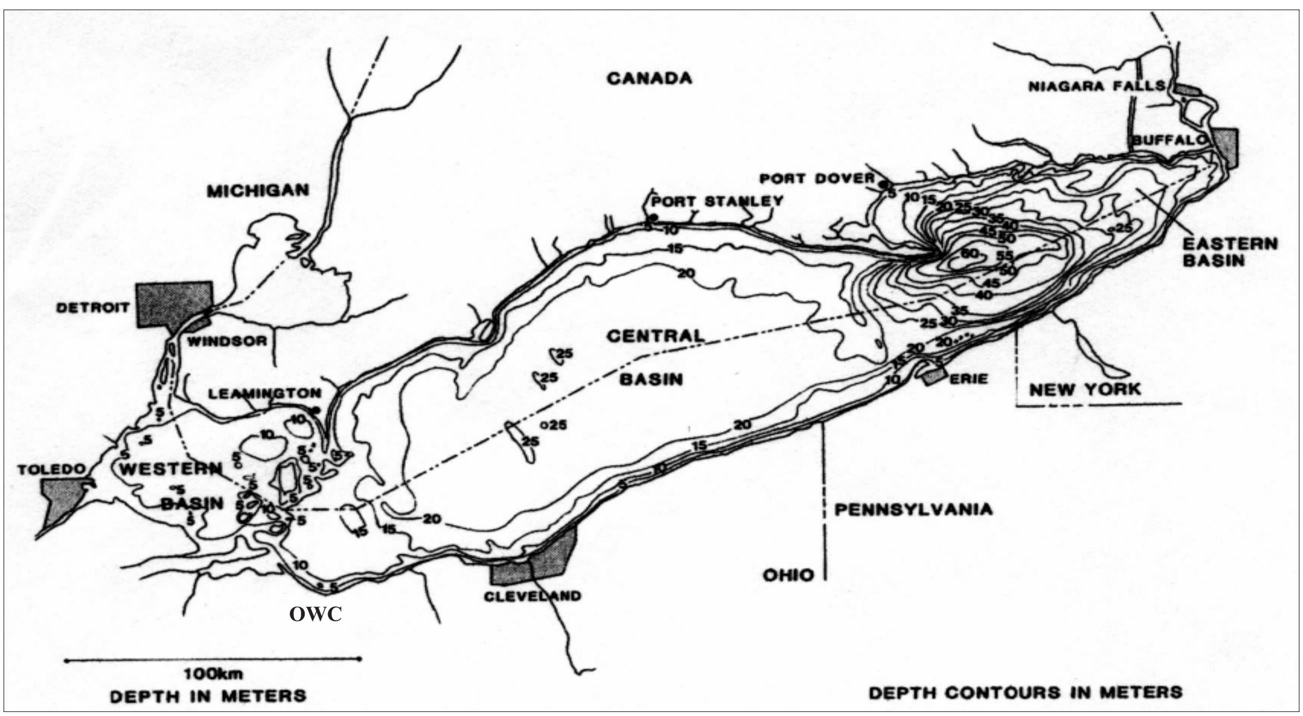

Figure 2.1. Bathymetric map of Lake Erie (from Bolsenga and Herdendorf 1993).

Geologic History

Precambrian Era

The earliest record of the geological history of north central Ohio is preserved in the igneous and metamorphic Precambrian rocks of the deep subsurface (see Geological Time Scale p. 13-7). These "basement" rocks are known only from deep well drilling and have been dated at more than 1 billion years old (Coogan 1996). In 1960 the Ohio Fuel Gas Company drilled a 1,340-m-deep well to the Precambrian basement in southeastern Florence Township. Based on southeastern dip of the basement surface at 75 m/km, Old Woman Creek drainage basin is underlain at a depth of about 1,000 m below sea level by metamorphic rocks of the Grenville Province (Owens 1967). These rocks are the remains of a Precambrian mountain range formed by plates that collided 1 to 2 billion YBP. The ancient Grenville Mountains were eroded to an undulating plain in north central Ohio, bounded on the west by a rift valley (similar to the modern Red Sea rift), before the onset of early Paleozoic deposition some 570 million YBP (Coogan 1996).

Precambrian rocks are shallowest in the vicinity of the rift, forming a structural feature known as the Cincinnati-Findlay Arch which extends from southwestern Ohio to western Lake Erie (Figure 2.2). The axis of this arch plunges gently to the north-northeast. As a result, Paleozoic rocks deposited on the Precambrian surface are thinner over the arch and oldest near Cincinnati because of the low relief of Ohio's terrain. Thus, the exposed rocks are progressively younger toward Lake Erie and likewise, younger on the flanks of the arch, east and west of the crest.

The Precambrian rocks underlying Lake Erie are covered by 700 to 1,600 m of Paleozoic sedimentary formations, with the shallowest basement being in the Island Region of western Lake Erie and the deepest near the Ohio and Pennsylvania shore between Cleveland and Erie (Summerson 1962). The oldest Precambrian rocks are primarily crystalline igneous and metamorphic rocks that represent a complex geologic history. This includes the emplacement of a vast, 11-km-thick mass of deep-seated granite and volcanically derived rhyolite, followed by faulting and rifting as molten basalt flowed into rift basins. About 1 to 2 billion YBP, a continental collision of two land masses formed the Grenville Mountains at the eastern end of the lake. Subsequent erosion of these mountains and the transgression of the first Paleozoic seas (570 million YBP) buried the Precambrian surface beneath a thick sequence of sedimentary rocks (Hansen 1996).

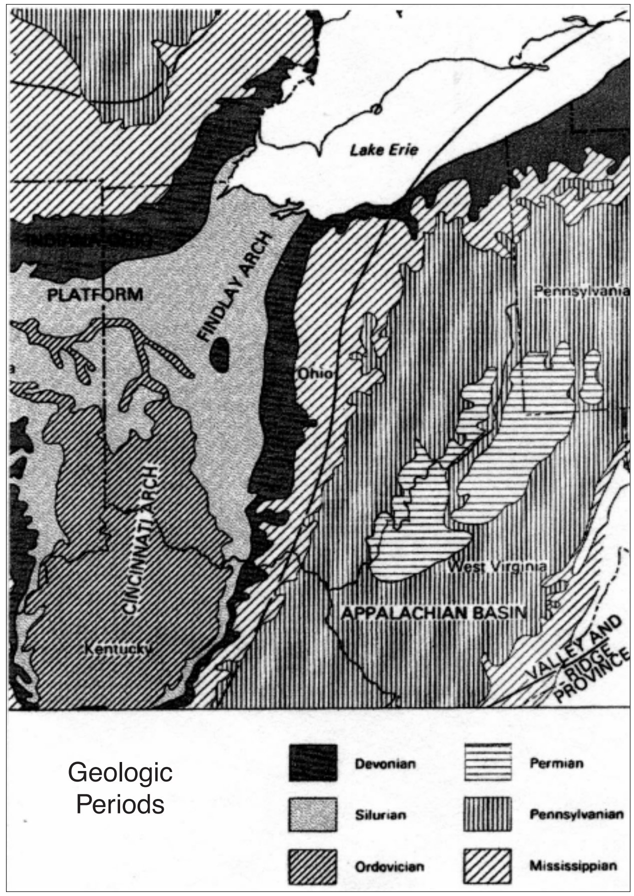

Figure 2.2. Bedrock structure of Ohio (from Feldmann and Hackathorn 1996).

Paleozoic Era

During the Cambrian Period (570 to 505 million YBP) Ohio was part of a broad coastal plain, comparable to the modern Gulf of Mexico coast, that slowly became inundated by the sea. The basement rocks were initially covered by deltaic sands and muds, then by marine carbonates. These sediments were lithified into several hundred meters of sandstones, shales, limestones and dolomites. This period ended with withdrawal of the sea, owing to uplift caused by the collision of the North America Plate with another plate to the east, giving rise to mountain building, known as the Taconic Orogeny.

During the Ordovician Period (505 to 438 million YBP) the ancestral North America continent lay astride the Equator, and Ohio was situated in the Southern Hemisphere. The early part of this period was characterized by subaerial erosion as north central Ohio stood above sea level. During the middle portion of this period the sea again onlapped the continent, resubmerging the eroded surface, and limestones were deposited as carbonate banks, reefs, and lagoon deposits. Late in this period the rocks show a transition from shallow-water carbonates to deep-water limestones and shales as Ohio became part of a rapidly subsiding basin at the culmination of the Taconic Orogeny. Late Ordovician formations are the oldest rocks exposed in Ohio—the noted fossiliferous beds of the Cincinnati area. The period ended when deposition of marine sediments ceased, owing to a drop in sea level which is attributed to glaciation in the Southern Hemisphere (Coogan 1996).

During the Silurian Period (438 to 408 million YBP) sea level rose, flooded the Ordovician surface, and resulted in marine deposition over the crest of the Cincinnati-Findlay Arch. Silurian rocks on the crest and flanks of the arch consist of shallow-water, subtropical, carbonate-bank deposits. Lockport Dolomite, only found in the subsurface rocks of Erie County, was deposited as a reef at this time, and now forms the caprock of Niagara Falls near the outlet for Lake Erie as well as outcrops which are being quarried at the crest of the arch in western Ottawa County, Ohio. The later stages of Silurian deposition reflect a relatively stable, but subsiding, shallow marine environment that periodically experienced lowered sea level and evaporation of the sea water to form thick salt beds (gypsum, anhydrite, and halite) in the Salina Group (Coogan 1996). For many years gypsum was quarried and mined from shallow deposits near Port Clinton, Ohio while rock salt (halite) is being mined from correlative beds more than 500 m beneath Lake Erie at Cleveland and Fairport Harbor, Ohio.

During the Devonian Period (408 to 360 million YBP) another plate collision occurred along the northeastern margin of North America at the start of the period which resulted in uplift, mountain-building, and erosion (Acadian Orogeny). Thus, a major unconformity separates Silurian rocks from Devonian rocks in north central Ohio. During the middle portion of the period, the land was again flooded and sedimentation began in clear seas with the deposition of carbonate sediments that would become the richly fossiliferous Columbus Limestone and other limestones and dolomites. A well drilled in southeastern Florence Township revealed a total thickness of 86 m for subsurface Middle Devonian carbonate rocks (Janssens 1969,1970). Toward the later part of the period, carbonates gave way to the deposition of clay and organic muds that would become the black Ohio Shale which underlies Old Woman Creek estuary. These sediments were deposited in a rapidly subsiding, relatively stagnant offshore marine basin. Overall the shale beds are poorly fossilized, but spectacular fish remains, such as the armored placoderm *Dunkleosteus*, have been found in the Lake Erie bluffs of nearby Lorain County (Newberry 1874). Meanwhile, far to the east, the Appalachian Mountains were being built as a result of another plate collision, forming a landmass known as Laurasia (elements of North America, Europe, and Asia).

During the Mississippian Period (360 to 320 million YBP) erosion of the ancestral Appalachian Mountains formed the Catskill delta, a clastic wedge of sediments deposited on a vast alluvial coastal plain that sloped gently westward (Dott and Batten 1976). In north central Ohio, the dark marine shales of Devonian Period were covered by fluvial, deltaic, and marginal-marine clastic sediments at the western extremity of the wedge. In the Old Woman Creek drainage basin, these depositional environments are represented by the Bedford Shale and Berea Sandstone. The Mississippian rocks form a band of hills and an escarpment 5 to 10 km south of the present Lake Erie shoreline and display characteristics of deltaic and nearshore marine deposition. Another major erosional event ended Mississippian deposition in Ohio and removed any younger Mississippian strata (e.g. Cuyahoga Formation) that may have been deposited on the Berea Sandstone, leaving these beds as the youngest Paleozoic rocks in the watershed.

During the Pennsylvanian Period (320 to 286 million YBP) and the Permian Period (286 to 245 million YBP), Ohio was near the equator and the climate was tropical. Rocks from these periods, exposed only in eastern and southeastern Ohio, indicate an early marginal-marine environment that became progressively more terrestrial, consistent with the ongoing development of the supercontinent of Pangea (Coogan 1996). Weathering has removed any trace of deposits that may have been laid down in Erie and Huron counties during these late Paleozoic periods.

Mesozoic Era and Cenozoic Era

During the Triassic, Jurassic, and Cretaceous Periods (245 to 66 million YBP) Ohio experienced uplift, erosion, and weathering. These processes removed all traces of any deposits from the Mesozoic Era, if any were ever present. The same can be said for the Tertiary Period (66 to 2 million YBP) of the Cenozoic Era. Extensive systems of stream valleys dissected the entire surface of Ohio, including the Erie basin, before onset of Pleistocene glaciation. During this 243-million year interval, several hundred meters of rock were likely eroded from Ohio's landscape (Coogan 1996). About 2 million YBP, in response to the cooling of the Earth's climate, continental glaciers moved south from Canada to cover about two-thirds of Ohio at their maximum extent. This event initiated the Quaternary Period, which consists of the Pleistocene Epoch (commonly called the Ice Age) and the Holocene Epoch (last 10,000 years of geologic history). The glacial and postglacial geological events in north central Ohio are discussed in detail in later sections (Glacial Geology and Evolution of Lake Erie).

Geomorphology

The branch of geology that deals with the general configuration of the Earth's surface is known as geomorphology. Specifically, it treats the description, classification, and development of present landforms in relation to underlying geologic structures, as well as the study of geologic changes as recorded in surface features (Bates and Jackson 1980). Several notable geomorphic features occur within the environs of Old Woman Creek. Progressing in a general way from north to south they include: (1) Lake Erie, (2) barrier beach, (3) Old Woman Creek estuary, (4) Star Island, (5) lake plain, (6) abandoned beach ridges, (7) Berea Escarpment, (8) Berlin Heights ravine, (9) till plain, and (10) the valley of Old Woman Creek which traverses the entire area from south to north (Figure 1.6). Each of these features is described in the following section.

Lake Erie

Old Woman Creek empties into the central basin of Lake Erie along the Ohio shore at Lat. 41°23'04" N and Long. 82°31'20" W. Lake Erie is one of the largest freshwater lakes in the world, ranking 9th by area and 15th by volume, with a surface area of 25, 657 km^2, maximum depth of 64 m, and a volume of 483 km^3 (Herdendorf 1982). Erie is the southernmost of the North American Great Lakes, geologically the oldest, and by far the shallowest with its entire water mass lying above sea level. Lake Erie is a relatively narrow lake, 388 km long by 92 km wide, with its long axis oriented west southwest-east northeast. This axis parallels the prevailing wind direction which causes the lake to react violently to storms, causing the production of high waves and wide fluctuations in water level.

Based on depth, Lake Erie is divided into three basins: western, central, and eastern (Figure 2.1). The shallow western basin contains a number of bedrock islands and shoals, and represents only 13% of the area and 5% of the volume of Lake Erie. Several passages in the chain of islands at the basin's eastern edge provide water circulation channels.

The central basin is the largest of the three basins, containing 63% of the lake's area and volume. This basin is separated from the western basin by the chain of islands and Point Pelee, Ontario (south of Leamington), and from the eastern basin by a relatively shallow, sand and gravel ridge which crosses the lake in a north-south direction between Erie, Pennsylvania and Long Point, Ontario (south of Port Dover). The central basin has an average depth of 18 m and maximum depth of 26 m. Except for the rising slopes of a bar extending south-southeastward from Point Pelee, the bottom of the central basin is extremely flat. This bar isolates a depression in the bottom between it and the western basin islands that is known as the Sandusky sub-basin.

The eastern basin is relatively deep and bowl-shaped, with a considerable portion of the bottom below 30 m deep and a maximum depth of 64 m (off the tip of Long Point, Ontario). The eastern basin comprises 24% of Lake Erie's area and 32% of its volume (Bolsenga and Herdendorf 1993). The glacially deposited ridge north of Erie, Pennsylvania contains a notch, known as the Pennsylvania channel, which provides a subsurface connection for water circulation between the central and eastern basins.

The varying depths of Lake Erie's three basins are attributed to differential erosion of the underlying bedrock by preglacial streams, glacial scour and deposition, and postglacial lake processes (Carman

1946). For approximately 250 million years prior to glaciation an extensive river system was carved into the bedrock of the region. The Pleistocene glaciers followed these preglacial valleys, scouring them deeper, broadening them, and smoothing their meanders as the ice moved southwestward through the area now occupied by Lake Erie.

As the ice overrode the resistant limestones which now form the brink of Niagara Falls, it dug deeply into the softer Devonian shales of western New York. The ice front was obstructed by the steeply rising Portage Escarpment, composed of resistant sandstones, which lies a few kilometers inland of the present lakeshore between Buffalo, New York and Cleveland, Ohio. Thus the ice was deflected west along an outcrop of soft shale where it scoured these beds to form the deep bottom of the narrow eastern basin. Farther west where the width of the shale belt is greater, glacial erosion resulted in the broader, but shallower, central basin. The western basin owes its islands and shallowness to the tough Devonian and Silurian limestones and dolomites which resisted glacial scour (Herdendorf 1989).

Old Woman Creek flows into the Sandusky sub-basin of the central basin near its southern extremity. The southernmost shore of the Great Lakes system is located on the Sandusky sub-basin at Ceylon Junction (Lat. 41°25'50" N), approximately 2 km east of the mouth of Old Woman Creek estuary. The triangular-shaped Sandusky sub-basin covers approximately 1,350 km^2 or about 8.5% of central Lake Erie. On the west it is bounded by Kelleys Island and Pelee Island, and on the east by the Pelee-Lorain Ridge, which is capped by the Lorain-Vermilion sand and gravel deposit, a ridge crossing the lake between Lorain, Ohio and Pelee Island, Ontario (Herdendorf and Krieger 1989). Over three-quarters of the bottom of the sub-basin has a depth of greater than 11 m, but nowhere does it exceed 15 m. Here the bottom is very flat; slopes of more than 0.5 m/km are nonexistent. Silt- and clay-sized particles make up more than 95% of the bottom material in this flat area. Water depths of 11 m or less are found only on the shoreward rising slopes of the sub-basin and on the ridge (Holcombe et al. 1997).

The Lake Erie nearshore bottom off the mouth of Old Woman Creek estuary slopes lakeward at a rate of 1.2 m /100 m for the first half km (Carter and Guy 1980) and then flattens to 0.12 m/100 m for the next 3.5 km (Holcombe et al. 1997). This yields a depth of approximately 10 m at a distance of 4 km from the shore. Typically, two prominent sandbars, about 0.5 to 0.8 m high, are located within 75 m of the shoreline. Sand deposits extend offshore for a distance of about 400 m where they grade into more silty deposits (Carter and Guy 1980).

Barrier Beach

The junction of Old Woman Creek and Lake Erie is marked by a barrier beach which separates the lake from the estuary (Figure 2.3). Based on 1956 aerial

Figure 2.3. Barrier beach at mouth of Old Woman Creek estuary (Charles E. Herdendorf).

photographs, Herdendorf (1963a) reported that a 520-m-long beach extended 275 m to the west and 245 m to the east of the creek mouth; the beach was nearly 60 m wide near its center and tapered to 15 m wide at the ends. Sand dunes, 1-2 m in height, that had formed along the eastern half of the beach were actively being cut by wave action as the bar migrated landward at a rate of about 1 m/yr. Herdendorf (1963a) further observed that the creek mouth was normally barred across, being open only during periods of heavy rainfall and high water levels. However, in recent years the bar has been open for longer periods of time. In 1990, the barrier beach was 418 m long and ranged from 85 to 14 m wide. The particle size of the barrier beach ranges from medium- to coarse-grained sand. The beach is dominantly a quartz sand. Purple and black patches or strands of garnet and magnetite, respectively, are common. The thickness of the sand is greater than 1 m (Carter and Guy 1980) and overlies glacial till that is exposed at lake level east of the beach.

Starting in 1983, daily records on bar openings and closings have been kept. Herdendorf and Hume (1991) reported that during the 8-year period 1983-1990 the inlet was open 59% and closed 41% of the time, but annual percentages ranged from about 30% to 70% for each condition. Using water year 1990 (1 October 1989 to 30 September 1990) as an example, water levels and bar conditions at the mouth show a marked seasonal trend (Figure 2.4). During summer months the estuary mouth is typically barred across. Late in the year, October to December, the water level in the estuary builds up to >1.5 m above LWD at which stage the barrier is usually breached. As the water level in the lake and estuary decline during the winter, the mouth once again bars across. In the spring the water level in the estuary again rises behind the bar until breaching occurs. However, this generalized seasonal pattern is often subject to disruption by short-term meteorological conditions. The rapid water rise in the estuary in the latter part of the year (Figure 2.5) appears to be the result of the damming-effect of the barrier bar; neither precipitation nor runoff (Figures 2.6 and 2.7) are sufficient to totally account for the nearly 500,000-m^3 increase in the water stored in the estuary prior to the fall breach. Overtopping of the bar by lake waves is also believed to supply a sizable quantity of water to the estuary, particularly during northeast storms (Herdendorf and Hume 1991). When the bar breaches a classical "ebb tide delta" is built into Lake Erie at the mouth of the inlet. Sand from the barrier is flushed into the lake through a narrow discharge channel and deposited when velocities of the exiting water drop below the transport threshold, about 2 cm/s for medium-grained sand (Herdendorf 1975).

OLD WOMAN CREEK ESTUARY

The estuary comprises the lower 3 km of the Old Woman Creek. Examination of the bathymetric map prepared by Herdendorf and Hume (1991) reveals the estuary to be a broad, shallow basin that has been modified by man-made structures which tend to constrict and segment the original basin (Figure 2.8). Construction of the U.S. Route 6 bridge about 120 m south of Lake Erie and the Conrail causeway and bridge another 1.2 km to the south has resulted in estuary's segmentation into three sections: (1) lake lagoon, (2) main basin, and (3) south basin. Figure 2.8 also shows that an incised channel runs the entire length of the estuary and carries discharge waters directly into Lake Erie. When the water level in the estuary is standing at the mean level of Lake Erie (elev. 174.1 m IGLD 1985 or + 0.6 m LWD) the average depth of the estuary is only 0.2 m. At typical water levels (elev. 174.5 m or +1.0 m LWD) the estuary has an area of 520,000 m^2, a volume of 190,000 m^3, and a mean depth of 0.4 m. Other morphometric relationships for the estuary are presented in Table 2.1. The lake lagoon, main basin, and south basin, respectively, comprise 4%, 82%, and 14% of the total estuary area.

The lake lagoon is a small, elongated basin (east-west direction) that lies between U.S. Route 6 and the barrier beach that separates the estuary from Lake Erie (Figure 2.9). The outlet channel presently runs along the west side of the sub-basin. The beach area east of the outlet channel is known as Oberlin Beach. Aerial photographs taken over the past 60 years show that this lagoon was at one time more circular, when the barrier beach forming its north side was more than 100 m farther lakeward. Recession of the shore, primarily the result of northeast storms, has taken place as waves overtopped the barrier bar and washed beach sand into the lagoon. Since 1937, the channel through the barrier bar has migrated from its present position to 200 m farther east and back again. The deepest portion of the lagoon occurs in scour channel near the U.S. Route 6 bridge (-1.5 m LWD). From the bridge to the lake the depth of the channel averages about -0.3 m LWD.

