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Processes in Sediment Deposition and Shoreline Changes in the Point Pelee Area, Ontario

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(Résumé en français)

INLAND WATERS DIRECTORATE,
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BURLINGTON, ONTARIO, 1977.

Frontispiece. Aerial photograph of Point Pelee (taken March 1973).

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Abstract

Ever since its formation as a much larger coastal feature some 4000 years ago, Point Pelee has been receding landward (i.e. northward and westward) under the influence of rising lake levels and increasing wave stress. Using some reasonable assumptions, we estimate the average rate of retreat since that time as being in the order of 2.5 m/yr (northward) and 0.25 m/yr (westward). More recent trends inferred from the historical record (reports, surveys and charts) indicate significant change from this overall trend. Average westward recession since 1918 for large portions of the east side of the Point now reaches more than 3 m/yr, and the partially submerged spit south of the Point has been greatly reduced in length. At the same time, however, some areas have remained stable or show a degree of accession over this period.

Sediment distribution patterns observed on the shoal and model calculations of littoral drift along both sides of Point Pelee show the following pattern.

(1) The dominant trend of sediment movement in the central and southern portions of the shoal is from west to east, in spite of the reverse direction predicted on the basis of the expected wave drift effect.

(2) In the more northern areas of the shoal, the pattern is not as clear because of depth limitations on survey coverage. However, observations of the changing trend of the submerged spit and other evidence suggest that depositional patterns in this area are highly variable. It is postulated, therefore, that this area constitutes a temporary storage and transfer area for sediments in the Point Pelee littoral drift system.

(3) Littoral drift on both sides of the Point often reverses in direction according to the prevailing wave climate, but on the east side the net direction was calculated to be southward at rates of ca. 25 000 m^3/yr. On the west side, net rates are lower at ca. 4000 m^3/yr toward the north.

Short-term monitoring of bottom currents in the area are for the most part consistent with the above sediment dispersal patterns, but the energy spectra of the currents suggest that agents such as lake circulation effects (especially those related to seiching) are of greater importance than waves in sediment distribution patterns on the shoal.

On the basis of the above information, it is concluded that there is little evidence that commercial dredging in the southernmost areas of the shoal is an important factor in shoreline changes on the Point. However, the dredging operations in the vicinity of the spit itself during the early 1900's, and the proximity of more recent operations (until 1973) to the postulated storage area in the northern areas of the shoal should definitely be considered as adverse factors in explaining the recent trends in shoreline changes at Point Pelee.

Résumé

Depuis sa formation il y a quelque 4000 ans, époque où elle était un élément de la rive beaucoup plus considérable, la Pointe Pelée a reculé vers l'intérieur des terres (c'est-à-dire vers le nord et l'ouest) sous l'influence des vagues et de la montée des niveaux lacustres. En nous fondant sur des hypothèses raisonnables, nous évaluons la vitesse moyenne de ce recul, depuis cette époque, à près de 2.5 m par année (vers le nord) et de 0.25 m par année (vers l'ouest). Plus récemment les rapports, les levés et les cartes indiquent que cette vitesse s'écarte beaucoup de ces derniers chiffres. Depuis 1918, le recul moyen en direction de l'ouest de vastes portions du côté est de la pointe atteint maintenant plus de 3 m par année, et la flèche partiellement immergée, au sud, a été largement réduite en longueur. Toutefois, au cours de la même période, certaines zones sont demeurées stables ou ont gagné sur le lac.

Les observations de la distribution des sédiments dans le haut-fond et les calculs fondés sur des modèles de la dérive le long des deux côtés de la Pointe Pelée mettent en évidence les phénomènes suivants.

(1) L'orientation dominante qui apparaît dans le mouvement des sédiments, dans les parties sud et centrale du haut-fond, est d'ouest en est, en dépit de la direction inverse prédite à partir de l'effet prévu de la dérive due aux vagues.

(2) Dans les parties plus au nord la sédimentation est moins connue à cause des limitations de profondeur sur les levés. Toutefois, l'évolution de la flèche immergée et d'autres faits portent à croire que la sédimentation y est très variable. En conséquence, on présume que ce secteur constitue un réservoir temporaire et une zone de transfert pour les sédiments dans le système de dérive le long de la pointe Pelée.

