Lakefloor Geomorphology of Western Lake Erie

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ABSTRACT. *Bathymetry of western Lake Erie, exceeding in detail any previous bathymetry, is an early result of a project conducted jointly by the U. S. National Oceanic and Atmospheric Administration and the Canadian Hydrographic Service. This bathymetry utilizes the entire archive of historic hydrographic data assembled since 1903 in the U. S. and Canada. Details of bottom configuration for the shallow (< 12 m) western portions of Lake Erie are highlighted using a 1-meter contour interval. The islands and reefs bordering and lying within the western basin have bedrock cores which are erosional remnants of the more resistant upper Silurian and lower Devonian dolomites and limestones. Overdeepened channels between the islands have been sites of postglacial nondeposition, and probably erosion, due to intense wind-driven water circulation through these restricted passages. The Pelee-Lorain Ridge is interpreted as a late Wisconsinan end moraine upon which sand deposits have been concentrated. The Point Pelee Ridge is apparently a morainic ridge, capped by sand deposits transported in part by longshore drift converging on Point Pelee. A fan-shaped feature with a surface depth of 10–15 m, which extends to the east of Point Pelee Ridge, may be a former shoreline delta of the Detroit River. This fan-shaped feature may have formed following opening of the Port Huron outlet about 4000 yr bp when the new River was actively eroding its channel and bringing a heavy load of sediment into Lake Erie—although subaqueous deposition of fan sediments is a possible alternate explanation. Sculptured drift-like features interpreted as relict spits extend northwestward and southeastward from the bedrock reefs in the western basin off Locust Point. Channels on the floor of the western Lake Erie basin underlying the main shipping lanes have been excavated by propeller wash where ship traffic increases speed, resulting in resuspension of bottom sediments. Dumpsites for dredge spoils excavated from channels are expressed in the bathymetry by a distinctive hummocky pattern in two areas.*

INDEX WORDS: Lake Erie, geomorphology, bathymetry.

INTRODUCTION

Hydrographic surveys in support of nautical charting for navigation have been conducted by U. S. and Canadian charting agencies in the Laurentian Great Lakes for at least 150 years. Since the early 1900s these surveys have generally adhered to high quality standards and the surveys have all been adjusted to standard physical datums established for each lake (Blust 1972). For Lake Erie the standard physical datum corresponding to "mean low water" was originally established in 1901, widely implemented in 1903, adjusted slightly in 1909, and adjusted again in 1933 (Blust 1972). The 1909 and 1933 adjustments in physical datum amounted to less than 0.2 meters; therefore bathymetric surveys

conducted since 1903 are used for bathymetric compilations without making any adjustments in the depth measurements. The bathymetric data from these surveys are stored in survey-sheet archives and bathymetric data bases at the NOAA National Ocean Service, the Canadian Hydrographic Service, and the NOAA National Geophysical Data Center. Only a small fraction of these sounding data appear on nautical charts, which are not designed to depict details of lake-floor topography. With the exception of a few compilations in specific small areas, these hydrographic survey data have never been used to full resolution for bathymetric mapping of the floor of the Great Lakes. The scale 1:400,000 bathymetric map published by the Canadian Hydrographic Service (1971) is excellent generalized bathymetry, but with its contour interval of 5 m it only yields limited information about bottom topography in Lake Erie. The same limitation applies to the scale 1:750,000 bathymetric map published by Ristic and Ristic (1985), which contains much useful information about Lake Erie but has a contour interval of 15 feet.

Considering the high value of lake floor bathymetry for a host of applications, several researchers and bathymetrists at the NOAA National Geophysical Data Center, the Canadian Hydrographic Service, and the NOAA Great Lakes Environmental Research Laboratory have resolved with the support of their agencies to pursue a low-key, long-term effort to assemble and compile the sum total of historic, good quality bathymetric data from all the Great Lakes into readily accessible bathymetric maps and data bases. Western Lake Erie was chosen for a pilot project. Objectives for this pilot project are (1) a complete and digitized bathymetric sounding data set, (2) bathymetric contours, (3) bathymetric maps, and (4) vector and raster data sets from digitized contours. In this paper we present the bathymetry resulting from this pilot project for western Lake Erie, together with a discussion of the lake bottom geomorphology as revealed by the new bathymetry.

COMPILATION METHODS

Bathymetric data control for western Lake Erie, from Canadian Hydrographic Office and U. S. Army Corps of Engineer/ NOAA National Ocean Service surveys, is shown diagramatically in Figure 1. In addition, highly detailed bathymetric surveys having track spacings as dense as a few meters were conducted by the Ohio Geological Survey in

shallow water areas surrounding reefs near Kelleys Island, the Bass Islands, and off Locust Point (Herdendorf and Braidech 1972). Bathymetric contours from these surveys were generalized and incorporated into the main compilation. About 75 per cent of the U. S.-collected bathymetric data were already in digital form at the beginning of this project. As part of this project, the bathymetric data from five additional sheets containing older U. S.-conducted hydrographic surveys were digitized; consequently, the bulk of U. S.-collected hydrographic data now reside in digital data bases.

An estimated 100,000 depth soundings from western Lake Erie were available for compilation of bathymetry. These soundings are represented on the survey sheets and in the digital data base in various units, for example whole meters, whole feet, meters and tenths, and feet and tenths. Within the digital data base, depth-unit discrepancies were easily resolved. Plots of the sounding data from the digital data base were run on a color electrostatic plotter, using color to delineate depth ranges and extremely small characters to minimize overwrite. In this way, a single data plot suffices over areas with varying data density—where data are dense, color bands make contouring relatively straightforward; where data control is less dense, depths can be read numerically. The idea was to minimize compilation time and expense by optimizing compilation scales and projections. For areas where data are contained only on survey sheets, bathymetric contours were compiled at scale on an overlay.