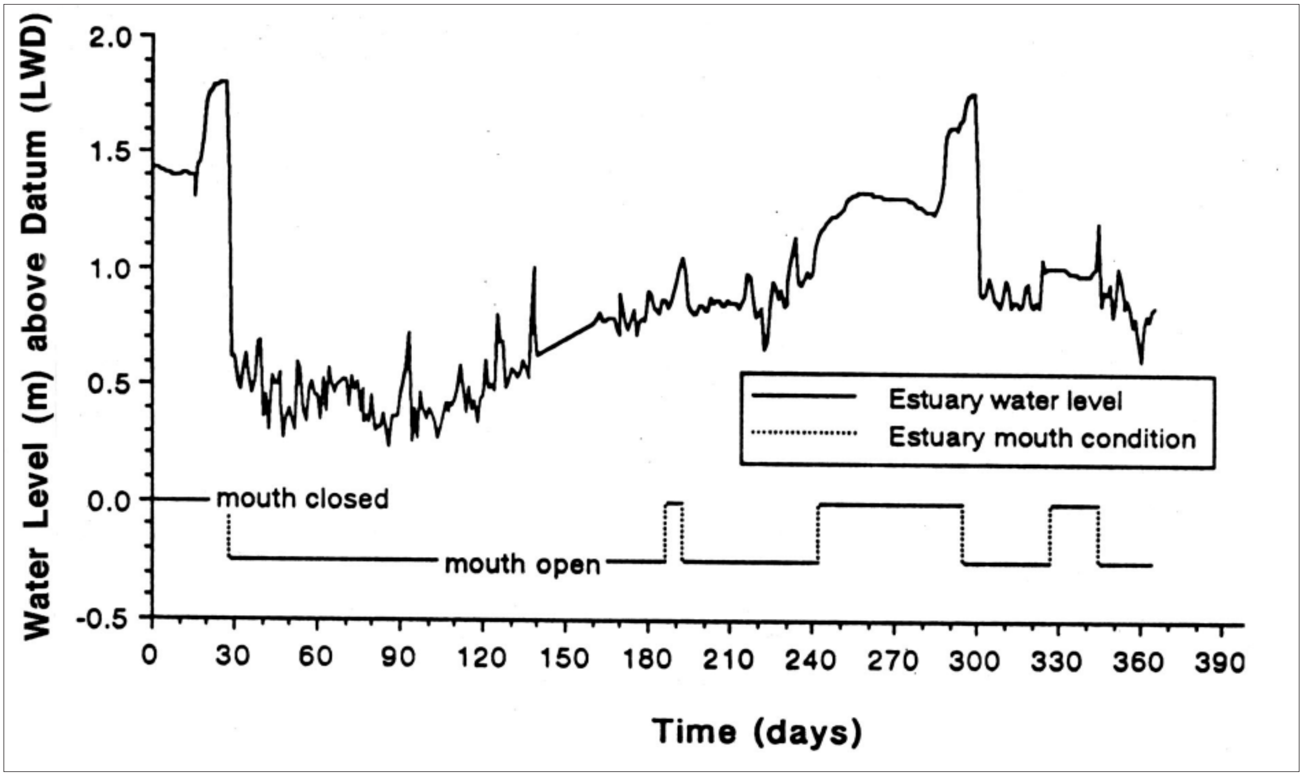

Figure 2.4. Water levels in Old Woman Creek estuary showing open/closed condition of inlet for water year 1990 (1 October 1989 to 30 September 1990).

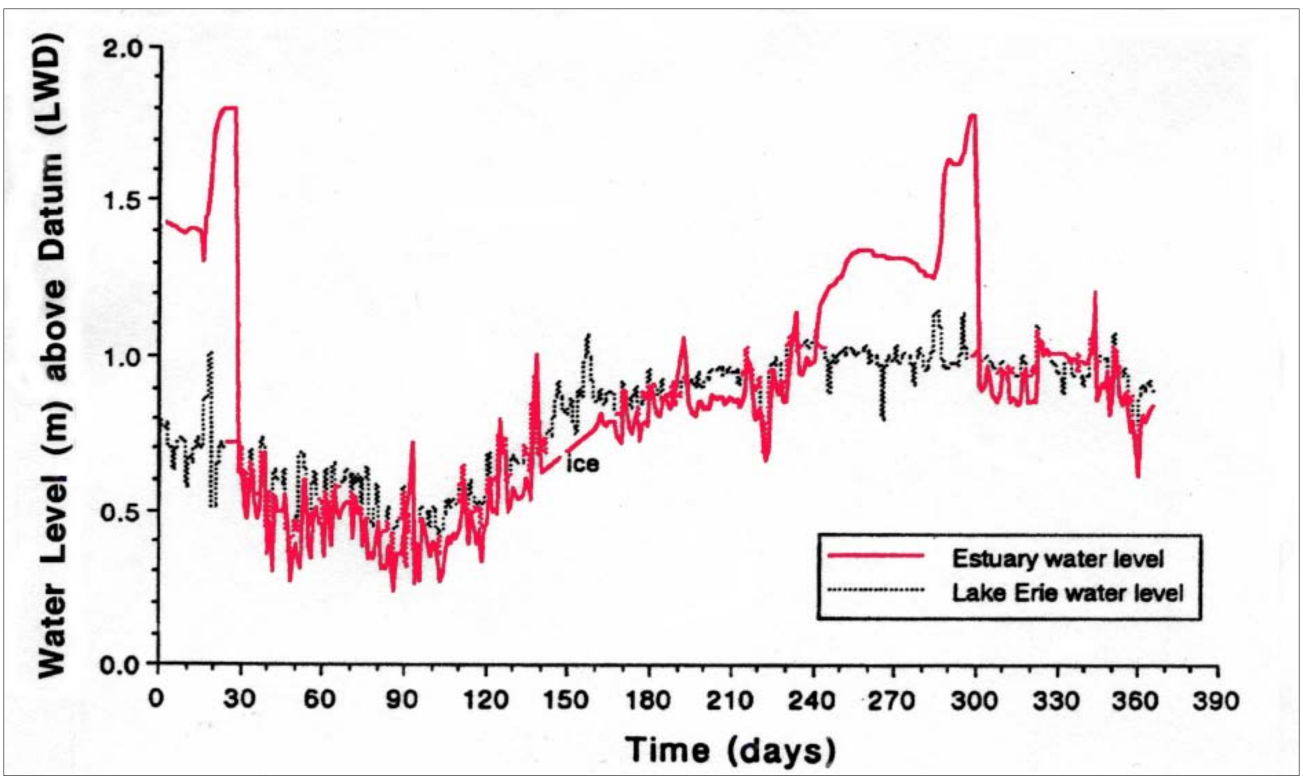

Figure 2.5. Water levels in Old Woman Creek estuary plotted versus Lake Erie water levels for water year 1990 (1 October 1989 to 30 September 1990).

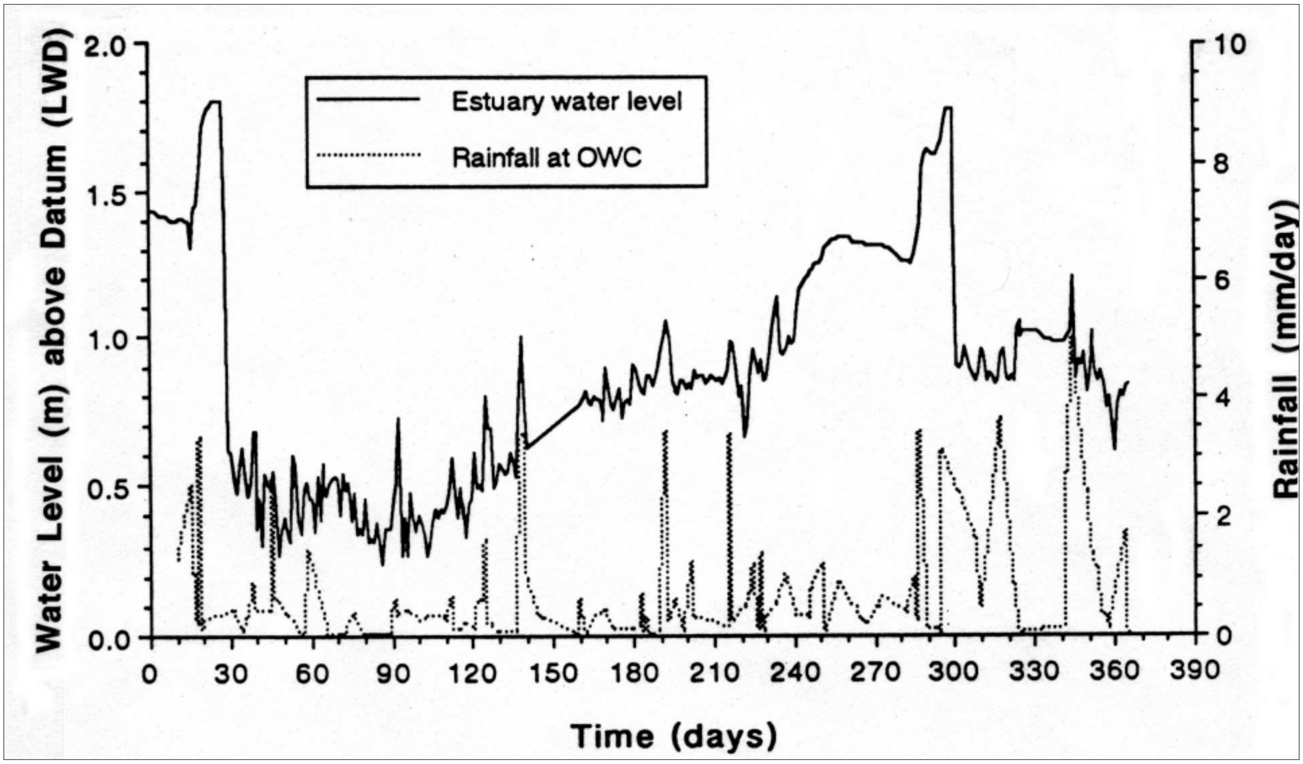

Figure 2.6. Water levels in Old Woman Creek estuary plotted versus rainfall for water year 1990 (1 October 1989 to 30 September 1990).

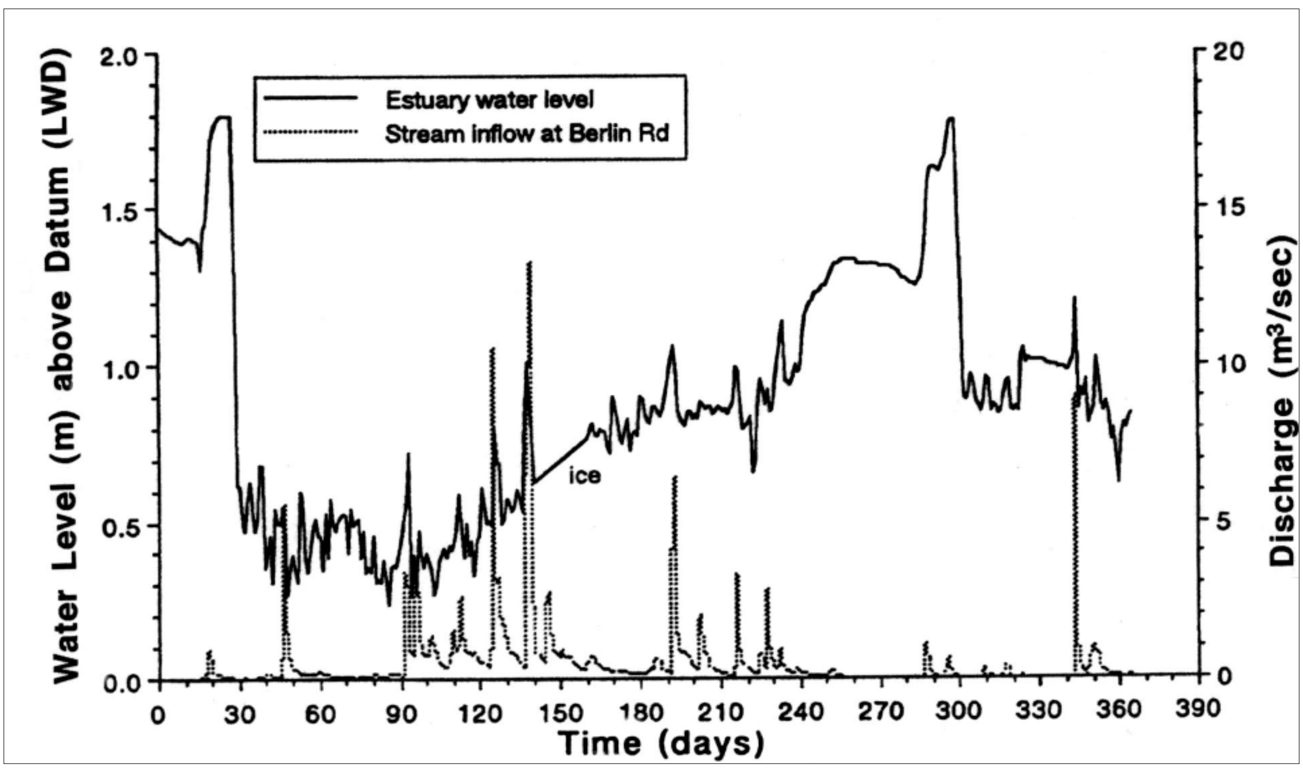

Figure 2.7. Water levels in Old Woman Creek estuary plotted versus stream inflow for water year 1990 (1 October 1989 to 30 September 1990).

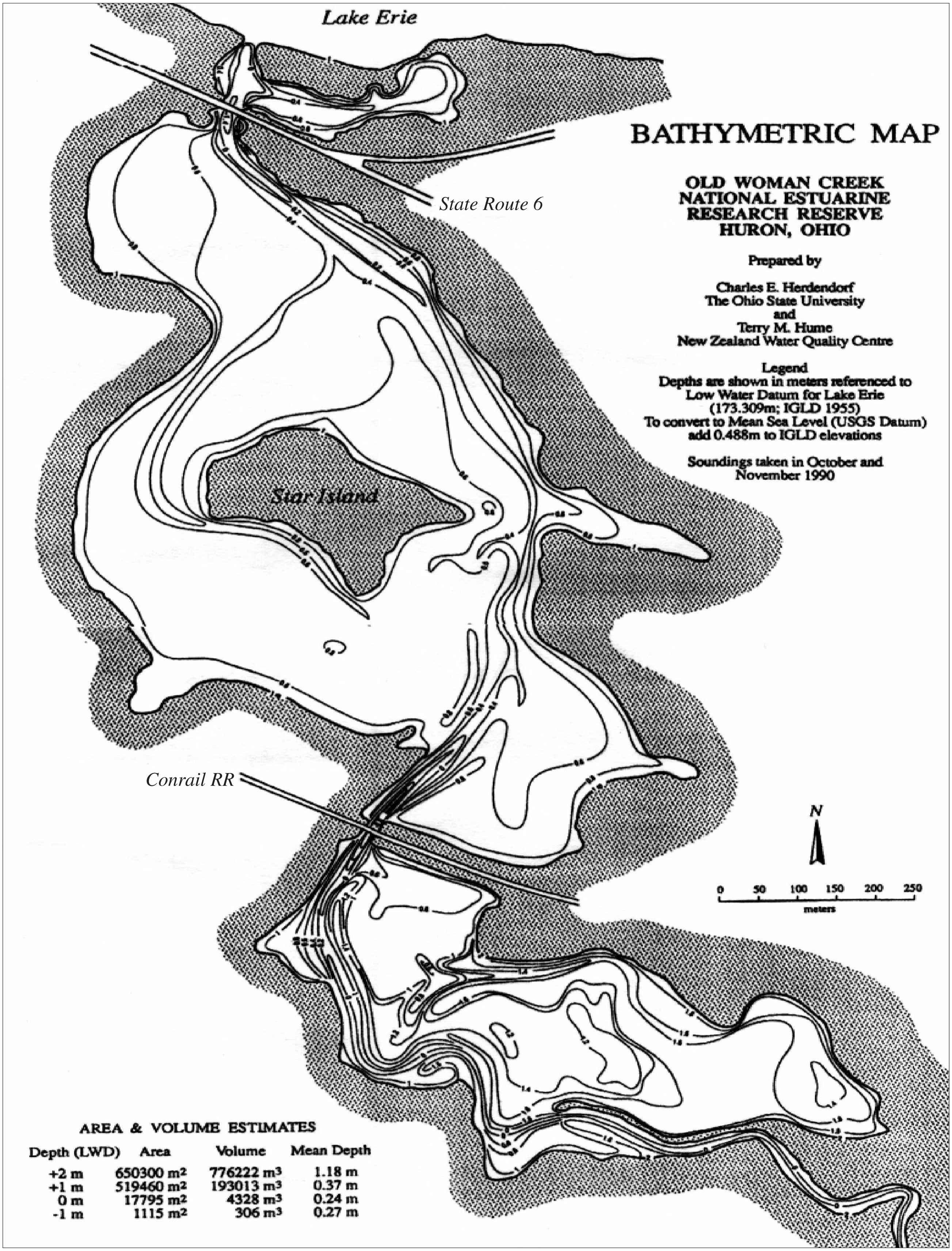

Figure 2.8. Bathymetric map of Old Woman Creek estuary (from Herdendorf and Hume 1991).

The main basin of the estuary is lacustrine-like and consists of a broad shallow basin (Figure 2.10) that is cut by a narrow channel along its eastern margin (Figure 2.11) and a secondary channel that splits off the main channel at the southern end of the basin and follows a course to the west. The channels are shallow, generally with bottom elevations a few tenths of a meter above LWD and only a few tenths of a meter below the surrounding bottom of the estuary (Herdendorf and Hume 1991). Star Island (Figure 2.12) is located between these channels near the center of this basin. A natural levee, that is more persistent in the south basin, extends into the main basin as far north as Star Island. The main basin is surrounded by relatively steep escarpments on all sides, including Star Island. Into the escarpments, on both sides but particularly the east side, intermittent tributaries have cut several deeply entrenched, but shallow, coves. The majority of the basin has a floor elevation ranging from +0.4 to +0.6 m LWD. This produces a depth that is particularly conducive to growth of dense beds of *Nelumbo lutea* (American water lotus). The highway and railroad constrictions at the north and south ends, respectively, of the basin are the deepest portions of the entire estuary. The channel at the U.S. Route 6 bridge is 18 m wide and has a maximum depth of -1.7 m LWD; whereas the channel at the Conrail bridge is 13 m wide and has a maximum depth of -0.9 m LWD.

The south basin (Figure 2.13) of the estuary is more riverine-like and is comprised of a narrow channel that extends south from the Conrail bridge to the vicinity of the Darrow Road bridge. The channel is relatively deep (maximum -0.2 to -0.7 m LWD) and flanked by natural levees along most of its course. A number of small, tributary-mouth lagoons are present along the estuary's west bank and an extensive lagoon and swamp forest is found along the east side of the estuary. This lagoon was a continuation of the main basin of the estuary, but it is now terminated on the north by the railroad causeway. The lagoon occupies an area with bottom elevations between +0.6 to +1.0 m LWD, whereas the swamp forest occurs where the bottom elevation ranges from about +1.0 to +2.0 m LWD. The deepest depths in the south basin occur in a narrow scour channel under the Conrail bridge (-0.7 m LWD).

TABLE 2.1. MORPHOMETRIC DATA FOR OLD WOMAN CREEK ESTUARY

Parameter	Dimension*
Maximum depth (z_m)	2.68 m
South basin	1.67 m
Main basin	2.68 m
Lake lagoon	2.46 m
Mean depth ($\bar{z}$)	0.37 m
Relative depth (z_r)	0.33%
Maximum length (l)	2000 m
Max. effective length (l_e)	1125 m
Maximum breadth (b)	670 m
Mean breadth ($\bar{b}$)	260 m
Closure index (ci)	0.02
Area (a)	519,460 m^2
Volume (v)	193,013 m^3
Shore length (l)	9616 m
Insulosity (i_n) [Star Is.]	7.64%
Shoreline development (d_l)	3.75
Volume development (d_v)	0.41
Orientation of main axis	335°
Slope of basin	
1.8 to 2.0 m	8.54%
1.6 to 1.8 m	1.89%
1.4 to 1.6 m	3.33%
1.2 to 1.4 m	2.86%
1.0 to 1.2 m	11.30%
0.8 to 1.0 m	1.79%
0.6 to 0.8 m	0.79%
0.4 to 0.6 m	0.92%
0.2 to 0.4 m	4.95%
0.0 to 0.2 m	12.14%
-0.2 to 0.0 m	5.98%
-0.4 to -0.2 m	8.75%
Mean slope (s)	1.85%
Length of contour lines (l_z)	
2.0 m	9,923 m
1.8	10,162 m
1.6	11,451 m
1.4	10,972 m
1.2	10,090 m
1.0	9,616 m
0.8	9,250 m
0.6	8,298 m
0.4	7,124 m
0.2	4,258 m
0.0	3,402 m
-0.2	2,892 m
-0.4	1,918 m
-0.6	505 m
-0.8	381 m
-1.0	235 m
-1.2	185 m
-1.4	133 m
-1.6	30 m

* based on water level of +1.0 m LWD
(= 174.49 m or 572.48 ft IGLD, 1985)

Figure 2.9. Lagoon at mouth of Old Woman Creek estuary (Charles E. Herdendorf).

Figure 2.10. Main basin of Old Woman Creek estuary from southern extremity (Charles E. Herdendorf).

Figure 2.11. Channel along eastern side of main estuary basin; upstream view from observation deck (Charles E. Herdendorf).

STAR ISLAND

The valley of Old Woman Creek within the estuary has two distinct channels between the Conrail and the U.S. Route 6 bridges resulting from a bifurcation about 150 m north of the railroad. This bifurcation has preserved an isolated remnant of the lake plain known as Star Island around which the creek flowed to the east and to the west at various times (Buchanan 1982). The roughly star-shaped island now lies near the center of the estuary (Figure 2.14). The distance between its east and west points is about 450 m and 275 m between it north and south points. The sides of the island rise rather steeply to a flat top about 9 m above the mean water level of the estuary. The entire island comprises an area of 45,000 m^2 (4.5 hectares) and its flat top has an area of nearly 1 hectare. Star Island is the only island in the estuary with an elevation significantly above that of the water surface.

The erosional, rather than depositional, origin of Star Island has been inferred from the accordant height of the island with the surrounding uplands and the from the largely undisturbed lake plain sediments on the island's surface (Buchanan 1982). The soil types of the island, Sisson silt loam and Tuscola loamy fine

*Figure 2.12. Prolific stands of common reed (*Phragmites australis*) flanking Star Island (David M. Klarer).*

Figure 2.13. Southern basin of estuary and surrounding swamp forest (Charles E. Herdendorf).

sand, also match those of the surrounding upland areas of the lake plain (Redmond et al. 1971). These soils formed in stratified limy silt and very fine sand that was deposited on the bottom of glacial lakes with levels higher than modern Lake Erie.

The majority of the erosion around Star Island is believed to have occurred during a period of rejuvenation of Old Woman Creek downcutting following glacial retreat (Buchanan 1982). The preservation of the island remnant appears to be the result of entrenched meanders of the creek bed at that time. The arcuate gorges around the periphery of the island, forming the points of the star shape, suggest that the active channel of the creek has eroded into the island from various directions at various times. The relative steepness of these erosional scars is most likely inversely proportional to the age of the channel erosion adjacent to the slope, which enabled Buchanan (1982) to develop a chronology for the erosional history of the island (Figure 2.15). Thus, the gently sloping north and northwest sides of the island have the oldest shorelines and represent the oldest channels while the steeply sloping southwest side represents the youngest.

Lake Plain

A band of relatively flat land paralleling the Lake Erie shore and extending inland approximately 5 km on the east side of the Old Woman Creek and 10 km inland on the west side is known as the lake plain (Figure 2.16). It is a nearly level to gently undulating plain broken only by the steep-sided valleys of the two main branches of the creek and several abandoned beach ridges. The surface topography of the lake plain slopes lakeward at an average of 2 m/km or 0.2% (Buchanan 1982). The lake plain is terminated to the south by the steeply rising Berea Escarpment.

The plain was covered by the waters of several glacial lakes that once occupied the Lake Erie basin. Conspicuous sand and gravel ridges, 3 to 6 m above the plain and 30 to 60 m wide, mark the former shorelines of these lakes (Herdendorf 1963b). The sediments deposited in these lakes form the surface material of the plain. These glaciolacustrine deposits consist largely of interlaminated clay, silt, and fine sand that overlie glacial till (Carter and Guy 1980). Generally, the soils of the lake plain mirror the underlying glaciolacustrine parent material. Lenawee-Del Ray association soils have formed on deposits rich

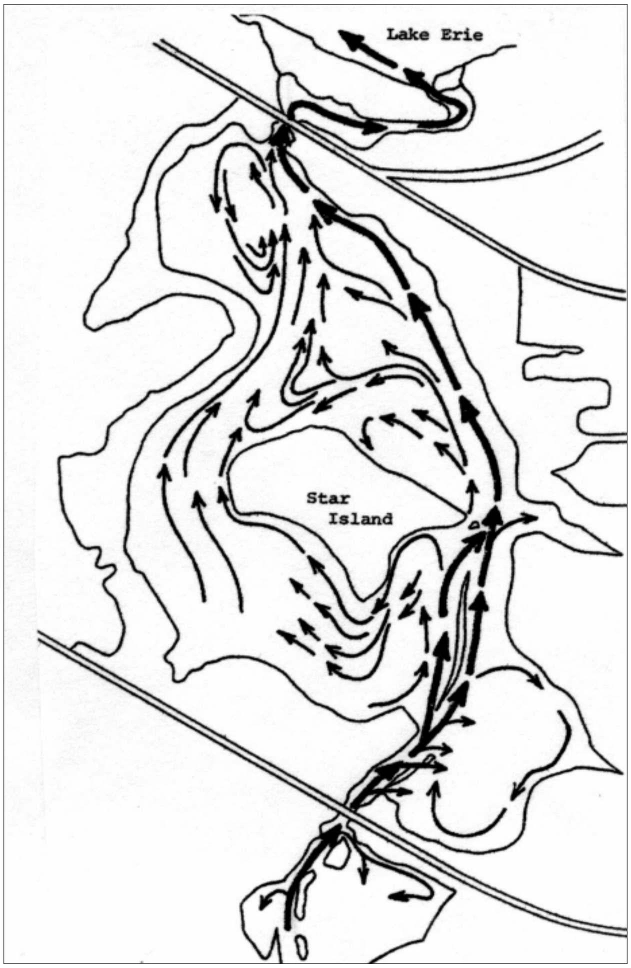

Figure 2.14. Dominant water circulation patterns in Old Woman Creek estuary (from Buchanan 1982).