(3) La direction de cette dérive des deux côtés de la pointe s'inverse souvent selon le régime de vagues, mais du côté est, on a calculé que, globalement, elle allait vers le sud et atteignait un débit de 25 000 m^3 par année environ. Du côté ouest, le débit est plus modeste: environ 4000 m^3 par année, et vers le nord.

L'observation à court terme des courants de fond de cette région correspond en majeure partie à la dispersion des sédiments, decrite plus haut, mais d'après le spectre d'énergie des courants, des agents tels que les effets de la circulation lacustre (spécialement ceux qui se rapportent aux seiches) primeraient sur les vagues en ce qui a trait à la répartition des sédiments sur le haut-fond.

En nous fondant sur les renseignements susmentionnés, nous pouvons conclure qu'il existe peu de preuves que le dragage industriel dans les zones les plus au sud du haut-fond représente un facteur important dans le remodelage de la rive de la pointe. Toutefois, le dragage dans le voisinage de la flèche au début du siècle, et la proximité des opérations plus récentes (jusqu'en 1973) dans la zone de réservoir postulée dans les secteurs nord du haut-fond devraient être sans contredit considérés comme des facteurs contraires dans l'explication de l'évolution récente de la rive à la Pointe Pelée.

Introduction

Point Pelee, a cuspate foreland extending southward for more than 12 km from the northern shore of Lake Erie in Essex County, is one of the more impressive natural features of the shoreline of that lake (Fig. 1). It comprises roughly 80 km^2 of wooded dunes, beaches, lowlands, and marshes, a large portion of which has been artificially drained for agricultural use. Point Pelee National Park, which occupies the southernmost portion, is a well-known natural preserve. To the south of the Point, a broad, sandy shoal continues for another 12 km.

