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PHYSICAL AND LIMNOLOGICAL CHARACTERISTICS OF NATURAL SPAWNING REEFS IN WESTERN LAKE ERIE

by

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INTRODUCTION

The recent resurgence of the walleye (*Stizostedion vitreum vitreum*) population has rekindled sport fishing interest in western Lake Erie. Each year for the past several years the number of recreational fishermen utilizing Lake Erie has greatly increased. Walleye have long been known for their abundance over gravel, bedrock and other types of firm bottoms, where the water is least turbid. The rock-bottomed reefs and shoals within the western Lake Erie island region are areas of particularly high concentrations of this species.

Walleye apparently rely on sight to find their prey (Regier et al. 1969). Efficient sight feeding, especially for a large fish seeking moving prey, requires sufficiently clear water to discern the prey at some distance. Such relatively clear water is found over the bedrock reefs in the island region. Experienced sport fishermen expect to find walleye concentrated around clean, hard bottoms, such as rocky reefs, gravel or clean sand, and at the edge of weed beds. Reefs are good feeding places for walleye. *Cladophora* beds (a filamentous green algae) harbor emerging insects and zooplankters. Zooplankton attract small fish, usually shiners, upon which walleye prey.

Scuba divers who have inspected reefs in western Lake Erie have observed walleye lying motionless on the rocky bottom during daylight. This daily "resting requirement" may tend to limit them to reefs and other hard bottoms. Silty or muddy bottoms with high organic concentrations tend to have lower oxygen concentrations. This is especially true during calm periods when currents and water mixing are slight. Walleye prefer not to rest in these areas because of their additional requirement for high oxygen concentrations.

Walleye commonly spawn over rock, rubble or gravel in streams, shallow offshore reefs or along shorelines of lakes (Eschmeyer 1950). Spawning runs of walleye persist in only two major Ohio streams, the Sandusky and Maumee Rivers. In the 1800's and the early part of this century many of the lake's other tributaries were productive spawning sites (Langlois 1954), but the construction of dams, siltation, excessive pollution and irregularity of stream flow due to man's activities have destroyed spawning sites. Today, the major existing spawning grounds in the Erie Basin are found on the reefs of the island region. These reefs are free from oxygen-consuming mud.

Researchers have postulated that walleye fry imprint some essential characteristics of their birthplace and that most sexually mature adults return to that birthplace to spawn. These factors would also favor the continued utilization of the reefs by future walleye populations.

In addition to walleye, at least five other sport fish species are known to be associated with the reefs and rocky shoreline areas of western Lake Erie (Trautman 1957 and 1981): yellow perch (*Perca flavescens*), white bass (*Morone chrysops*), channel catfish (*Ictalurus punctatus*), smallmouth bass (*Micropterus dolomieui*) and freshwater drum (*Aplodinotus grunniens*). Baker (1980) lists the best fishing areas and times for these species.

During the period 1967 to 1970, the Ohio Department of Natural Resources, Division of Geological Survey conducted a cooperative study with the U.S. Fish and Wildlife Service (Anadromous Fish Program, Project Ohio AFCS-1) to determine the physical characteristics of the reefs and surrounding areas in western Lake Erie (Figure 1). This investigation was undertaken to provide State and Federal fisheries biologists with information in support of their resource management programs, paticularly as the physical makeup of the reef area relates to the spawning, nursery, and feeding grounds of important sport and commercial fish species. The information contained in this paper has been derived largely from the results of this study (Herdendorf 1968, 1970, and 1980 and Herdendorf and Braidech 1972). The purpose of this paper is to present information on natural reefs in Lake Erie, in the hope that these data will be useful in planning the placement and configuration of artificial reefs in other areas of the Great Lakes.

LAKE ERIE REEF AREA

The western Lake Erie reef area (sometimes referred to as the Island Region) encompasses that part of western Lake Erie between longitude 82°37'W to 83°08'W and south from latitude 41°45'N (west of the Bass Islands) or the international boundary (east of the Bass Islands) to the Ohio mainland shore. The region is roughly bounded on the northwest by West Sister Island, on the north by North Bass Island, on the northeast by Middle Island, on the east by Kelleys Island, on the southeast by Cedar Point, on the south by the Ohio mainland and on the southwest by Locust Point. This is an area consisting of approximately 940 km^2, including 24.6 km^2 of islands (Figure 1).

In contrast with the other basins of Lake Erie (central and eastern), a number of bedrock islands, reefs and shoals are situated in the western basin. These form a partial divide between the western and central basins. The entire western basin (west of a line from Pelee Point, Ontario to Cedar Point, Ohio) has an area of 3275 km^2, 13 percent of Lake Erie. However, its volume, at 24.2 km^3, is only 5 percent of the volume of the entire lake because of its shallowness. The average depth of the western basin is only 7.3 m. The lake bottom is quite flat except for the sharply rising islands and reefs.

In the western half of the island region the lake bottom slopes gently lakeward from the mainland shoreline at 0.6 m/km. Between the Bass Islands and Kelleys Island this slope is 1.2 m/km and it increases to 2.9 m/km lakeward of Cedar Point. The steepest bottom slopes are found near the islands and reefs. In South Passage the bottom gradient exceeds 11.4 m/km. The maximum depths in the region are found in the inter-island channels. The deepest sounding, 19 m, was made in a small depression north of Starve Island Reef. Another depression north of Gull Island Shoal is 17 m deep. Elsewhere in the region "deeps" do not exceed 14 m.

The islands and reefs are arranged in three roughly north-south belts. The most westerly belt lies north of Locust Point and includes at least 12 reefs and West Sister Island. The middle belt extends from Catawba Island (peninsula) through the Bass Islands and consists of at least 14 reefs and 10 islands. The early belt encompasses Marblehead peninsula, Kelleys Island and at least 7 reefs. This arrangement of the islands and reefs seems to be controlled mainly by the gentle folding structure of the underlying bedrock and its relative resistance to weathering.

The shores of all the islands are rockbound and rugged, with bluffs along the majority of the island coasts. The highest elevations are normally on the west shore, except for West Sister Island, where the bluffs are highest along the east shore. The west shore of South Bass Island reaches a height of 21 m above the mean lake level, the highest elevation in the island region. Small beaches composed of sand, cobbles or boulders are found at indentations in the shoreline. The most extensive sand beach lies along the north bay of Kelleys Island.

DEFINITION OF A LAKE ERIE REEF

The Ohio Revised Code, Section 1531.01 (DD), defines reef as:

> "an elevation of rock, either broken or in place, or gravel shown by the latest United States chart to be above the common level of the surrounding bottom of the lake, other than the rock botom, either broken or in place, forming the base or foundation rock of an island or mainland and sloping from the shore thereof."

A reef also means,

> "all elevations shown by such chart to be above the common level of such sloping base or foundation rock of an island or mainland, whether runing from the shore of an island or parallel with the contour of the shore of an island or in any other way, whether formed by rock, broken or in place, or from gravel."

Definition (CC) of the same section of the Ohio Revised Code describes an island as:

> "a rock or land elevation above the water of Lake Erie having an area of five or more acres above water."

The Ohio Revised Code does not define the word shoal. However, the National Ocean Survey charts use the terms reef and shoal for similar topographic features and they are considered synonymous in the paper.

Using the legal definition as a guide, there are over 30 reefs or reef clusters shown on National Ocean Survey charts of the island region, but only 8 of these are officially named. For convenience, the other prominent reefs are labeled on Figure 2 with names used by local fishermen.

Thirteen of these reefs were selected for special study by the Ohio Department of Natural Resources, Division of Geological Survey (Herdendorf and Braidech 1972). Depth soundings were made with a recording echo sounder and detailed bathymetric (depth contour) maps were constructed for each reef. The surface acres for each one-foot depth interval for these reefs are given in Table 1. A bathymetric map for Gull Island Shoal is presented in Figure 3 as an example of the complex nature of a reef top. Detailed maps for the other reefs may be obtained from the Ohio Division of Geological Survey, Fountain Square, Columbus, Ohio 43224.

PHYSICAL CHARACTERISTICS

The least depths over the reefs range from 0.3 m above low water datum (173.3 m above mean water level in the Gulf of St. Lawrence at Father Point, Quebec) for Gull Island Shoal to 9 m below this datum for Northwest Reef. The mean water level for Lake Erie is approximately 0.6 m above this datum. Most of the reefs are conical in shape and elongated, as are many of the islands, in a northeast-southwest direction. Two factors appear to have influenced this elongation: (1) vertical joint systems in the bedrock are oriented parallel to the elongation (Hartley 1962) and (2) the major movements of glacial ice, as deduced from grooves found on most of the islands, was from northeast to southwest.

Typically, the reefs consist of bedrock (limestone and dolomite deposited during the Devonian and Silurian Periods, 350-425 million years ago) and associated rock rubble and gravel (Figure 4). The topography of the reef tops ranges from rugged surfaces caused by bedrock pinnacles and large boulders to smooth slabs of horizontally bedded rock. In places the submerged bedrock has the appearance of low stairs, with the steps dipping slightly to the east from the fringe of the reef to its crest.

Because all of the bedrock formations that form the reefs are carbonate material, abundant solution cavities, many up to 1 or 2 cm in diameter, have formed in the rocks. These cavities are important features in that they are often the site of walleye egg deposition. Eggs held in these depressions are protected from wave attack and strong currents which could wash them onto soft sediment beds where they could be smothered.

The bedrock core of the reef is commonly masked by rubble composed of both local (broken fragments of the bedrock) and glacial origin, ranging from small pebbles to boulders up to 1.5 m in diameter. On the upper portions of the reefs, isolated patches of sand and gravel commonly fill vertical joint cracks and small depressions in the bedrock; at the fringes of the reefs sand and gravel or glacial till lap over the rock. Glacial till consists of a random mixture of gravel, sand, silt and clay.

In 1964, the author made a number of underwater observations of the bedrock reefs and shoals in western Lake Erie. The objective of this investigation was to determine the extent and character of the rock on the lake bottom, particularly to relate surface features to solution processes, water movements and utilization by aquatic organisms. SCUBA dives were made from the Ohio Geological Survey research boat GS-1 on seven major reefs: Ennis Reef, Gull Island Shoal, Kelleys Island Shoal, Niagara Reef, Starve Island Reef, Toussaint Reef and West Reef. The previously unpublished results of these observations are presented below:

Ennis Reef

Ennis Reef is located on the International Boundary approximately 3.2 km NNW of North Bass Island. The reef is elongated east-west with the majority of its area in Canada. Its dimensions are roughly 1000 m by 300 m with a least depth of 4 m below low water datum.

Diving was done July 7 at 1145 hrs in 6-7 m of water, visibility was good, 2-3 m, and surface water temperature was 24°C. The bottom is composed of pebbles and cobbles lying on sheets of bedrock that are exposed as patches of barren rock. The cobbles are composed of Silurian dolomite (Tymoctee Dolomite). It has a weak HCl acid reaction and contains no fossil. Most of the cobbles are angular with some being sub-rounded on the edges. The dolomite is fine-grained, medium soft, yellow-brown on fresh surfaces and weathers to a reddish-brown. Solution cavities 1.3 cm in diameter and over 2.5 cm deep are common on most of the cobbles; some of the cavities extend completely through the cobbles giving them a very porous appearance. The exposed slabs of bedrock still in place have sharp, raised features up to 1.3 cm high. "In situ" bedrock apparently makes up only a minor percentage of the bottom.

The bottom fauna observed included freshwater drum (Aplodinotus grunniens), unionid clams and various snails.

Gull Island Shoal

Gull Island Shoal lies 4.8 km north of Kelleys Island near the International Boundary. It is 2.4 km long, nearly 1.2 km wide and is roughly triangular-shaped with the steepest point toward the NE. During normal (mean) water levels two small islands are above water.

Investigation of the shoal was made on June 23 at 1100 hrs in the vicinity of the islands and to the east. The larger island is 45-60 m long, 9-12 m wide, and 0.5-1 m high with a north-south elongation. A long, narrow spit at the south end of the island is made up of large glacial erratics of igneous material. The remainder of the island is composed of boulders, cobbles and pebbles of Devonian limestone (Columbus Limestone) with numerous coral fossils including Favosites, Hexagonaria and Synaptophyllum. The shoreline on the west side has small amounts of sand and gravel. Approaching this island from the east, the bottom for about 100 m offshore is a slab of bedrock lacking in solution cavities or a covering of rubble debris. Filamentous algae (Cladophora) are common in this area. Near the shore the bottom is composed of rounded limestone pebbles and cobbles.

The smaller island trends east-west and is separated from the larger by a channel 1.5 m deep and 100 m wide. This island is 30 m long and about 8 m wide with a long, narrow spit extending to the east and covered by a few inches of water. The spit is made up of mixed pebbles and gravel of limestone and igneous erratics. The main part of the island is limestone and rises slightly above water level. None of the large erratics noted on the larger island were observed on the smaller. Eastward from the spit the bottom drops off very rapidly to 1.5 m deep and is composed of rubble between the islands except for a 3 m long slab of bedrock near the channel's center.

The cobbles and pebbles on the bottom are coarse, crystalline limestone that are lacking in solution cavities. The limestone is light, gray-brown in color and contains numerous calcite crystals. Most of the cobbles are smooth, well-rounded and very fossiliferous.

Kelleys Island Shoal

Kelleys Island Shoal is located about 2.4 km NE of Long Point of Kelleys Island. In outline, the shoal is somewhat "L"-shaped with the ends trending south and east. The shoal is 2500 m long and 600 m wide with a least depth of 0.6 m below low water datum.

Diving was done on July 30 at 1000 hrs in 3-4 m of water. Visibility was only fair, 1-2 m. The southeast edge of the shoal is composed of limestone and dolomite rubble (Columbus Limestone and Lucus Dolomite). Northward, thin-bedded layers of Devonian dolomite (Lucus Dolomite) forms the bottom. The rubble is angular pebbles, cobbles, and boulders of fine-grained, buff-colored dolomite and coarse-grained, gray limestone. The cobbles contain numerous solution cavities up to 1.3 cm deep but none completely through the rock. The rock is medium hard and non-fossiliferous. The bedrock layers dip SSE at 5^{o}-10^{o} and have low step-like appearance toward the north. The top of the bedrock has a solution cavity surface similar to that of the rubble.

Niagara Reef

Niagara Reef lies approximately 17 km NNW of Port Clinton and 13 km west of Put-in-Bay. The reef is nearly circular with a diameter of 1500 m and least depth of 1 m.