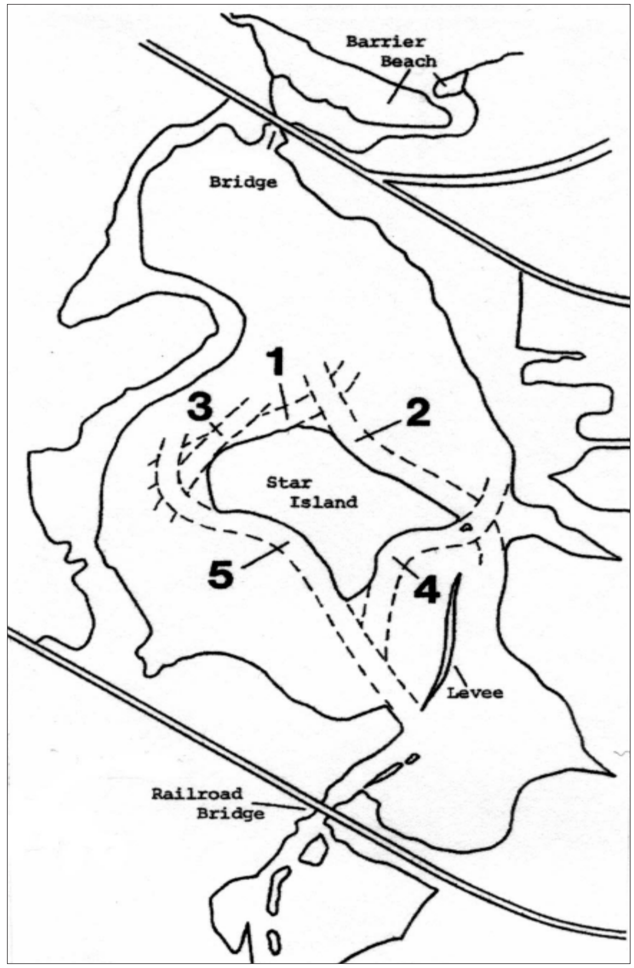

Figure 2.15. Channel migration chronology at Star Island in Old Woman Creek estuary (from Buchanan 1982).

in clay and silt; whereas deposits containing more silt and fine sand have produced soils of the Kibbie-Tuscola-Colwood and the Sisson-Tuscola associations (Redmond et al. 1971).

ABANDONED BEACH RIDGES

Several stages of six glacial lakes covered the lake plain with water depths 15 to 70 m higher than modern Lake Erie, the most prominent of these include Lakes Maumee, Arkona, Whittlesey, Wayne, Warren, and Lundy (Carney 1911). The abandoned, sandy beaches of these lakes form a series of more or less parallel ridges trending northeast-southwest at the southern edge of the lake plain (Figure 2.17). The topographic profile of this part of the watershed is that of successively lower lake-plain terraces with a several-meter-high beach ridge and sand dunes at their southern terminus (Herdendorf 1963b). The major ridges (Maumee, Whittlesey, and Warren) are confined to a 2-km-wide belt because of the rather rapid rise in the land surface at the southern edge of the lake plain as the plain merges with the Berea Escarpment (Figure 2.18). Where the ancient shorelines coincided with outcrops of Berea Sandstone, wave-cut, headland features such as vertical cliffs, overhangs, arches, and caves were produced (Figures 2.19 and 2.20). The reader is referred to the section of this Chapter titled Evolution of Lake Erie: Glacial and Postglacial Lakes for more detailed information on glacial lakes associated with the abandoned beach ridges.

Studies of concentrations of erratic boulders in Erie and Huron counties by Campbell (1955) showed that the highest numbers are associated with the ancient beach ridges. The large accumulations are thought to be a result of severe shore erosion at the base of the ridges or possible ice rafting of rock fragments from

Figure 2.16. Lake plain south of Old Woman Creek estuary (Charles E. Herdendorf).

Figure 2.17. Abandoned beach ridge and dune of glacial Lake Maumee at Berlinville, Ohio (Charles E. Herdendorf).

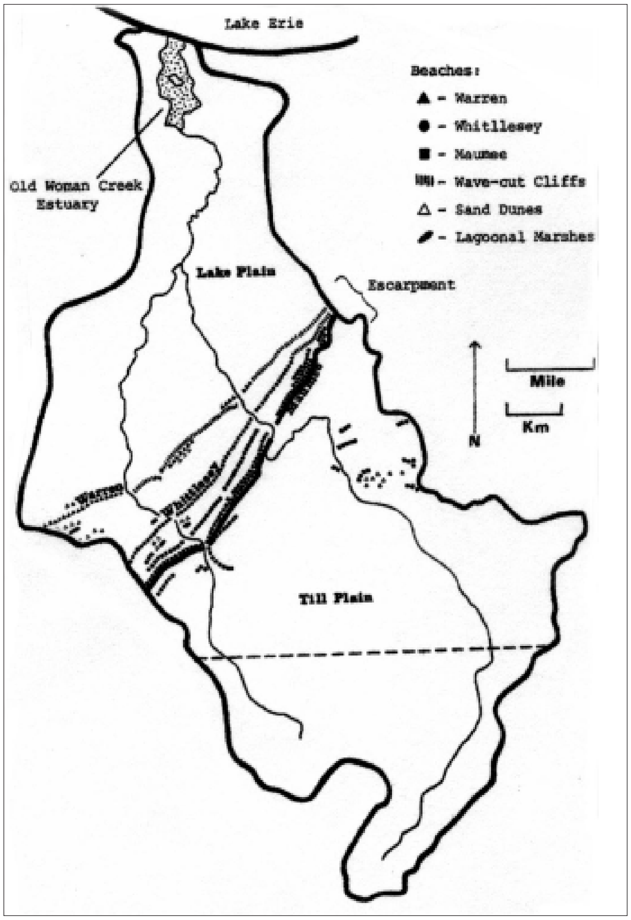

Figure 2.18. Abandoned beach ridges and wave-cut cliffs in Old Woman Creek watershed; trends of ridges are aligned with the Huron River embayment to the east of the watershed (from Buchanan 1982).

glaciers located to north. Deposits of bog iron ore and peat occur locally in association with the former marshy areas or lagoons between the beach ridges. The reddish-brown Vaughnsville loam has formed on the bog iron deposits. This soil is best developed north of Mason Road in Vermilion Township (10 km northeast of Berlin Heights) and south of Hill Road in Berlin Township (2 km southeast of Berlin Heights). The soils that developed on the gently sloping, sandy beach ridges are in the Arkport-Galen and Mahoning-Bogart-Haskins-Jimtown associations (Redmond et al. 1971).

BEREA ESCARPMENT

The Berea Escarpment is the erosional surface expression of the northern edge of the Berea Sandstone outcrop (Figure 2.21). Berea Sandstone is the most resistant bedrock formation exposed in the watershed. Erosion has left it standing proud, well above the surrounding shale beds. The escarpment occurs in a nearly 2-km-wide band that extends in a northeast-southwest direction across the midsection of the watershed. Impressive rock gorges have been cut through the escarpment by the east and west branches of Old Woman Creek. The surface topography of the escarpment slopes lakeward at an average of 17.5 m/km or 1.75% (Buchanan 1982). The local relief of the escarpment near Berlin Heights approaches 60 m.

The base of the escarpment lies at an elevation of about 201 m (660 ft) and rises to a maximum elevation of 259 m (851 ft) northeast of Berlin Heights. The steepness of the escarpment's north slope is governed by the relative erosion resistance of the underlying rocks. From an elevation of 201 to 213 m (660 to 700 ft) the slope is steep (1 m vertical in 7 m horizontal) in response to the hard, black Ohio Shale. From 213 to 219 m (700 to 720 ft) the escarpment is more terrace-like (1 m vertical in 20 m horizontal) under the influence of the soft, gray Bedford Shale. From 219 to 259 m (720 to 850 ft) the slope once again becomes steeper (1 m vertical in 4 m horizontal) where underlain by resistant Berea Sandstone which forms the caprock for the escarpment.

Soils of the escarpment are within the Mahoning-Bogart-Haskins-Jimtown association, especially those of the Berk series (Redmond et al. 1971). Typically these soils are acid, light-colored, well-drained, and underlain by weathered sandstone from which they have formed.

BERLIN HEIGHTS RAVINE

The ravine of Old Woman Creek at Berlin Heights exhibits the maximum relief in the watershed. From the floor of the creek to the top of the gorge, the vertical height of the walls reach a maximum of 27 m and the width ranges from 100 m to nearly 200 m. The ravine begins at the foot of the Berea Escarpment, near the place where the Ohio Turnpike crosses the east branch of Old Woman Creek, and extends south (upstream) for about 2 km to Ohio Route 61. The creek bed drops 35 m in a series of riffles as it passes through the ravine. Impressive exposures of Berea Sandstone can be seen in the upper walls of the ravine and Ohio Shale crops out in the bed of the stream (Figure 2.22). A similar but less spectacular gorge occurs on the west branch of Old Woman Creek where the stream cuts through the Berea Escarpment in the vicinity of Berlinville.

Figure 2.19. Wave-cut features in Berea Sandstone 30 km east of Berlin Heights, Ohio (Charles E. Herdendorf).

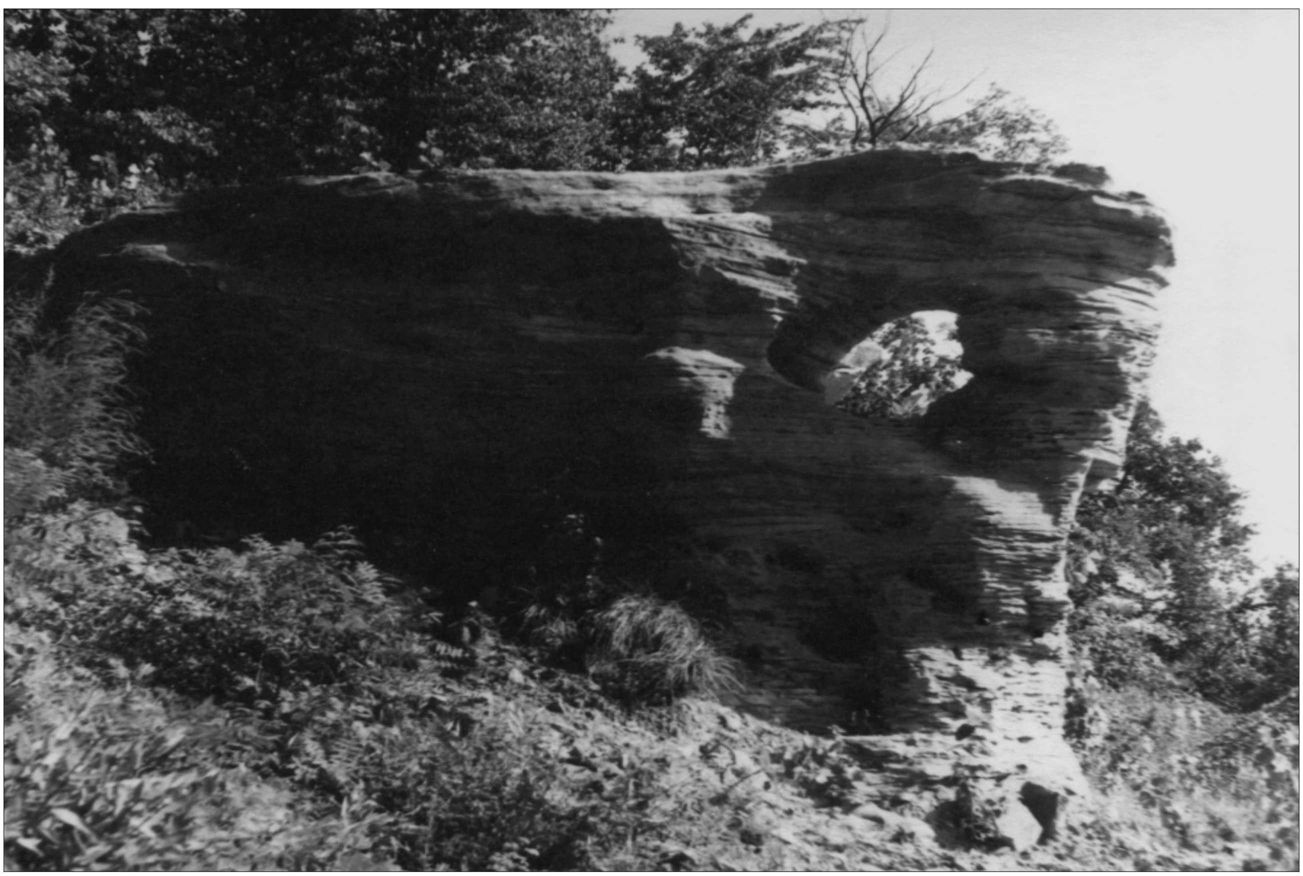

Figure 2.20. Berea Sandstone cliff (at same location as Figure 2.19) sculptured by wave action during glacial Lakes Maumee and Whittlesey (Charles E. Herdendorf).

Figure 2.21. Wave-etched sandstone cliff of glacial Lake Maumee near crest of Berea escarpment at Berlin Heights, Ohio (Charles E. Herdendorf).

Figure 2.22. Downstream view from floor of Berlin Heights ravine (Charles E. Herdendorf).

TILL PLAIN

The southern half of the watershed consists of glacial till plain (Figure 2.23). This plain lies southeast of the highest Lake Maumee beach ridge which generally coincides with the lakeward slope of the Berea Escarpment. The surface topography of the till plain slopes lakeward at an average of 5 m/km or 0.5% (Buchanan 1982). The till plain is a large expanse of glacially deposited ground moraine that extends beyond the limits of the watershed to the Defiance end moraine in southern Huron County (15 km south of Berlin Heights). The till plain is more rolling than the lake plain and represents an area over which the ice edge advanced and retreated rapidly without halting (Herdendorf 1963b). The plain is only moderately dissected by the tributaries of Old Woman Creek and lake plain about 2 km south of the estuary.

The channel of Old Woman Creek as it passes through the till plain drops from an elevation of 270 to 229 m (885 to 750 ft). The average gradient for this 12-km section is 3.4 m/km or 0.34 %. The stream gradient is less steep than that of the surface topography of the till plain because of the effects of channel cutting into the till surface. The heights of valley walls in this section range from nil at the headwaters to 8 m near Berlinville. The dendritic stream pattern of Old Woman Creek in the till plain is classified as being in a "late youthful" development stage (Buchanan 1982).

At an elevation of 229 m (750 ft) significant exposures of bedrock appear in the creek valley and continue to an elevation of 186 m (610 ft) as the creek traverses the 3.7 km of the Berea Escarpment (Figure 2.24). The stream gradient for this section is 11 m/km or 1.1%. The erosion of deep gorges and ravines in the bedrock of the escarpment has also reduced the stream gradient below the gradient of the surface topography. The gorges in this section have valley walls up to 27 m high. The dendritic stream pattern of Old Woman Creek shows some rectangular influences within the rock exposures of the escarpment and is classified as being in a "youthful" development stage (Buchanan 1982).

Below an elevation of 186 m (610 ft) and on to its mouth, a distance of 8.7 km, Old Woman Creek traverses the lake plain. The stream gradient in this section is only 1.3 m/km or 0.13%, although the lacustrine sediments in the section are easily eroded yielding some deep channels. The wide floodplain, U-shaped valley, and meandering pattern of the creek all reflect a "mature" stage of stream development (Buchanan 1982). The heights of valley walls in this section range from 8 to 12 m.

BEDROCK GEOLOGY

The bedrock exposed in the Lake Erie region was formed during the middle portion of the Paleozoic Era, that span of time from 300 to 500 million YBP. Geologists have named 62 bedrock formations that crop out in the states and province which surround Lake Erie (Bolsenga and Herdendorf 1993). The varying depths of Lake Erie's three basins are attributed to differential erosion of the bedrock by preglacial streams, glaciers, and postglacial lake processes (Carman 1946). This erosion is largely in response to the hardness and structure of the underlying formations. Lake Ontario is separated from Lake Erie by resistant

Figure 2.23. Rolling glacial till plain southeast of Berlin Heights, Ohio (Charles E. Herdendorf).

Figure 2.24. Tributary stream to Old Woman Creek crossing Berea escarpment north of Berlin Heights, Ohio (Charles E. Herdendorf).

Silurian limestones and dolomites of the Niagara Escarpment. However, the central and eastern basins of Lake Erie are underlain by nonresistant shale, shaly limestone, and shaly sandstone of Late Devonian Age, which dip gently to the southeast. Inland along the south shore, eastward from Cleveland, the Portage Escarpment, composed largely of Mississippian sandstone, rises 100 m above the level of the lake and forms the northwest front of the Appalachian Plateau.

An outcrop belt of Devonian shales swings inland between Cleveland and Sandusky and continues southward through central Ohio in response to the structural pattern of the bedrock. The shallow western basin is underlain by Silurian and Devonian limestones and dolomites on the northward plunging end of the Findlay Arch of the Cincinnati Anticline. Glacial erosion had relatively slight effects on these resistant rocks other than to form impressive grooves such as those found on Kelleys Island and the Bass Islands. The glacial scour was probably controlled by the preglacial stream valleys, resulting in the shallow basin and the island chain.

The bedrock in the islands area of western Lake Erie is sedimentary in origin and was deposited as lime muds in shallow, warm Silurian and Devonian seas, which covered the region from 410 to 375 million YBP. The existence of evaporite beds such as halite (rock salt) and gypsum indicate that several isolated basins occurred at this time. Enclosed by barrier reefs, the waters were repeatedly evaporated to form the massive salt deposits. Halite deposits in the vicinity of Cleveland are currently being mined 700 m below the lake bottom. The warm, clear conditions of the Devonian sea can be inferred from the abundant fossil corals and other invertebrates found in the rocks on Kelleys and Johnson Islands.

While the shallow Devonian sea occupied the islands area, the Appalachian Mountains were being built to the east. Investigations of plate tectonics (Bird and Dewey 1970; Kennett 1982) indicate that the collision of the northwest coast of Africa and that of eastern North America (Appalachian Orogeny) caused sediments to be folded into a formidable mountain chain. Erosion of these newly formed mountains resulted in the deposition of shales and sandstones which cover the limestones in central and eastern Lake Erie.

Much of the south shore of central Lake Erie is a wave-cut bluff composed of hard, black shale (Ohio Formation) of the Late Devonian Age. Bluff heights are 20 to 24 m east of Cleveland where shale and siltstone outcrop near lake level and only form the basal bluff structure when present. Bedrock, however, does form much of the lake bottom to 1.5 km offshore intermittently from Vermilion, Ohio to Erie, Pennsylvania.

Following the deposition of the black Devonian shales, during the Mississippian and Pennsylvanian periods, new deltas were built from the north into the shallow mid-continent sea where Lake Erie is now located. Sandstones and shales were deposited inland from what is now the lake's south shore to form the red beds of the Bedford Shale, the ridge-forming strata of the Berea Sandstone and the "pudding stone" quartz pebbles of the Sharon Conglomerate. Each of these formations has been quarried for building materials. When deeply buried beneath a caprock, the sandy beds of these formations are excellent aquifers and reserves for gas and oil.

PREGLACIAL TOPOGRAPHY

A long period of erosion ensued following the deposition of the Upper Paleozoic rock and little is known of the geologic processes for over 250 million years. Here, the geologic record stops until the glacial deposits of the Late Cenozoic. Deep river valleys were cut into the bedrock surface during this interval, including a major drainage system in the vicinity of Old Woman Creek (Herdendorf 1963b). Figure 2.25 illustrates the magnitude of this ancient valley which is now filled with glacial drift.

Edwin Lincoln Moseley, Sandusky High School science teacher, announced in the 22 July 1909 edition of the *Erie County Reporter* that he had traced an ancient rock valley from Willard, in southwestern Huron County, through Norwalk and Milan to the shore of Lake Erie at the mouth of Old Woman Creek. He discovered the ancient valley by inspecting water well records which showed it to be over 2 km wide, filled with over 50 m of glacial drift, and probably formed by a larger river than any now flowing in this part of the state. The deepest wells that did not penetrate rock were found between Milan, Ohio and Lake Erie. Moseley concluded that when the ice which formed a thick covering over the region in the glacial period

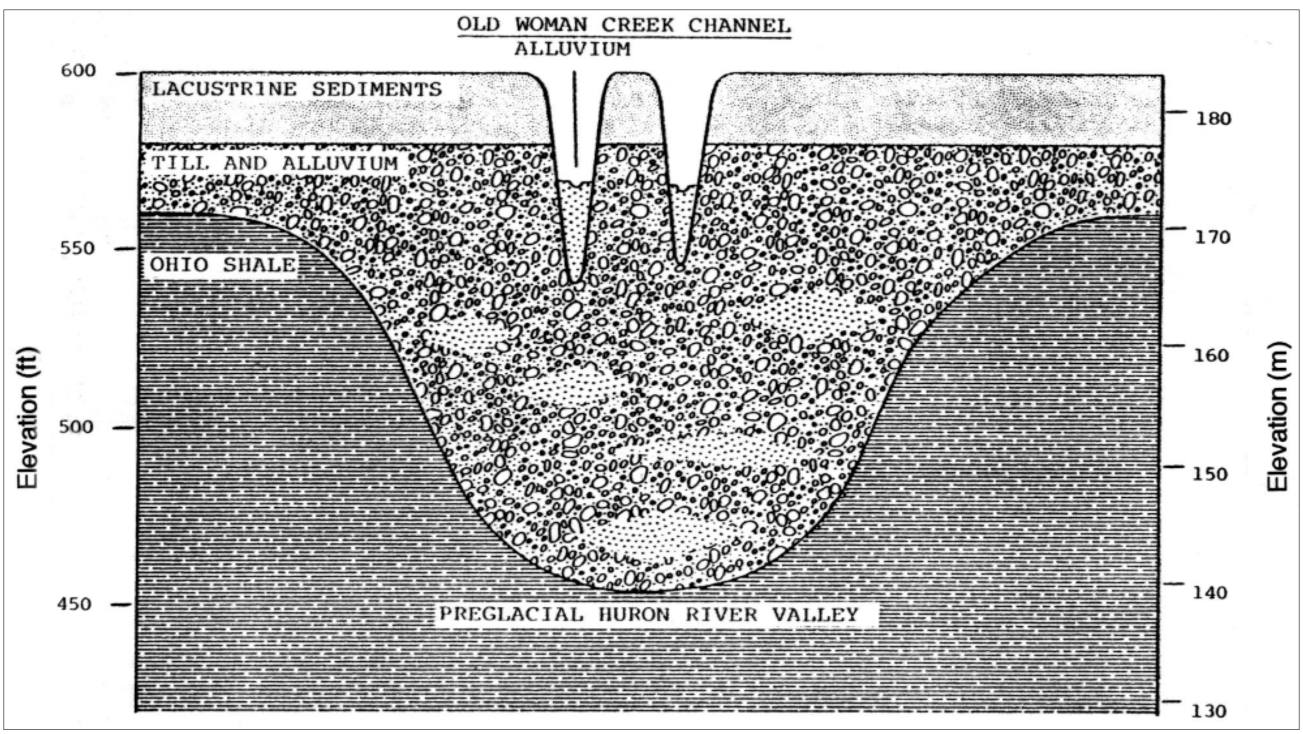

Figure 2.25. Cross-section of buried preglacial Huron River valley at mouth of Old Woman Creek; valley width 4 km (from Herdendorf 1963b, Buchanan 1982).

finally melted away it left behind great quantities of clay and gravel which filled the valley so completely that its existence was not suspected (Frohman 1973).

Exposed Bedrock Formations

Paleozoic rocks, mainly shales and sandstones, of the Late Devonian and Early Mississippian Periods are exposed within the Old Woman Creek drainage basin (Figures 2.26 and 2.27). Subsurface formations, mainly limestones and dolomites, of the Silurian, Late Devonian, and Middle Devonian Periods underlie these rocks, but are themselves exposed in the western portions of Erie County, Ohio. The following section provides a lithologic description of each bedrock formation exposed in Erie County. These descriptions are modified from Herdendorf (1963b,1966,1967).