In areas of relatively smooth topography the slightest discrepancies between surveys, run at different times and separately calibrated, can pose problems in reconciling bathymetry. Discrepancies were discovered between old wire-line and more recent echo-sounding surveys in the U.S. sector of the western Lake Erie Basin. In flat offshore parts of the western basin known to be underlain by mud, acoustic depths run up to 1/2 meter shallower than wireline depths. We interpret this discrepancy as due to the lead weight used in old wireline surveys sinking into the bottom slightly when lowered into mud having a high fluid content (Verber 1957) — or, alternatively, currents or vessel movements deflected the wireline from the vertical during surveys. "Noise" appearing in several sectors of Canadian surveys apparently resulted from a very small depth calibration discrepancy between two sets of Canadian surveys, run separately in 1975 and in 1977, with the latter surveys filling in intervals between tracklines of the former surveys. This
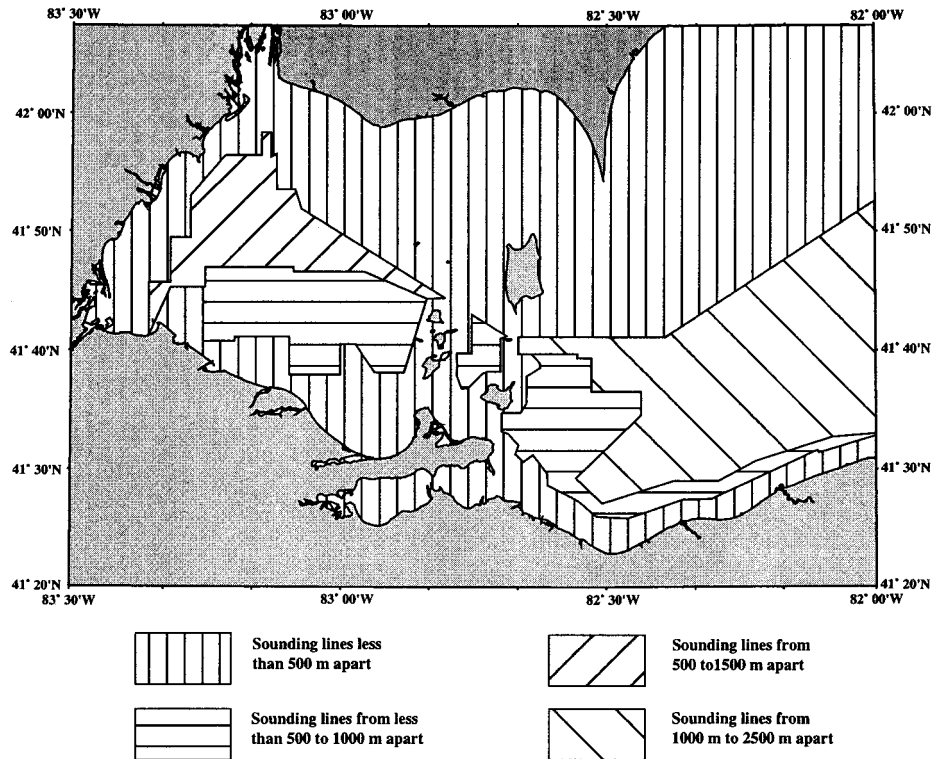
FIG. 1. Diagram showing bathymetric data control. Trackline spacing varies across the area, being generally less than 1,500 m in areas containing shoals which are hazardous to navigation, including the shoal areas south of Point Pelee, reef areas near the Islands and off Locust Point, and in several near shore areas near harbors. In most other areas track spacing generally varies between 1,000 and 3,000 m.

noise was eliminated by adjusting the surveys which yielded slightly greater depths to agree with those yielding slightly shallower depths.

BATHYMETRY OF WESTERN LAKE ERIE

Bottom topographic features of western Lake Erie are highlighted in the new bathymetry using a 1-meter contour interval (Plate 1, inside back cover). Many features are revealed for the first time; others are previously known but are now more clearly delineated. The western basin of Lake Erie is shallow, being generally less than 12 meters depth throughout its extent. Deeps north of Kelleys Island and south of South Bass Island are greater than 12 meters as are depths east of the islands in Sandusky Basin. First-order topographic features are therefore of no more than a few meters vertical

relief. Work on the geology of western Lake Erie has been conducted at least since 1873, when G. K. Gilbert reported on the geology of West Sister Island (Gilbert 1873). An up-to-date synopsis of the geology and geomorphology of Lake Erie is contained in a paper by Herdendorf (1989).