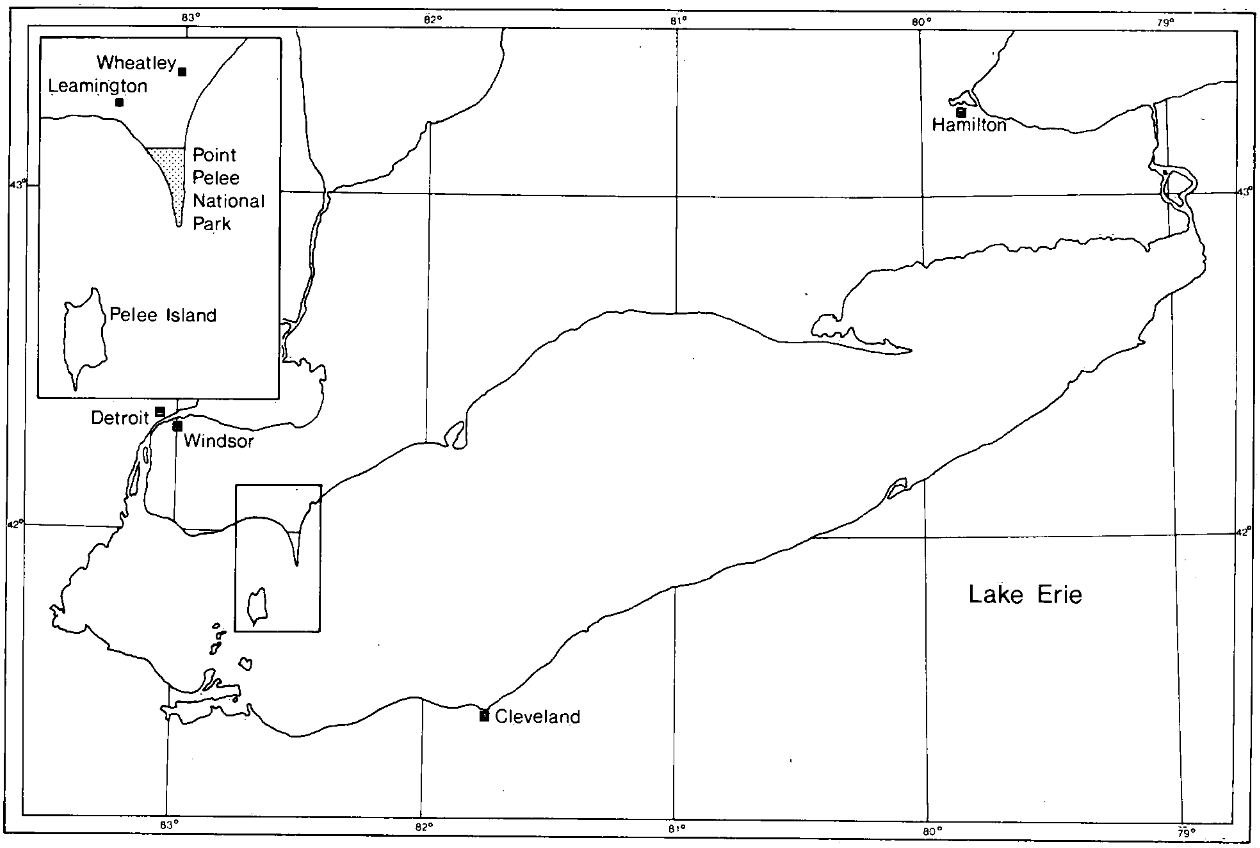

Figure 1. Location map of the study area.

Shoreline recession has been a major cause for concern for the inhabitants of Point Pelee for decades (section 2.2.3) and a variety of causes have been cited, ranging from natural (rising lake levels) to man-induced (conflicting land-use, sand-mining). However, almost all of these causes have been proposed in the absence of any clear knowledge of either the mode of origin of Point Pelee or the long-term trends and short-term processes and responses that determined the evolution of this landform. Basic questions dealing with the origin of the landform itself, the character, sources, and quantities pertaining to the deposits that make up Point Pelee and its associated depositional features are still largely unanswered. For instance, until now it was generally believed that the landform was a simple cuspate spit formed by accretionary processes and that the erosion taking place represented an abnormal reversal of this trend. Recent research has cast considerable doubt on this model of formation. So, although the main problem at Point Pelee, from an economic point of view, is shoreline recession, before this problem can be understood and alleviated, the fundamental physical processes (of which recession represents only a highly visible part) must be studied and documented.

The report presented here is directed toward this goal and will address itself particularly to the following aspects of coastal sedimentation in the vicinity of Point Pelee. (1) The critical review of the existing literature and results of investigative reports on trends and developments in the coastal zone at Point Pelee, with a view to providing a long-term perspective on coastal evolution at Point Pelee. (2) The quantitative definition of the sedimentary deposits making up the Point Pelee complex, with special emphasis on the heretofore undefined Pelee Shoal entity, aimed at interpreting the past and present depositional conditions there. (3) The examination of the dominant components in the physical process regime of the area, which, together with process-related sediment parameters, will contribute to the development of a conceptual model of sedimentation for the Point Pelee - Pelee Shoal complex. (4) The utilization of the insights gained in the above aspects in commenting on the probable impact of offshore commercial sand-dredging operations on the sedimentation regime at Point Pelee.

1.1. REPORT CONTENTS

The format of the report follows the above separation. Chapter 2 summarizes the salient points gleaned from the literature and historical records dealing with the origin of the landform and the evolution it has undergone up to the present, and establishes quantitative values for the historical shoreline changes that have occurred. Chapter 2 also examines in a general way the probable causes of these changes and introduces the background for the offshore dredging controversy, which will be discussed later in the report. Chapters 3 and 4 present the results of field studies undertaken by Canada Centre for Inland Waters in 1974 into the sediments and physical processes characterizing the Point Pelee depositional complex (encompassing the Point itself, the bordering nearshore zone, and the shoal entity to the south). Finally, Chapter 5 combines the results from both areas (sediments and processes) into a statement on the dynamics of sediment deposition around Point Pelee and the impact on this depositional system of commercial dredging south of the Point.