Early Mississippian Period

Berea Sandstone. This sandstone formation is gray, blue, or buff, medium- to fine-grained, clay-bonded, thin-layered to massive, cross-bedded and ripple-marked. Principal grains are clastic subangular to subrounded quartz showing secondary enlargement; with lesser amounts of microcline, orthoclase, plagioclase, muscovite, leucoxene, zircon, tourmaline, calcite, chlorite aggregates, and rims of siderite; bonding material chert, sedimentary rock fragments, and clay. Formation is divided into three parts: (1) lower channel sandstone, present only as fills in erosion valleys in the Bedford and Cleveland Shales (Figure 2.28), characterized by steep walls, rounded basal profiles, and meander patterns; (2) middle massive sandstone, strongly crossbedded and containing flow rolls (Figure 2.29); (3) upper thinly bedded marine sandstone, 6 to 10 m thick, with upper surface of beds showing distinct oscillation-type ripple marks (Figure 2.30). Fossils are rare. Formation is highly resistant, forming ridges and hills in the southeastern part of the county, and influencing orientation of Pleistocene beach ridges and lake bluffs. Northern edge of outcrop, particularly along Chappel Creek in northwestern Florence Township exhibits complex and possibly glacially related folding, faulting, and overturning. Since mid-1800s at least 10 sites have been worked for dimension, grind, and crushed stone, although most of these small quarries have been abandoned. Several untapped sandstone hills and the Berlin Heights escarpment appear to be potential sources of quarry stone.

Some controversy has developed concerning the channel fills in basal portion of the Berea Sandstone. The “channels” have had several explanations. Burroughs (1911) interpreted irregularities in the Berea, such as the deep quarries at South Amherst, Lorain County, Ohio, as channels excavated into the underlying strata and filled with sands. Cushing et al. (1931) noted that shales at the base of the Berea are often highly disturbed (tilted and faulted) in the vicinity of large channels and concluded that these disturbances “were effected by the currents that brought in the Berea sands, the underlying mud being shifted about and slumping along the channel sides.” Pepper et al. (1954) considered the channels to be deep valleys cut into the underlying shales and filled from the north during the deposition of the Berea delta. Lewis (1976,1988) interpreted the “channels” as synsedimentary (accompanying deposition; contemporaneously formed) slumps in a marine distributary system that were built from the east or southeast. He also suggested that the upper part of the Berea sandstone may have originated as eolian dunes. Burrows (1988) disagreed with Pepper et al. by identifying the “channels” as localized slumps into the Bedford Shale. Wells et al (1991), while not denying the presence of some channels in the Berea and slumps initiated by cutting and/or loading along channel axes, concluded that most “Berea channels” are primarily mass movements of sand into mud, supporting the view of Lewis (1988).

In north central Ohio the Berea Sandstone exhibits numerous structural anomalies (Herdendorf and Struble 1975). Local and in some cases intense deformation has occurred along the northern outcrop of this formation, whereas a few kilometers to the south the beds are only gently warped. The most striking structural features are found between the Huron and Vermilion Rivers in the valleys of Chappel Creek and Old Woman Creek. About 3 km north of Florence, at a place 120 m downstream from the Furnace Road bridge over Chappel Creek, overturning and faulting have jumbled the Berea Sandstone. Here the beds dip steeply (56°) to the south (S 20° W) while approximately 30 m father downstream the dip is only 10° in the same direction. The first outcrop of sandstone is 3 m thick and 15 m long, extending at a steep angle from the creek bed to the top of the bluff (Figure 2.31). The second, which is separated from the first by a covered interval of glacial till, is nearly the same thickness and persists from the stream bed to the top of the bluff.

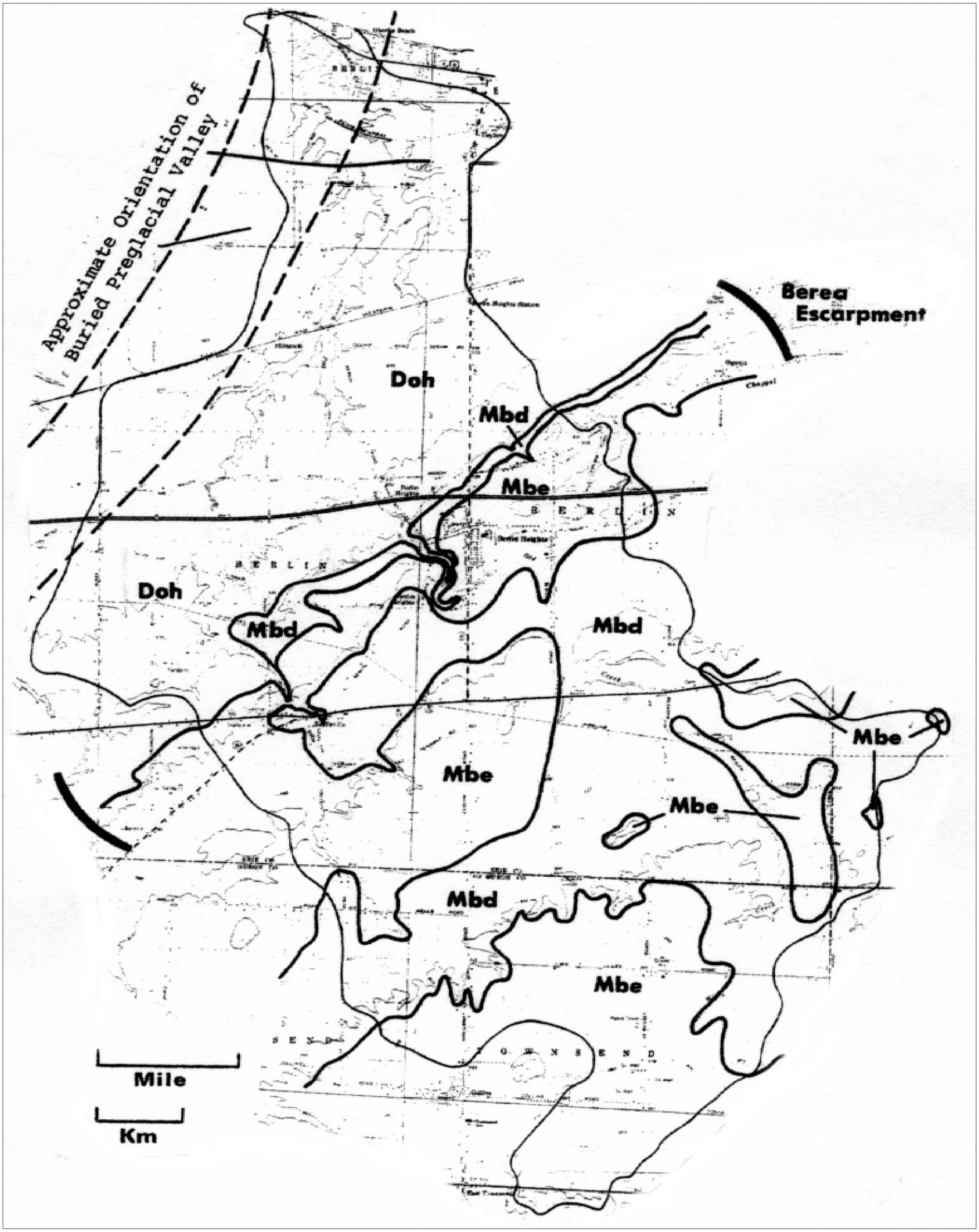

Figure 2.26. Geologic map of bedrock formations underlying Old Woman Creek watershed (from Herdendorf 1966, Buchanan 1982). Legend: Doh= Ohio Shale (Cleveland and Huron Shales), Mbd= Bedford Shale, Mbe= Berea Sandstone.

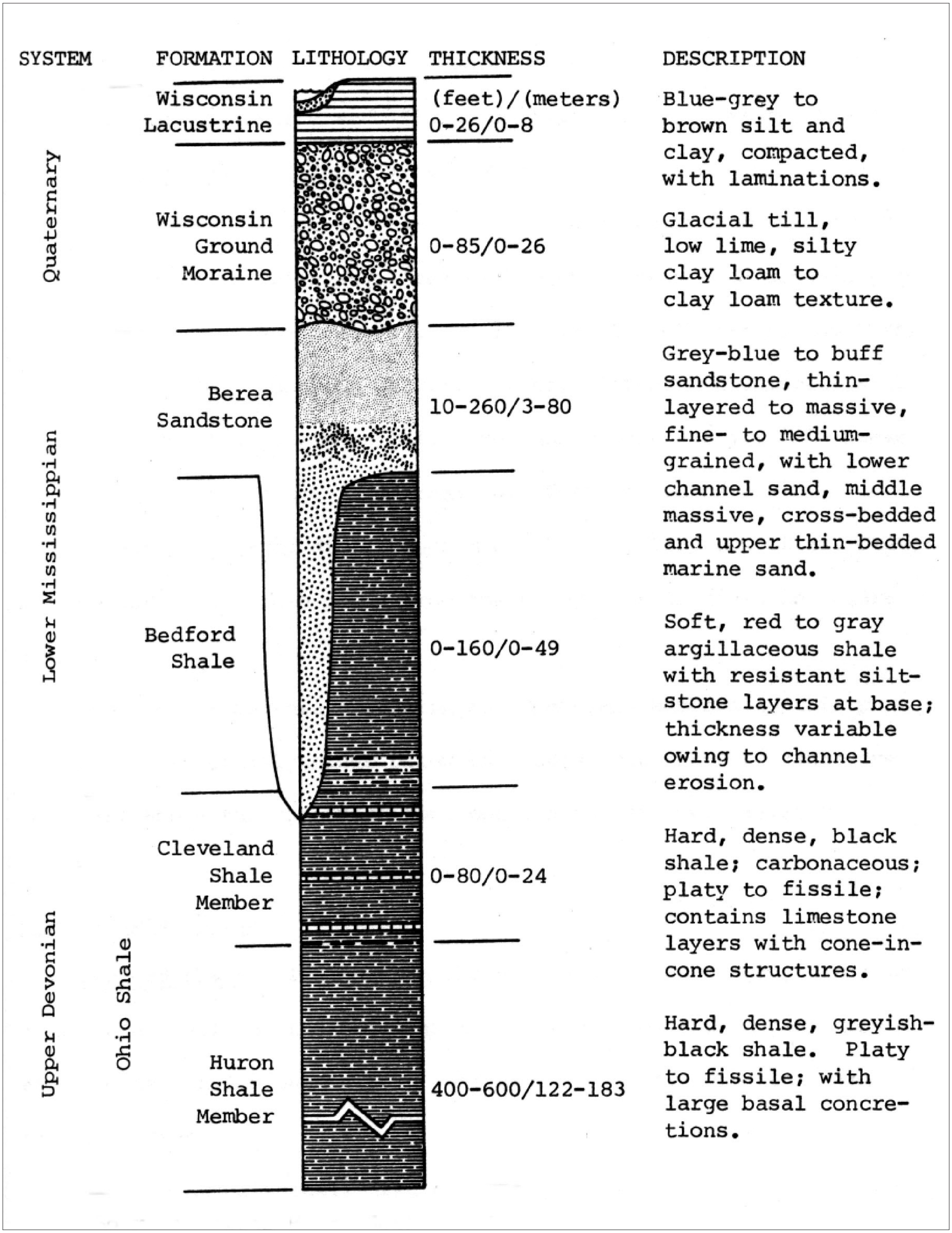

Figure 2.27. Stratigraphic column of bedrock formations exposed in Old Woman Creek watershed (from Herdendorf 1966, Buchanan 1982).

Figure 2.28. Berea Sandstone channel (top) into Ohio Shale (bottom) at Berlin Heights ravine (Charles E. Herdendorf).

Figure 2.29. Flow roll in Berea Sandstone at west wall of Berlin Heights ravine (Charles E. Herdendorf).

Figure 2.30. Oscillation ripple marks in Berea Sandstone along the West Branch of Old Woman Creek north of Berlinville, Ohio (Charles E. Herdendorf).

Because the second outcrop has a more gentle dip it is nearly 100 m long (Figure 2.32). On close inspection of these outcrops, Herdendorf (1963b) concluded from up-side-down oscillation ripple marks and cross-bedding truncated downward that both outcrops were overturned strata; the first being overturned 124° and the second 170°. This overturning appears to be a very local phenomena—less than 100 m farther downstream (north) similar beds occur in a right-side-up position near the top of the bluff.

The explanation for these unusual bedrock structures may lie in the fact that in preglacial times the Berea Sandstone outcrop most likely extended across north central Ohio as a terrace-like landform, cut only by north-flowing streams. This feature must have presented a formidable barrier to ice movement. When it was eventually overridden, large blocks or slabs of sandstone may have been fractured and dislodged from the northern edge. Such a process may account for the overturned strata in the Chappel Creek valley (Herdendorf 1963b, 1966). As the force of the ice dislodged the slab, it could have been easily pushed or dragged across the surface of underlying clay shale formation (Bedford Shale). The slab may have moved only a short distance before being rolled over which may have caused the fracture separating the two blocks. The force of the frictional drag along the bottom surface of the ice sheet may have also caused the broken, rumpled, and faulted shale beds in the stream valleys between Lake Erie and the sandstone outcrop. Hartley (1962) observed similar structural features in the shale beds along the lake shore east of Vermilion, Ohio.

Bedford Shale. This shale formation is bluish-gray to pink to reddish-brown, clayey, plastic, soft, indistinctly bedded (Figure 2.33); thin basal and upper gray beds separated by thick red shale unit. Thin resistant lenses, concretionary siltstone to very fine sandstone, occur in the basal shale and form 7- to 15-cm ledges along exposure; particularly well developed along the Vermilion River in Florence Township. Locally, siltstone layers and thin red and gray shale laminations occur at the base of the gray shale; upper gray shale beds are somewhat arenaceous and contain sandy flow rolls. Red and gray shales are composed of quartz; illite, chlorite, kaolinite, and hematite which imparts color to red shales; siltstone layers contain angular to subangular grains of quartz and feldspar cemented by hematite, pyrite nodules, and a small

Figure 2.31. Overturned Berea Sandstone in valley of Chappel Creek, northwest Florence Township, Ohio (Charles E. Herdendorf).

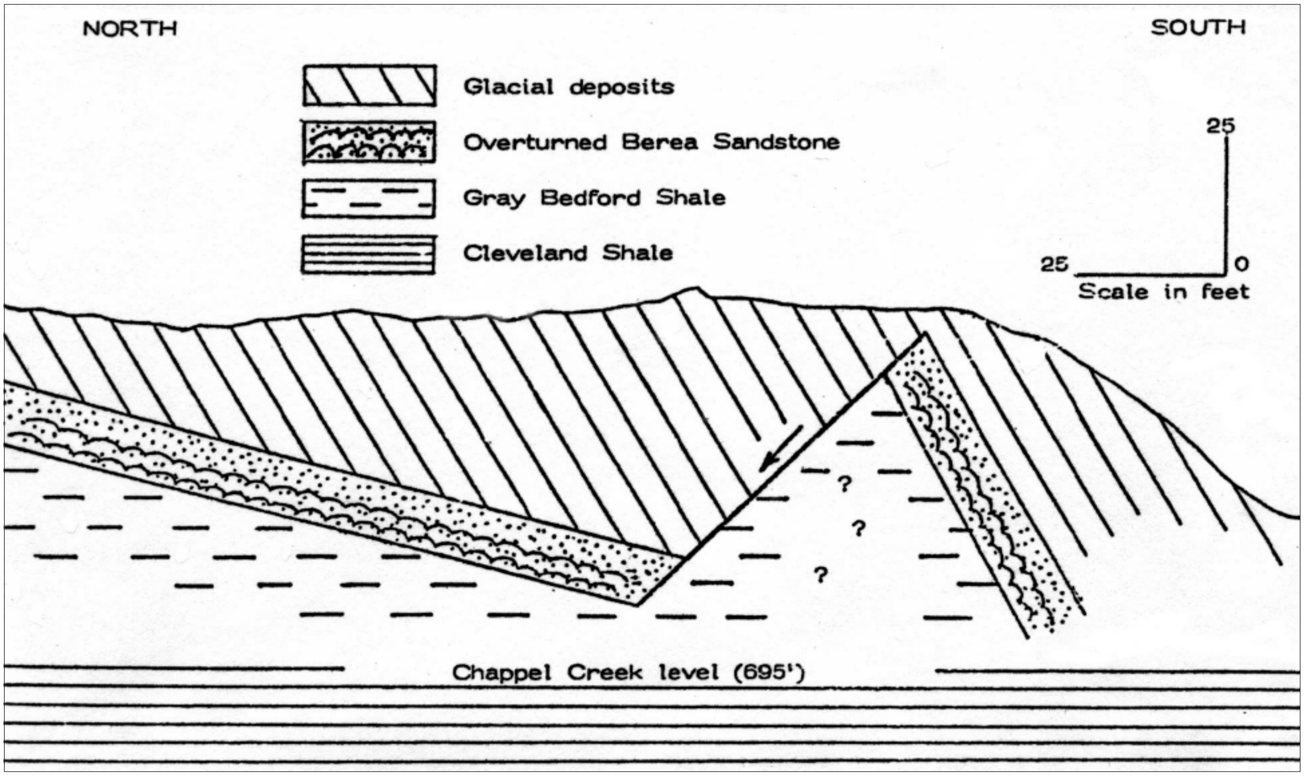

Figure 2.32. Cross-section of overturned Berea Sandstone in the valley of Chappel Creek (from Herdendorf 1963b).

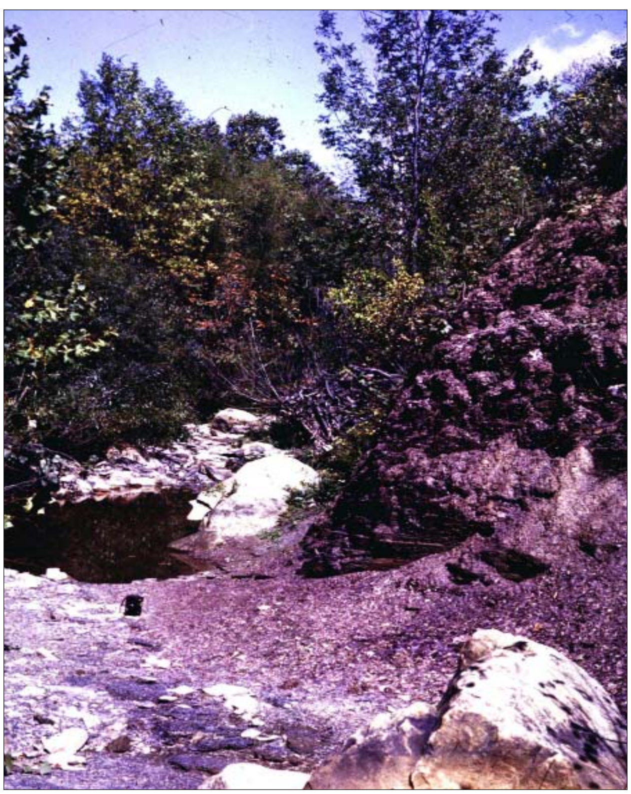

Figure 2.33. Red Bedford Shale in valley of Chappel Creek, Florence Township, Ohio (Charles E. Herdendorf).

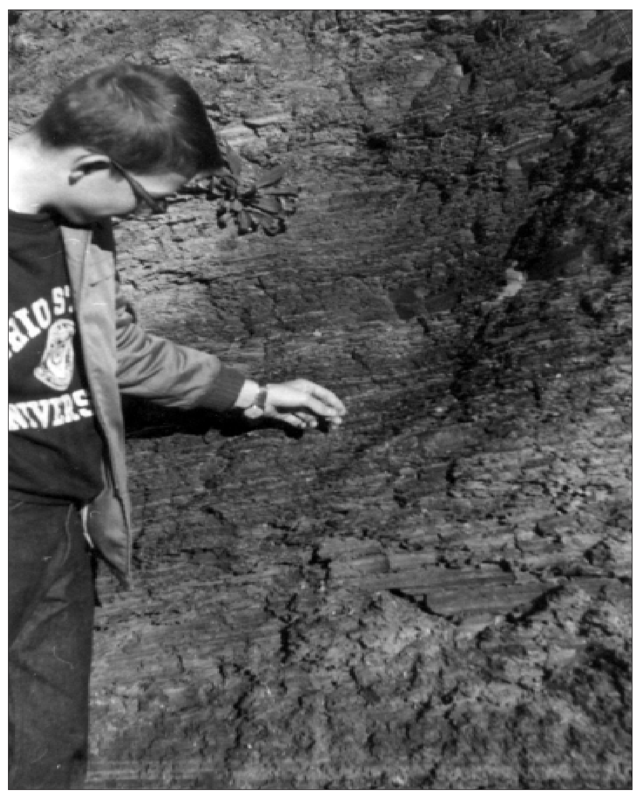

Figure 2.34. Laminated red and gray Bedford Shale beds, Henrietta Township, Ohio (Charles E. Herdendorf).

pelecypod, *Paleoneilo bedfordensis* Meek. Red shale weathers rapidly to sticky red mud that obscures outcrops by slumping, colors surface soil red, and often stains underlying outcrops. The thickness of this formation is highly variable due to pre-Berea erosion channeling. Red shale is not mined for ceramic purposes in Erie County, but similar deposits in Lorain and Cuyahoga Counties are producing clay shale for the brick and tile industry. Potential sources of clay shale are beds exposed along the Vermilion River and Chappel Creek in Florence Township (Figure 2.34).

Late Devonian Period

Within the Old Woman Creek watershed, the Late Devonian Period is represented by the Ohio Shale. This thick layer of rocks consists of two prominent members which underlie the northern portion of the watershed: the Cleveland Shale and the Huron Shale.

Cleveland Shale. This shale formation (Figure 2.35) is black, hard, dense, platy to fissile, abundantly carbonaceous; contains pyritic and septarian concretions and persistent limestone layers, 1 to 7 cm thick, characterized by cone-in-cone structure (Figures 2.36 and 2.37). Shale beds contain grains of quartz, pyrite, illite, and chlorite. Limestone is composed largely of calcite with argillaceous, pyritic, and hematitic material. Septarian concretions have fine matrix of quartz and clay minerals with veins of intergrown quartz, chalcedony, and pyrite crystals. Fresh chips of shale give off a petroliferous odor. Fossils are scarce; a few brachiopods, such as *Retichonetes aurora* (Hall) and *Orbiculoidea* sp., common in carbonaceous layers. Shale has pronounced vertical joint system at near right angles. Shale is resistant to weathering; weathered surfaces are brownish-gray to coffee color. Sulfate efflorescences are common on dry shale exposures. Best exposures of formation are along Vermilion River, Chappel Creek, and Old Woman Creek in Florence, Vermilion, and Berlin Townships.

Strata of the Bedford Shale and the Cleveland Shale formations in the vicinity of Old Woman Creek watershed typically dip to the southeast at approximately 4 to 5 m/km. In most exposures the shale beds appear nearly flat-lying or only gently warped. However, in the vicinity of sandstone channels or slump features, the shale beds are commonly folded,

Figure 2.35. Outcrop of Cleveland Shale along the West Branch of Old Woman Creek north of Berlinville, Ohio (Charles E. Herdendorf).

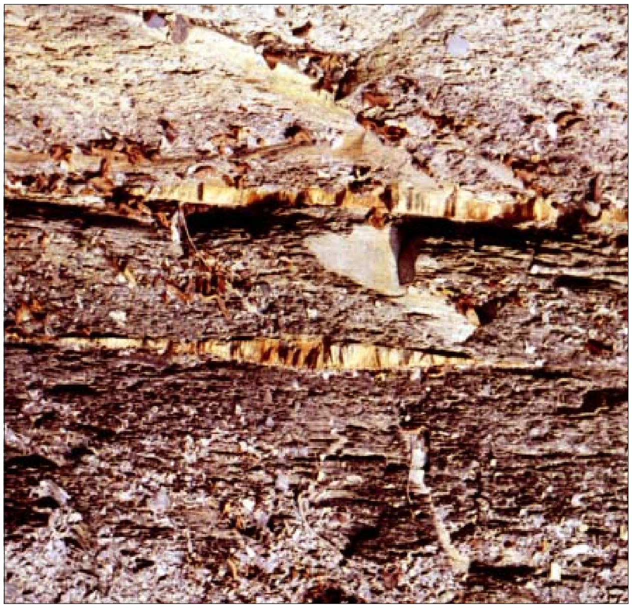

Figure 2.36. Lens of cone-in-cone limestone in the Cleveland Shale (Charles E. Herdendorf).