THE ISLANDS AREA

A geological sketch map, constructed from information shown on geological maps of Ohio (Herdendorf and Braidech 1972), Ontario (Freeman 1978) and Michigan (Geological Survey of Michigan 1987), summarizes the geology of bedrock units underlying western Lake Erie (Fig. 2). These bedrock units consist of upper Silurian and lower Devonian dolomites, limestones, and shales which dip gently to the north and east around the northern
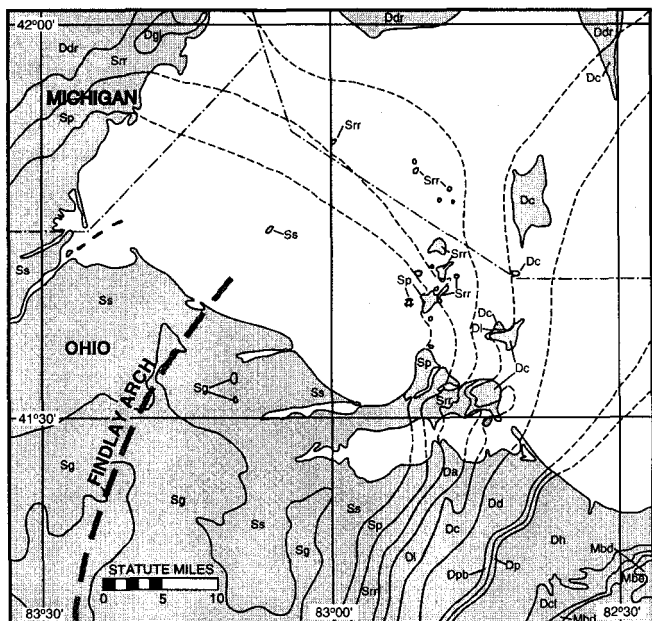
System	Group	Formation	Symbol	Lithology	Thickness (feet)
Mississippian		Berea	Mbe	Sandstone	10-50
		Bedford	Mbd	Shale	0-150
Devonian		Cleveland	Dcl	Shale	30-70
		Huron	Dh	Shale	600
		Prout	Dp	Limestone	15
		Plum Brook	Dpb	Shale	35
		Delaware	Dd	Limestone	35
		Columbus - Dundee	Dc	Limestone	60
	Detroit River	Lucas	Ddr Dl	Dolomite	30-75
		Amherstburg	Da	Dolomite	60-80
		Garden Island	Dgi	Dolomite	
Silurian	Bass Islands	Raisin River	Srr	Dolomite	40-60
		Put-in-Bay	Sp	Dolomite	35-60
	Salina		Ss	Dolomite	670
		Guelph	Sg	Dolomite	200-450

FIG. 2.   Bedrock geology, extended beneath western Lake Erie, is shown by dashed lines (adapted from Herdendorf and Braidech 1972, Freeman 1978, and Geological Survey of Michigan 1987).

end of a broad structural high, the Findlay Arch. Successive strata within these rock units vary in their resistance to erosion. The islands and reefs bordering and lying within the western basin have bedrock cores which are erosional remnants of the more resistant strata. Glacial erosion was intense over these resistant topographic outliers as evidenced by the widespread occurrence and spectacular nature of glacial pavement, striae, and grooves on bedrock surfaces of Pelee Island, the Bass Islands, and Kelleys Island (Fisher 1922, Mohr 1931). Topography of the islands is relatively flat and is somewhat controlled by the elevation and dip of hard bedrock surfaces, the less resistant overly-

ing strata having long since been stripped off by glacial erosion. Cliffs surrounding the islands have their highest relief to the west, reflecting the gentle easterly dip of strata. Highest relief within western Lake Erie, about 15–20 meters, occurs on and in waters adjacent to the Bass Islands. The islands and reefs occur mainly in two north-south bands, the western band (Bass Islands, Catawba Island, Middle and East Sister islands) formed on erosional remnants of resistant upper Silurian dolomites of the Put-in-Bay and Raisin River Formations, and the eastern band (Marblehead, Kelleys Island, Pelee Island) formed on erosional remnants of resistant lower Devonian limestones of the Columbus Formation (Fig. 2).

Topography-forming processes at work in western Lake Erie are strongly affected by wind-driven water circulation. The lake is shallow, it is frequently subject to strong winds blowing across its surface predominantly from the west-southwest (Federal Climate Complex Asheville 1992, Fig. 3), and constricted passages are present which impede the flow of water into and out of the western lake basin. Lake Erie water circulation is complex and controlled by many variables (Saylor and Miller 1983), but the first-order effects are fairly evident. Strong southwesterly winds remove water from the western basin, lowering lake level and causing strong eastward flow through the island channels. Return flow of about equal magnitude through the same island channels occurs when strong southwesterly winds diminish and lake levels return to normal in the western basin. Also, less frequent but stronger northeast storms cause similar flows through the channels. Two-way flow, which has also been measured through the straits, is probably established when the lake comes to equilibrium for a given wind condition (See Herdendorf and Braidech 1972). Seiche with a period of about 14 hours is also a factor in moving water back and forth through the island straits (Saylor and Miller 1983).

The natural channels which occur in the straits between the Bass Islands and adjacent to these islands to the west are well illustrated in the bathymetry (Plate 1). Many of these channels probably owe their positions and trends to what appears to be prevailing east-west jointing in the bedrock; at present they are similar to tidal channels, being the sites of concentrated flow resulting from the wind-driven water circulation. These channels are overdeepened and are eroded through limestone and dolomite bedrock; obviously they are, at present,
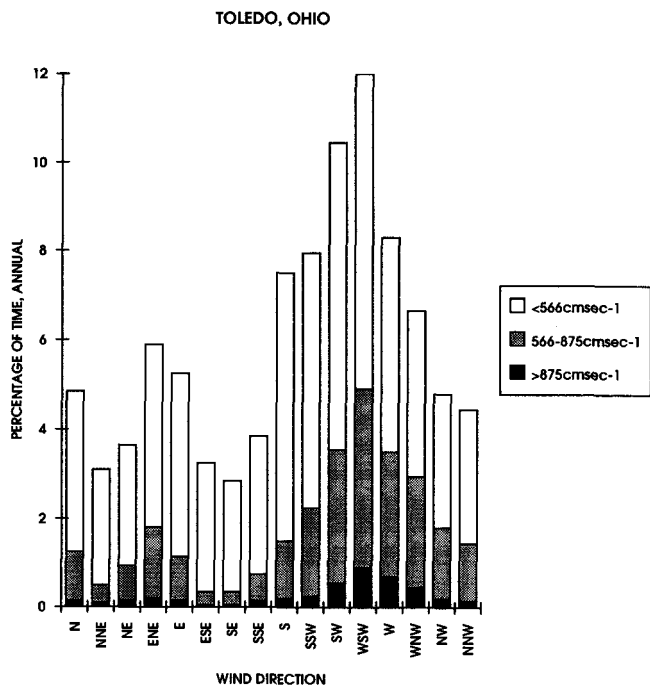
TOLEDO, OHIO