SCUBA diving was performed on June 17 at 1600 hrs in 3 m of water. The bottom is covered with cobbles and boulders of Silurian dolomite (Greenfield Dolomite). Bedrock is exposed only as small patches of flat rock with numerous raised features. The dolomite is hard, massive fine-grained and gray-brown in color. The cobbles are angular and contain numerous shallow solution cavities from 0.6 to 1.3 cm deep.

Starve Island Reef

Starve Island Reef is located one mile SSE of Starve Island and 8 km west of Kelleys Island. It is the smallest of the reefs investigated, less than 500 m in diameter, and circular in outline. The least depth over the reef is 2.1 m below low water datum.

Diving was done on July 30 at 1300 to 1400 hrs in 6 m and 3 m of water. At 6 m the bottom is composed of coarse sand, gravel, pebbles and cobbles. The sand and gravel contain numerous glacial erratics. Some silty material was found between the cobbles and in dead clam shells. The cobbles are composed of hard, fine-grained dolomite (Put-in-Bay Dolomite). The dolomite cobbles are angular to sub-rounded and contain some small solution cavities.

At 3 m the bottom material is coarser: pebbles, cobbles and boulders with only a little gravel. None or only small solution cavities 0.6 to 1.3 cm deep were noted on dolomite cobbles. Well-rounded igneous erratics of cobble size are common and have no solution cavities. The dolomite is hard, coarse-grained, medium gray on fresh surfaces and yellow-brown where weathered. No "in situ" bedrock was observed.

The visibility was poor, 0.5 m, and no fish or live clams were observed; only a few live snails were noted.

Toussaint Reef

Toussaint Reef is about 4.8 km SW of Niagara Reef and 14.5 km NW of Port Clinton. The reef is 1200 m long, 300 m wide and elongated northeast and southwest. The least depth over the reef is 1 m below low water datum.

SCUBA diving was performed on July 30 at 1600 hrs in water 3-4 m deep. The bottom is composed of medium soft Silurian dolomite (Greenfield Dolomite), pebbles, cobbles and boulders. The dolomite rubble is reddish- to yellow-brown, angular to sub-rounded and nonfossiliferous. The soft, weathered dolomite rocks contain deep solution cavities and the harder pieces contain none. Some sand and gravel was noted between the coarser material.

Large area of bedrock slabs occur in shallower water north of the rubble area. Here the surface is rough because of sharp raised features rather than solution cavities. Large rectangular boulders and cobbles are common but not numerous over the bedrock area.

The visibility was only fair, 1 m. The bottom is covered with a thin silty layer which was easily stirred up. The rubble area is similar in appearance to that of Niagara Reef.

West Reef

West Reef lies 1.6 km west of North Bass Island. The reef is roughly circular in shape with a diameter of about 1000 m. The least depth over the reef is 1.5 m below low water datum.

Diving on West Reef was done on July 9 at 1500 hrs in 3-4 m of water. The bottom is composed of gravel, pebbles, cobbles and boulders of Silurian dolomite (Tymochtee Dolomite). No bedrock was noted. The dolomite rubbles are fine-grained, gray to yellow-brown with yellow band, angular, hard and often lath-shaped. Solution cavities are not as abundant as at Ennis Reef, but they are quite common. The average cavity is 1.3 cm deep and 1.3 cm in diameter.

An abundant bottom fauna of unionid clams, snails and flora of ilamentous algae (Cladophora) was observed. The visibility was good, 2-3 m.

From this very brief survey of the reefs in western Lake Erie it is impossible to draw any definite conclusion. However, the following general trends appear evident:

1) dolomite reefs appear to be more readily affected by solutioning than limestone reefs;

2) soft, fine-grained dolomite appears to be more readily affected by solutioning than hard, coarse-grained dolomite;

3) reefs with abundant solution cavities and angular fragments appear to be more prolific in bottom fauna than areas of smooth bedrock; and

4) shallower areas appear to be more affected by wave action, hence more rounding and less affected by solutionging, hence less solution cavities.

LAKE SEDIMENTS

The unconsolidated sediments within the island region were deposited by glaciers and prehistoric lakes. During the Pleistocene Epoch, or "ice age," the region was covered by several continental ice sheets and later by a series of glacial lakes, resulting in the deposition of glacial till followed by the deposition of lake sediments. The surface over which the glaciers moved was a stream-cut terrain underlain by Devonian and Silurian bedrock. Glaciation moderately scoured the rock surface during the ice advance, forming features such as the spectacular grooves on Kelleys Island. It also buried much of the preglacial topography under a blanket of till. Lacustrine (lake) sediments, largely fine sand, silt, clay and organic deposits such as peat, now cover most of the till and bedrock. Bedrock comprises only 6 percent of the bottom surface in the island region. Gravel accounts for another 9 percent, sand for 26 percent and silt/clay mud for 59 percent of the lake bottom (Figure 4). Peat is a minor constituent found locally in nearshore areas at Cedar Point and Locust Point. These deposits consist of organic material which accumulated in marshy areas between the shoreline and offshore barrier beaches. Shoreward migration of the beaches has left the peat deposits in their present, open-water position.

Consequently, it can be seen that a relatively small percentage of the water area of the island region is underlain by bottom types preferred by walleye. Therefore, careful selection of fishing sites should yield the best results.

SEDIMENT DEPOSITON AND RESUSPENSION

Recent multispectral scanner images of the western basin of Lake Erie indicate large masses of turbid water along the south shore and in the islands area are most often associated with high tributary flow (Figure 5). However, several images taken during periods of relatively low tributary flows, when the introduction of sediment to the basin from these sources was at a minimum, also show turbid water in the reef area. The turbid masses have been correlated with wind storms and associated waves which have resuspended bottom sediments in the shallow water areas of the basin. Data gathered by the Ohio Department of Natural Resources, Division of Geological Survey (Herdendorf 1968, Herdendorf and Braidech 1972) have been reanalyzed in an attempt to quantify the magnitude of sediment resuspension in the reef area during the spring, summer and early fall months.

Premise and Methods

Annual sedimentation can be expressed by the simple equation:

$$S = D - R,$$

where S is net sedimentation, D is the total material deposited and R is the material lost through sediment resuspension or erosion. Data obtained from sediment collection devices placed on several bedrock reefs and shoals in the western basin of Lake Erie (Figure 6) indicated that a considerable amount of material (over 200 mm annually) was deposited during the spring, summer and fall of 1967, 1968, and 1969. However, information gathered during SCUBA diver surveys of the reefs shows that the sediment veneer over the bedrock is seldom greater than a few millimeters and is commonly absent. Therefore, if sedimentation in the above formula is considered to be zero, then sediment resuspension would be equal to the sediment deposited (material retained in the collection devices). Based on this premise the quantity of sediment resuspension in the western basin has been calculated.

The sediment collection devices (Figure 7) used to measure deposition/resuspension consisted of 2-liter wide-mouth Nalgene jars fitted with 40 cm-long drop tubes. The drop tubes were constructed of 54 mm-diameter PVC plastic tubing. To insure stability of the collectors while underwater, they were placed in a frame constructed of steel rods which were welded to a base plate. The plate, in turn, was secured to a 150 kg steel platform. Each platform held two collectors. On station, the collectors were filled with water and the platform was fitted with a marker buoy and lowered to the bottom. The collectors were normally retrieved bimonthly (April-October) and the platforms reset with fresh collection jars. Collected sediment was measured and analyzed for grain size by sieve and hydrometer methods. Selected samples were analyzed for percent volatile solids on ignition as an indicator of organic content.

Deposition and Resuspension

Data from sediment collectors on six reefs indicate that a considerable amount of material was deposited during the spring, summer, and fall of 1967, 1968, and 1969. The amount of sediment deposited during 16 periods of collection on Starve Island Reef, 11 on Crib, Toussaint, and West Reef, 10 on Kelleys Island Shoal, and 9 on Gull Island Shoal was monitored. Information from collectors set in deep water southwest of Gull Island Shoal for 3 periods of collection and another set in deep water 1.6 km southwest of Gull Island Shoal for 6 periods was also obtained. During the approximately 102-day study in 1967, an average thickness of 1.0 mm/day of material was deposited. In 1968 the 173-day study yielded an average of 1.4 mm/day. A 175-day study in 1969 indicated an average rate of 1.0 mm/day for the reefs and 1.4 mm/day at the deepwater stations. Data from the deepwater collectors appear to be more indicative of permanent sedimentation.

Considerable variation was noted in the amounts of sediment collected on the individual reefs. Toussaint Reef, which is only 5.6 km from the shoreline and is near the mouth of the Toussaint River, received the most sediment, over twice the amount that was collected on West Reef, Gull Island Shoal, or Kelleys Island Shoal, the reefs located the farthest from the mainland. Starve Island Reef, located in South Passge, received the second highest amount of sediment. This is probably due to its proximity to the Portage River flow and to the fact that high velocity currents in the constricted passge are capable of carrying more and larger particles. Crib Reef, only 2.1 km of Toussaint Reef, received considerably less sediment than Toussaint, indicating a shoreward source area for the sediment.

Seasonal variations in the deposition rates are also conspicuous. The spring deposition rate on Toussaint Reef was over 2 mm/day, but the summer rate was only 1 mm/day (Figures 8 and 9). In 1967 and 1968 the other reefs showed similar patterns, with a progressive decrease in the amount of sediment collected from May to August. In 1968, a sharp rise in the rates ws noted in the fall. Data from 1969 do not show as distinct a pattern but in general the trends are the same except for a high peak in early July at two of the stations (Figure 10). This peak correlates with a severe storm that occurred on July 4, 1969, which may have caused significant resuspension of bottom sediment.

The results of grain size analyses of material obtained from the 1967 sediment collectors are given in Table 2. In 1967, over 50 percent of the collected sediment on each reef fell between 20 and 45 microns in diameter, the medium and coarse grades of silt. The highest percentages of sand were deposited in the spring. The high-velocity currents in South Passage may explain the 11.2 percent sand, the highest recorded, found in the spring collections at Starve Island Reef. Only small percentages of clay-sized particles were found in the spring samples; however, both Starve Island Reef and Toussaint Reef yielded fairly high percentages of clay during the summer. The trend of coarser sediment in the spring and finer material in the summer and fall was common to all the reefs. Similar patterns were observed for 1968 and 1969 samples.

Volatile-solids determinations (Table 2) indicate that contemporary sediments average about 10 percent organic matter. The highest concentration occurred on West Reef, the reef farthest from the mainland. The next highest concentration occurred on Crib Reef, the shallowest reef and the one with the most noticeable growth of filamentous green algae. An interesting peak in the percentage of volatile solids on both Starve Island and West Reef was noted for the period June 2-26, 1967. The increase in organic content corresponds to the period immediately following the spring plankton bloom when the remains would settle and become incorporated in the bottom sediments. A similar peak occurred for Crib Reef, but not until the following collection period, June 26 to July 10, 1967. Toussaint Reef showed a general increase in organic content throughout the 1967 period of collection.

Based on the observations that virtually all of the material deposited on the reefs was eventually resuspended, it is possible to estimate the rate and amount of resuspension in western Lake Erie. Considering the portion of the basin most susceptible to this process (Maumee Bay eastward through the island area to the central basin at water depths less than 8 m), approximately 600 km^2 or a water volume of 2.7×10^9 m^3 are affected. Also considering a mean deposition rate of 1.0 mm per day, a mean water depth of 4 meters, and assuming that resuspension occurs at least as fast as deposition (this is probably a minimum rate assumption), this would produce a resuspension concentration of 250 mg/l or a quanitity of 6.75×10^5 metric tons of sediment within a single day.

LAKE CURRENTS

Lake currents were measured at 68 stations in the island region under various wind conditions during a 10-year period (Herdendorf 1970). The data from these measurements were plotted to create generalized current maps (Figure 11). One of the most striking features of these plots is that winds from any direction will normally drive surface currents downwind, while subsurface currents are often opposed to the wind. To compensate for the loss of surface water blown downwind, a returning flow of water is created along the bottom. Wind direction, bottom topography and shoreline configuration appear to be the major factors controlling current patterns.

The average recorded velocity for surface and bottom currents was 14.4 cm/sec and 7.7 cm/sec, respectively. The highest velocities were found in restricted areas such as inter-island channels and in the vicinity of reefs. Currents in excess of 25 cm/sec were found at 35 percent of the stations, while currents above 50 cm/sec were measured at only one station.

WATER QUALITY

Suspended sediments and associated chemical contaminants in the reef area of western Lake Erie originate from at least four sources: 1) land runoff and channel erosion via tributaries, 2) resuspension of bottom sediments and erosion of shore material by wave action, 3) vessel operation, including dredging and 4) atmospheric contributions. Because the Maumee River is one of the major contributors of sediment and chemical contaminants the high level of these materials has been suspected of having a profound effect on the western basin of Lake Erie (Table 3).

In the spring of 1976 (late February to June) a series of water quality surveys were conducted in western Lake Erie. The following discussion of the results of this study will serve to illustrate the general water quality conditions in the reef area during the critical spawning period for many Lake Erie fish species.

Water Temperature

Late February temperatures show Maumee Bay water at 5°C warmer than Detroit River flow. The Maumee River appears to be influencing the Michigan and Ohio nearshore areas. By mid-March the warming trend had spread westward to the islands area but the northern portion of the Michigan shore remained at a minimum temperature. April and May temperature contours (Figure 12) show the classical pattern of cooler Detroit River flow penetrating deeply into the western basin and the small area of warmer water influenced by the Maumee River.

Conductivity

Conductivity is a reliable indicator of dissolved contaminants in tributary discharge and it is sueful in tracing flow patterns within the lake. In late February Maumee River flow was about 33 percent more mineralized than mid-basin water and appeared to be flowing northward along the Michigan shore and southeastward along the Ohio shore. In early March (Figure 13) this trend continued with the mid-basin being influenced by the Detroit River. The conductivity patterns for mid-April show the sweep of Ohio shore water masses northeastward through the islands area. The low-conductance water of the Detroit River was three times lower in mineralization than the Maumee River.