Figure 2.37. Limestone lens from Cleveland Shale showing detail of cone-in-cone structure (Charles E. Herdendorf).

faulted, and sometimes contorted or interbedded with the basal sands of the Berea Sandstone (Herdendorf and Struble 1975).

Huron Shale. This shale formation is grayish-black, hard, dense, platy to fissile; contains large concretions, 0.3 to 2 m in diameter, and septarian nodules in its lower part. Huron and Cleveland Shales are essentially identical in lithologic character; and in Erie County the contact between these two black shales has been arbitrarily drawn below the lowest cone-in-cone limestone layer and above the uppermost zone containing large concretions (Hoover 1960). Upper part of Huron Shale, and possibly lower part of Cleveland Shale, is interstratified with thin, soft, clayey, less resistant, bluish-gray shale beds which probably represent a minor western interfingering of Chagrin Shale which separates the two black shales in northeastern Ohio. Huron Shale is best exposed along the Huron River in the vicinity of Milan where large concretions can also be observed. Other outcrops include the Lake Erie bottom west of Huron at Boulder Shores (which receives its name from the large concretions in the shale), the bluffs of Sawmill Creek west of Huron (Figure 2.38), and the lake bluffs immediately east of Vermilion.

Subsurface Bedrock Formations
Middle Devonian Period

Prout Limestone. This limestone formation is dark gray to bluish-gray to blue, very hard, siliceous, fossiliferous. Formation is divided into four parts: (1) basal compact, crystalline, bluish-gray limestone, (2) soft shaly blue limestone with numerous silicified bryozoans, corals, and crinoid stems, (3) compact, hard, crystalline, gray limestone, and (4) dark gray to black chert layer with pyrite at top. Brachiopods *Atrypa reticularsis* and *Stropheodonata demissa* are common in the soft blue limestone. Prout limestone is exposed at "Slate Cut" in northwestern Huron Township, along Plum Brook and "Deep Cut" inside the NASA property in Perkins Township, east of Bloomingville, along Pipe Creek in Oxford Township, and at Strong's Ridge in

Figure 2.38. Concretion (80 cm diameter) in the Huron Shale, Sawmill Creek west of Huron, Ohio (Charles E. Herdendorf).

southern Groton Township. Quarrying, on a limited scale, has been done at the latter two locations (about 20 km west of Old Woman Creek watershed). Chert from this formation was used by early native inhabitants for tools and weapon points.

Plum Brook Shale. This shale formation is blue, soft, argillaceous, fossiliferous; contains thin layers of dark, hard, fossiliferous limestone. The lower portion contains layers of hard nodules which are often pyritic. Numerous pyrite crystals occur in the beds exposed at the Norfolk & Western Railroad cut at Bemis Road in southern Groton Township in Erie County. Other exposures are located on Plum Brook in the NASA property and along Pipe Creek east of Bloomingville. Common fossils include trilobite *Phacops rana*, brachiopods *Spirifer pennatus*, *Chonetes deflectur*, and *Stropheodontal*; corals *Favosites* and *Zophrentis*, and bryozoan *Fenestealla*. Formation rapidly weathers to marly, blue clay shale which obscures outcrops. Shale may have potential ceramic value. Prehistoric native Americans may have used a near-lithographic limestone member of this formation as stone from which pipes were carved. This “pipestone” is believed to have been quarried by early inhabitants north of Hunt Creek in Groton Township.

Delaware Limestone. This limestone formation is dark to bluish-gray, thin-bedded to massive, with calcareous shale partings; siliceous, dense, tough, durable and contains some chert. Composition of rock is that of an impure limestone. Limestone is of marine origin and fairly fossiliferous. Delaware Limestone ranks as a good building stone and has also been used for crushed stone and concrete aggregate. This stone is presently being quarried in Perkins and Groton Townships of Erie County. Several outcrops occur from the east side of Sandusky southeast to Bellevue, generally at old quarry sites.

Columbus Limestone. This limestone formation is light gray to buff, moderately thin-bedded to massive crystalline, locally dolomitic and somewhat earthy in appearance. Cherty layers and nodules also occur locally. Columbus Limestone has been taken in past years from two quarries in Margaretta Township as well as from the two quarries mentioned in the Delaware Limestone discussion. Outcrops occur southeast of Sandusky and Castalia as well as eastern Kelleys Island where large grooves clearly show the glaciated surface of the Columbus Limestone.

Early Devonian Period

The subsurface rocks underlying the watershed from the Early Devonian Period are represented by two formations within the Detroit River Group: the Lucas Dolomite and the Amherstburg Dolomite.

Lucas Dolomite. This dolomite (dolostone) formation is gray to brown drab, thin-bedded to massive, carbonaceous parting common between layers, locally calcareous, and very resistant. Fresh surface often yields strong petroliferous odor. Formation has been quarried for crushed stone, fluxstone, and concrete aggregate in the two above operations in Margaretta Township and is now being worked in a quarry on western Kelleys Island. Outcrops are limited because of the mantle of glacial drift.

Amherstburg Dolomite. This dolomite formation is drab to brown, open or even cavernous in texture, massive bedding, resistant. Rock is true dolomite in composition. Exposures are obscured in Erie County owing to the thickness of glacial drift.

Late Silurian Period

Below the Detroit River Group strata another group of dolomites, Bass Island Group, occurs. This deeper group includes the Raisin River Dolomite, Put-in-Bay Dolomite, Tymochtee Dolomite, and the Greenfield Dolomite.

Raisin River Dolomite. This dolomite formation is blue-gray to drab, thin-bedded to shaly, argillaceous. Stone is fairly pure dolomite. Glacial drift and lake sediments mantle the formation in Erie County. Part of northwestern Margaretta Township is probably underlain by Raisin River Dolomite.

Put-in-Bay Dolomite. This dolomite formation is gay-to-drab-to-light-brown, medium bedded, rough textured, crystalline, weathers with irregular knobby surface. Composition of the stone is a dolomite of fair purity. Best exposure in Erie County is Crystal Rock Spring in northwestern Margaretta Township. Glacial drift mantles most of this formation.

Tymochtee Dolomite. This dolomite formation is dark bluish-gray to brown, thin-bedded to shaly, calcareous shale partings, contains gypsum and anhydrite. Dolomite in thin layers is coarse grained, fairly tough, moderately homogeneous, and composition approaches that of a true dolomite. Occurs in western Margaretta Township. Outcrops obscured by glacial drift.

Greenfield Dolomite. This dolomite formation is bluish-gray to light drab to dark brown, thin bedded to massive, generally dense and hard, but some layers are granular or vesicular. Underlies western Margaretta Township, under Sandusky Bay, but is deeply buried by glacial drift and bay sediments.

Evolution of Lake Erie: Glacial and Postglacial Lakes

Lake Erie owes its origin to physiographic changes induced by Late Cenozoic (Pleistocene) glaciers. During the long time interval between the deposition of Paleozoic sediments and the first glacial advance (250 million years), erosive forces cut a mature drainage system into the rocks that underlie present Lake Erie (Figure 2.39). As advancing or retreating ice sheets paused, ridges (or moraines) of glacial till were built up at the ice margins, damming the natural drainage. Large glacial lakes formed between the moraines and the ice front (Figure 2.40). Lake Erie and Old Woman Creek estuary are remnants of a series of glacial lakes that, at its earliest and highest stage, extended as far southwest as present day Fort Wayne, Indiana and drained in that direction via the Mississippi River system. As the ice retreated from this position other outlets were uncovered and new lake stages were formed at successively lower elevations. In a few instances readvances of the ice blocked outlets and temporarily caused higher lake levels. Sandy beach ridges and wave-cut cliffs, 2 to 7 km inland of the estuary, mark the position of these former lakes (Figure 2.41).

When the last glacier retreated from the Niagara River area a new and final outlet was available at present-day Buffalo, New York. Initially this outlet was at a considerably lower elevation than at present because of crustal depression under the weight of the glacial ice. Thus, the last glacial lake quickly drained through this new opening and much of the present bed of Lake Erie was dry for an extended period. Eventually the Niagara outlet began to rebound from its depressed position and modern Lake Erie was formed as the lake waters flooded the shore and tributary mouths, creating freshwater estuaries. The chronology and elevations of the glacial and postglacial lake stages in the Erie basin are illustrated in Figures 2.42 and 2.43. The following section will describe the Lake Erie evolution process in more detail and discuss how it influenced the geologic history and existing landforms in the vicinity of Old Woman Creek.

For more than a century researchers such as Spencer (1891,1894), Leverett (1902), Carney (1911), Leverett and Taylor (1915), Bretz (1953,1964), Hough (1958,1962,1963,1966), Hartley (1958,1961b), Forsyth (1959,1973), Goldthwait et al. (1961,1965), Dreimanis (1964,1969), Lewis et al. (1966), Herdendorf (1968), Lewis (1969), Calkin (1970), Calkin and Feenstra (1985), Dorr and Eschman (1970), Prest (1970), Dreimanis and Karrow (1972), Herdendorf and Braidech (1972), Terasmae and Dreimanis (1976), Karrow and Calkin (1985), Larsen (1987,1994), Herdendorf and Bailey (1989), Pengelly et al (1997), Coakley et al. (1999), Holcombe et al. (1999), and Lewis et al (1999a,b) have contributed materially to understanding the sequence of events which have taken place in the evolution of Lake Erie. The lake chronology begins about 14,500 YBP when the last Pleistocene glacier, known as the Wisconsinan ice sheet, temporarily halted in its retreat. Although the ice front was in a stationary position over northwest Ohio, northeast Indiana, and southeast Michigan (rate of ablation and rate of advance in equilibrium), forward transport of drift continued under the ice, creating the Fort Wayne end moraine at the ice margin (Figure 2.44). The position of this moraine lies approximately along the drainage divide between the St. Lawrence River and Mississippi River systems, about 30 km southwest of the Old Woman Creek drainage basin. As the ice eventually retreated from the Fort Wayne moraine, water was ponded between the ice front and the moraine, thus starting a 2,000-year sequence of glacial lakes in the Erie basin.

Glacial Lake Maumee (14,400–13,800 YBP)

Lake Maumee was the first of the large glacial lakes to form in the Erie basin as the ice retreated. Lake Maumee had three, or possibly four, stages (water levels) in response to minor ice advances and retreats which altered the lake's outlet (Calkin and Feenstra 1985). The highest stage (Lake Maumee I) had a surface elevation of 244 m (800 ft) above sea level

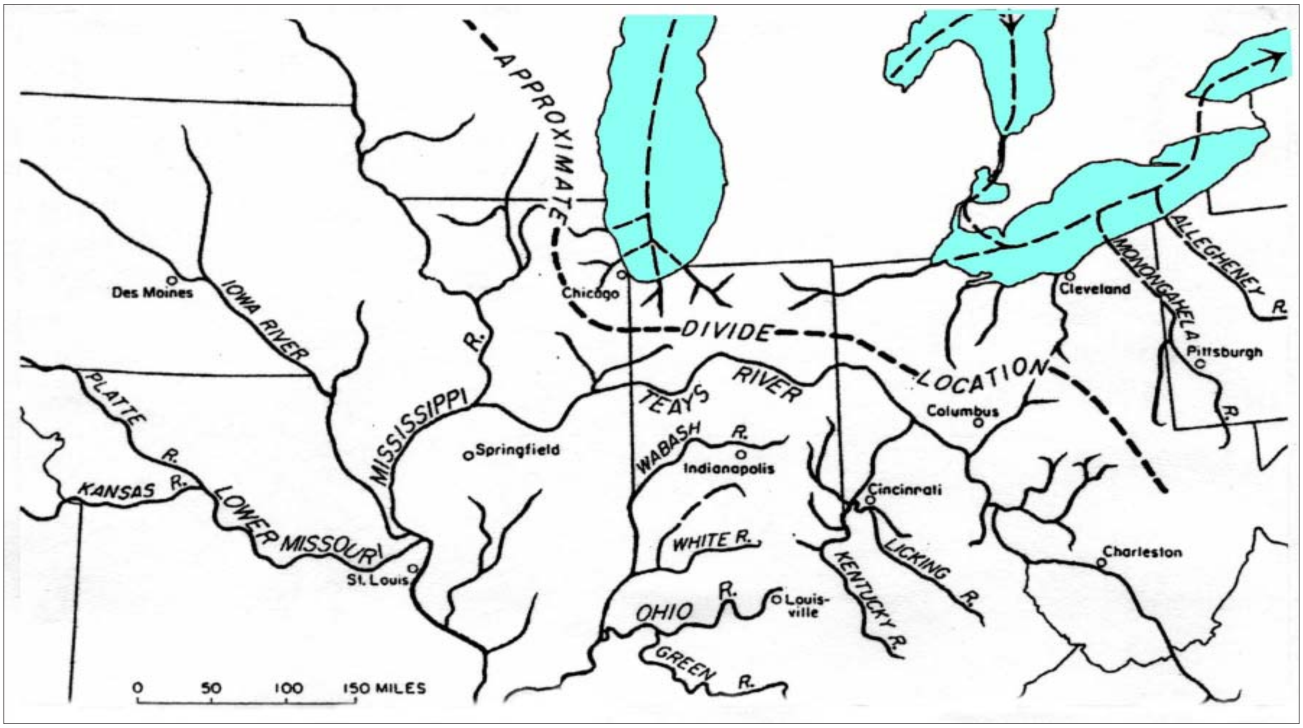

Figure 2.39. Preglacial drainage patterns in southern Great Lakes Basin (from Thornbury 1965).

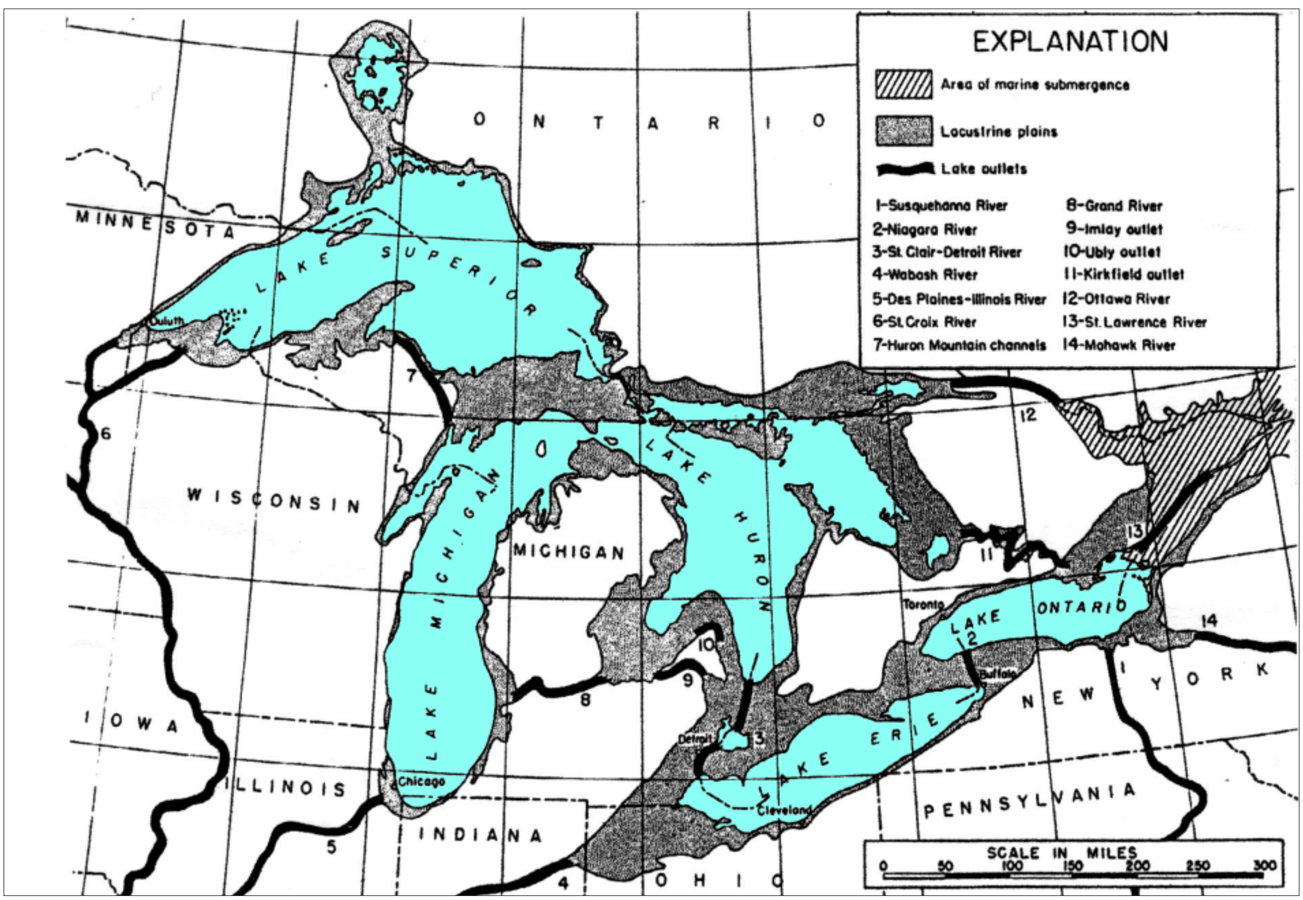

Figure 2.40. Extent of glacial lakes in the Great Lakes basin, showing outlets (from Leverett and Taylor 1915).

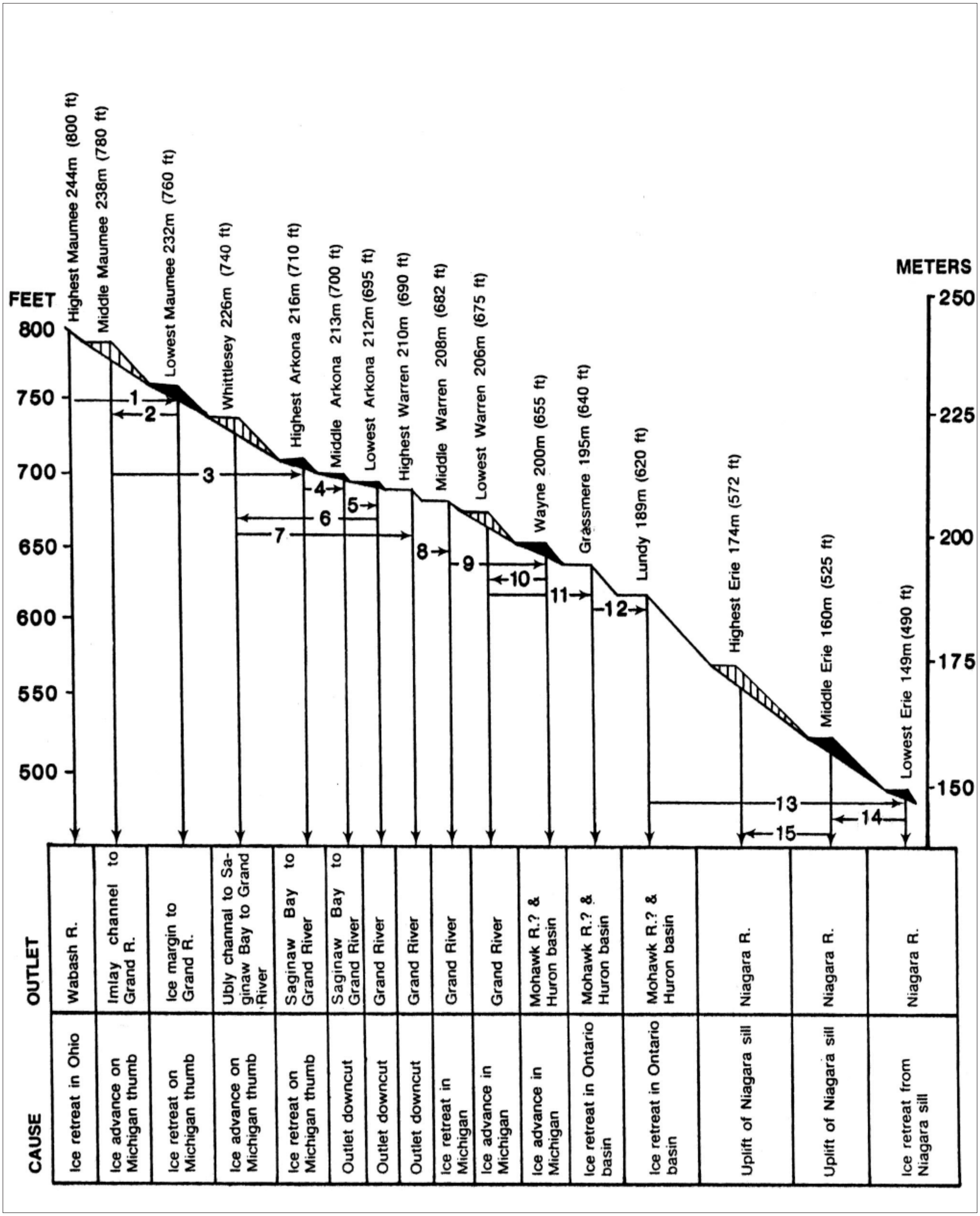

Figure 2.41. Number sequence of glacial beach ridges in the vicinity of Old Woman Creek. Note: beaches shown in black were submerged, after formation and partially destroyed; beaches with vertical lines were not submerged after formation and are more prominent features of the present landscape (from Hartley 1958).

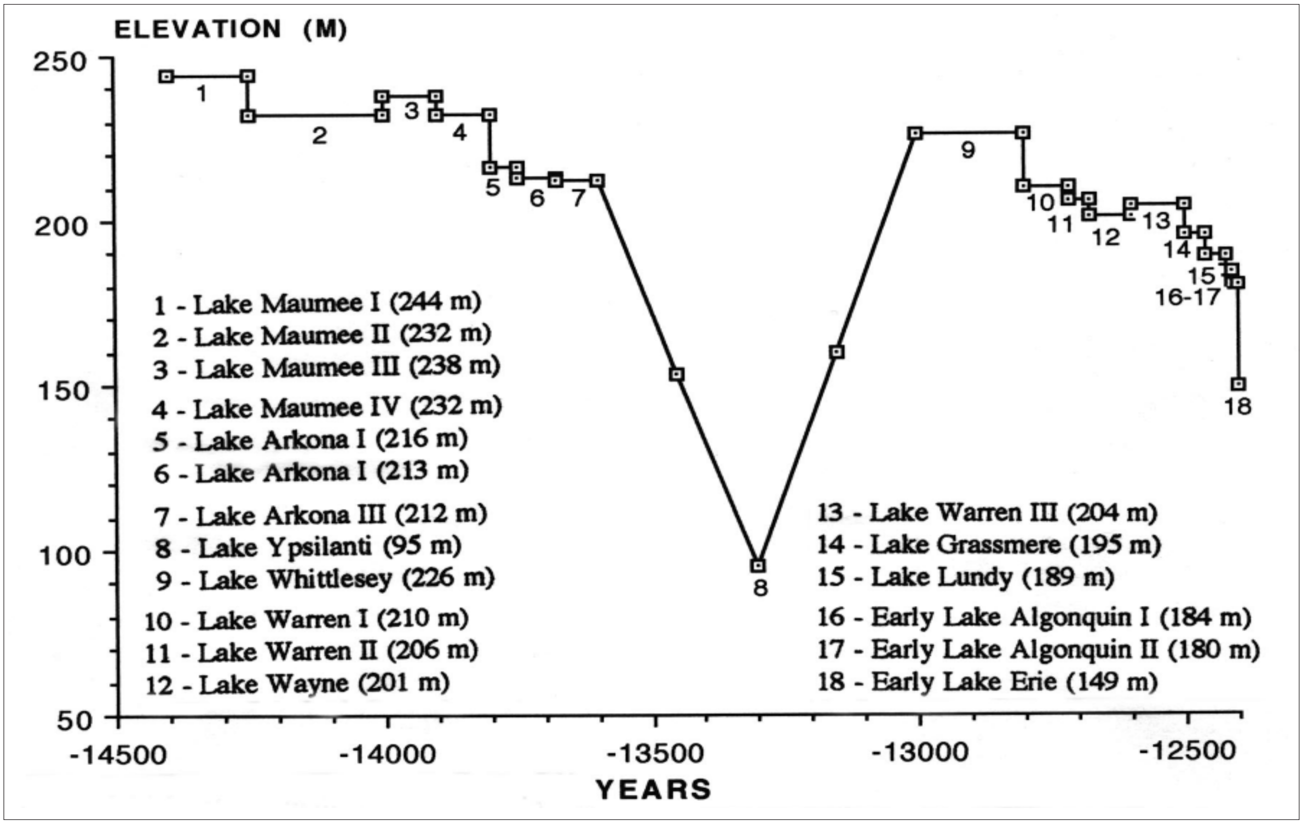

Figure 2.42. Glacial lake stages in the Erie basin, elevations in meters above sea level (modified from Calkin and Feenstra 1985).