FIG. 3.   Percent frequency of strong winds as a function of wind direction at Toledo Airport based on hourly weather observations recorded over a 25-year time period, 1955 to 1990 (Federal Climate Complex Asheville 1992).

sites of non-deposition and probably continued erosion. Corrosion [solution action] may also have been an important agent of erosion. Deepest channel depth is the 19-meter Starve Island Deep. Here erosion may have cut through the lower Devonian carbonates and exposed highly soluble evaporites of the upper Silurian Salina Formation. Valleys coinciding with these channels were probably already in existence before waters of present Lake Erie rose into the area, and these valleys are related to the pattern of subaerial drainage which probably developed in pre-Pleistocene time and continued to be active during early and middle postglacial Lake Erie time. The zones of weakness in the bedrock associated with the prevailing pattern of east-west joints have probably been a controlling factor in the patterns of glacial erosion and pre- glacial drainage.

Between the islands and along the strike of the more resistant strata, reef-like areas of elevated topography having geometrically complex surfaces stand out in marked contrast to the surrounding relatively smooth sediment-covered areas (Plate 1).

The larger of these areas of elevated complex features occur south of South Bass Island; adjacent to the channels between the Bass Islands; west of North Bass Island; intermittently along strike north of North Bass Island; northeast of Kelleys Island; intermittently between Kelleys Island and Pelee Island; south and east of Pelee Island; and intermittently between Pelee Island and Point Pelee. These areas are apparently outliers of exposed or intermittently exposed resistant bedrock, and most have been identified as such in previous studies (Bolsenga and Herdendorf 1993). These areas/features probably have been swept clean of sediments or have remained sediment free in present-day Lake Erie by virtue of their rising to shallow depths as topographic outliers. Away from the channels and areas of bedrock topography occurring between the Islands along the strike of resistant strata, former subaerial drainage channels have been sediment-filled and no longer exhibit much topographic expression.

THE PELEE-LORAIN RIDGE, POINT PELEE RIDGE, AND ADJACENT AREAS

A low ridge extends southeastward from Pelee Island almost to the Ohio shore (Plate 1). This ridge (or parts thereof) has been referred to in previous reports as the Pelee-Lorain Ridge (Lewis *et al.* 1966), the Pelee-Lorain Moraine (Coakley 1972), the Lorain-Vermilion Sand and Gravel Deposit (Hartley 1960), the Lorain-Vermilion Morainic Sand and Gravel Bar (Herdendorf 1989), and the Pelee Moraine (Sly 1976). In keeping with the principles for naming water-covered features advocated by the U. S. Board on Geographic Names, we refer to the feature as the Pelee-Lorain Ridge. In previous literature it has been assumed that this ridge is continuous between Point Pelee and its southern terminus near the Ohio shore. This new bathymetry shows clearly, however, that the Pelee-Lorain Ridge is not continuous with Point Pelee but is instead continuous with Pelee Island, 20 kilometers to the southwest! The name Pelee-Lorain Ridge is still valid because the island has the same name as the point. The southern part of the Pelee-Lorain Ridge was described by Hartley (1960), who mapped ridge-top bathymetry, and extent and thickness of sand deposits. Although Hartley's contours provide significant details of ridge-top bathymetry, a complete set of tracklines for these contours are not available; therefore we chose to include this bathymetry as a separate illustration (Fig. 4). The

southern part of the ridge is capped with sand and gravel deposits, overlying a foundation of till deposits. Its broad, hummocky crest increases to about 2–2.5 m relief toward its southern end, where a northwest-southeast trending valley separates the main ridge from a delta-shaped broad swell lying southwest of the main ridge.

West of the Pelee-Lorain Ridge lies a shallow, 12–14 m deep basin which has been referred to as the Sandusky Basin. This basin lies at a depth of 12–14 m and slopes gently downslope from west to east, having local relief of 1–2 m. Topographically it resembles a fan and it may have been the site of a shallow lake and/or marsh and/or delta during early and middle Lake Erie time. In terms of basin configuration and continuity of the bounding walls, the Sandusky Basin appears as an integral part of the central Lake Erie Basin, except for the interposition of the Pelee-Lorain Ridge. Formation of the Pelee-Lorain Ridge may therefore have been the event which separated the Sandusky Basin from the central Lake Erie Basin.

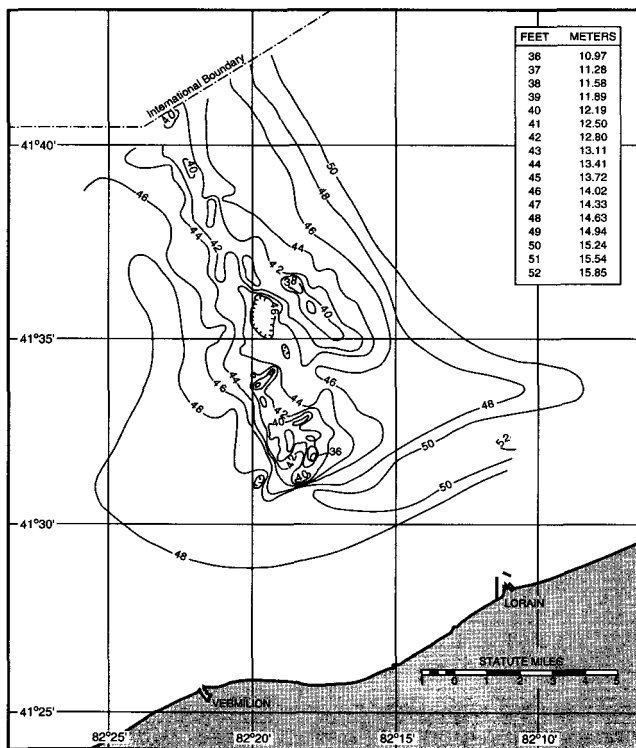The Pelee-Lorain Ridge has been interpreted as