While some detail has been eliminated from the report for the sake of conciseness, as many of the basic data as possible were included in summary form to enable the informed reader to judge the validity of the conclusions. It is also hoped that the report will be useful to planners and engineers as a source of basic data and concepts on this complex coastal area.

1.2. SUMMARY OF CONCLUSIONS

The major conclusions presented in the report are as follows.

(1) Point Pelee was probably formed some 4000 years before present, through the merging of fringing beaches built up around the promontory of the Pelee-Lorain moraine. These beaches were formed in large measure from the sandy material eroded from the shorelines to the northeast and northwest and the material

discharged onto the existing shoreline by postglacial streams. As lake levels rose, these fringing beaches and dunes retreated landward or were submerged, the latter forming the shoal structure to the south of the present Point Pelee. The materials comprising Point Pelee and its adjacent shoals are for the most part relict[1] deposits that have been reworked and redistributed to their present configuration. In other words, the present form of Point Pelee is the result of <u>erosion</u>, rather than accretion, as in the normal mode of spit formation.

(2) Present-day sedimentological processes are characterized by low levels of longshore drift (less than 25 000 m^3/yr),[2] which on the east side is usually directed southward during easterly wind and wave conditions. Storm surges which usually accompany such conditions cause washover of the east beaches, resulting in the one-way transfer of considerable beach material to the backbeach and marshes behind. The major sources for these sediments are the erosion of bluffs to the east, and adjacent offshore deposits. During periods of southerly to westerly winds and waves, the direction of littoral drift on the east side is predominantly northward. It appears, therefore, that an area of temporary storage for littoral material exists to the south of the tip of Point Pelee, extending southward to the depth limit of breaking waves (a distance of about 2 km). On the west side of the Point, the calculated net amount of littoral drift is much lower at approximately 4000 m^3/yr (which is the margin of error of the calculation), and is directed northward under all conditions except during westerly or northwesterly waves, when drift is toward the south. The most probable sources of littoral drift materials on the west side are the southern shoreline portion and the western portion of the temporary storage area just south of the tip of the Point. The material transported northward is presumed to be deposited in another temporary storage area at the extreme north of the west reach in the Leamington - Sturgeon Creek area. In summary, the west side appears to be stable or changing slowly, whereas the east side has a net erosion.

On the shoal, the net direction of bottom transport, both for the period studied and over the long-term (on the evidence of the sediment distribution), is east-southeastward. Evidence of northward transport of significant volumes of bottom materials is lacking. Such transport, especially from the northern portion of the shoal (in the vicinity of the postulated storage area) could occur at those times of the year (fall months) when southerly wave action is greatest.

(3) Sand dredging close to the tip of the Point, in particular the land-based operations allowed between 1912 and 1918, were apparently instrumental in removing vast quantities of sand directly from the submerged spit. The subaerial portion itself was reduced approximately 1 km in length as an alleged result of these operations. At this time the northernmost channel now visible on the shoal was probably opened or widened, facilitating greater sand transfer from the east to the west side, and vice versa. Excavation of the area on such a scale would also be expected to intensify the local wave climate and lead to increased recession along adjacent reaches.

Although it is unlikely that dredging at 1973 levels would have any appreciable effect on the wave energy distribution at Point Pelee, the proximity of the focus of dredging operations to the critical storage area south of the tip would pose a definite risk of interference with this source of

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[1]Earlier sedimentary bodies laid down when different depositional conditions prevailed in the area.

[2]Longshore drift at Long Point has been estimated by Liard (1975) at 510 000 m^3/yr.

material for beaches on the Point, and thus could cause recession in these areas. A more definite conclusion in this regard must await more specific research.

1.3. SUGGESTED FUTURE RESEARCH

Although the data and interpretation presented herein are deemed sufficient to satisfy the specific objectives of the study, there is clearly a need for further research into some areas in order to verify and elucidate some of the factors that, for a variety of reasons, could not be covered in this study. The major areas of future research are identified below and include the work that is presently in progress.

(1) Additional data on nearshore bathymetry and sediment distributions to the west of the Pelee Shoal as far as Pelee Island would complete the sediment distribution picture presented here and add considerably to the evaluation of the volume of granular material comprising these deposits. This work has been prepared for publication by St. Jacques and Rukavina (1976).