Suspended Solids

The late February survey of suspended solids shows the effect of peak Maumee River discharge with highly turbid conditions in Maumee Bay and adjacent portions of western Lake Erie. The early March survey shows the moderately high concentrations of solids in the Ohio and Michigan nearshore areas. The mid-April survey indicates sediment resuspension along the Ohio shore and west of the Bass Islands. The northern portion of the Michigan shore shows the influence of the less turbid Detroit River flow. By the later part of April (Figure 14) the turbid water had moved progressively eastward into the islands area. The mid-May survey indicates a significant clearing of the western basin water. In February the highest concentrations of the volatile, largely organic, fraction of the suspended solids were found in Maumee Bay and the adjacent shorelines indicating a high discharge of organic debris. In mid-April an additional high concentration occurred west of the Bass Islands possibly indicating high algae (diatoms) populations.

Phosphorus

The early March (Figure 15) survey illustrates the typical phosphorus pattern in the western basin of Lake Erie. The Maumee River was discharging water containing over 900 ppb of total phosphorus (Table 3) while the Detroit River concentration was less than 50 ppb. The Detroit River flow penetrated deeply into the basin, encountering the Ohio shore near Locust Point. The area of sediment resuspension appears to be confined to the areas of greater than 100 ppb of total phosphorus.

Chlorophyll

Chlorophyll _a_ contour patterns for late February and mid-April (Figure 16) are similar to the patterns for volatile suspended solids. This is particularly the case along the Michigan shore and west of the Bass Islands where concentrations are high, indicating a high rate of primary productivity. These areas are also supplied with high nutrient concentrations from the Maumee River which further fosters algal growth.

Trace Metals

Trace metals surveys for cadmium, chromium, copper, lead, mercury, nickel and zinc were conducted during peak runoff in late February and early

March. All of the metals, except cadmium, show a definite gradient from high concentration in the Maumee River to low concentration in the middle portion of the western basin. Mercury (Figure 17) and zinc concentrations decreased rapidly in a lakeward direction from Maumee Bay in February during peak flow. However, in early March this is less discernible as the flow of the Maumee decreased and the flow of the Detroit River reached its peak. Metals contamination of western Lake Erie by these two tributaries appears to be significant, but concentrations diminish in the vicinity of the reefs.

CONCLUSIONS

All of the submerged rock exposures within the reef area project above the surrounding bottom, and are generally swept clean of sediments by the currents. The relatively clean surface indicates that no permanent sedimentation is taking place on the reefs. However, sediment collectors that have been mounted on the reefs indicate that a considerable amount of sediment is being transported over the reefs to be deposited in deeper water. Because the reefs project above the bottom, they are generally areas of higher energy due to the forces of waves and currents. The habitat created closely simulates the environment found in the riffles of streams. Several fish species, particularly the walleye which commonly spawns in streams, appear to have enjoyed success in Lake Erie because of the availability of this type of habitat.

If artificial reefs of similar materials and configurations were to be constructed in other parts of the Great Lakes, particularly the central basin of Lake Erie, it is anticipated that they would also significantly enhance the fishery.

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Tables

Depth (feet)	Cone Reef	Crib Reef	Gull Island Shoal	Kelleys Island Shoal	Lakeside Reef	Little Pickerel Reef	Locust Point Reef	Middle Harbor Reef	Mouse Island Reef	Niagara Reef	Round Reef	Scott Point Shoal	Starve Island Reef	Toussaint Reef	West Reef
above 0			1.8												
0-1			4.0					0.1							
1-2		0.2	5.3					1.3							
2-3		0.9	21.9	0.1				2.4							
3-4		2.2	19.1	0.6				0.8		0.1				0.1	0.8
4-5		2.8	21.6	0.8			0.1	7.3		0.4				0.1	0.1
5-6		5.0	15.9	1.8			0.4	6.8		0.7				2.3	1.6
6-7		2.9	13.8	5.1			3.2	6.3		1.4	0.1			11.9	5.8
7-8		9.0	15.7	11.7			10.2	6.8		2.7	0.6		0.1	11.8	5.8
8-9		10.3	17.9	23.2			16.4	6.9		5.4	5.5		0.4	13.6	9.7
9-10		9.5	25.8	43.1			13.9	6.9	0.1	7.0	8.9		0.5	17.3	12.5
10-11	0.1	14.7	23.9	24.0			15.8	20.8	0.6	6.1	19.1	0.4	0.5	24.0	
11-12	1.4	17.8	22.0	20.4			22.6	30.3	1.2	9.5	16.9	1.1	0.5		
12-13	9.2	20.5	34.3	18.0	0.1		23.9	42.7	4.2	17.2	16.7	5.1	0.6		
13-14	8.5	42.0	32.2	17.3	0.1			90.3	4.7	14.0		11.8	0.7		
14-15	9.2	48.2	28.3	15.5	0.1			116.1	4.3	13.8		14.5	0.8		
15-16	12.1		22.6	17.9	0.5	0.1			5.1	10.9		27.2	0.7		
16-17	12.2		21.4	16.0	1.3	0.3			5.6	10.7		30.1	1.6		
17-18	10.7		21.2	26.4	2.5	2.2			6.0	14.1		46.2	1.8		
18-19	15.0		32.8	26.2	6.2	2.1			7.5	25.4		67.5	3.8		
19-20	19.0		30.4	30.4	4.9	6.8			5.4	37.1		71.2	5.7		
20-21				30.2		12.5						87.3			
21-22				36.6		9.9									
22-23				34.8											
23-24				36.1											
24-25				34.2											
Totals	97.4	186.0	431.9	470.4	15.5	33.8	106.6	345.8	44.2	176.5	67.8	362.4	17.7	81.1	36.3

Table 1. Acreage Between Depth Contours for Prominent Reefs

Location	Volatile Solids	Sand	Silt Course	Silt Medium	Silt Fine	Clay
Toussaint Reef						
May - June	9.2	3.0	0.0	84.8	8.7	3.5
July - August	10.1	2.1	3.6	71.7	8.8	13.9
Starve Island Reef						
May - June	9.5	11.2	6.3	70.8	11.7	0.0
July - August	9.3	1.4	12.4	37.6	18.8	29.8
Crib Reef						
May - June	9.5	2.0	30.7	51.6	10.5	5.2
July - August	12.4	2.9	39.7	22.1	35.3	0.0
West Reef						
May - June	11.4	4.1	37.8	47.3	10.8	0.0
July - August	10.6	3.4	33.9	46.6	9.3	6.8
Mean						
May - June	9.9	5.1		92.7		2.2
July - August	10.6	2.5		84.9		12.6

TABLE 2. Percent Volatile Solids and Particle Sizes in Sediment Collector Samples: 1967

River	Year	Runoff (cm)	Soluble Reactive Phosphorus Total Load (m tons)	Soluble Reactive Phosphorus Conc. (mg/l)	Soluble Reactive Phosphorus Unit Area Load (kg/ha/yr)	Total Phosphorus Total Load (m tons)	Total Phosphorus Conc. (mg/l)	Total Phosphorus Unit Area Load (kg/ha/yr)	Nitrite & Nitrate (N) Total Load (m tons)	Nitrite & Nitrate (N) Conc. (mg/l)	Nitrite & Nitrate (N) Unit Area Load (kg/ha/yr)	Total Suspended Solids Total Load (m tons)	Total Suspended Solids Conc. (mg/l)	Total Suspended Solids Unit Area Load (kg/ha/yr)
Maumee	1975	32	604.0	.116	.37	3190.0	.608	1.95	33,600.0	6.28	20.5	1,590,000.0	304.0	970.0
	1976	26	412.0	.096	.25	2240.0	.523	1.64	13,600.0	3.16	8.30	1,220,000.0	301.0	744.0
Portage	1975	29	39.5	.127	.36	153.0	.476	1.38	2,380.0	7.42	21.5	79,400.0	248.0	716.0
	1976	24	31.2	.116	.28	106.0	.396	.95	944.0	3.51	8.52	44,700.0	168.0	403.0
Sandusky	1975	32	63.3	.068	.20	476.0	.514	1.47	4,060.0	4.35	12.5	273,000.0	293.0	842.0
	1976	21	57.7	.083	.18	316.0	.455	.98	2,400.0	3.45	7.41	156,000.0	225.0	481.0
Huron	1975	28	25.3	.091	.26	117.0	.417	1.22	923.0	3.31	9.61	71,700.0	257.0	746.0
	1976	25	36.6	.154	.38	70.3	.295	.73	530.0	2.23	5.52	44,000.0	184.7	458.0

1. Data Source: Heidelberg College, River Studies Laboratory

TABLE 3. Tributary Loading to Lake Erie from Northwestern Ohio Streams[1]

Figures

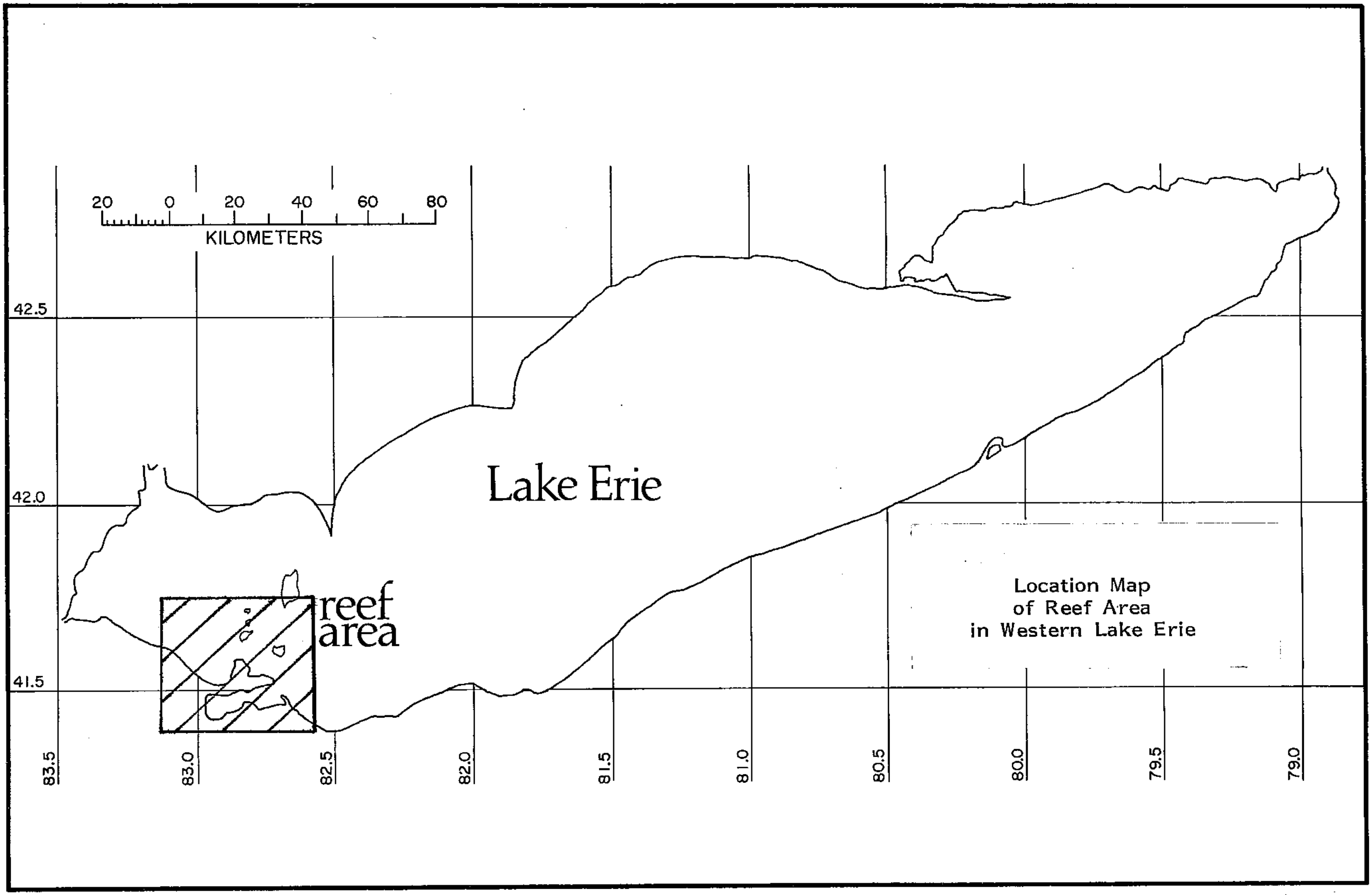
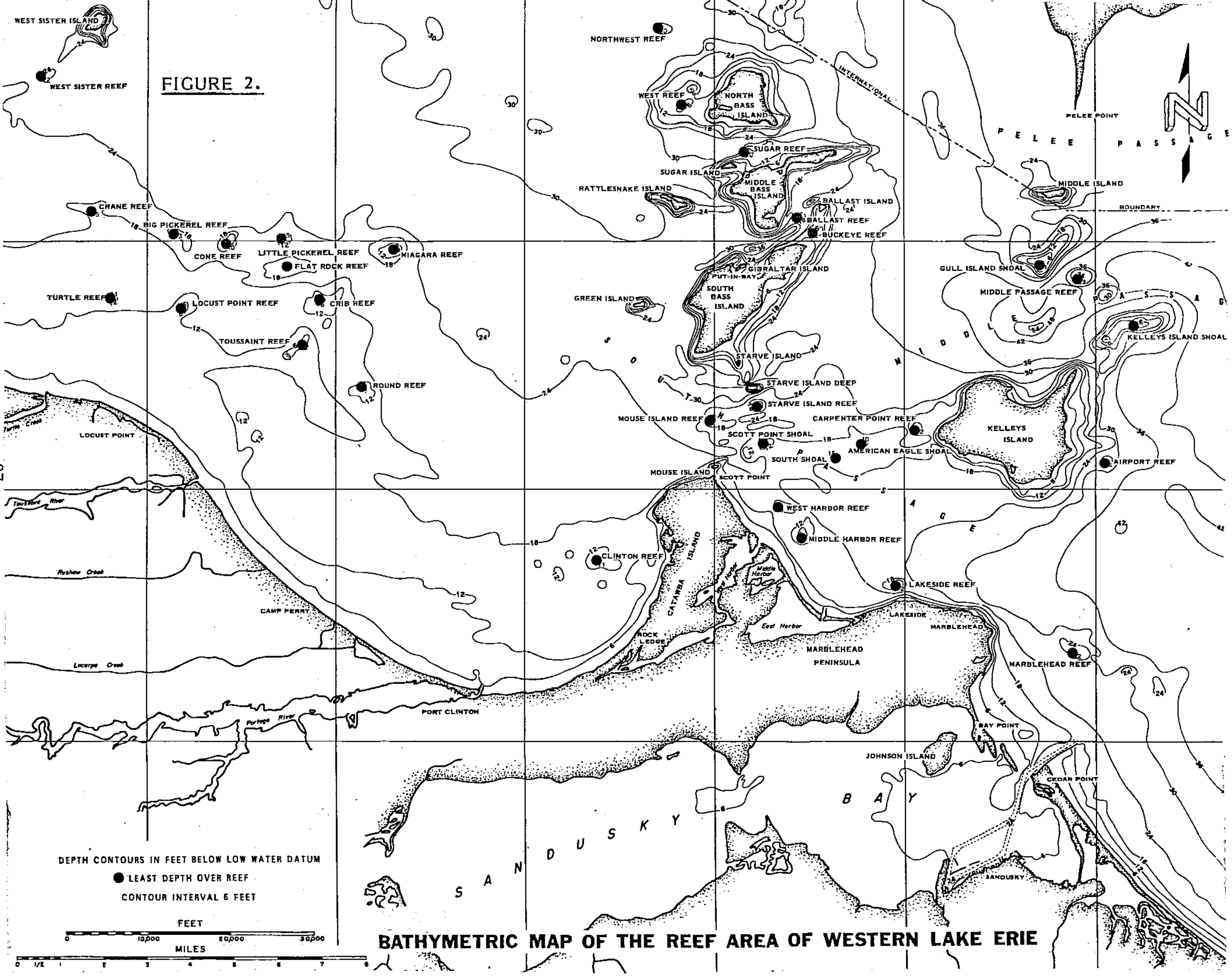


FIGURE 1. Natural Reef Area of Western Lake Erie

FIGURE 2.