FIG. 4. Detailed bathymetry of a portion of the Pelee-Lorain Ridge (from Hartley 1960). Contour interval is 2 feet.

end moraine probably associated with a readvance of the retreating Wisconsin Ice Sheet, and probably correlating with the proglacial Lake Maumee II (Hartley 1960, Herdendorf 1989). Having 10–12 meters crestal depth, the ridge was probably at or near zero depth some time prior to 4000 y B.P. Deposits of sand and gravel were probably concentrated on the Pelee-Lorain Ridge when rising lake level exposed the ridge for a time to a shore and shallow water regimen. Thickness of sand and gravel, being generally less than 1 meter on the ridge crest in its middle section, increases to 4–5 m at the ridge's southern end, forming a sand and gravel deposit which has been mined commercially (Hartley 1961). The channel which separates this ridge from the Ohio shore is interpreted as the site of a stream which led from the islands area to the central basin during the postglacial time of lowered lake level. The channel can be traced upstream through the main passage between Kelleys and Pelee islands, although position of the channel is ill-defined across the Sandusky Basin. Presumed channel gravels and soil zones were encountered in this channel at depths of 20–25 meters below present lake level (Herdendorf 1989), indicating that it was probably an active stream channel until flooded prior to 4000 y B.P. by rising water levels. Muds have been deposited in this channel since flooding occurred (Hartley 1961, Lewis *et al.* 1966). A cross-section constructed from boring logs across the channel and the southern portion of the ridge (Hartley 1960) shows that the sand deposits extend southward out over the muds which partially fill the channel, and that the sand deposits are stratigraphically young relative to most of the channel muds. This suggests that concentration and deposition of the sand deposits on the southern ridge was a relatively recent event compared to deposition of most of the channel muds; and that net longshore sediment drift was from northwest to southeast along the axis of the ridge. Northwest-southeast sediment drift is also suggested by the increase in thicknesses of sand toward the southeast.

A well-formed submerged delta-like feature at the 10-meter water depth lies off the Black River (Plate 1). Previous surveys have revealed that this feature is covered by a veneer of sand up to 2.5 m thick overlying till (Hartley 1961). This sand cover continues upslope to the shoreline and for 5 to 10 km along the shore in either direction from the mouth of the Black River (Pincus 1960). It is reported that whereas this feature is capped by sand which is poorly sorted, with particle sizes ranging

from clay to cobbles, the sands farther north on the Pelee-Lorain Ridge beyond the channel are generally well-sorted (Hartley 1961). This delta-like sand accumulation may lie atop an extension of the end moraine forming the Pelee-Lorain Ridge, isolated from the rest of the ridge by the channel. Its position opposite the present mouth of the Black River suggests that the Black River contributed deltaic sediments when lake levels were 10–12 meters lower than at present. Poorly sorted sands capping the feature suggests, however, local occurrence of lag deposits which have as their source the underlying till.

A small fan whose topographic expression is not well-defined has formed on the steep slopes off Sandusky Bay. Spits partially enclose the entrance to the bay. The fan and the spits are associated with deposits of very fine sand, in contrast to those lying off Lorain, Cleveland, and Fairport, which are largely composed of coarse sand, pebbles, and gravel (Hartley 1961). It is noted that Sandusky Bay is a drowned estuary and that the Sandusky River drains a large area of western Ohio characterized by low relief and low stream gradients and underlain by Silurian carbonates and Devonian shales. On the other hand, the Black River (and the streams farther east debouching into Lake Erie) are short higher-gradient streams draining higher-relief provinces underlain by Mississippian sandstones which here occur near the lake shore. Gradients of these streams would have been even higher during Early and Middle Lake Erie times when the Lake Erie Basin was isostatically depressed; it is also quite possible that these streams drained larger areas of Ohio before isostatic rebound resulted in an increased southward tilt of the Ohio land surface.

Areas of exposed bedrock have been identified off the southern shoreline west and east of Vermilion, and east of Lorain (Pincus 1960). These areas of exposed bedrock, which show up clearly in the bathymetry (Plate 1), are characterized by a fine-scale topography unlike that occurring along other sectors of the south shoreline. Several ledges are clearly delineated; as many as three separate ledges occur in parts of both areas. These ledges are presumably the erosional surface expression of stratification in the underlying upper Devonian shales.

A ridge includes Point Pelee and extends offshore south-southeast for a distance of about 10 km, where it ends abruptly. This ridge, which we will refer to as the Point Pelee Ridge, has 6–8 m of total relief and extends up to depths of less than 5 m

(Plate 1). On its broad crest it displays fine-scale relief resembling dunes and beach ridges. The ridge has been described and studied by Coakley (1972, 1978), who interprets present Point Pelee together with the subject ridge as moraine associated with the Pelee-Lorain Ridge on which 3500 y B.P.-to-recent sand deposits have been concentrated. Since 3500 y B.P. the subaerial extent of Point Pelee has diminished as a consequence of continued rising water levels. Sand transport and deposition were apparently more prolific in the past 3,500 years than at present. Thickness of the sand is highly variable up to a maximum thickness of 10 m. Sources for the sand include in-place sand concentrated by winnowing of glacial till deposits, and sand from eroding till deposits which lie principally to the north along the Ontario shore in both directions, with sand having been transported by longshore sediment drift converging on Point Pelee (Fig. 5). Apparently sand sources and the transport mechanisms have adjusted to the changing water circulation and shoreline configurations concomitant with rising water levels. It is noted particularly that depth contours converge from north to south along the western shore of Point Pelee (Plate 1), suggesting that Point Pelee has recently evolved into a narrower spit projecting farther south.