(2) Further stratigraphic data on the deposits making up the shoal are required to provide more details on the postglacial environment of deposition in the area. Such data would refine the concept of the mode of formation of the Point Pelee landform and associated deposits. This work should include a program of seismic profiles across the shoal, with the addition of more boreholes for stratigraphic control, especially in the southern portion of the shoal. The cores of all the boreholes should also be subjected to further analysis, especially of their fossil content, e.g. pollen and molluscs.

(3) Further studies should also be carried out on the genesis of both the sand ridges on the Point and those on the shoal. The former are presently being studied by staff of the University of Windsor.[3] In the case of the latter, it is still uncertain whether they are preserved from an earlier time in the history of the deposits. A program of side-scan sonar transects and coring would define these features more clearly, as well as throw light on the existence of mass transport of shoal sediments by migrating bed forms.

(4) The importance of a storage area for littoral drift located just south of the Point should be verified to obtain a detailed littoral drift budget for the Point. This could be done by detailed profile studies over an extended period of time. Special attention should be given to depth changes within the two transverse channels just south of the spit.

(5) As far as lake processes are concerned, an attempt should definitely be made to acquire data on currents pertaining to the fall and spring. Because of weather and ice problems, this might entail the development of suitable technology to collect data over long periods in an automated mode under rather rigorous conditions. This is probably the best way of determining the frequency and intensity level of north-south directed transport vectors and thus the degree and extent of sediment interchanges between the shoal area and the beaches of Point Pelee.

(6) The wave refraction program at CCIW should be modified to investigate and predict the changes in refraction patterns that result from wave passage over dredged holes and trenches on the shoal.

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[3]A. Trenhaille, Department of Geography, University of Windsor; personal communication.

(7) Refinements in existing models of bottom currents associated with circulation effects in western Lake Erie should be undertaken based on the current records collected in the area, with some emphasis on the seasonal changes in these current fields.

(8) A study into the mechanics and distribution of onshore-offshore movement of littoral sediments at Point Pelee is suggested. This would contribute greatly to our knowledge of sediment transfers between the inner and outer nearshore zone, and also aid in estimations of sediment budgets.

CHAPTER 2

The Origin of Point Pelee, Historical Trends in Shoreline Processes, and Dredging Impacts on the Coastal Sediment Regime

Before discussing the processes that are presently affecting the Point Pelee foreland and associated shoal deposits, it would help to review the existing literature record, including scientific reports, historical maps and accounts and other information that may be useful in indicating how the Point and shoal were originally formed and to identify whatever long-term trends are observable in the evolution of its shorelines. This record goes back as far as the mid-1800's, soon after settlement by Europeans became established on Point Pelee, and therefore should indicate both a reasonable long-term perspective of the net result of coastal processes at Point Pelee, as well as the impact of human interference with these processes.

2.1. THE ORIGIN OF THE POINT PELEE - PELEE SHOAL FEATURE

Of all the modes of origin that have been postulated to date for the Point Pelee - Pelee Shoal complex, that proposed by Coakley (1976) is the most detailed and up-to-date. This reconstruction was based on previously published plots of the time history of lake levels in the western basin of Lake Erie (Lewis, 1969) and on radiocarbon dates of material from boreholes on Point Pelee (Fig. 2). Coakley placed the origin of Point Pelee as a sandy foreland enclosing a marsh at approximately 4000 years ago when lake levels were 3 to 4 m lower than at present. The suggested mode of formation was the transgressive merging of beach ridges that had been built up on the flanks of the Pelee-Lorain moraine, a cross-lake ridge deposited by a minor ice advance during the late Wisconsin period. At the time of formation, the Point Pelee foreland was probably much larger than at present (Fig. 3), but since that time it has retreated landward to its present position under the influence of a gradual but steady rise in lake levels, leaving the present shoal area as an indication of its prior position. Another interesting idea put forward in this reconstruction was that the Point was also pivoting toward the west, i.e. erosion on the east side was occurring concurrently with a net accretion of the west side (as indicated by the shift in orientation of successive beach ridges on that side), as a probable result of progressive directional changes in the sector of dominant wave action.