BATHYMETRIC MAP OF THE REEF AREA OF WESTERN LAKE ERIE

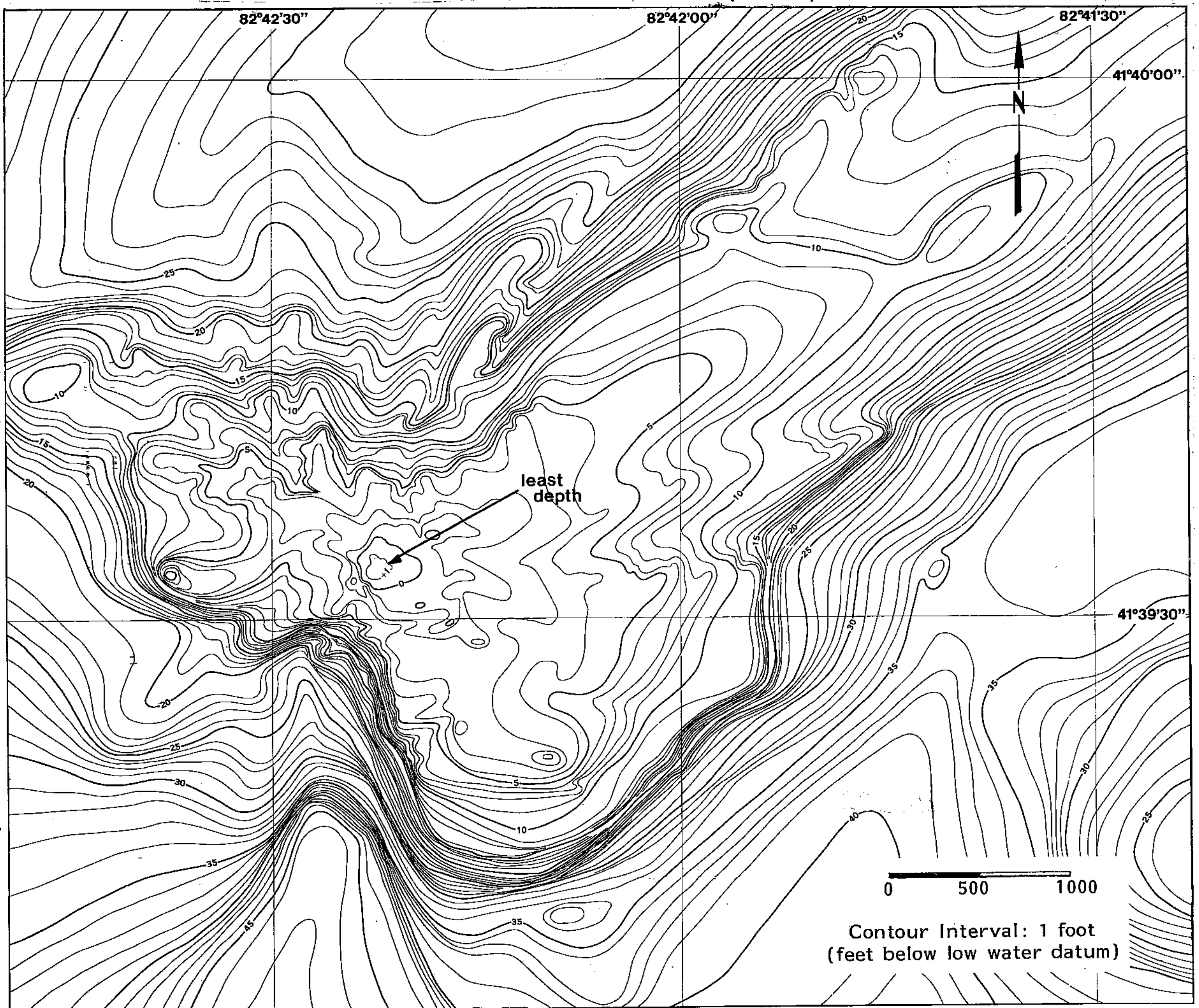
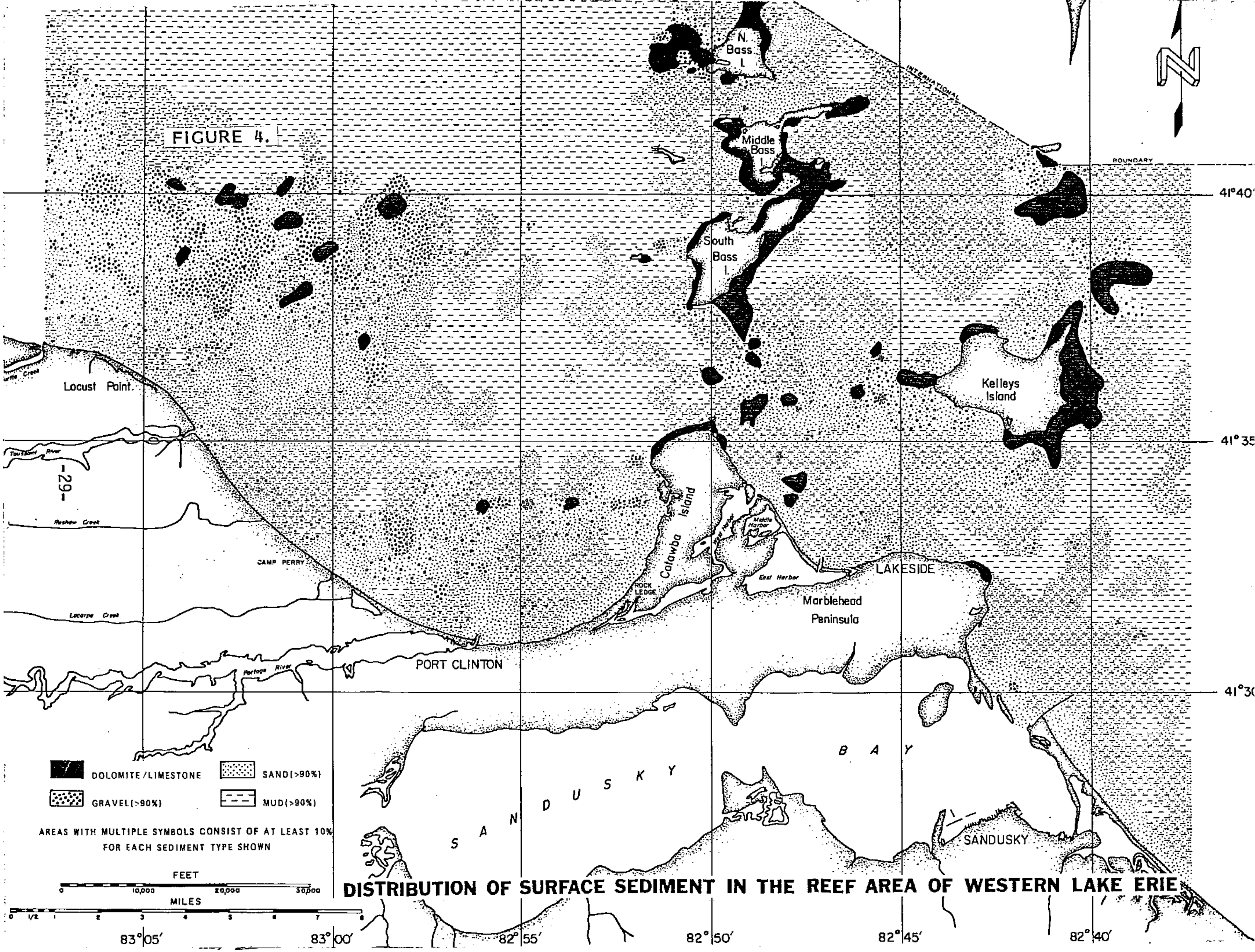


FIGURE 3. Gull Island Shoal

FIGURE 4.



DISTRIBUTION OF SURFACE SEDIMENT IN THE REEF AREA OF WESTERN LAKE ERIE

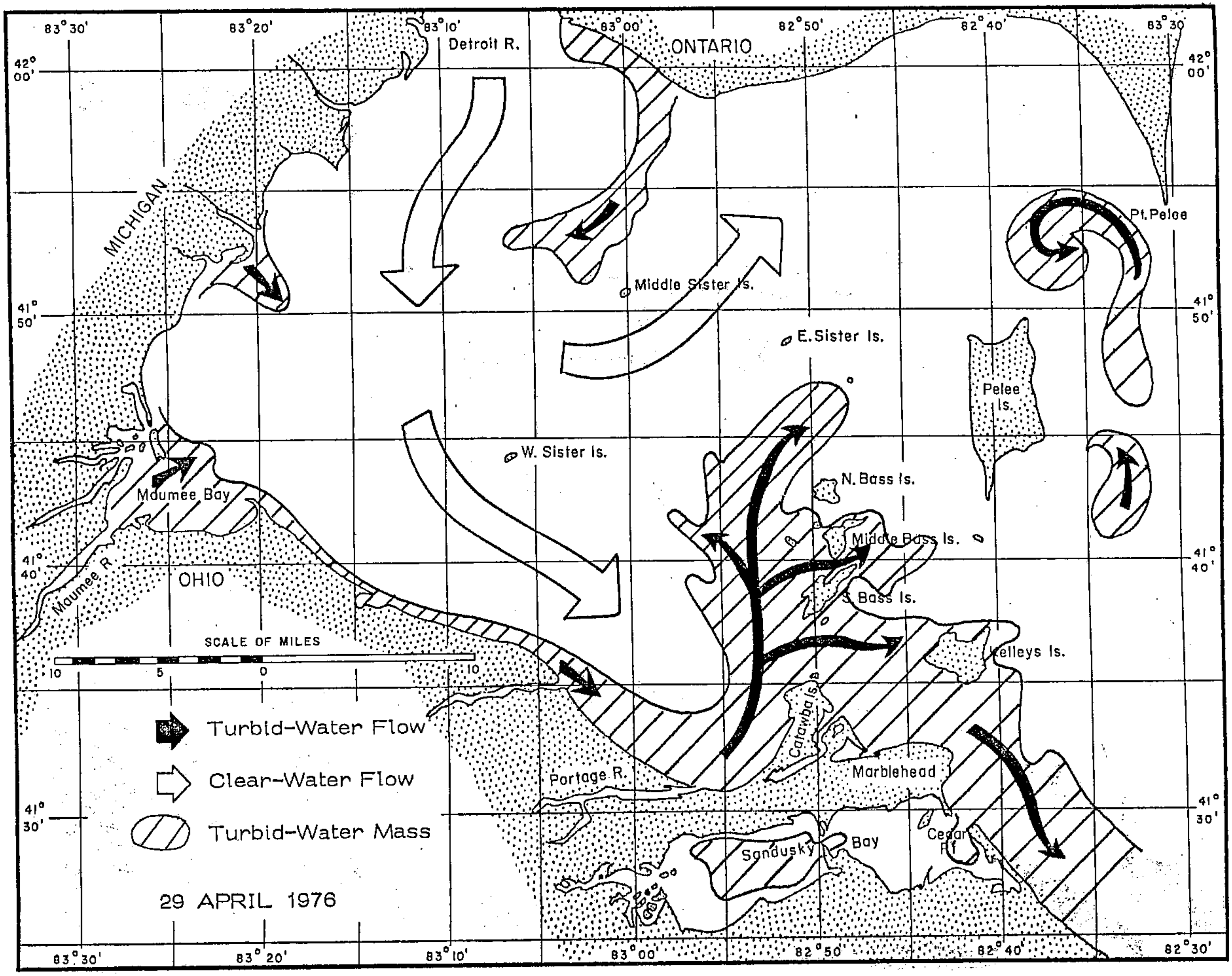


FIGURE 5. Water Flow patterns in Western Lake Erie from NASA Ocean-Color Scanner Imagery-WQ72