Extending to the east of the Point Pelee Ridge is a fan-shaped delta-like body of sediments which crests at 11–12 meters below present lake level. This fan is recognizable downslope to a depth of 18 m and it extends as far south as the Pelee-Lorain Ridge. This feature has apparently been constructed by sediments brought onto the fan at a point directly east of the southern tip of the Point Pelee Ridge. Because of its crestal depth of 11–12 m we believe that this fan may have been principally formed at the time when lake level was at about 10–15 m lower than at present, prior to deposition of the shallower 3500 y B.P.-to-present sands on the Point Pelee Ridge. If this fan is in fact a relict shoreline feature, it may have been formed by the Detroit River when the Port Huron outlet was first opened up and the newly formed Detroit River was eroding its channel and bringing a heavy load of sediment into Lake Erie. At about the same time or perhaps soon afterward, sands were being deposited in the main postglacial channel in the Western Basin, also as a result of heavy sediment influx from the Detroit River (Herdendorf and Bailey 1989); these sediments filled the channel and spilled over into a large part of the Western Basin, mostly eliminating topographic expression of the
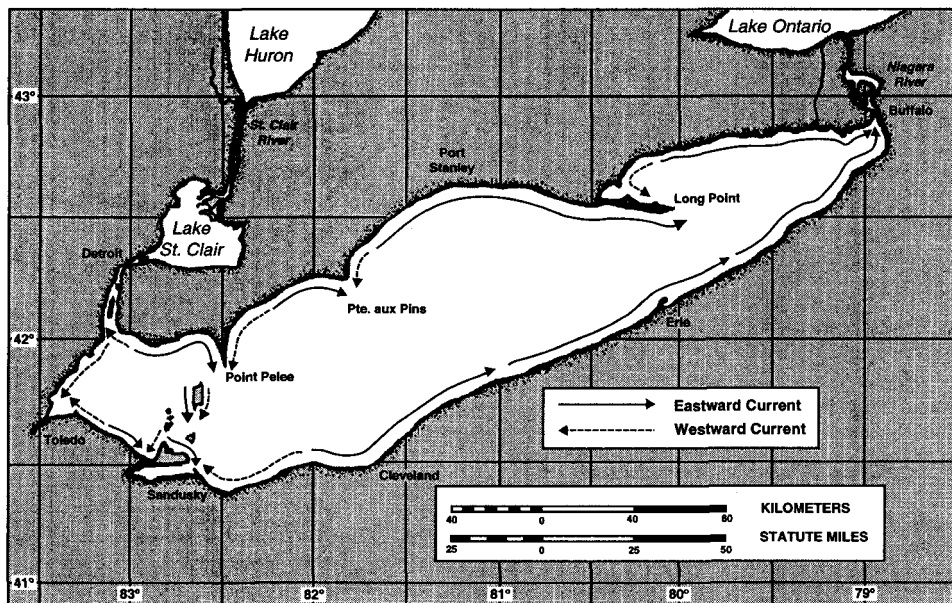
FIG. 5. *Directions of net longshore sediment drift along the shorelines of western Lake Erie (from Bolsenga and Herdendorf 1993).*

channel. Location of the main Detroit River Channel may have coincided with a trough in the till surface extending through the Western Basin as shown by Hobson *et al.* (1969), and by Herdendorf and Bailey (1989) (Fig. 6). Formation of the fan east of the Point Pelee Ridge as a relict shoreline feature probably began and ended when water levels were in the range of 15 to 11 meters lower than at present; active fan deposition would have ceased here when rising water levels flooded the Western Basin, extending westward the Lake Erie outlet of the Detroit River.

An alternate interpretation for formation of the Point Pelee Fan is that strong west-to-east currents have swept around the end of the Point Pelee Ridge and carried sediments formerly deposited on the ridge eastward. Another possible channel route for the early Detroit River is through the channels north of North Bass Island and Kelleys Island and through the Lorain Valley (Fig. 6).

It is noted that, whereas the delta of the St. Clair River is a well-developed feature extending into Lake St. Clair, no such comparable delta occurs at the mouth of the Detroit River. Apparently, at the time of opening of the Port Huron outlet, lake level in Lake St. Clair was very near its present level; in contrast to Lake Erie, where at this time lake level was 10–15 lower than at present.

WESTERN BASIN

Sculptured sediment drift-like features extend both NW and SE from the bedrock reefs (Locust Reef, Crib Reef, etc.) in the area just northeast of Locust Point, Ohio (Plate 1). These features are probably relict spits which formed in the last 4,000 years when rising water levels brought Lake Erie water up to levels 4 to 7 meters below present lake level, at which time the reefs and surrounding shallow areas formed headlands which were subject to erosion by wave action. Once water level rose sufficiently to drown the reef area headlands and remove them from the zone of intense wave action, spit formation ceased. The shallower southeastern relict spit, adjacent to a slightly higher-elevation part of the now-drowned headland, probably was the site of active deposition up to a more recent time than the northwestern spit. The relict spits and the former headland are underlain by sand and gravel at present (Herdendorf and Braidech 1972), in contrast to deeper parts of the western basin of Lake Erie. Apparently the reef area is still sufficiently shallow that strong water circulation prevents deposition of mud. It is noted that today the adjacent headland (Locust Point) is still a site of net longshore divergence (Fig. 5).