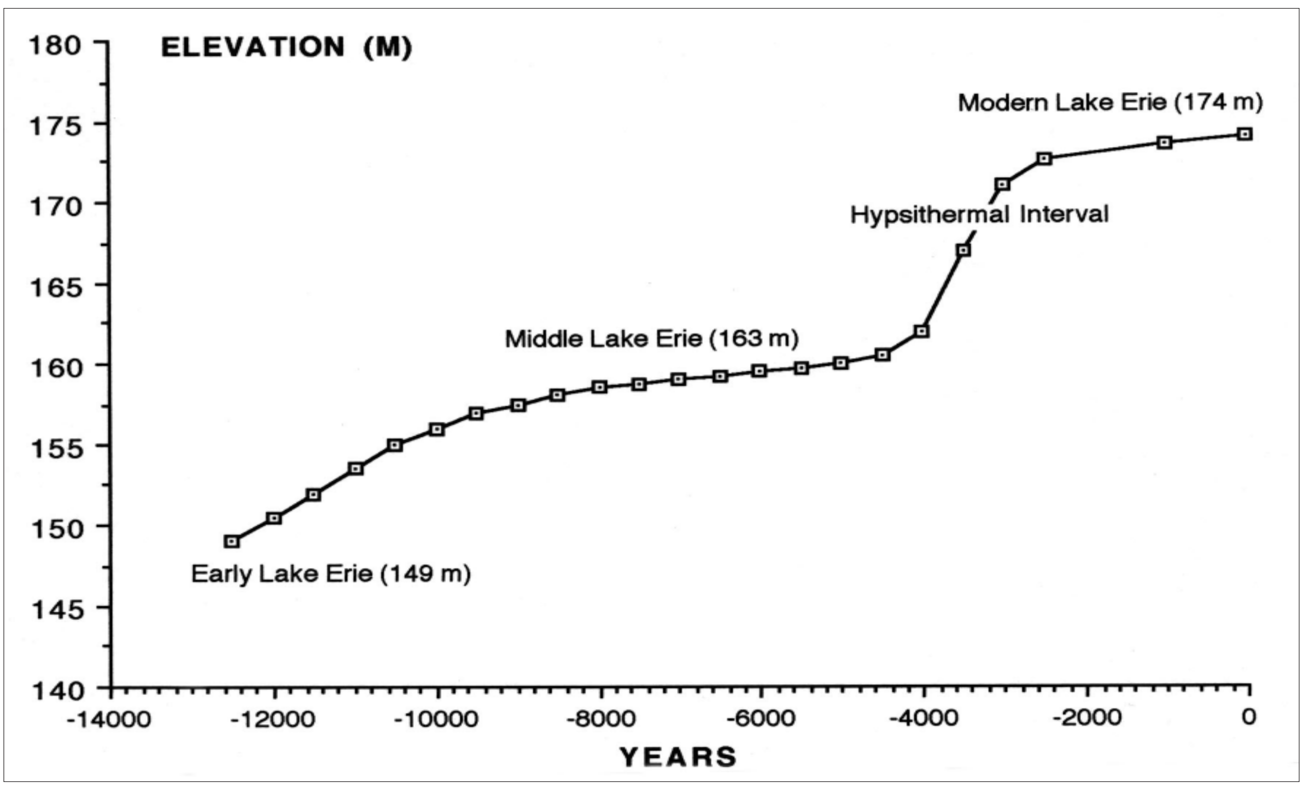

Figure 2.43. Postglacial lake stages in the Erie basin (modified from Herdendorf and Bailey 1989).

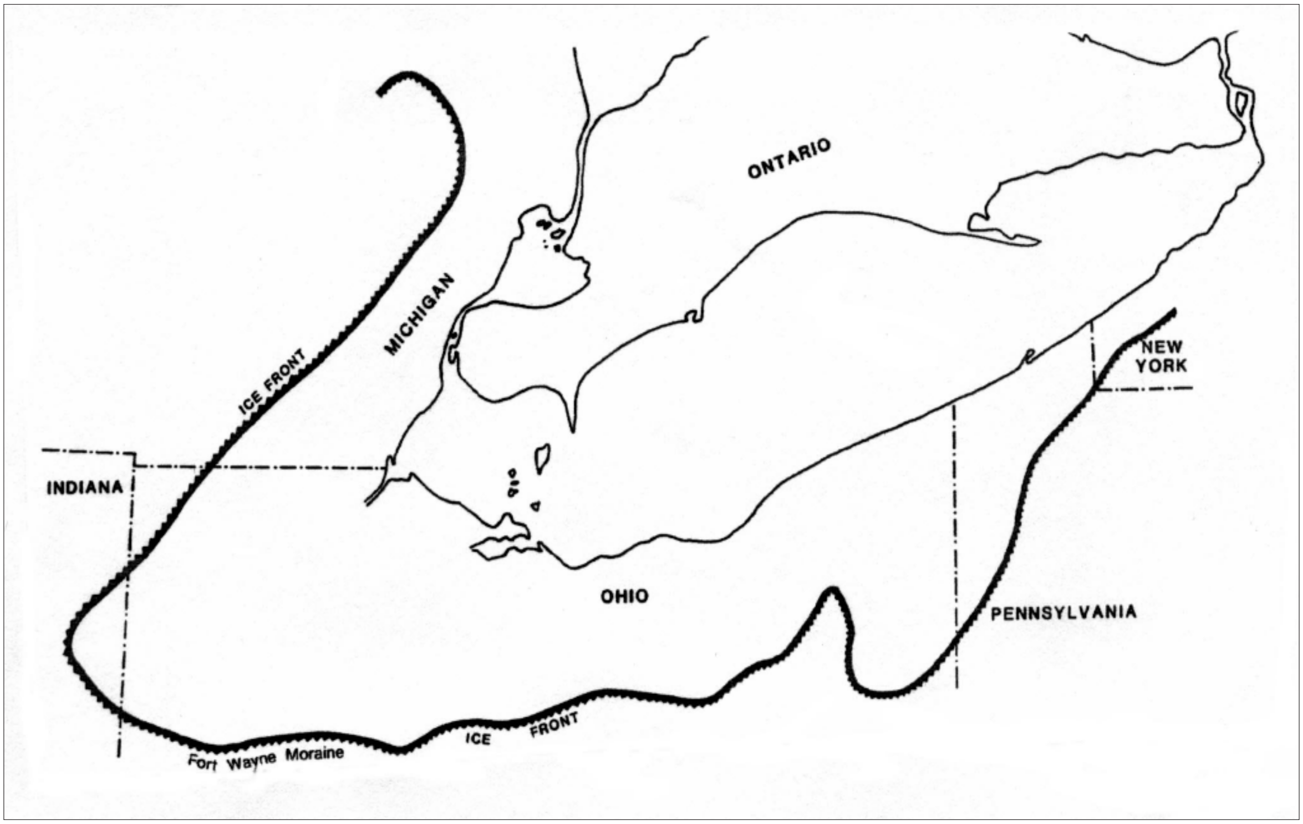

Figure 2.44. Wisconsinan glacial ice front immediately prior to the beginning of glacial lake stages in the Lake Erie basin (from Herdendorf 1989).

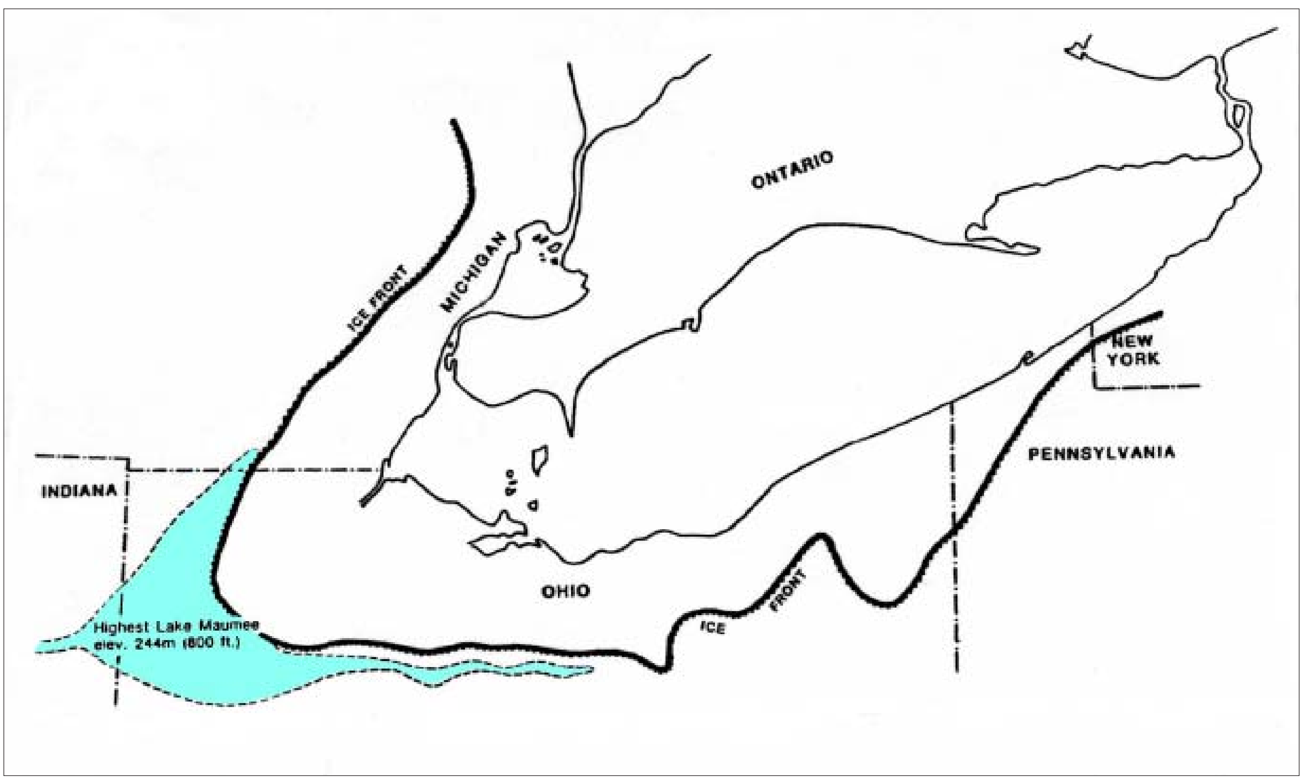

Figure 2.45. Glacial Lake Maumee I, highest Maumee stage (from Herdendorf 1989).

and occurred while the ice front was again stationary in northwestern Ohio, creating the Defiance moraine, some 20 to 30 km farther north of the Fort Wayne moraine (Figure 2.45). The outlet for this stage was to the southwest at Fort Wayne, Indiana via the Wabash-Ohio-Mississippi rivers to the Gulf of Mexico. The maximum water depth of Lake Maumee I was about 30 m. With a surface area of 5,000 km^2, this was the smallest glacial lake stage in the Erie basin. Because the ice front was still at least 10 km south of Norwalk, Ohio this stage is not represented by beach ridges or lake cliffs in the Old Woman Creek watershed. However, Campbell (1955) suggested that as the ice front retreated from the Defiance moraine, Lake Maumee I was enlarged and elongated to the east before the initiation of the next lake stage. Isolated sand ridges and a sizable dune field about 2 to 3 km southeast of Berlin Heights, at elevations ranging from 244 m to 247 m (800 to 810 ft), may be evidence of this stage within the Old Woman Creek watershed.

The second and lowest stage (Lake Maumee II) had a surface elevation of 232 m (760 ft) (Figure 2.46). This stage resulted from renewed ice retreat in Michigan which opened an outlet to the west at Imlay via the Grand River to Lake Chicago in the Lake Michigan basin (Figure 2.40). Bottom deposits in the Erie basin (e.g. sand and gravel on a glacial till ridge) indicate that during this stage the ice front stood between Point Pelee, Ontario and Avon Point, Ohio (Pelee moraine), and then hooked to the east northeast as marked by the Euclid-Lake Escarpment moraine in northeastern Ohio (Goldthwait et al. 1961). Another lobe of ice apparently stood in the Lake Erie islands area at the same time, the front extending from Point Pelee southwest to Catawba Point, Ohio and then northwesterly toward the present mouth of the Detroit River (Hartley 1958,1961b). The lowest elevation of the till surface under Lake Maumee II was found by seismic surveys to be about 143 m (470 ft) in a depression 15 km north of the present Old Woman Creek mouth (Hobson et al. 1969), yielding a maximum water depth of 89 m (290 ft) for this glacial lake stage. This stage of Lake Maumee had a surface area of approximately 19,000 km^2.

In the vicinity of Old Woman Creek, Lake Maumee II is represented by an intermittent, sandy beach ridge that traverses the watershed in a northeasterly direction from 1 km west of Berlinville to 2 km northeast of Berlin Heights. North of the latter village, and Mason Road, the ridge is about 15 m below the crest (lakeward side) of the Berea Escarpment and is more or less continuous at an elevation of 232 m (760 ft) into the valley of Chappel Creek.

The third and mid-elevation stage (Lake Maumee III) had a surface elevation of 238 m (780 ft) (Figure 2.47). The rise in lake level is attributed to a minor readvance of the ice front in Michigan which allowed the lake to drain through both the Imlay channel to the Grand River in Michigan and the Fort Wayne channel to the Wabash River in Indiana (Figure 2.40). The ice front in the Erie basin had retreated to a temporary pause north of Cleveland (Erieau moraine) and then halted north of the Ohio-Pennsylvania line, creating a large end moraine. This feature, known as the Norfolk moraine, is marked by a very wide sand and gravel ridge which extends from near Erie, Pennsylvania to the base of Long Point, Ontario (Sly and Lewis 1972). Because of the massive size of the moraine, the ice front apparently occupied this general position during several of the ensuing glacial lake stages. The lowest elevation of the undissected till surface under Lake Maumee III was found by seismic surveys to be about 98 m (320 ft) in a broad depression about 100 km northeast of the present Old Woman Creek mouth (Wall 1968), yielding a maximum water depth of 140 m (460 ft) for this lake stage. Lake Maumee III had a surface area of approximately 42,000 km^2 and was the largest of the Maumee glacial lake stages.

In the vicinity of Old Woman Creek, the Lake Maumee III stage is represented by a prominent sand ridge upon which Ohio Route 61 was built southeast of Berlinville, Berlin Road between Berlinville and Berlin Heights, and Mason Road northeast Berlin Heights. At an elevation of 238 m (780 ft), the Lake Maumee III ridge lies slightly to the south of, parallel to, and at some places merges with the less pronounced Lake Maumee II beach deposits. Where Humm Road intersects Mason Road (near the eastern edge of the Old Woman Creek drainage basin) a massive outcrop of Berea Sandstone forms an escarpment that reaches an elevation of 259 m (850 ft) which precluded the development of beach ridges. However, at elevations of approximately 237–240 m, the exposed rocks show evidence of wave cutting and undermining. Dissection of the sandstone hills along the northern edge of the escarpment strongly influenced the Lake Maumee shoreline, resulting in embayments with numerous rocky islands, sand spits, and dunes (Figure 2.18).

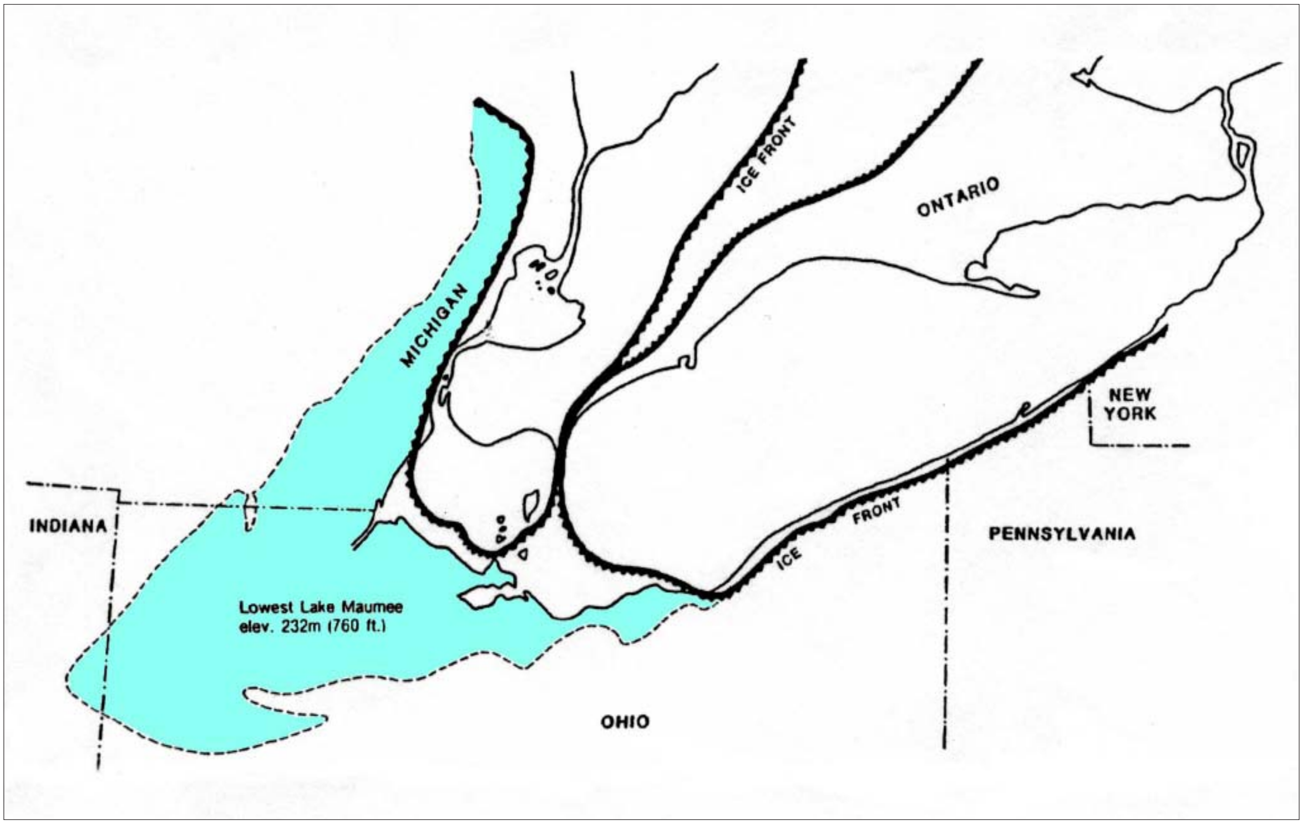

Figure 2.46. Glacial Lake Maumee II and Lake Maumee IV, lowest Maumee stages (from Herdendorf 1989).

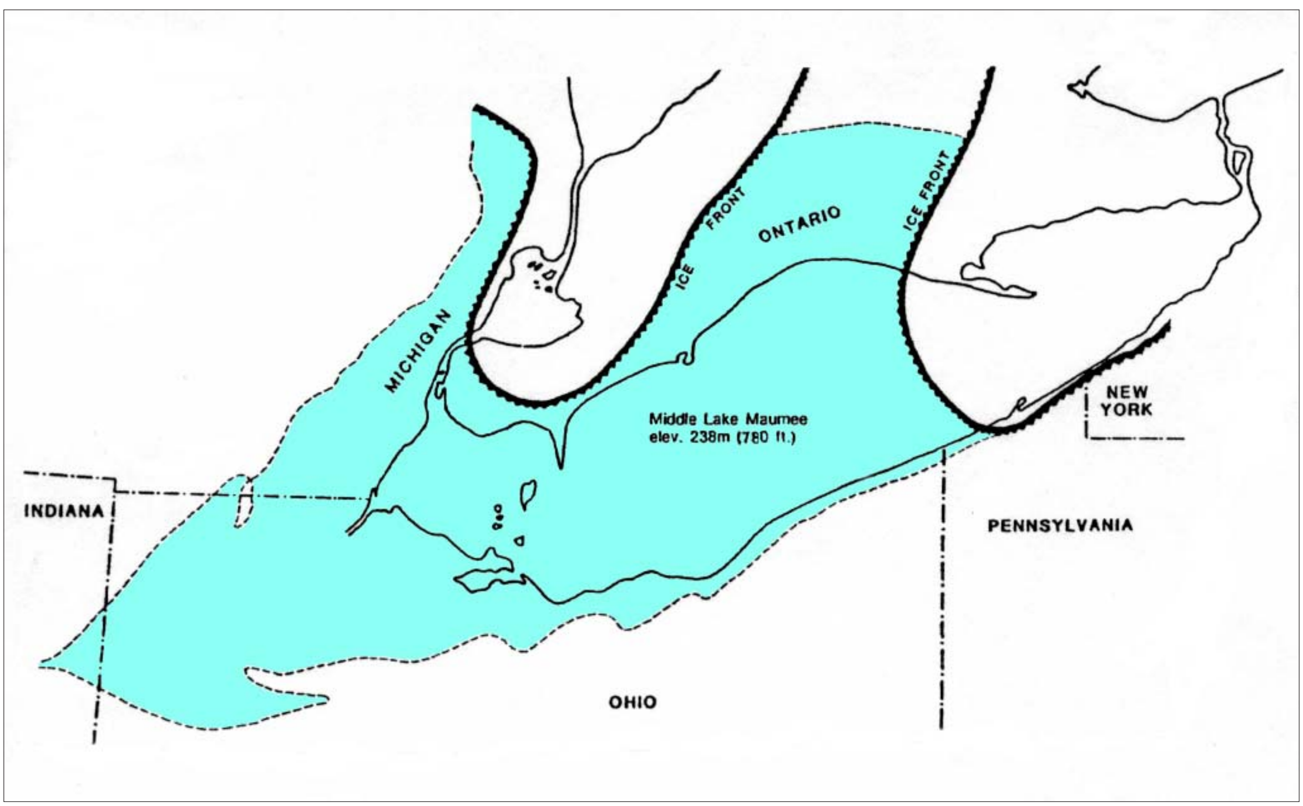

Figure 2.47. Glacial Lake Maumee III, middle Maumee stage (from Herdendorf 1989).

Wave erosion of these sandstone outcrops and the moraines furnished much of the sand for building the adjacent beach and dunes (Herdendorf 1963b).

In the Chappel Creek drainage basin (watershed to the east of Old Woman Creek) an abandoned stream valley, known as Florence Valley, was formed as a result of the capture of a tributary of the Vermilion River during the time of Lake Maumee III (Hole and Redmond 1970). The capture of the former west fork of the Vermilion River increased the length of the ancestral Chappel Creek by nearly 3-fold.

A fourth stage (Lake Maumee IV) has been postulated by Fullerton (1980) at the same elevation as Lake Maumee II, elevation 232 m (760 ft). Lowering the lake to this elevation can be explained by downcutting of the outlet channels which thereby dropped the level of the lake. This reoccupation hypothesis appears to have some merit based on the notable beach ridges found in the vicinity of Berlin Heights at the Maumee II/IV elevation. Normally when a lake raises in elevation, beaches formed at a lower level are destroyed, as would have been expected in the case of Lake Maumee III raising 6 m (20 ft) over the previous Maumee II level. However, if following Lake Maumee III, the old Maumee II level was reoccupied then a beach would be rebuilt at the old level and would not be later destroyed by overtopping. The gradual erosion of the outlet channels would also help to explain the merging of the Maumee II and Maumee III beach ridges described above.

GLACIAL LAKE ARKONA (13,800–13,600 YBP)

Lake Arkona was created when renewed ice retreat in Michigan allowed water to flow into Saginaw Bay forming a continuous lake in both the Erie and Huron basins. Lake Arkona drained to the west via the Grand River (Figure 2.40). Downcutting of the outlet (Hough 1958) or isostatic events and climate-related changes in the water budget (Larsen 1985a,b) resulted in three lake stages at surface elevations of 216 m (710 ft), 213 m (700 ft), and 212 m (695 ft), known as respectively as Lake Arkona I, II, and III. During this time the ice front also retreated to the northeast as evidenced by three beaches in northwestern Pennsylvania (Calkin and Feenstra 1985). Because Lake Arkona also extended into the Huron basin (Saginaw Bay area), it had a surface area of 74,000 km^2 and was one of the largest glacial lakes to form in the Erie basin. The maximum depth of this stage was about 118 m (387 ft).