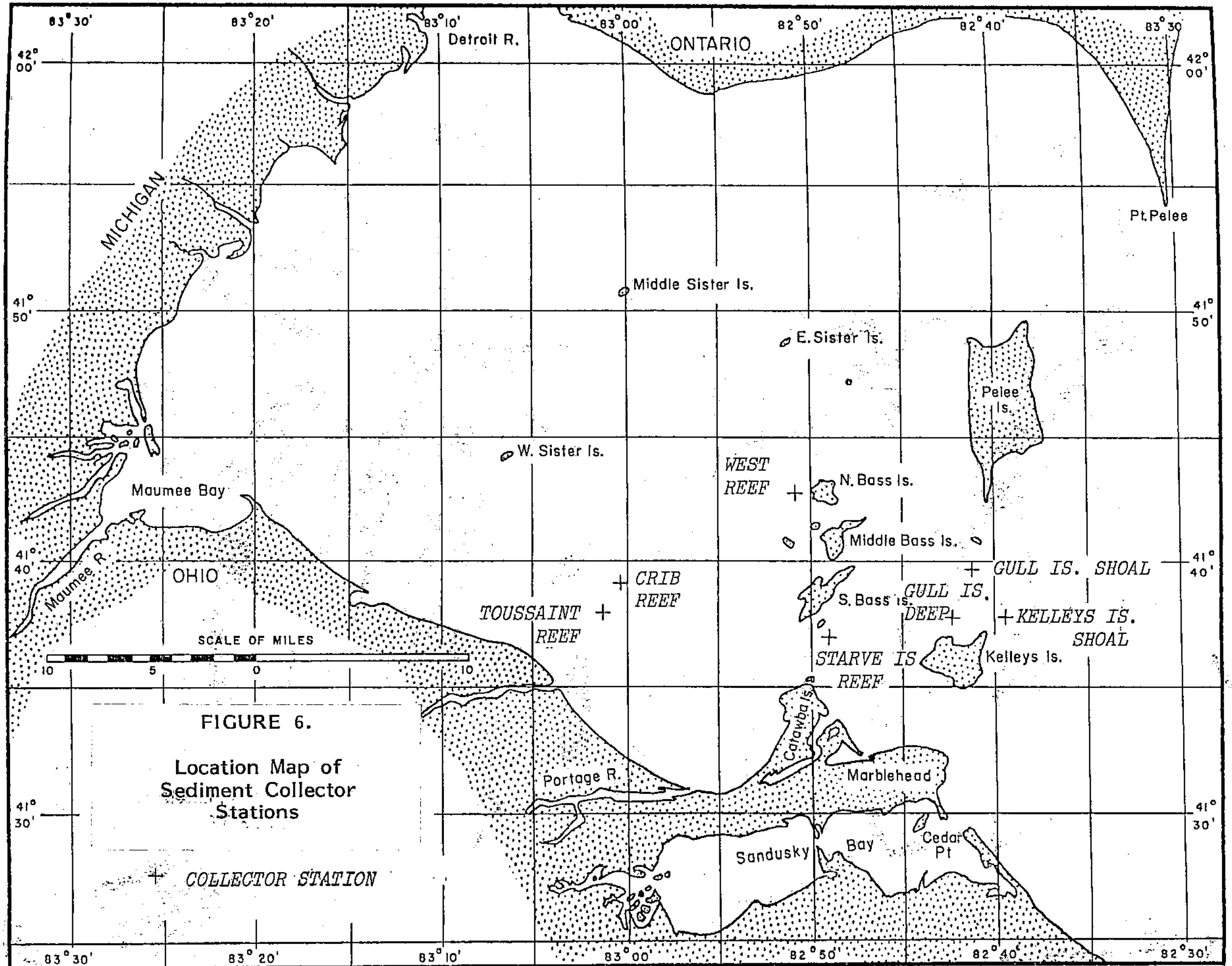


FIGURE 6.