So, contrary to other hypotheses that propose building of the Point through accretion of littoral drift over the years, the above theory maintains progressive erosion as the main factor in the development of Point Pelee.

2.2. HISTORICAL SHORELINE TRENDS AT POINT PELEE

Because it is only conceptual reconstruction of postglacial events and is thus open to different interpretations, the above hypothesis can only be used to provide a semiquantitative idea of the rates of shoreline retreat or advance at Point Pelee since its formation. However, if it is assumed that the spit at that time extended as far south as where Southeast Shoal Light now stands, then we can conclude that over 4000 years the spit has receded some 10 000 m landward (northward), giving an average rate of retreat of about 2.5 m/yr. Similarly, if

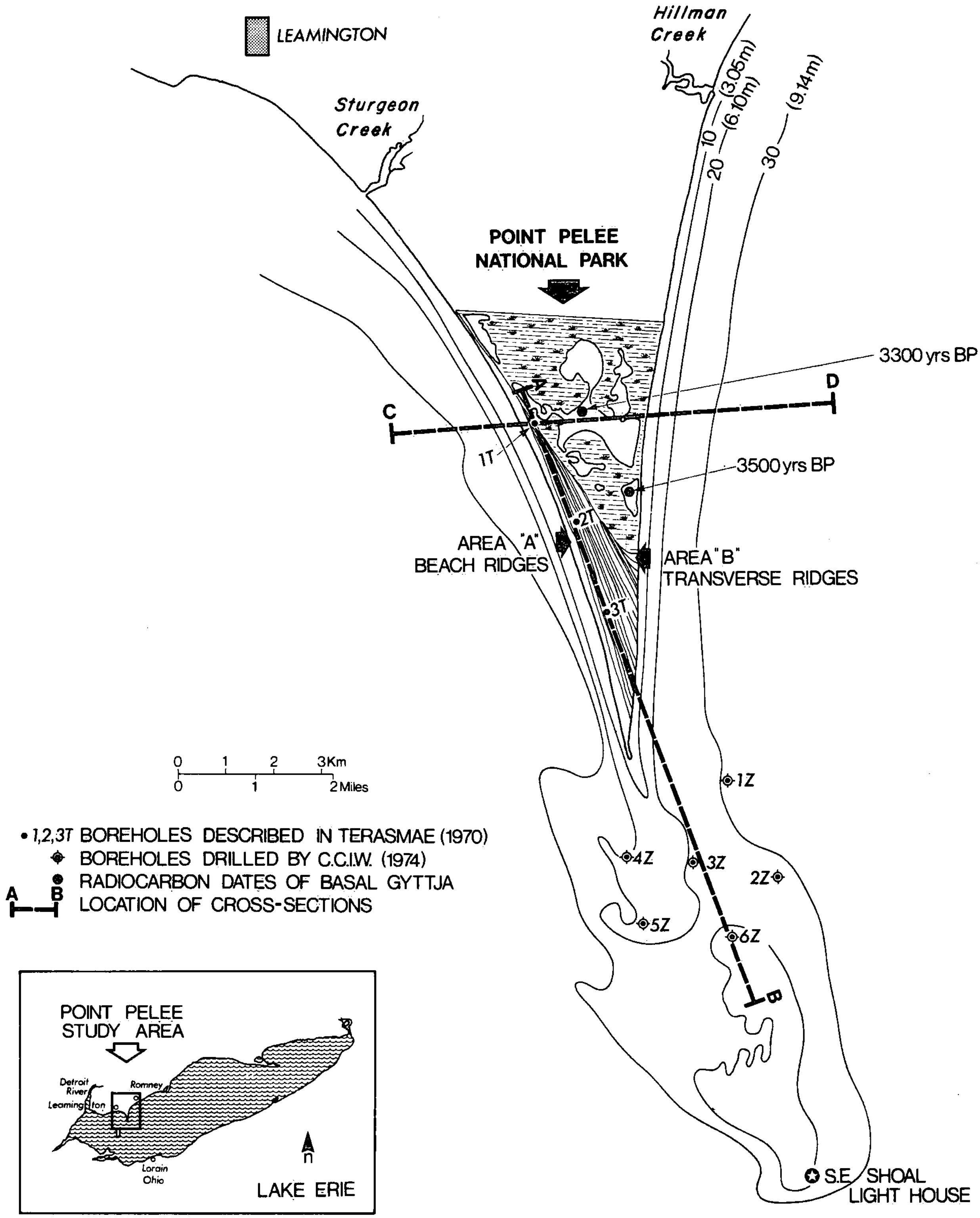

Figure 2. Location of geomorphological features and borehole locations in Point Pelee National Park and vicinity. The positions of the beach ridges and dunes were taken from the same aerial photographs that comprise the frontispiece. Boreholes and radiocarbon dates within the Park were taken by Terasmae (1970) and are labelled T. Those labelled Z were collected as part of the CCIW study in 1974.