In the vicinity of Old Woman Creek, Lake Arkona beach deposits have been mapped at the 216-m (710-ft) elevation in Vermilion Township, east and west of Joppa Road (Herdendorf 1966). No other Lake Arkona beaches have been reported in Erie County, but wave-cut features, at the elevations of the lower Lake Arkona stages, occur in the shale bedrock along the lower part of the Berea Escarpment between the valleys of Old Woman Creek and Chappel Creek (Carney 1911). The poor representation of Lake Arkona (e.g. beach ridges) can be explained by subsequent lowering (to Lake Ypsilanti level) and then raising of the water in the Erie basin to an even higher elevation (to Lake Whittlesey level) which caused most of the beach ridges to be destroyed by wave action.

LAKE YPSILANTI (13,600–13,000 YBP)

General ice retreat throughout the Great Lakes region brought an end to Lake Arkona. The ice may have retreated far enough to the east at this time to uncover very low outlets in that direction which resulted in the first nonglacial lake in the Erie basin, known as Lake Ypsilanti (Kunkle 1963). Some researchers place this low-water stage between Lake Arkona I and II (Dorr and Eschman 1970). The buried St. David Gorge (northwest of the Niagara River whirlpool) may have been cut into the Niagara Escarpment at this time as an outlet for the low lake stage (Forsyth 1959) and subsequently filled with drift when the glacier readvanced to create Lake Whittlesey. Sub-bottom seismic reflection surveys by Wall (1968) showed a channel cut to an elevation of 79 m (260 ft) in the glacial till about 120 km east northeast of Old Woman Creek. This implies that the weight of glacial ice depressed the Niagara Escarpment 95 m (310 ft) below its present elevation. This magnitude of depression is also indicated by isostatic adjustments as measured by warping in Lake Maumee strandlines in Michigan, but it is about twice the amount that can be explained by Lake Arkona warping (Leverett and Taylor 1915), leaving a question as to the level of the low water stage. In any case, the Lake Ypsilanti channel is believed to be cut into Port Stanley till (deposited by retreating ice during Lake Maumee) and filled with lake clays deposited in Lake Whittlesey and later glacial lake stages (Calkin and Feenstra 1985). The channel cut into the till is less than 8 km wide at its maximum extent. Therefore, Lake Ypsilanti was probably a long, narrow lake about 30 m (100 ft) deep in the central part of the Erie basin, but may have flared out to a broader lake in the eastern end of the basin as indicated by the deeper till surface. Lake Ypsilanti's surface area was probably less than 5,000 km^2. The Port Huron glacial readvance closed the Niagara outlet and brought this low stage in the Erie basin to an end.

GLACIAL LAKE WHITTLESEY (13,000–12,800 YBP)

The Port Huron ice front reoccupied the Norfolk moraine area, blocking outlets to the east and transferring drainage to the west via Ubly channel in Michigan to Lake Saginaw and the Grand River (Figure 2.40). The elevation of this outlet at 226 m (740 ft) created glacial Lake Whittlesey (Figure 2.48). The most pronounced beach ridges, both in height and quantitiy of sand, in the Erie basin mark the former shoreline of Lake Whittlesey (Forsyth 1959). Beach ridges in northeastern Ohio reach a phenomenal height of 21 m (70 ft). This is remarkable considering that Lake Whittlesey only existed for approximately 200 years. Wave erosion of the Berea Sandstone along the Lake Whittlesey shoreline in northcentral Ohio appears to have contributed large quantities of beach-building material. Near the end of the Lake Whittlesey stage, the ice retreated somewhat in the eastern part of the Erie basin, resulting in only weakly developed beach ridges near Dunkirk, New York. Based on the elevation of the channel cut into the till off northeastern Ohio (Wall 1968), the maximum depth of Lake Whittlesey was about 147 m (482 ft), the deepest glacial lake in the Erie basin. With a surface area of 59,000 km^2, this was also the largest glacial lake confined primarily to the Erie basin.

In the vicinity of Old Woman Creek watershed, the Lake Whittlesey shoreline is generally parallel the Lake Maumee shoreline, but it is much more regular (Figure 2.18). Because of the steepness of the Berea Escarpment, the Maumee and Whittlesey shorelines are typically no more than 0.5 km apart. From the watershed boundary near Berlinville, northeast to Mason Road near Berlin Heights, the Whittlesey shoreline consists of a continuous sand and gravel ridge. As the escarpment becomes more prominent to the northeast, the shoreline is expressed as a wave-cut cliff in the Berea Sandstone. This feature continues to the eastern boundary of the watershed where sandy ridges resume and extend to the valley of Chappel Creek (Herdendorf 1966).

GLACIAL LAKES WARREN AND WAYNE (12,800–12,500 YBP)

Further ice retreat in the "Thumb" area of Michigan ended the Lake Whittlesey stage and initiated the Lake Warren sequence (Figure 2.49). Because ice still ocuppied the Niagara Escarpment, Lake Warren drained along the ice margin into Saginaw Bay and then westward via the Grand River. Lake Warren appears to have consisted of three stages: a high stage (Lake Warren I) at an elevation of 210 m (690 ft), a mid-elevation stage (Lake Warren II) at 206 m (675 ft), and a low stage (Lake Warren III) at 204 m (670 ft). Downcutting of the outlet appears to have caused the decreasing stage elevations. Between Lake Warren II and III, a short-lived low water stage existed with a radically different outlet. Known as Lake Wayne, this stage had an elevation of 201 m (660 ft) and may have drained eastward through the Mohawk River valley in New York (Hough 1958). Later, Hough (1963,1966) was less certain of an eastern outlet. However, only a minor retreat of the ice margin that held in Lake Warren would be needed at the Niagara Escarpment to allow drainage eastward via the Mohawk outlet. Fullerton (1980) suggested that the Lake Wayne stage may have been followed by a brief episode of an even lower lake level, when waters in the Erie basin fell to a level below the Niagara Escarpment. Eschman and Karrow (1985) pointed out that the subsequent rise in lake level to that of the lowest Warren stage (Lake Warren III), is best explained by advance of the ice margin which closed off the eastern outlet. Larsen (1985b) postulated that the rise in water level may have resulted from climatic changes so that Lake Warren III may have drained both east and west, simultaniously. Totten (1985) plotted radiocarbon dates for deposits from Lake Maumee to Early Lake Erie and noted a uniform and gradual rate of lake level decline through the Lake Warren stages, then another uniform but more rapid rate of decline from Lake Wayne to Early Lake Erie. He interpreted the break in slope as indicative of outlets being opened to the east. The Warren highest stage (Lake Warren I) was a large lake with a surface area of 62,000 km^2, including the Saginaw embayment (Eschman and Karrow 1985). The maximum depth in this stage was about 107 m (350 ft).

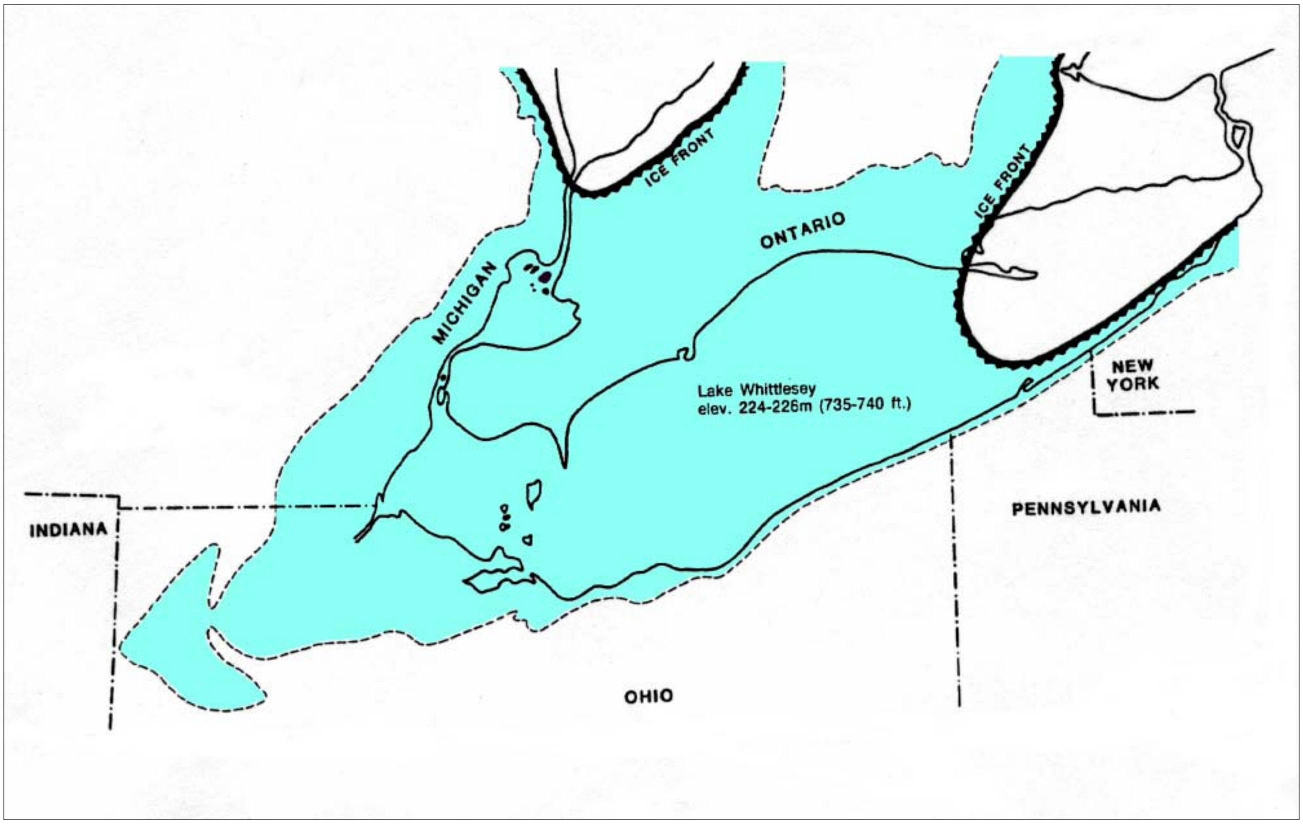

Figure 2.48. Glacial Lake Whittlesey (from Herdendorf 1989).

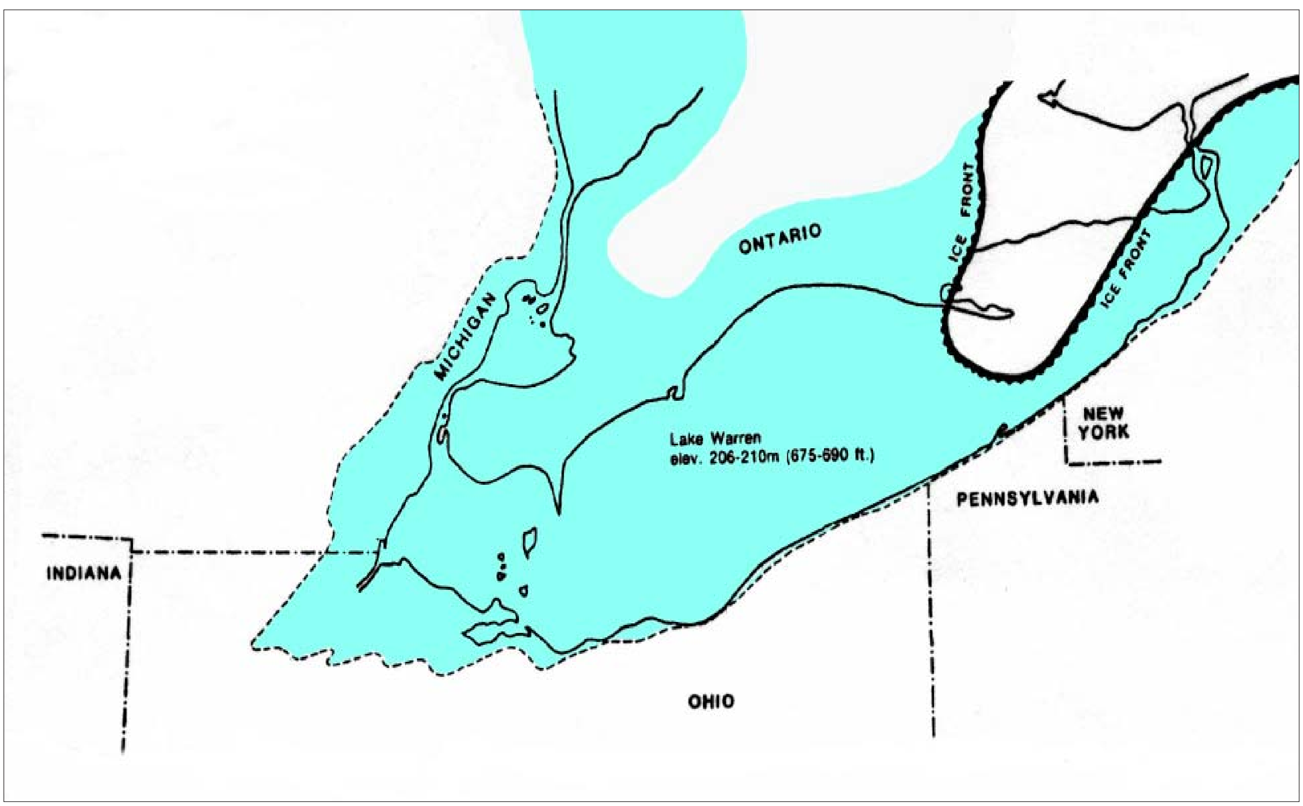

Figure 2.49. Glacial Lake Warren (from Herdendorf 1989).

In the vicinity of Old Woman Creek, the highest Lake Warren stage (I) is well represented by wave-cut cliffs starting at the west branch of the creek north of Berlinville and extending northeast to the valley of Chappel Creek. The cliffs are cut into the Ohio Shale at the base of the Berea Escarpment at an elevation of 210 m (690 ft). The only beach ridges mapped in the watershed at this elevation are north of Berlinville, immediately south of the cliffs, where they are backed by sand dunes. West of the west branch of the creek, the lower Lake Warren stages (II and III) are marked by beach ridges and abundant sand dunes at elevations ranging from 204 to 207 m (670 to 680 ft). Some of the more southerly of these dunes are at a higher elevation and may have been formed during the highest Lake Warren stage. To the northeast, the only mapped features of the lower Lake Warren stages are low beach ridges at the 204-m (670-ft) elevation between Frailey Road and Joppa Road in Vermilion Township. The only Lake Wayne features in eastern Erie County are also located in the same area – low, arcuate beach ridges at an elevation of 201 m (660 ft).

GLACIAL LAKES GRASSMERE AND LUNDY (12,500–12,400 YBP)

Renewed retreat of the ice margin from its position during the lowest stage of Lake Warren caused the water level to drop to an elevation of 195 m (640 ft), creating Lake Grassmere. This drop in lake level resulted in the final abandonment of the Grand River valley in Michigan as an outlet for lakes in the Huron and Erie basins (Eschman and Karrow 1985). Further retreat of the ice in the Huron basin dropped the lake elevation to 189 m (620 ft) and initiated a stage known as Lake Lundy. These stages were short-lived and are marked by weak and discontinuous shore features in the Huron and Erie basins. Neither the direction of drainage nor the outlet channels of Lake Grassmere and Lake Lundy have been determined with certainty (Calkin and Feenstra 1985). Some investigators believe that drainage continued to the west during these stages; while others contend an eastward outlet. In addition to the filling the Erie basin, Lake Grassmere and Lake Lundy also occupied much of the southern half of the Huron basin. Both lakes had surface areas of approximately 75,000 km^2 (Prest 1970).

In the Old Woman Creek watershed, evidence of the Lake Grassmere and Lake Lundy shorelines have only been found in the vicinity of Shinrock. To the south of this community, at an elevation of 195 m (640 ft), low beach ridges have been mapped between the two main branches of Old Woman Creek. North of this community, at an elevation of 187 to 189 m (615 to 620 ft), three low sandy ridges have been identified that run east-west between the Huron River valley and Old Woman Creek. The drop in water level from glacial Lake Lundy to nonglacial Early Lake Erie may have been marked by brief pauses that in turn are represented by weak and intermittant shore features. Calkin and Feenstra (1985) postulated that two Early Lake Algonquin stages (Huron basin), at elevations of 184 m (605 ft) and 180 m (590 ft), extended into the Erie basin. Low, sandy ridges at the lower elevation have been observed by the authors on the west side of the Old Woman Creek estuary, within 1 km of the present Lake Erie shoreline. These features may represent an Algonquin stage; or, alternatively, higher, modern Lake Erie levels (3,000 to 1,000 YBP) as postulated by Barnett (1985) and Coakley and Lewis (1985).

EARLY LAKE ERIE (12,400–8,000 YBP)

The glacial lake stages in the Erie basin ended when the ice margin reteated sufficiently into the Ontario basin to allow water in that basin to fall below the Niagara Escarpment. This removed the direct glacial influence in the Erie basin and initiated the present lake. Forsyth (1973) described a catastrophic flood of water over the escarpment that incised a channel in the moraines and bedrock, resulting in a low water stage in the Erie basin. The Niagara threshold, still depressed by glacial loading, was 25 to 30 m below the present Lake Erie level (Hartley 1958, Coakley and Lewis 1985). Hartley (1958) presented a compelling argument for a low stage at 25 m below the current level based on field evidence, while Coakley and Lewis (1985) used radiocarbon dates and contours on the glacial till surface to show a minimum level at least 30 m below the present lake level. Known as Early Lake Erie, this low stage had an elevation of 149 m (490 ft) or lower and a surface area of approximately 11,200 km^2 (Figure 2.50). The evolution of Lake Erie from this low water stage to its present level involves glacio-isostatic rebound, changes in discharge waters to the lake, and climatic fluctuations (see Climatology Chapter for discussion of air temperature trends during glacial and postglacial periods).

Initially, Early Lake Erie received discharge from Early Lake Algonquin (Huron basin) via the newly formed St. Clair River-Lake St. Clair-Detroit River system (Calkin and Feenstra 1985). Early Lake Erie may have consisted of: (1) a marshy western basin through which an extention of this river system flowed via Pelee Passage (Hobson et al. 1969, Herdendorf and Braidech 1972), (2) a shallow central basin lake that flowed to the east via a channel cut through the Norfolk moraine, and (3) a deeper eastern basin lake which drained to the east over the Niagara Escarpment. Differential glacio-isostatic uplift of the Niagara River outlet was rapid from about 12,400 to 11,400 YBP, over 2.0 m/century, followed by a slowing of the uplift rate to less than 1.0 m/century from 9,000 to 8,000 YBP (Figure 2.43) (Lewis 1969, Coakley and Lewis 1985). Early in this period, about 12,000 YBP, flow into the western basin was interrupted when the Kirkfield outlet (Figure 2.40) for Lake Algonquin (Huron basin) was opened to Lake Iroquois (Ontario basin) by deglaciation, lowering the level in the Huron basin and stopping drainage to Early Lake Erie (Kaszycki 1985). For the next 7,000 years drainage from the upper lakes bypassed Lake Erie. Isostatic uplift continued to raise the level water in the Erie basin, but cessation of over 90% of the lake's former inflow must have created stagnant and perhaps eutrophic conditions. In fact, Lewis et al. (1999b) concluded that the lake was a closed basin.

Following Lake Algonquin, the upper Great Lakes went through a series of successively lower stages until the North Bay-Ottawa River outlet was opened to the St. Lawrence embayment of the Atlantic Ocean (Figure 2.40). The lowest stages were Lake Chippewa (Michigan basin) and Lake Stanley (Huron basin). For at least 5,000 years the level in the Michigan and Huron basins was controlled by uplift of the Ottawa River outlet (Prest 1970). This period of gradually rising levels lasted until the Lake Nipissing stage (Huron basin) when water was again transferred to the Erie basin via the St. Clair - Detroit River system.

At the beginning of the low water stage the shoreline of Early Lake Erie was at least 65 km east northeast of the present Old Woman Creek estuary. During this stage, Old Woman Creek excavated a 15-m deep channel through lacustrine sediments (deposited during the higher lake stages) and in glacial till (deposited in the 44-m deep preglacial Huron River valley) (Herdendorf and Hume 1991). The depth of the channel is considerably greater than would be expected under the current stream environment and is likely the result of the lower base level of the stream during the low stage which accelerated its erosion capabilities (Buchanan 1982).

MIDDLE LAKE ERIE (8,000–4,000 YBP)

After 10,000 YBP the rising water in the Erie basin slowed and at 8,000 YBP it leveled off at an elevation between 157 to 163 m (515 to 535 ft), remaining there for about 4,000 years (Figure 2.43). Hartley (1958) called this intermediate stage Middle Lake Erie. Forsyth (1973) explains this stable-level period as a possible reponse to decreased precipitation and increased evaporation during the Xerothermic or Hypsithermal Interval (Sears 1942, Phillips 1989) which counter-balanced the isostatic uplift. Near the close of this stage, between 5,000 to 4,000 YBP, drainage from the upper lakes returned to Lake Erie as a result of continued glacial uplift around North Bay, Ontario. This ended upper lakes drainage to the Ontario basin and created the Lake Nipissing stages in the Huron basin (Lewis 1969, Calkin and Feenstra 1985). This event (a major new inflx of water from the upper lakes), plus more humid climatic conditions, may have sharply increased water levels in Lake Erie and given impetus to the formation of a large delta (Figure 2.51) in western Lake Erie at the mouth of the ancestral Detroit River (Herdendorf and Bailey 1989). Deposition of a massive delta in Lake St. Clair is also believed to have taken place at this time (5,000 to 3,500 YBP). Radiocarbon dates for lacustrine clays (7,300 YBP) underlying the pre-modern St. Clair River delta show that formation of the delta began during Lake Nipissing time (Raphael and Jaworski 1982, Kaszycki 1985) and not during Lake Algonquin time (12,400 to 10,600 YBP) as ascribed by earlier investigators (Flint 1957). Coakley et al. (1999) also found evidence of a "Nipissing flood" in borehole data from Point Pelee.

A radiocarbon date of 7,690+210 YBP was obtained from sediment deposited about 6 m (20 ft) below the present level of Old Woman Creek estuary (Buchanan 1982). Based on radiocarbon dates from the western basin of Lake Erie (Lewis 1969, Herdendorf and Braidech 1972, Sly and Lewis 1972), Middle Lake Erie was at an elevation of about 159 m (522 ft) at this time or 15 m (49 ft) below the present

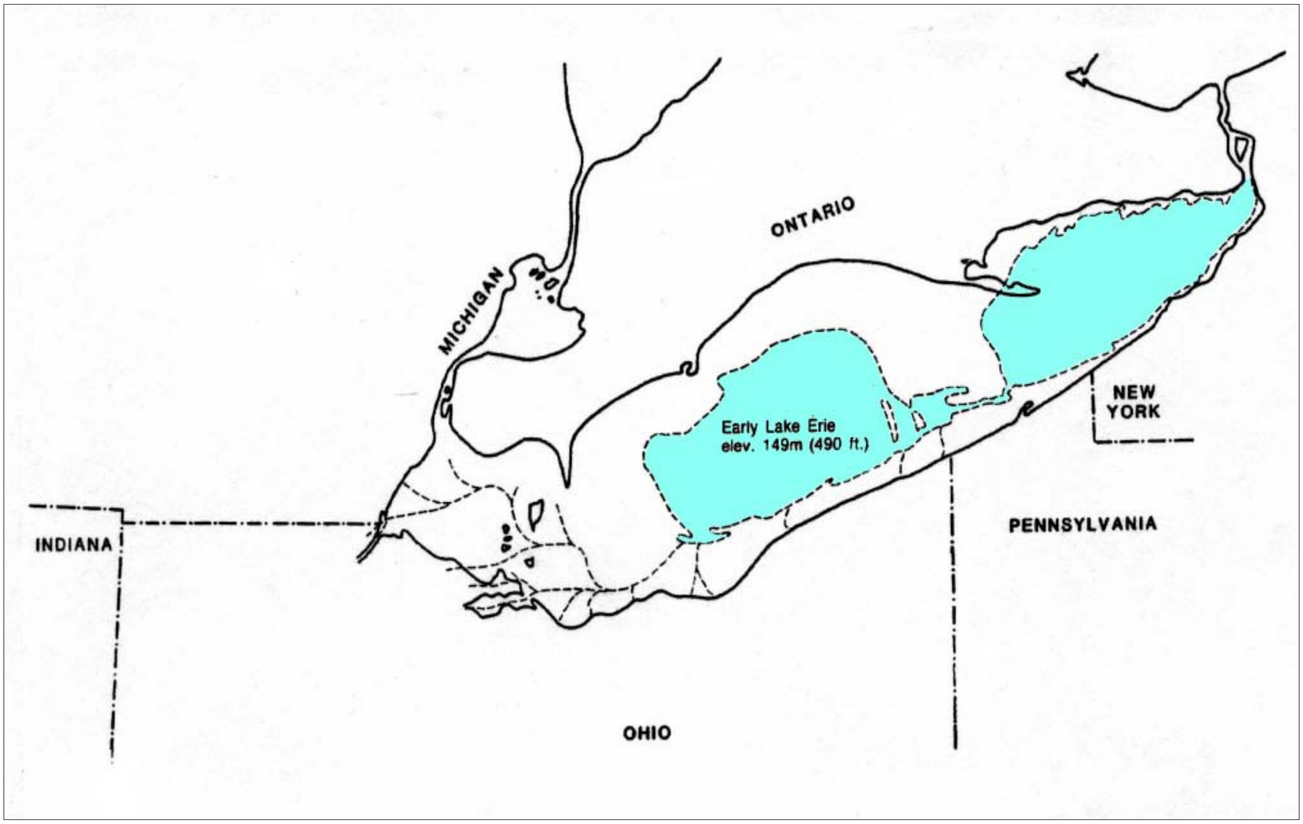

Figure 2.50. Early Lake Erie, circa 10,000 YBP (from Hartley 1958, Herdendorf 1989).