Location Map of Sediment Collector Stations

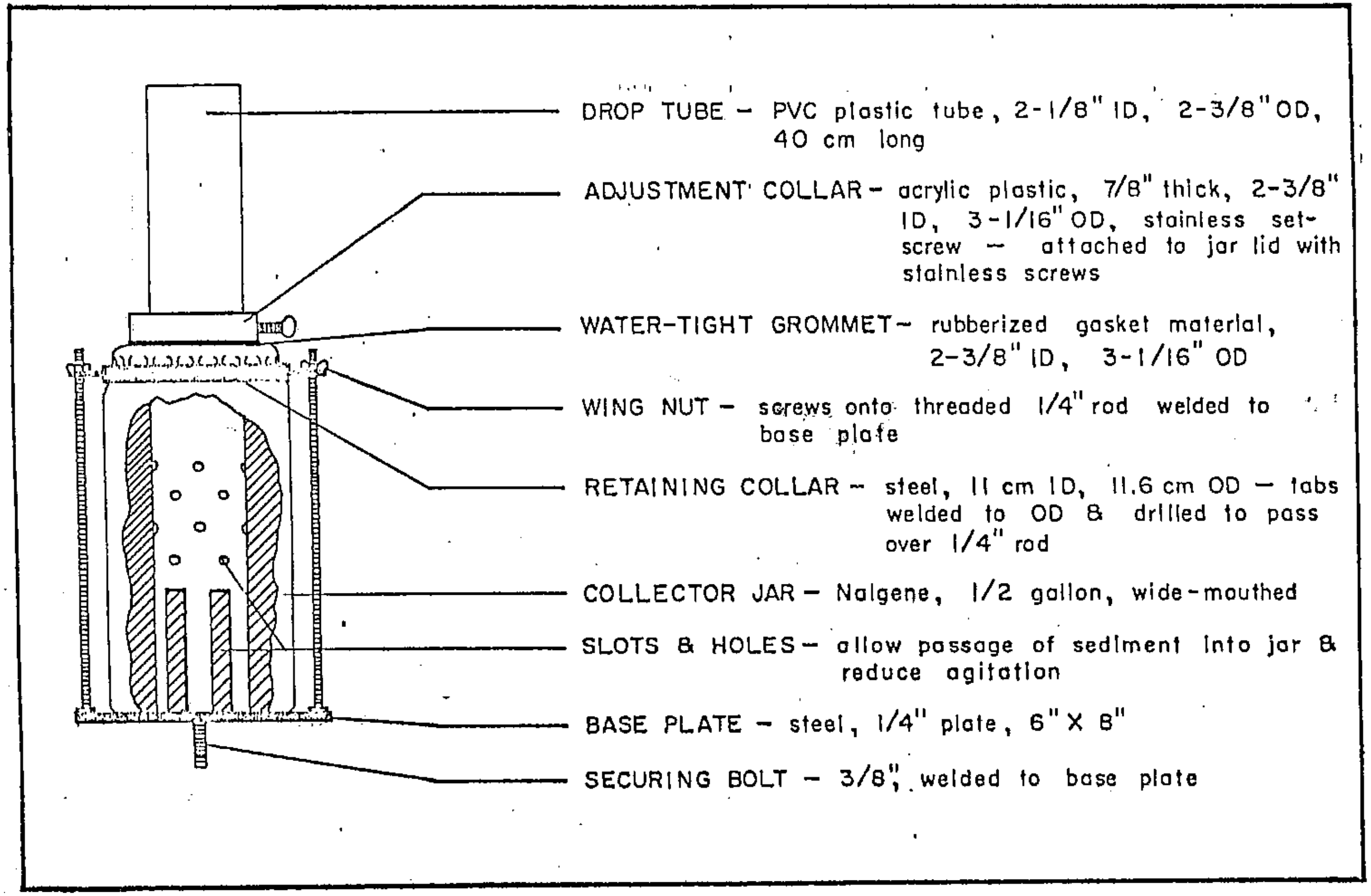


FIGURE 7. Sediment Collection Device

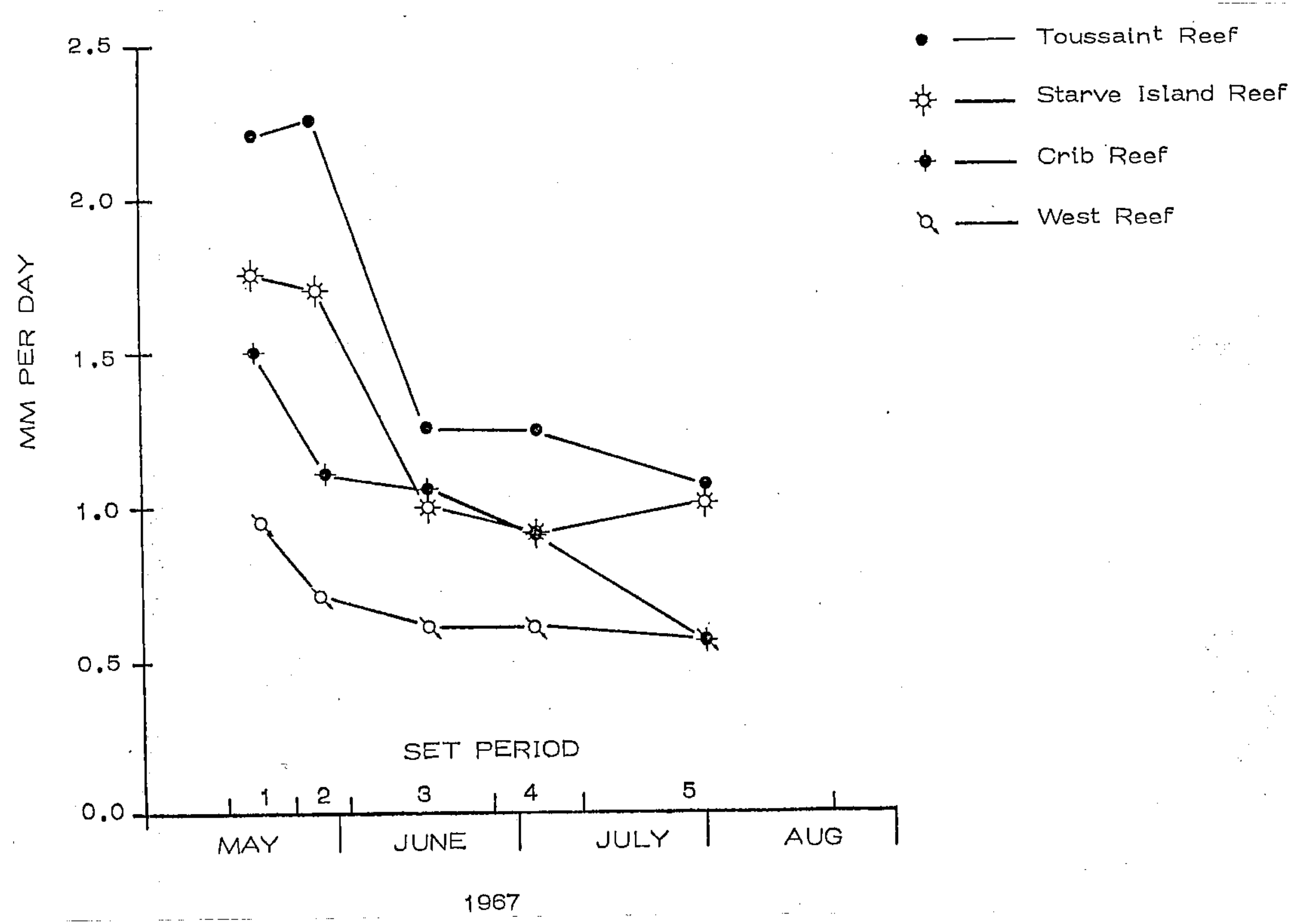


FIGURE 8. Mean Daily Sediment Rate in Western Lake Erie: 1967

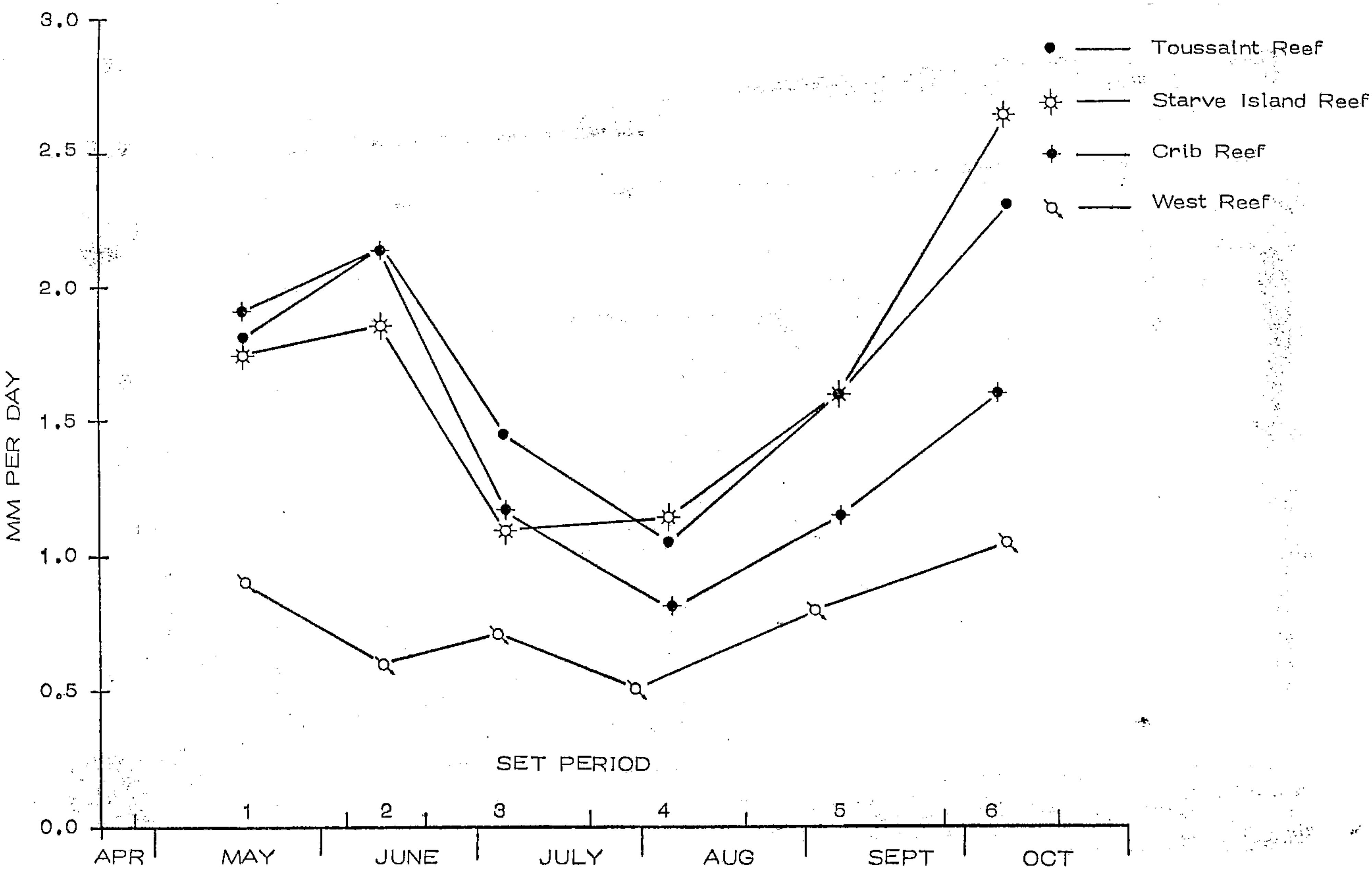


FIGURE 9. Mean Daily Sediment Deposition Rate in Western Lake Erie: 1968

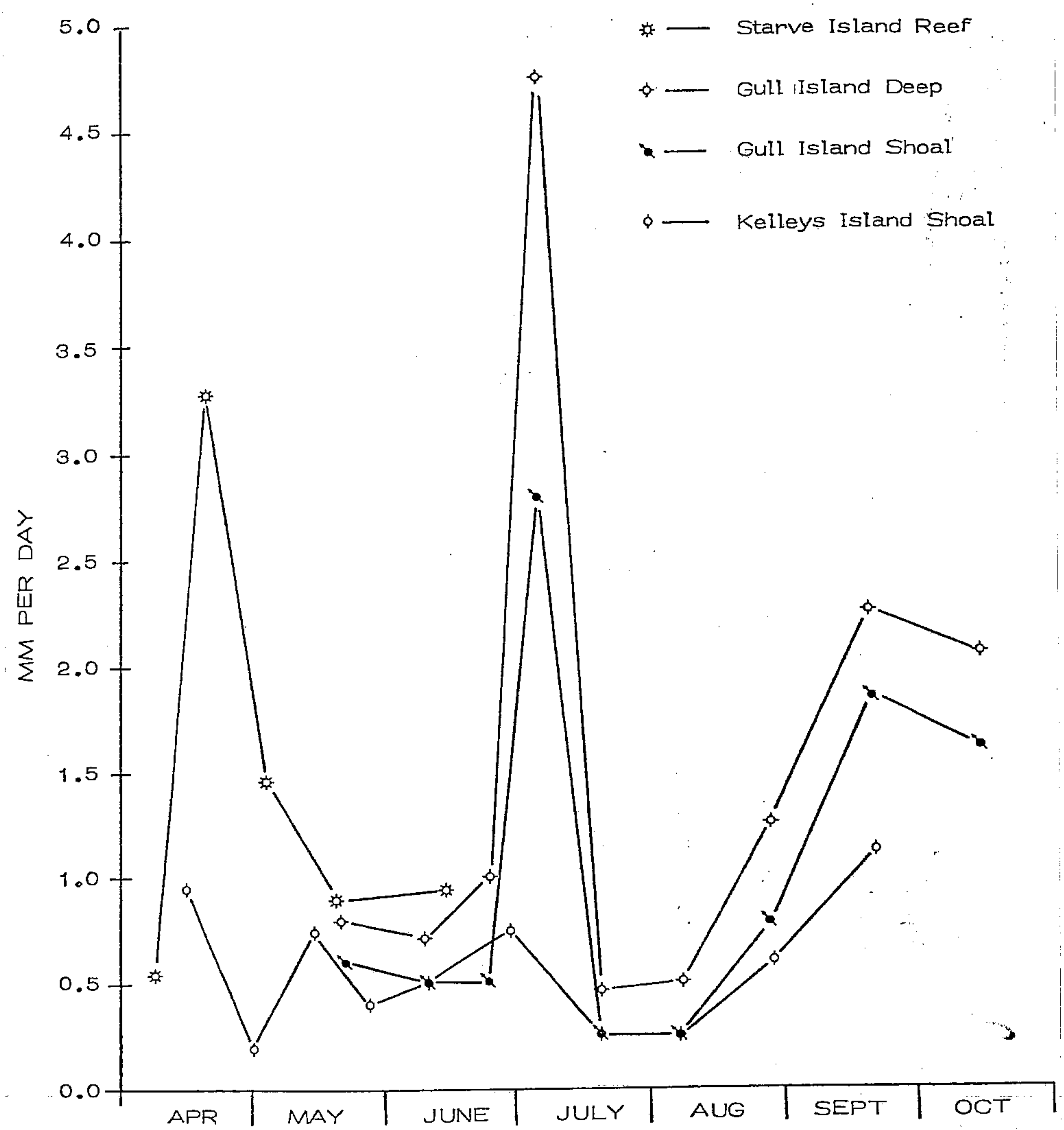
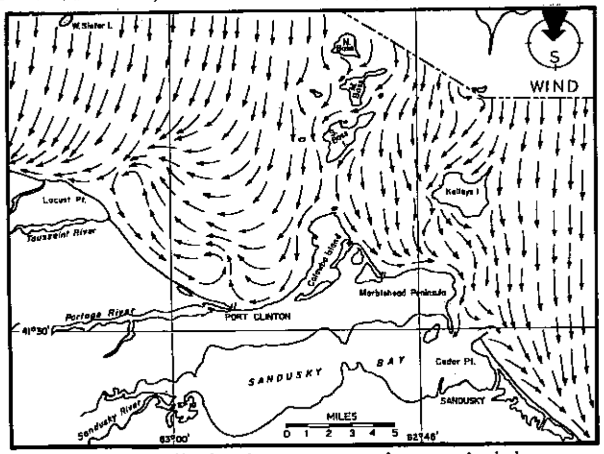
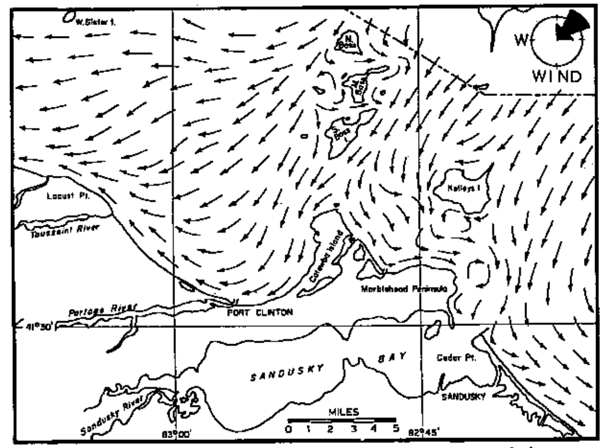


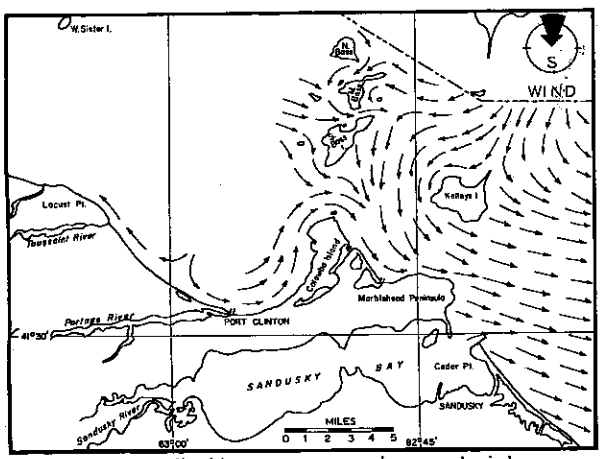
FIGURE 10. Mean Daily Sediment Deposition Rate in Western Lake Erie: 1969



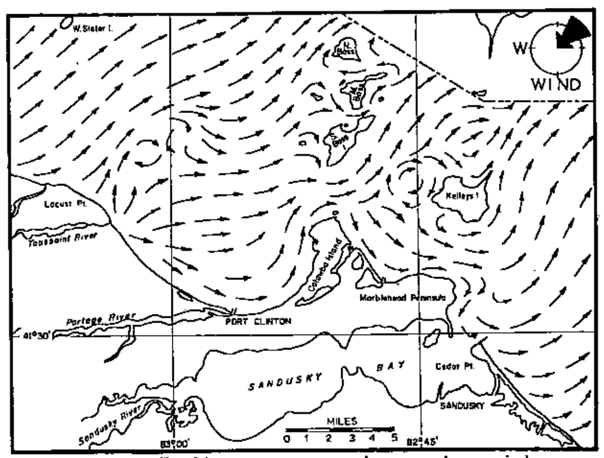
A, Generalized surface currents, moderate north wind



C, Generalized surface currents, moderate northeast wind

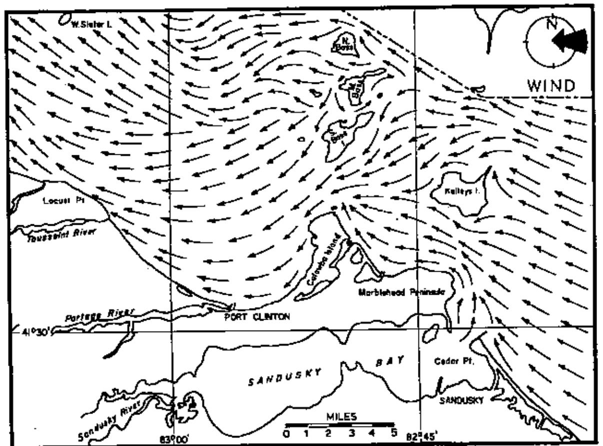


B, Generalized bottom currents, moderate north wind

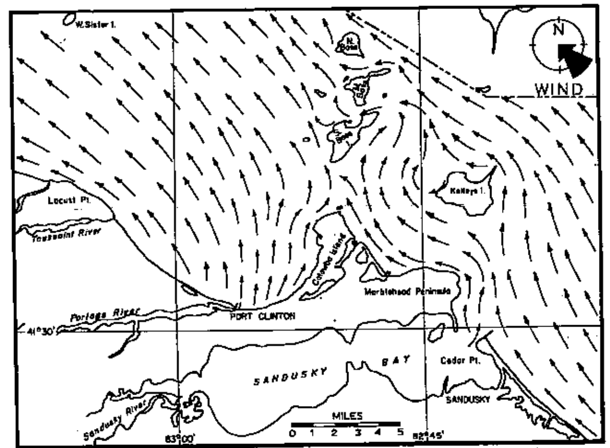


D, Generalized bottom currents, moderate northeast wind

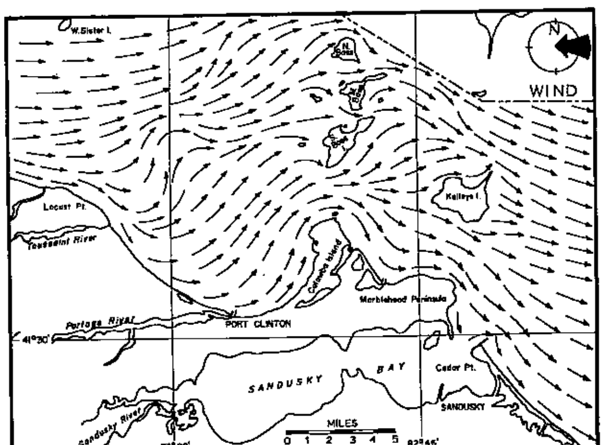
FIGURE 11. Surface and Bottom Currents in the Reef Area of Western Lake Erie



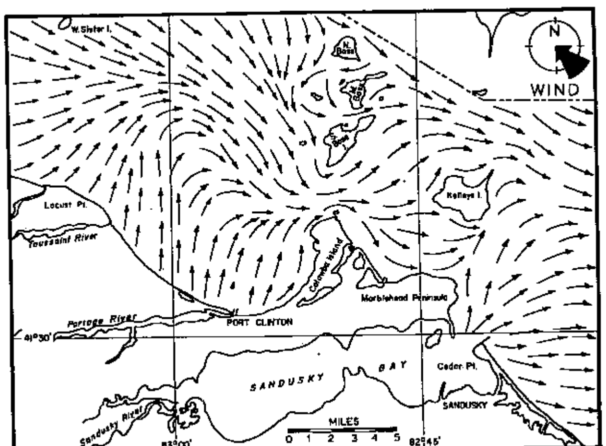
E, Generalized surface currents, moderate east wind



G, Generalized surface currents, moderate southeast wind

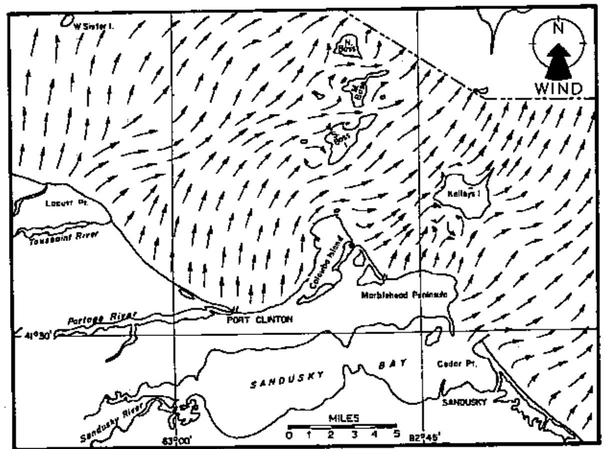


F, Generalized bottom currents, moderate east wind

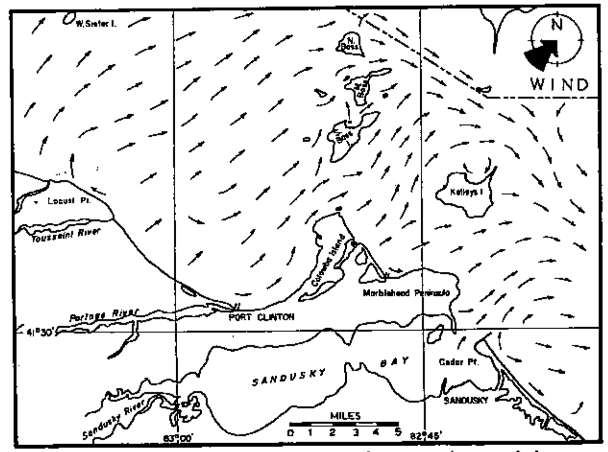


H, Generalized bottom currents, moderate southeast wind

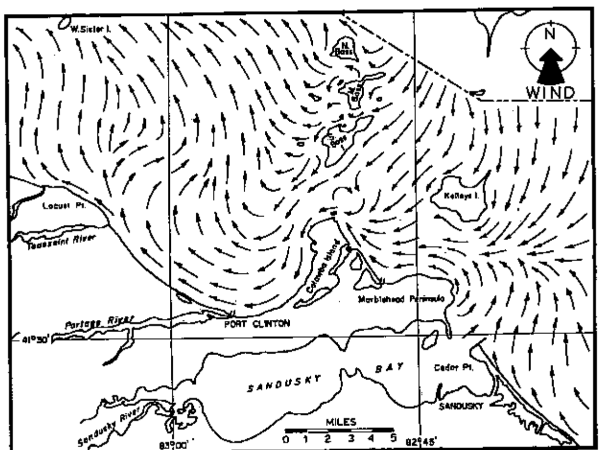
FIGURE 11. Surface and Bottom Currents in the Reef Area of Western Lake Erie (continued)