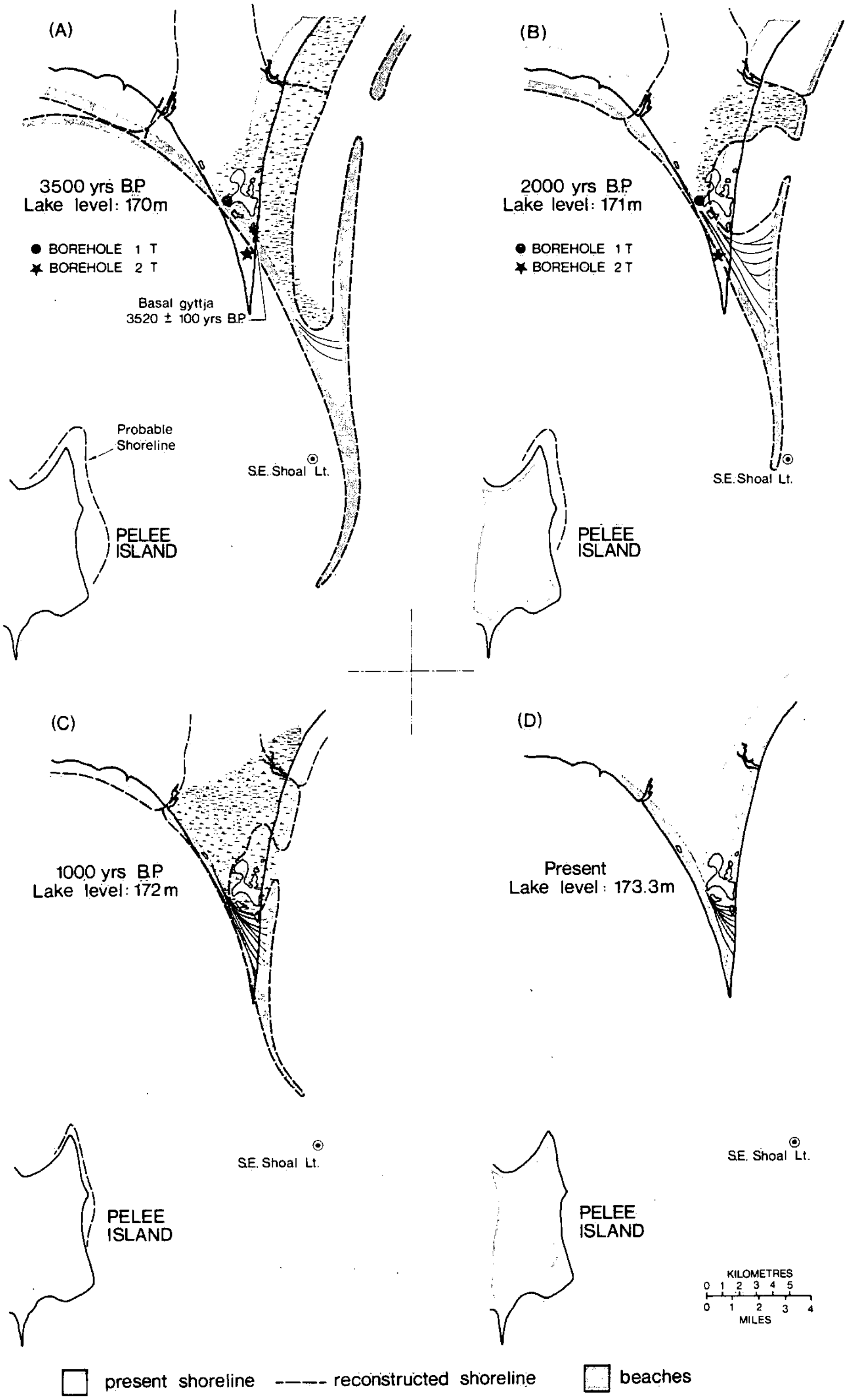

Figure 3. Reconstruction of the evolution of the Point Pelee foreland, 3500 years ago to the present (from Coakley, 1976).

the maximum distance from the innermost beach ridge on the west side to the present shoreline is taken as 1000 m (Fig. 2), then the average rate of <u>advance</u> at this location is about 0.25 m/yr over 4000 years. Similar estimates are not possible for the east side because all traces of the original shoreline have apparently been obliterated by subsequent wave action. However, the obvious truncation of the ponds in the marsh near the east shore indicates that the amount of shoreline <u>retreat</u> there would be at least of similar magnitude.

There are obvious shortcomings in the practical use of such estimates, in particular the long time period over which the rates are calculated and the unverified nature of the underlying assumptions. In looking for a more reliable estimate of the rates of shoreline changes and thus, indirectly, the intensity and distribution of coastal processes, the following sources will now be examined: (1) comparison of present-day maps, aerial photographs, and surveys with those dating back as far as possible; (2) administrative and scientific reports dealing with shoreline processes and developments from the archives of various government agencies.[4]

2.2.1. Comparison of Hydrographic Maps and Charts

Most of the early hydrographic maps of western Lake Erie show the position of presently existing coastal landmarks in the area, including Point Pelee itself, Lighthouse Point on Pelee Island, and Southeast Shoal Lighthouse. Also shown on the older maps are features that are no longer present, such