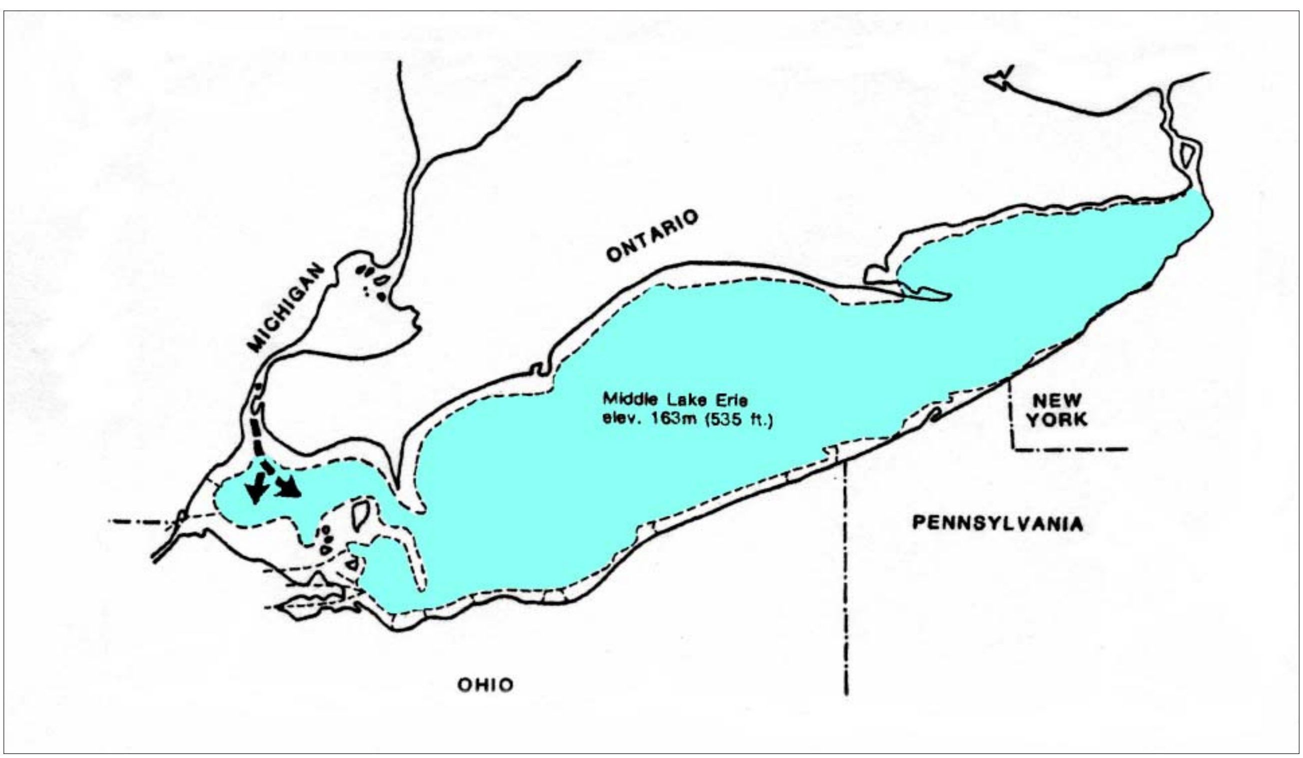

Figure 2.51. Middle Lake Erie, circa 4,000 YBP, at inception of ancestral Detroit River delta (from Herdendorf and Bailey 1989).

level of the Lake Erie. Thus, at about 7,700 YBP, the site of the present estuary was merely a point along a stream channel some 7 km inland (southwest) of the lakeshore. Because the erosion base level was 15 m lower than present, Buchanan (1982) calculated a 2.3 m/km gradient for the stream, nearly twice the present gradient of the lower course of Old Woman Creek. The steeper gradient would have generated stream velocities of 1 to 13 m/sec, permitting the stream to transport coarser material to the site of the future estuary than that which is presently being deposited there. As the lake level rose, the shoreline transgressed toward the south, reducing the gradient so that finer and finer sediments were deposited at the site. This assumption is supported by the textural gradation observed in the core, from sandy sediment at the bottom of the core, through a sandy silt portion, to predominantly silty clay material in the upper two-thirds of the core.

MODERN LAKE ERIE (4,000 YBP– PRESENT)

As Lake Erie rose to its approximate current level (Figure 2.1), 174 m (570 ft), about 4,000 to 3,500 YBP, the south shore tributary channels which were deeply incised into lacustine sediment and glacial till during the low water stage of Early Lake Erie, were flooded by lake encroachment, creating estuarine-type mouths (Herdendorf 1990, Holcombe et al. 2003). In Ohio alone, 42 km^2 of estuary waters were formed at the mouths of 18 tributaries for a total linear distance of 160 km (Brant and Herdendorf 1972). As coastal erosion proceeded and beach-building sand was delivered to the littoral zone, massive sand spits were built at Point Pelee and Long Point in Ontario, at Presque Isle in Pennsylvania, at Woodtick Peninsula in Michigan, and at Cedar Point and Bay Point in Ohio. At the same time, barrier beaches and bars were formed across the mouths of most of the estuarine tributaries. The barriers served to control water levels, influence sediment deposition, and enhance wetlands development within the estuaries.

Both the rise in lake level and the deposition of material within the Old Woman Creek channel served to reduce the stream gradient and water velocities. As a result, finer and finer sand and silt were deposited until about 4,000 YBP. Since that time only fine silts and clays have been transported into the estuary (Buchanan 1982). Additional pollen analysis and radiocarbon dating (4,220+20 YBP) of peat in a sediment core at 2 m (7 ft) below the present level of Old Woman Creek, elevation 172 m (564 ft) by Reeder and Eisner (1994) indicate that water levels have remained at depths sufficient to support the growth of shallow water vegetation for at least the past 4,000 years. These researches noted that even under heavy sediment loading and moderate water level fluctuations (1 to 3 m), the estuary remained a wetland and did not fill in, suggesting that the barrier bar at the mouth of the estuary facilitates a hydraulic equalibrium, whereby excess sediment is flushed out of the estuary.

Lake Erie waters have now reached a near-stable level, although minor crustal warping appears to have continued to the present (Calkin and Feenstra 1985). A study by the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data (1977) showed the maximum relative deformation rate for all measured sites in the Erie basin is less than 64 mm/century. The study report concluded that present crustal movement rates for Lake Erie are minimal between the inlet and outlet of the lake, consequently there is little effect on mean lake level with time.

SURFICIAL GEOLOGY AND SEDIMENTOLOGY

GLACIAL DEPOSITS

Approximately one million years ago, great ice sheets began to move southward and westward out of Canada and into the Erie basin. Several glacial lobes, some as much as 2 km thick, moved up pre-glacial river valleys. One of these, the Erigan River valley, ran in a general northeast direction up the basin now occupied by modern Lake Erie (Spencer 1891). The scouring action of the glacier enlarged the valley, forming a broader and deeper Erie basin (Bolsenga and Herdendorf 1993). During and after the retreat of the last glacier, up to 35 m (115 ft) of glacial till and 76 m (250 ft) of sediment have been deposited in the glaciated valley (Wall 1968) to give modern Lake Erie a much smoother and flatter bottom than it had when water first filled the basin.

As the Pleistocene glaciers followed the ancient streams into Ohio, the valleys were scoured deeper and the meanders were smoothed. The resistant bedrock that underlies Erie and Huron counties was not deeply cut by glacial ice, but profound erosion features are evident in the area, such as the spectacular glacial grooves in the Columbus Limestone on Kelleys Island and the massive overturned slabs of Berea Sandstone in the Chappel Creek valley, Florence Township (Figure 2.31). As the ice sheets moved over the land a sheet of rock debris, or ground moraine, was deposited. When the glaciers paused in their advance or retreat, ridges known as end moraines were built up of rock debris at the ice margins. The debris, referred to as glacial till, is composed of a heterogeneous mixture of rock fragments ranging in size from clay to boulders. In places, end moraines were deposited in such a way as to dam the natural drainage and thereby form large lakes in the scoured depressions.

Nearly all unconsolidated material overlying the bedrock in the vicinity of Berlin Heights and the Old Woman Creek drainage basin is glacial in origin, deposited either directly by the Wisconsinan ice sheet or in glacial lakes that were predecessors of Lake Erie (Figure 2.52). Gently rolling ground moraine, late Wisconsinan in age (Campbell, 1955), covers the southern portion of the Old Woman Creek drainage basin to an average depth of 8 m (25 ft). Notable exceptions are hills of Berea Sandstone, which have little or no till cover, and, at the estuary mouth where a buried valley is filled with 44 m (147 ft) of glacial drift and lake sediments (Buchanan 1982). South of the present shoreline, beach deposits of six glacial lake stages have been recognized: Lake Maumee, Lake Whittlesey, Lake Arkona, Lake Warren, Lake Wayne, and Lake Lundy, from highest to lowest. Glaciolacustrine deposits formed in these lakes are thin and discontinuous except in the vicinity of the beach ridges, and are best exposed in the present lake bluffs (Figure 2.53). Widely scattered lagoonal deposits are present in the beach ridge area and in places contain minor deposits of peat and bog ores.

Figure 2.52. Lake Erie shore bluff at Vermilion, Ohio showing pebble-rich glacial till clay overlying Ohio Shale (Charles E. Herdendorf).

Figure 2.53. Lake Erie shore bluff east of Old Woman Creek showing glaciolacustrine deposits (Charles E. Herdendorf).

Huron River Embayment

Immediately west of the Berea Escarpment in southeastern Erie County, a sharp southerly indentation is present in all of the abandoned shorelines of the glacial lake stages (Figure 2.18). The Huron River entered the lakes through this bay and was the primary factor in controlling sedimentation in the area. Carney (1911) applied the name “Huron River embayment” to this area which encompassed the northern part of Old Woman Creek watershed and extended westward to the base of Cedar Point and southward to Norwalk. Campbell (1955) referred to the body of water within this area at the various lake stages as “Huron Bay.”

The bedrock of the embayment comprises an area of lower elevation, carved out of shale, when compared to the higher elevations of the more resistant sandstone of the escarpment to the east and the limestone terrain to the west. While the bay existed, the limestone terrain formed either a northeasterly trending peninsula or a

Figure 2.54. Lake Erie shore bluff west of Cranberry Creek showing laminated lacustrine deposits (Charles E. Herdendorf).

string of islands. Likewise, the eastern edge of the embayment was controlled by the position of the Berea Escarpment and exhibits wave-cut features.

GLACIOLACUSTRINE DEPOSITS

Sediments deposited in the glacial lakes comprise the Lake Erie bluffs from Cranberry Creek west to Huron (Figure 2.54). These glaciolacustine deposits consist largely of interlaminated clay and silt; the clay laminations are dark brown and the silt layers are light brown on weathered surfaces. The mineralogy of the clay is illite with minor amounts of chlorite (Carter and Guy 1980). Near the contact with the underlying till, the clay and silt laminations are poorly defined and there is typically a zone of deformed clay and silt.

The glaciolacustrine deposits that comprise the lake bluff at Ceylon Junction, 1.4 km east of Old Woman Creek estuary, were studied by Goodman (1956) and found to consist of sand (1.6%), silt (68.2 %), and clay (30.2%). When fresh these lake deposits are typically bluish gray, but exposed surfaces have brownish-gray and yellow-brown mottles caused by oxidation and staining. Exposures in the Lake Erie bluffs in the vicinity of the estuary indicate that the ancient lake deposits constitute only the upper 6 m (20 ft) of the sediment. These beds show distinct interlaminations of silt and clay. Contorted stratification occurs in the lower 3 m of the lacustrine beds at Oberlin Beach (Figure 2.55). This disturbed stratification has been attributed to pene-contemporaneous slumping or distortion caused by ice flows associated with a minor ice advance or reworking by wave action (Campbell 1955, Herdendorf 1963b).

Varves

The bluffs of Old Woman Creek estuary, particularly those on the east side of the estuary immediately south of the U.S. Route 6 bridge (Figure 2.56), and the Lake Erie bluffs fronting Oberlin Beach to the east of the estuary mouth exhibit glaciolacustrine varves. These sedimentary beds are composed of a sequence of laminae deposited in a glacial lake in a year's time. Each varve consists of a thin pair of graded glaciolacustrine layers seasonally deposited by meltwater streams in a glacial lake which existed in front of the glacier (Figure 2.57). The glacial varves at Old Woman Creek include a lower "summer" layer, composed of relatively coarse-grained, light-colored silt and very fine sand produced by rapid melting of ice in the warm months, which grades upward into a thinner "winter" layer, consisting of very fine-grained clayey sediment, often organic and dark-colored,

Figure 2.55. Lake Erie shore bluff at Oberlin Beach, adjacent to Old Woman Creek mouth showing contorted lacustrine beds resulting from ice action during a glacial lake stage; varved bedding exhibited in upper layers (Charles E. Herdendorf).

Figure 2.56. East bluff of Old Woman Creek estuary exhibiting varves in lacustrine sediments (Charles E. Herdendorf).

Figure 2.57. Close-up view, same location as Figure 2.56, showing structure of varves (Charles E. Herdendorf).

slowly deposited from suspension in quiet water while the streams were ice-bound. A sedimentary feature that is characterized by the repetition of a pair of unlike laminae showing a gradation in grain size from coarse below to fine above is said to possess diatactic structure (Bates and Jackson 1980). Campbell (1955) measured interlaminated lacustrine deposits west of the Huron River that averaged 8 mm per couplet, but she was uncertain if they represented true glacial varves because diatactic structure could not be demonstrated. However, the interlaminated silts and clays at the estuary appear to have been deposited in the higher glacial lakes stages from Lake Maumee to Lake Lundy.

Counting the number of couplets can provide a measure of the time sequence represented by a particular deposit. For example, varve couplets measured by the authors near the mouth of Old Woman Creek estuary average 10.3 mm in thickness. The maximum height of the varved deposits ranges from 6.1 m (20 ft) on the lakeshore to 3.7 m (12 ft) in the estuary. Hence, the bluffs near the mouth of the estuary represent a depositional period of nearly 600 years or about 36% of total time that higher glacial lakes covered the estuary site.

Postglacial and Modern Sediments

Stream Deposits

The oldest alluvial sediments were deposited within the channel of Old Woman Creek and on the narrow floodplain across which the channel migrated about 8,000 YBP. These sediments exist 6 m below the current estuary floor and consist of coarse to fine sands and silts deposited in the more swiftly flowing channel of the creek when the level of Lake Erie was much lower and the stream possessed a higher gradient. As the lake rose, the stream gradient of Old Woman Creek was reduced and the site of the estuary experienced increasing amounts of sediment deposition involving finer and finer sediments. As deposition progressed and the floor of the estuary rose in elevation, the size of the area over which the creek channel migrated increased, eventually to encompass and laterally enlarge the deep valley cut in the underlying lacustrine sediments and till by the early, erosive channel of the creek. Currently, only silts and clays are transported into and deposited in the estuary of Old Woman Creek (Buchanan 1982).

Estuary Deposits

Within the last 100 years, the combined effects of rising lake levels and sediment deposition may have decreased the water depth in the estuary to such a degree that shallow-water aquatic vegetation has begun to colonize its floor (Buchanan 1982). The first indication of this colonization are zones of dark, organic-rich sediments with plant debris in the upper 1 m of cores recovered from the estuary. Using recent lake-level records and aerial photographs, Buchanan estimates that shallow water depths, between 15 to 30 cm, are necessary for such vegetation to flourish and that conditions such as these were present in the estuary between the 1920s and 1960s. A more recent core (Reeder 1989) reveals deeper, organic-rich layers which may indicate even earlier low-water/high productivity periods in the estuary. Using Buchanan's radiocarbon data, the sediment depositional rate in the estuary over the last 8,000 years has averaged 0.70 mm per year. Most likely this rate has been greatly accelerated in the last 100 years due to agricultural development within the drainage basin. Current depositional rates in the estuary are estimated by Buchanan to be 10 mm per year.

Matisoff et al. (1998) demonstrated that the type of soil tillage has an influence on the erosion rate in Old Woman Creek watershed and the ultimate delivery of sediment to the estuary. They selected several drainage sub-basins for study where agricultural management included either tilled or no-till practices. By using a radioactive isotope of beryllium as a tracer, they were able to track soil erosion losses for each sub-basin for a single rainstorm event in 1996. The results of the study showed the advantages of no-till practice in controlling soils loss.

Practice	Mean Sub-basin	Erosion Rate
Tilled	2.17 km^2	7.1 tonnes/km^2
No-till	2.17 km^2	0.8 tonnes/km^2

Because most of Lake Erie's undisturbed estuary inlets are barred across a significant portion of the year, it has been postulated that the presence of such barriers control, to a large part, sediment infilling within the estuary. Buchanan (1982) noted that recent depositional rates in Old Woman Creek estuary may range as high as 1 cm/yr in response to increased agricultural activity upstream and the damming effect of the barrier bar at the estuary mouth. He also concluded that colonization of the estuary floor by aquatic plants has only become possible in that period of time represented by the upper meter of sediment (100 years assuming a sedimentation rate of 1 cm/yr), because water depth appears to be the dominant control for plant abundance.

More recent findings show a quite different picture. Water levels in Lake Erie have varied considerably in the past 12,000 years, falling from 247 m to 146 m then up 174 m above sea level due to isostatic adjustment following deglaciation. Approximately 4,000 to 5,000 YBP the lake stabilized near its present level and has fluctuated only a few meters up and down since. Once the lake stabilized, barrier bars were deposited across the drowned mouths of most of the tributaries, forming what is now referred to as freshwater estuaries. Sediment cores (Reeder 1989) indicates that peat layers composed of aquatic plant material extend for several meters below the estuary floor and yield radiocarbon dates of 4,000 to 5,000 YBP. Apparently colonization by aquatic plants is not a new feature of the estuary, but there must have been some mechanism operating through time to control water level at depths optimal for plant growth.

Sediment Chemistry

The chemistry of the sediments and the interactions between the sediments and the overlying waters in Old Woman Creek estuary have received attention by the scientific community. Frizado et al. (1986) studied the mineralogy of the sediment in the Old Woman Creek estuary and determined that its probable sources were (1) glacial till, lacustrine sediment, and soils and (2) Berea Sandstone in approximately equal parts. However, they believed that the sediment load of the Berea Sandstone was probably overestimated due to the export of fine grained particles from the tills, sediments, and soils out of the estuary. Frizado et al. (1986) and Mancuso (1986) measured the concentration of selected metals in the interstitial waters and determined that the chemistry of these waters is not related to the bulk mineralogy of the sediments. However, the concentrations of many of the trace metals were higher in this interstitial water than in the overlying waters. This suggested that these waters may serve as a source of trace metals to the estuary. Matisoff and Eaker (1989, 1992) measured or calculated three different fluxes—direct solute flux across the sediment water interface, diffusional fluxes calculated pore water chemical concentrations, and seepage fluxes from groundwater. In the estuary they concluded that diffusional fluxes were insignificant to seepage fluxes and these were in turn insignificant to the direct fluxes. These fluxes between the sediments and the overlying waters are significantly impacted by activities of the benthic fauna. Pfister and Frea (1989) examined the movement of cadmium from the overlying waters into the sediments. They determined that bacteria enhanced this downward movement.

Buchanan (1982) examined the percentage of organic content in a sediment core from Old Woman Creek estuary. The abrupt increase in organic content at approximately 150 cm below surface was interpreted as a change in water levels in the estuary (and in the lake) that would make the estuary suitable for in situ macrophytic growth. Prior to this period, Buchanan considered any organic matter in the sediments as being transported from the terrestrial watershed. He supports his hypothesis by noting that the sediments above this zone contain matted rootlets and other remains of plant material, while those below do not contain such material. Buchanan (1982) also reported thin bands of largely inorganic silty-clays between the high organic layers in the upper 150 cm of the core. He believed that these thin layers of low organic content represented periods when lake levels were too high to permit the growth of aquatic macrophytes in the estuary.

Beach Deposits

Old Woman Creek does not enter Lake Erie in the typical way—it must first pass through the barrier beach. At times the barrier is opened by a channel which leads to the lake (Figure 2.58), but often it is closed by sand bars (Figure 2.59). When the estuary mouth is completely sealed off by the barrier beach, the creek waters must percolate through the sand to find their way to the lake. Wind storms over the lake and rainstorms over the watershed can produce the forces necessary to breach the barrier and allow Old Woman Creek to flow freely to the lake. Once these violent events have subsided however, the shifting sands of the coast can quickly close the channel and the estuary is again isolated from the open lake. The barrier is critical to the protection and maintenance of coastal wetlands. By separating estuary from the lake, fragile aquatic plants are protected from wave attack. The beach allows the waves to break and roll up a gentle slope, dissipating energy and reducing the waters ability to erode the shoreline and undermine vegetation.

At the mouth of Old Woman Creek, the barrier beach is composed of medium- to coarse-grained sand (Figure 2.60). Quartz dominates these grains, but patches of reddish-purple garnet and black magnetite are common (Figures 2.61 and 2.62). These three materials are typically arranged in density layer, with the heavier magnetite lowest on the beach, followed by garnet, then quartz. Waves carrying the grains of sand onto the beach are effective in sorting these minerals by their specific gravity (Herdendorf 1963b). The beach sand has a maximum thickness of 7 m and overlies glacial till that is exposed at the shoreline east of the barrier beach.

Figure 2.58. Barrier beach at Old Woman Creek estuary mouth showing an open channel (Charles E. Herdendorf).

Figure 2.59. Barrier beach at Old Woman Creek estuary mouth showing a closed channel (David M. Klarer).

Figure 2.60. Layered beach sand in the barrier bar at the mouth of Old Woman Creek estuary (Charles E. Herdendorf).

Figure 2.61. Patches of reddish-purple garnet and black magnetite grains on the predominately quartz sand beach at the mouth of Old Woman Creek estuary (Charles E. Herdendorf).

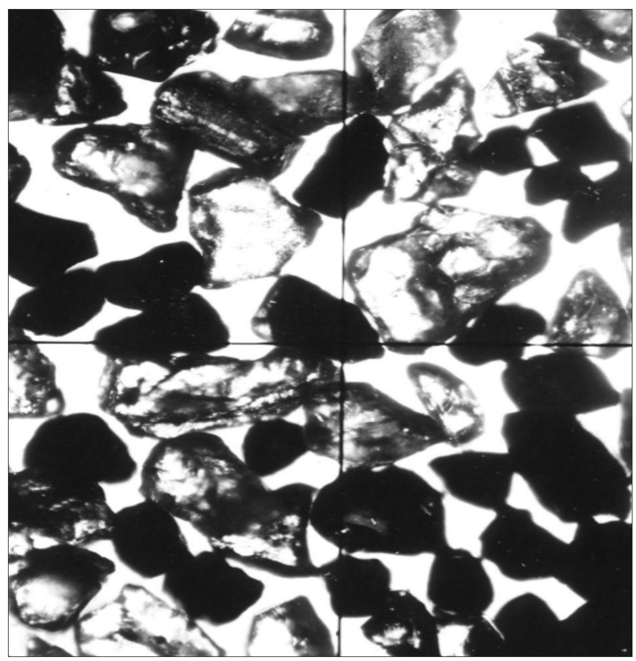

Figure 2.62. Photomicrograph of angular garnet (light) and magnetite (dark) beach sand grains from the Old Woman Creek barrier beach (Charles E. Herdendorf).