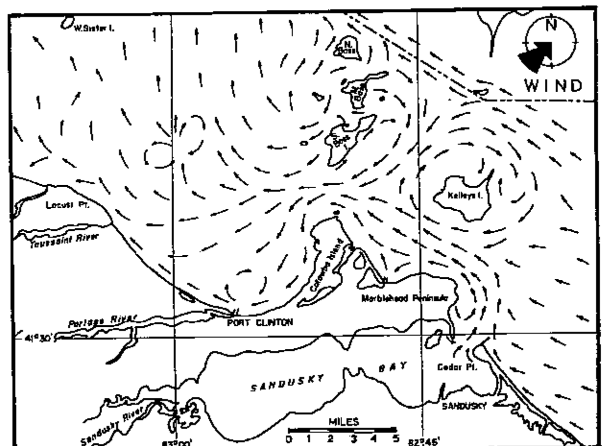
I, Generalized surface currents, moderate south wind



K, Generalized surface currents, moderate southwest wind

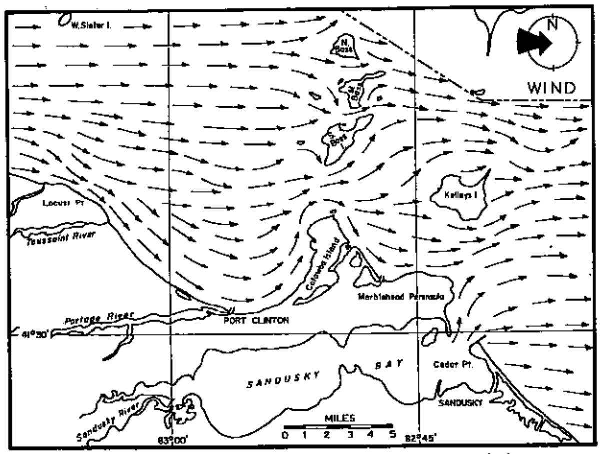


J, Generalized bottom currents, moderate south wind

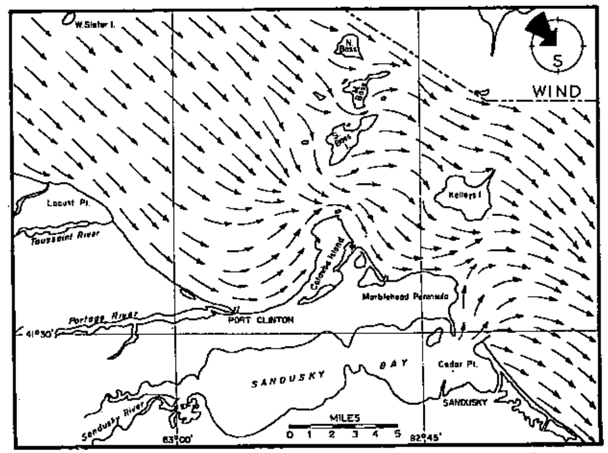


L, Generalized bottom currents, moderate southwest wind

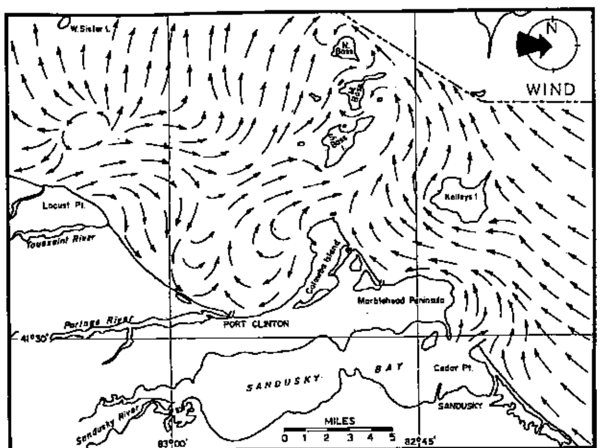
FIGURE 11. Surface and Bottom Currents in the Reef Area of Western Lake Erie (continued)



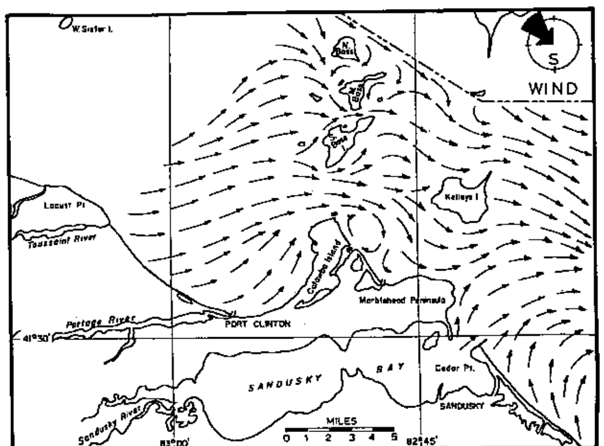
M, Generalized surface currents, moderate west wind



O, Generalized surface currents, moderate northwest wind



N, Generalized bottom currents, moderate west wind



P, Generalized bottom currents, moderate northwest wind

FIGURE 11. Surface and Bottom Currents in the Reef Area of Western Lake Erie (continued)