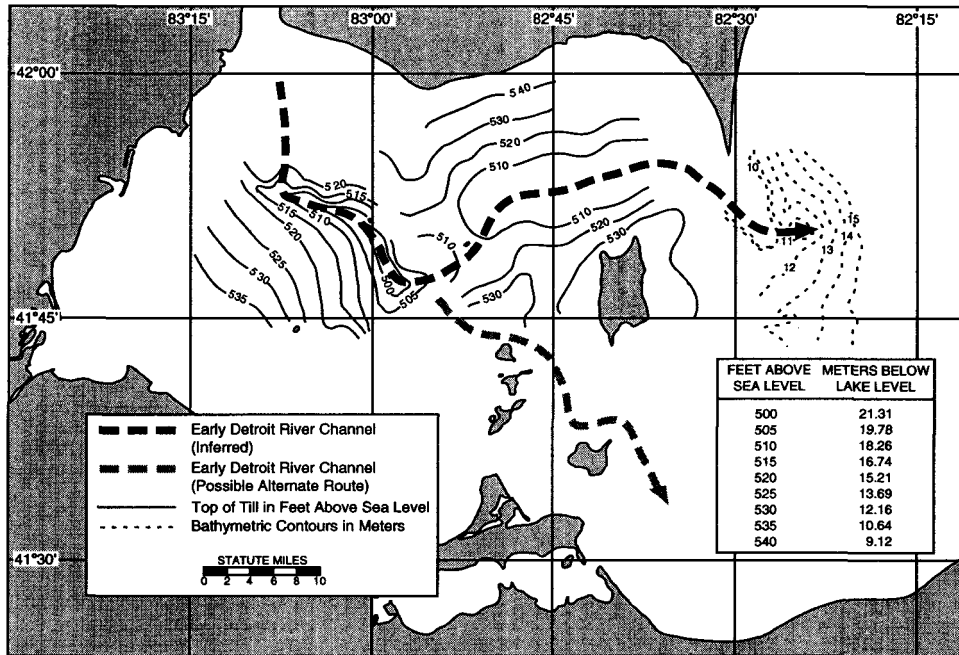Topographic lineations on the lake floor in the

FIG. 6. *Possible position of the former Detroit River channel and fan in western Lake Erie interpreted from maps of the surface topography of glacial till underlying the western Lake Erie basin (Hobson et al. 1969, Herdendorf and Bailey 1989), and by the bathymetry shown in Plate 1. Note that the channel is deep over less resistant strata of the Salina and Detroit River Groups, and shallows where it crosses the more resistant Bass Islands Group and the Columbus/Dundee Limestone (compare with Fig. 2). An alternate possible Detroit River channel leading through the channels north of North Bass Island and Kelleys Island, and through the Lorain Valley, is also shown.*

bay between Locust Point and Catawba Island are parallel to the system of bedrock lineations which are evident in channels between islands and which also occur on land in adjacent areas of Ohio, resulting in the well-defined trellis drainage pattern.

A fan-shaped sediment accumulation occurs off the Maumee River (Plate 1), which has been a significant deposition site for fluvial sediments brought into Lake Erie following glaciation and at present. This fan probably began forming at its present location only after the most recent rise of Lake Erie water into this area. It has obviously been shaped not only by sediments brought in by the river and deposited, but also by sands brought onto the fan by longshore sediment drift. Two spits partially enclose Maumee Bay, one which extends southeastward from the north shore, and one which extends northwestward from the south shore. These

two spits do not meet but instead extend past one another, the south shore spit being positioned farther offshore than the north shore spit. The natural offshore extension of the Maumee River Channel apparently swings southward around the southern end of the north shore spit, then northward around the northern end of the south shore spit, crossing twice the dredged channel leading into Toledo Harbor. Position of the Maumee River Channel is obviously a consequence of formation of the spits. Hartley (1960) reports mostly silt/clay muds in the channel area between the spits. The spits are built of sand and gravel deposits, obviously the result of converging net longshore transport of sand and gravel along the lake shores toward Maumee Bay (Fig. 5). Sand and gravel deposits were evidently continuous between Cedar Point and Turtle Island until dredging of the Toledo Channel separated Tur-

tle Island from the rest of the spit. Therefore, the Turtle Island segment of the spit is probably no longer the site of active sand and gravel accumulation. Instead, sand being transported northwestward along the shore is probably accumulating in the Toledo channel itself.

RECENT ANTHROPOGENIC RELIEF

Dual parallel channels underlie the main shipping lanes in the western basin, coinciding with eastbound and westbound lanes where the lanes are separated by 1.2 kilometers and ship traffic can increase speed (and propeller rpms) (Plate 1). These channels, which extend across the basin floor at depths well in excess of dredged channel depth, are the result of resuspension of sediments due to propeller wash. Confirmation was obtained by (1) overflying a large freighter, courtesy of the U. S. Coast Guard, and photographing the muddy wake which extended for miles behind the ship, and (2) taking note of other eyewitness accounts. Surficial sediments underlying the western basin are described as unconsolidated muds with a high fluid content. Similar side-by-side channels which occur underneath the shipping lanes leading south from the Detroit River to Toledo may also be the result of propeller wash (Plate 1). Excavation of sediments from beneath shipping lanes is effective in this area, because much of the sediment resuspended in the wake is moved away from the shipping lane by currents before it can settle back through the water column and be redeposited.