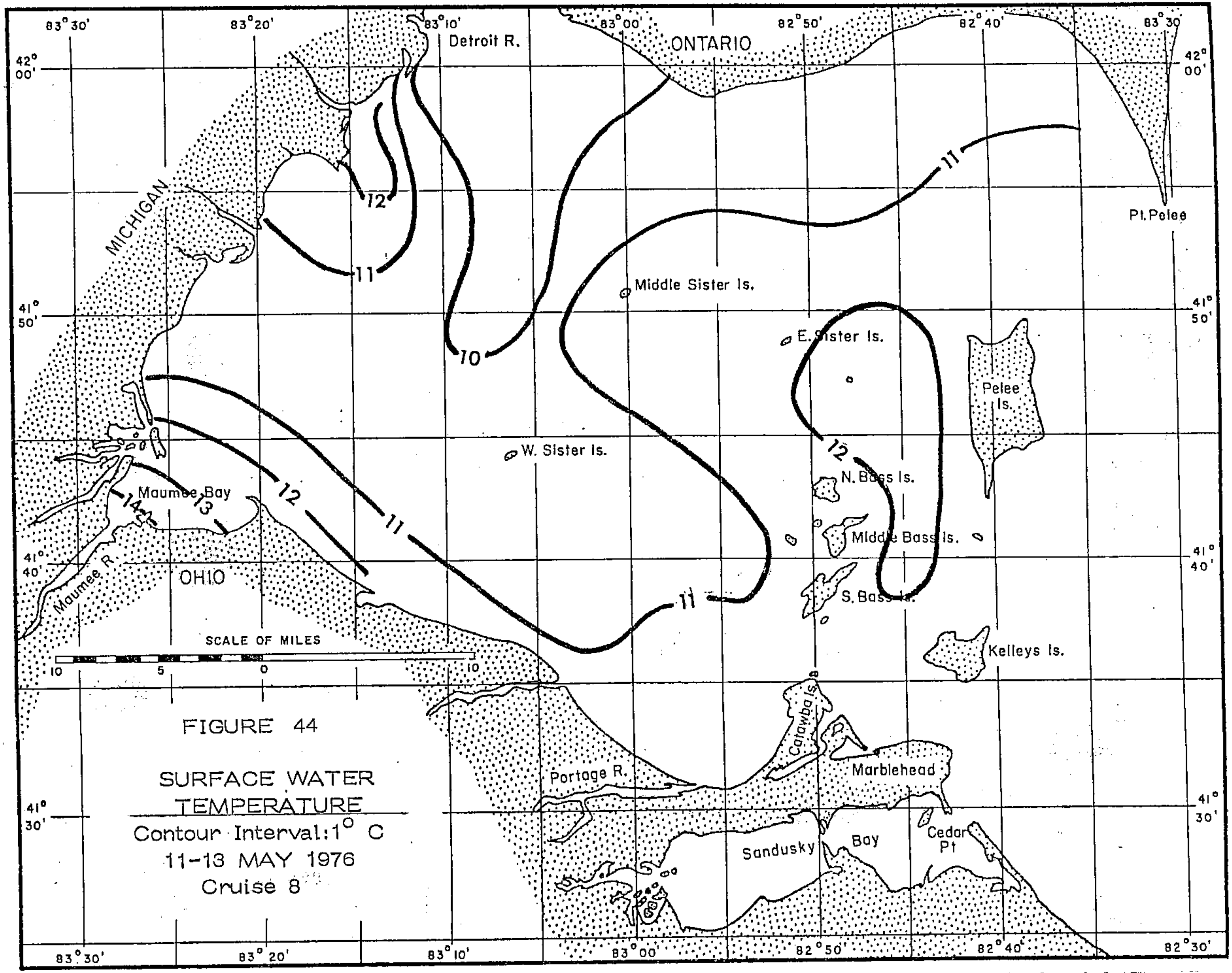


FIGURE 44

SURFACE WATER TEMPERATURE

Contour Interval: 1° C
11–13 MAY 1976
Cruise 8

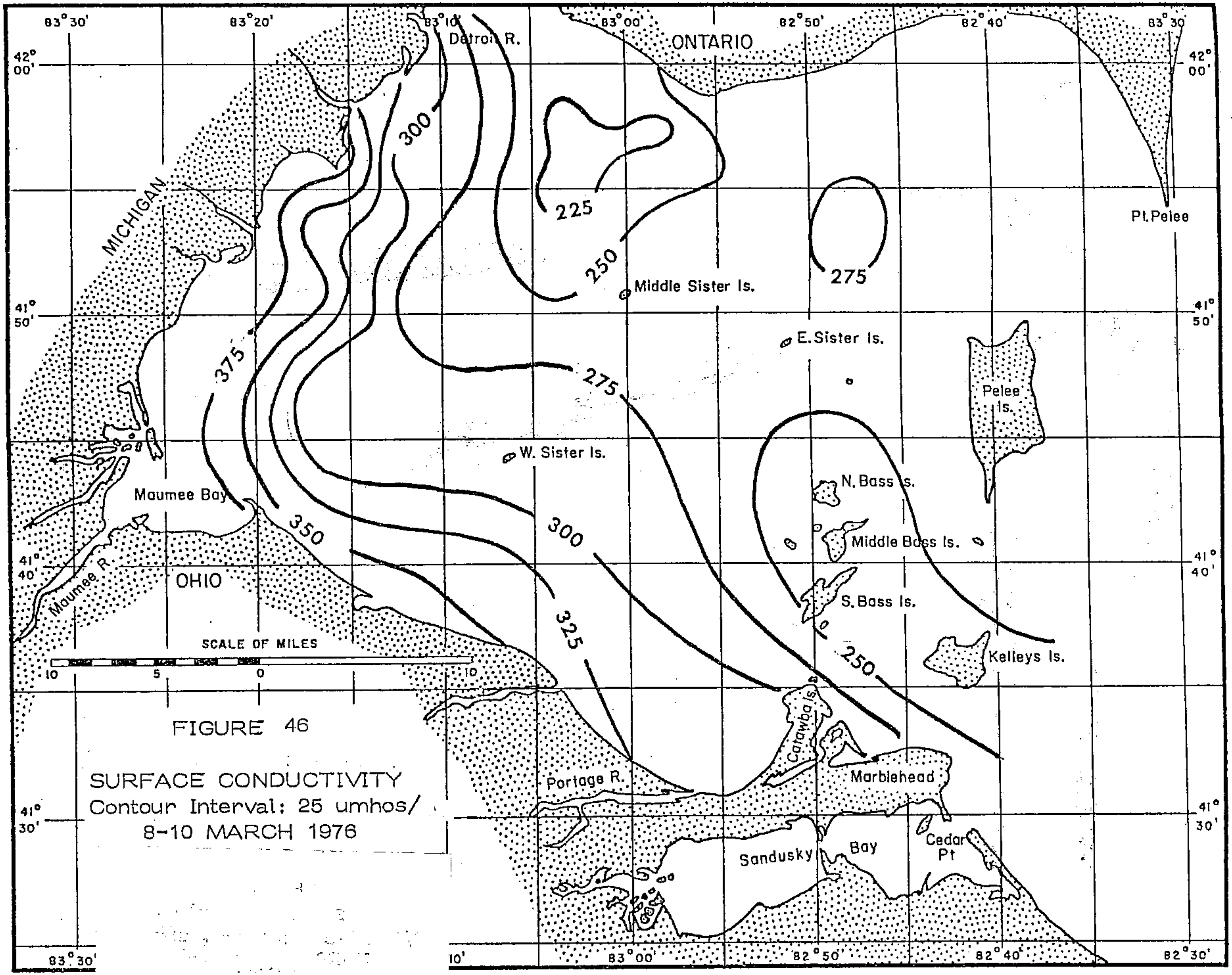


FIGURE 46

SURFACE CONDUCTIVITY
Contour Interval: 25 umhos/
8-10 MARCH 1976

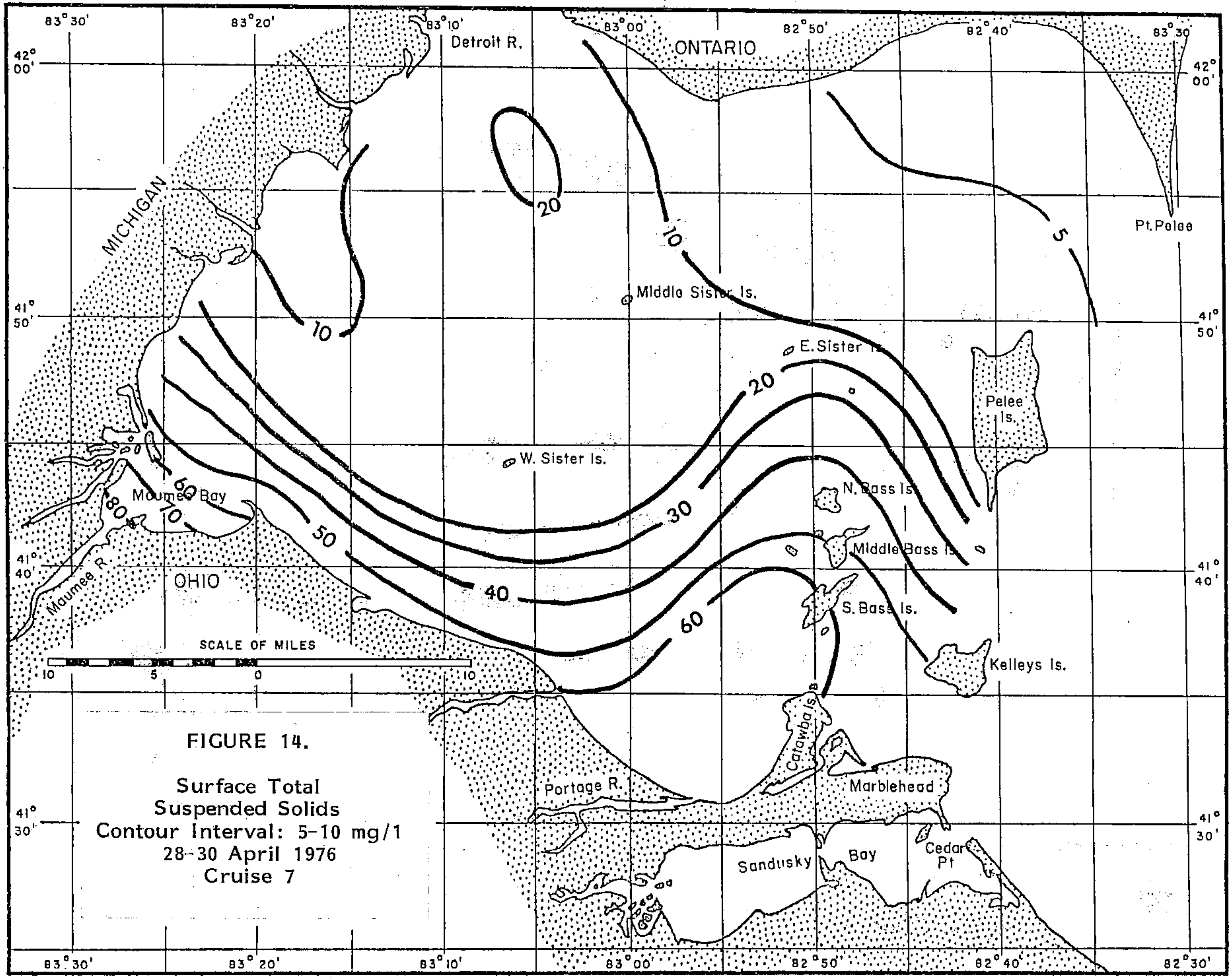


FIGURE 14.

Surface Total
Suspended Solids
Contour Interval: 5-10 mg/1
28-30 April 1976
Cruise 7

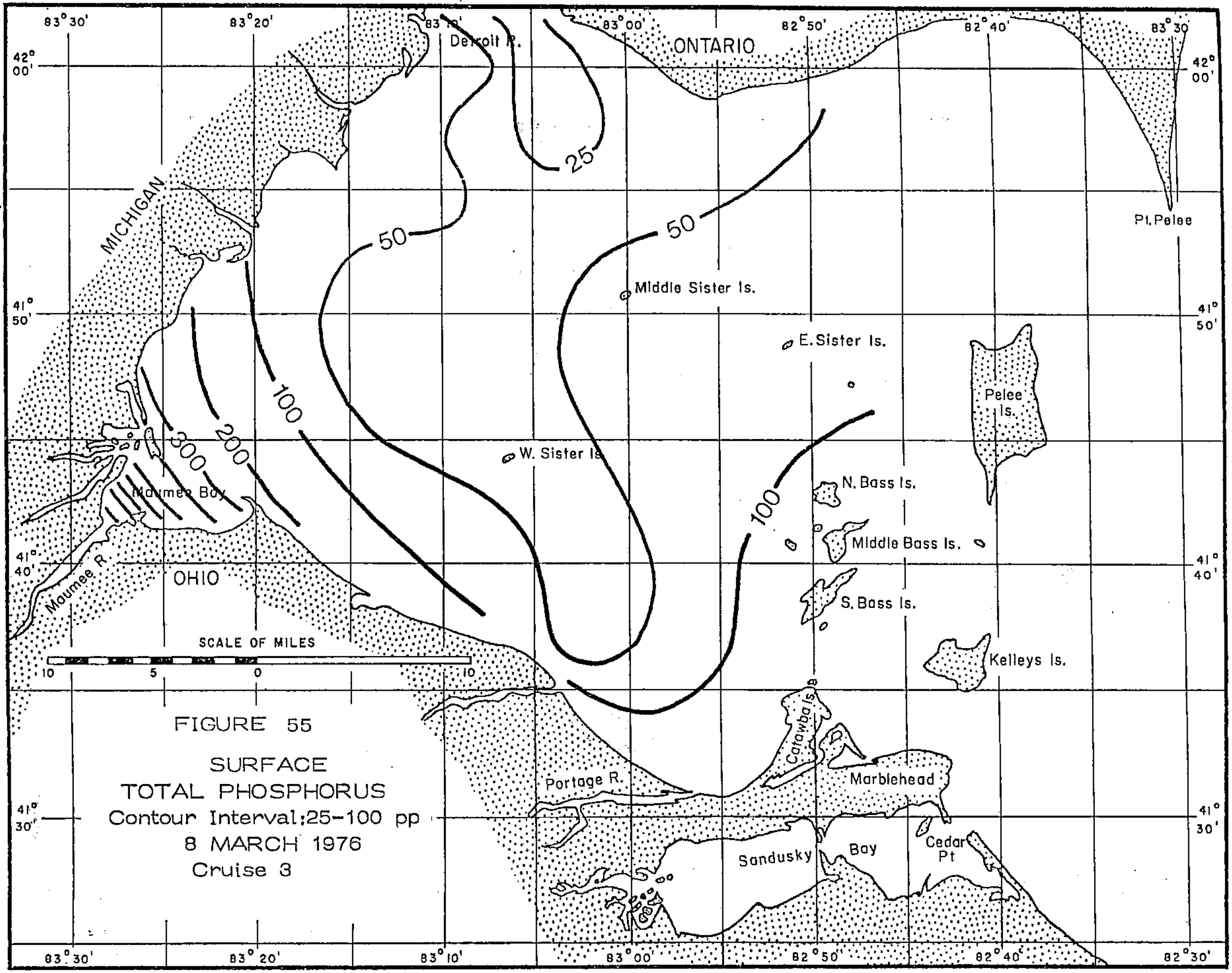


FIGURE 55

SURFACE
TOTAL PHOSPHORUS
Contour Interval: 25-100 pp
8 MARCH 1976
Cruise 3

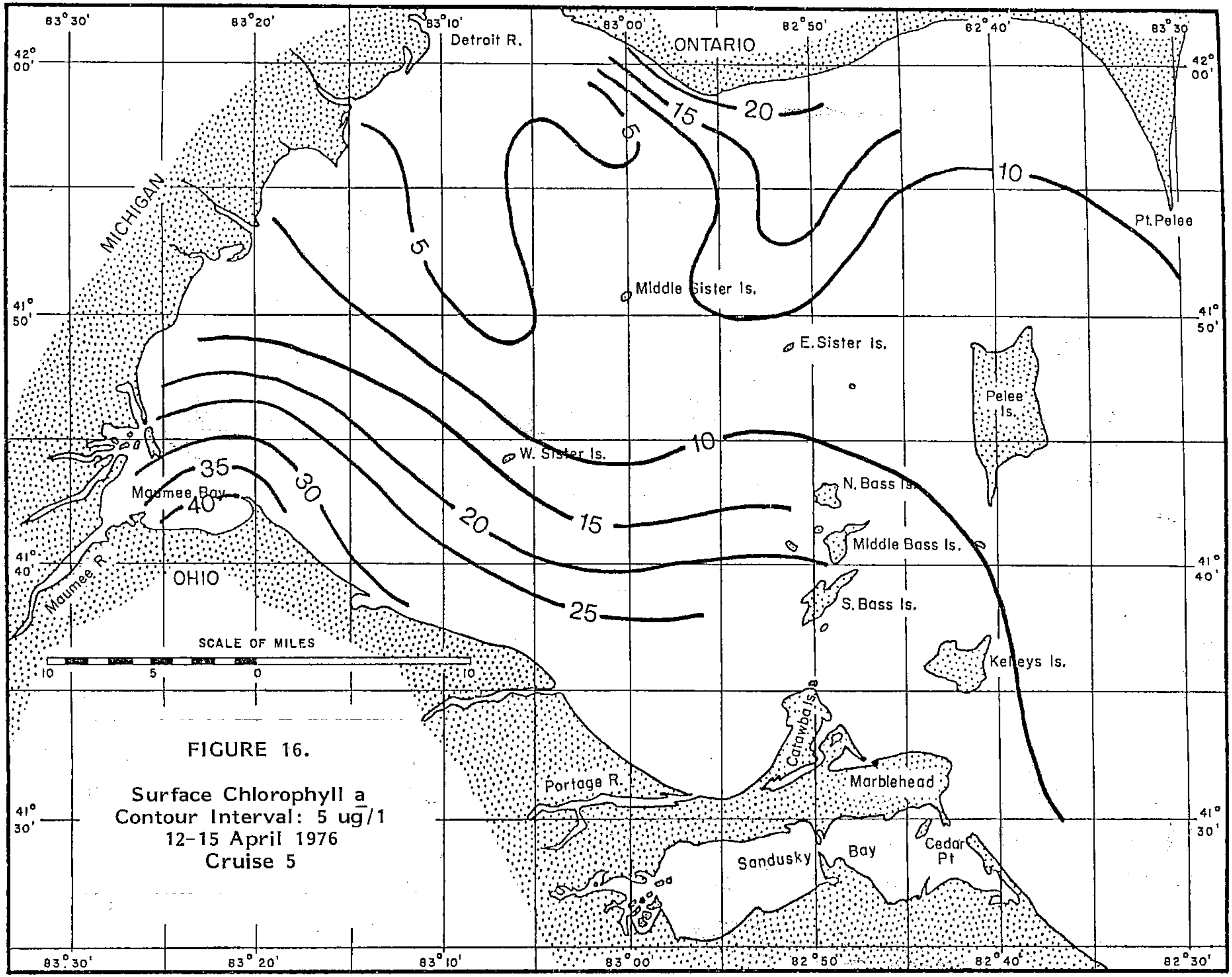


FIGURE 16.

Surface Chlorophyll a
Contour Interval: 5 ug/1
12-15 April 1976
Cruise 5

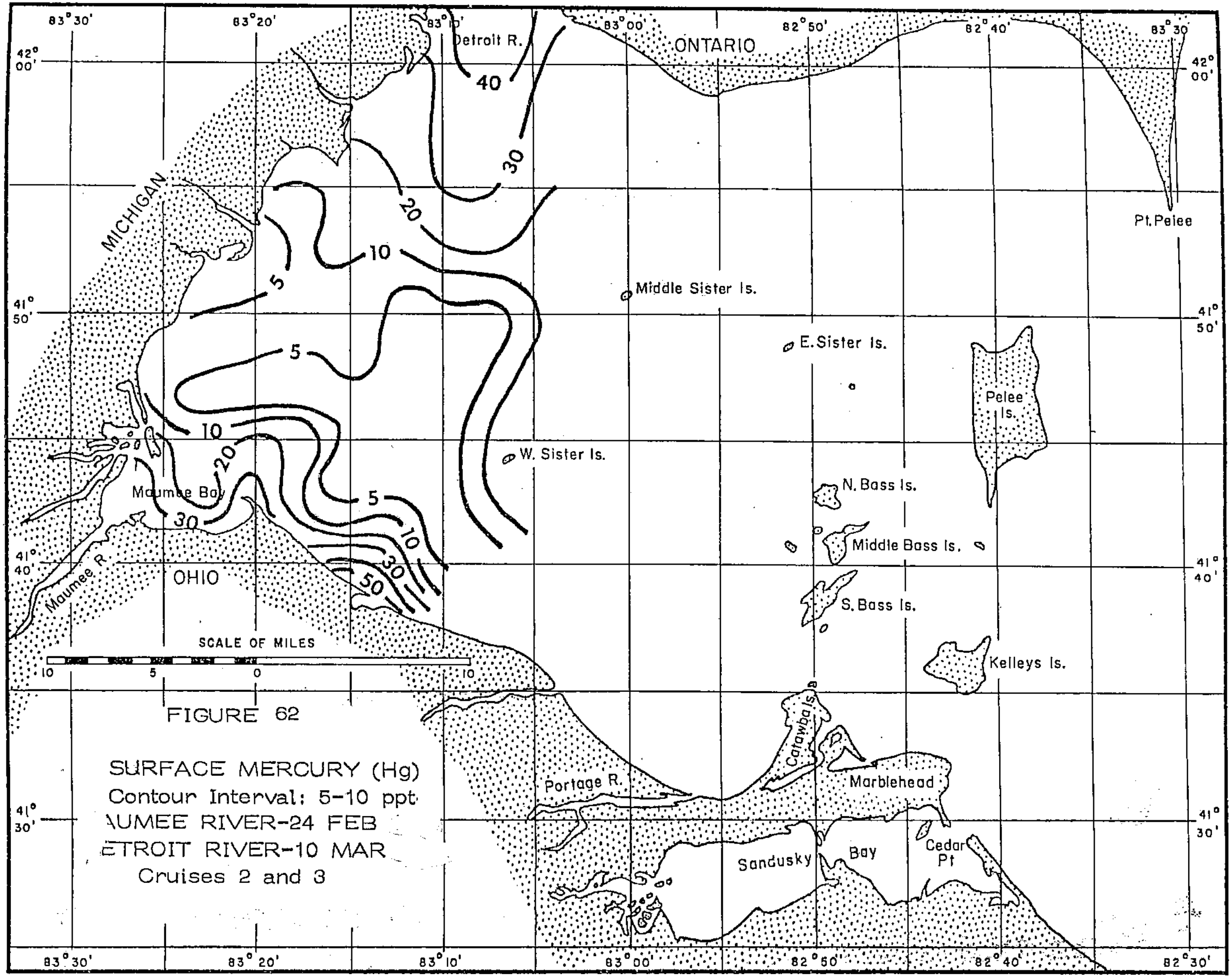


FIGURE 62

SURFACE MERCURY (Hg)
Contour Interval: 5-10 ppt
\UMEE RIVER-24 FEB
ETROIT RIVER-10 MAR
Cruises 2 and 3