A former dumpsite for dredge spoils north of the Toledo dredged channel in the extreme western part of the lake shows up clearly (Plate 1). This feature, approximately 3.2 km × 5.0 km in areal extent, is about double the area designated on the navigation chart (NOAA Chart no. 14830, 3/21/92), clearly suggesting that a large amount of dumping occurred well outside the designated dump area. Another discontinued dumpsite for harbor-channel dredgings is evident just west of the dredged west outer channel of the Detroit River. Both of these dumpsites are characterized by a distinctive small-scale hummocky topography. Three additional former dumpsites, one east of Marblehead Peninsula, one north of Huron Harbor, and one about 2 miles north of Vermilion Harbor, are much less apparent in the bathymetry or not seen at all. The lack of topographic expression for these sites may be due to the fact that these areas are under the influence of relatively strong bottom currents that move through the west-

ern basin via South Passage. The two remaining dumpsites shown on NOAA Chart no. 14830, 1992, are not represented by the bathymetry. One site north of Lorain was only actually used prior to the late 1930s, leaving over 30 years until the survey date of 1960 for the topographic expression to be removed by wave and current action. The other site, about 10 miles northwest of Vermilion, was only used from mid 1970 to 1991; no evidence of the dredge spoils is present in the bathymetry because no dumping had occurred when the survey for the area was conducted in 1960.

CONCLUSIONS

Western Lake Erie bedrock units consist of upper Silurian and lower Devonian dolomites, limestones, and shales which dip gently to the north and east around the northern end of the Findlay Arch. The islands and reefs bordering and lying within the western basin have bedrock cores which are erosional remnants of the more resistant strata. Natural channels occur in the straits between the Bass Islands and adjacent to these islands to the west. These channels owe their positions and trends to the prevailing east-west jointing in the bedrock and are sites of concentrated flow resulting from wind-driven water circulation. Topographic lineations on the lake floor in the bay between Locust Point and Catawba Island display the same east-west pattern as the island channels and the trellis stream drainage of the adjacent Ohio shore.

Topography-forming processes at work in western Lake Erie are strongly affected by wind-driven water circulation: the lake is shallow, it is frequently subject to strong winds blowing across its surface, predominantly from the west-southwest, and constricted passages are present which impede the flow of water into and out of the western lake basin.

The bathymetry reveals for the first time that the north end of the Pelee-Lorain Ridge, interpreted as an end moraine associated with a readvance of the retreating Wisconsin Ice Sheet, originates at the southern tip of Pelee Island and not at Point Pelee as previously suggested. A channel separates this ridge from the Ohio shore which is interpreted as the site of a subaerial stream which led from the islands area to the central basin during the postglacial time of lowered lake level. A well formed submerged delta-like feature occurs off the Black River which could alternately be an extension of the end moraine forming the Pelee-Lorain Ridge.

The Sandusky River drains a low-relief area underlain with mostly fine carbonates and shales while the Black River drains a higher relief area underlain by rock strata containing coarse sand, pebbles and gravel. These discrepancies may explain the different characteristics of the sand deposits found offshore in each area.

The Point Pelee Ridge, extending south-southeast of Point Pelee, has been interpreted as moraine associated with the Pelee-Lorain Ridge, on which sand deposits have been concentrated from about 3500 y B.P. to present. Subaerial extent of Point Pelee has diminished as a consequence of continued rising water levels. Sources for the sand deposits include in-place sand concentrated by winnowing of glacial till deposits, and sand from eroding till deposits exposed along the Ontario shore in both directions, with sand having been transported by net longshore drift converging on Point Pelee.

A fan-shaped delta-like body of sediments extends to the east of Point Pelee Ridge. With its top depth of 10–11 m and morphology distinct from the Point Pelee Ridge, this fan may have been a former delta of the Detroit River when the Port Huron outlet was first opened and the newly formed Detroit River was eroding its channel and bringing a heavy load of sediment into Lake Erie. Alternately, or at a different time, the early Detroit River may have flowed through the channel north of North Bass Island and Kelleys Island and through Lorain Channel.

Sculptured sediment drift-like features interpreted as relict spits extend both northwestward and southeastward from the bedrock reefs in the western basin off Locust Point. The spits probably formed when water level was 4 to 7 meters below present lake level, when the reefs and surrounding shallow areas formed a headland which was subject to erosion by wave action.

Position of the natural offshore extension of the Maumee River channel is interpreted as a consequence of the formation of two spits which partially enclose Maumee Bay. Transport of sand and gravel along the lake shores converging on Maumee Bay resulted in the deposits which make up the spits.

Channels are revealed in the western Lake Erie basin underlying the main shipping lanes in water depths exceeding the dredged channel depth limit of 8.5 meters. These channels have been excavated by propeller wash in the open shiplanes where ship traffic increases speed, resulting in resuspension of the highly fluid muds that make up the surficial sediments in the area. These resuspended muds

are then moved away from the shipping lanes by currents before much of the sediment can be redeposited.

Two discontinued dumpsites, one north of the Toledo dredged channel and one just west of the dredged west outer channel of the Detroit River, are expressed in the bathymetry by their distinctive hummocky patterns. Three other dumpsites, one east of Marblehead Peninsula, one north of Huron Harbor, and one about 2 miles north of Vermilion Harbor, are expressed to a lesser degree or not at all, probably due to the fact that these areas are under the influence of relatively strong bottom currents through South Passage.

One dumpsite, northwest of Vermilion, does not show up in the bathymetry because it was used after the bathymetric survey for this area was conducted. Another site, north of Lorain, was used in the late 1930s, about 30 years before the hydrographic survey was conducted, leaving a substantial period of time for wave and current action to remove topographic expression.

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