as the Dummy Light, once located 4 km to the south of Point Pelee on a low bank called the Dummy Island (Fig.4). A comparison of the position of dynamic features such as the tip and shorelines of Point Pelee with reference to the more stable bedrock-controlled points might indicate whether measurable changes in position have taken place, which might be related to historical trends in shoreline processes and evolution.

Table 1 presents positions of these features that were extracted from maps dating from 1849 to 1950. Comparison of shoreline positions on both sides of the Point from these maps is seen to be virtually impossible, as charting standards and the datums used are different from those of today. However, on some maps (e.g.

Table 1. Historical Positions of Prominent Features, Vicinity of Point Pelee (1849-1950)

	Point Pelee	Dummy Light	Lighthouse, Pt. Pelee Island
1849* U.S. Coastal Survey Chart 31	W 82° 30′ 00″ N 41° 54′ 25″	Not yet built	W 82° 37′ 50″ N 41° 50′ 00″
As above, revised 1898	W 82° 30′ 00″ N 41° 54′ 10″	W 82° 29′ 50″ N 41° 52′ 20″	W 82° 37′ 50″ N 41° 50′ 00″
U.S. Lake Survey 1900	W 82° 30′ 30″ N 41° 54′ 25″	W 82° 30′ 25″ N 41° 52′ 15″	Not shown
Kindle's map 1933	N 82° 30′ 30″ N 41° 54′ 25″	W 82° 30′ 25″ N 41° 52′ 20″	W 82° 38′ 25″ N 41° 49′ 55″
Can. Hydrogr. map, 1950	W 82° 30′ 35″ N 41° 54′ 35″	No longer shown	W 82° 38′ 24″ N 41° 49′ 50″

*There is obviously a systematic error of 30″ in longitude in these figures, as even Lighthouse Point (a bedrock promontory on Pelee Island) shows such a shift in longitude

[4]Much of this information was compiled by K. East, Parks Canada. For further information on history and land use at Point Pelee, refer to Battin (1975).

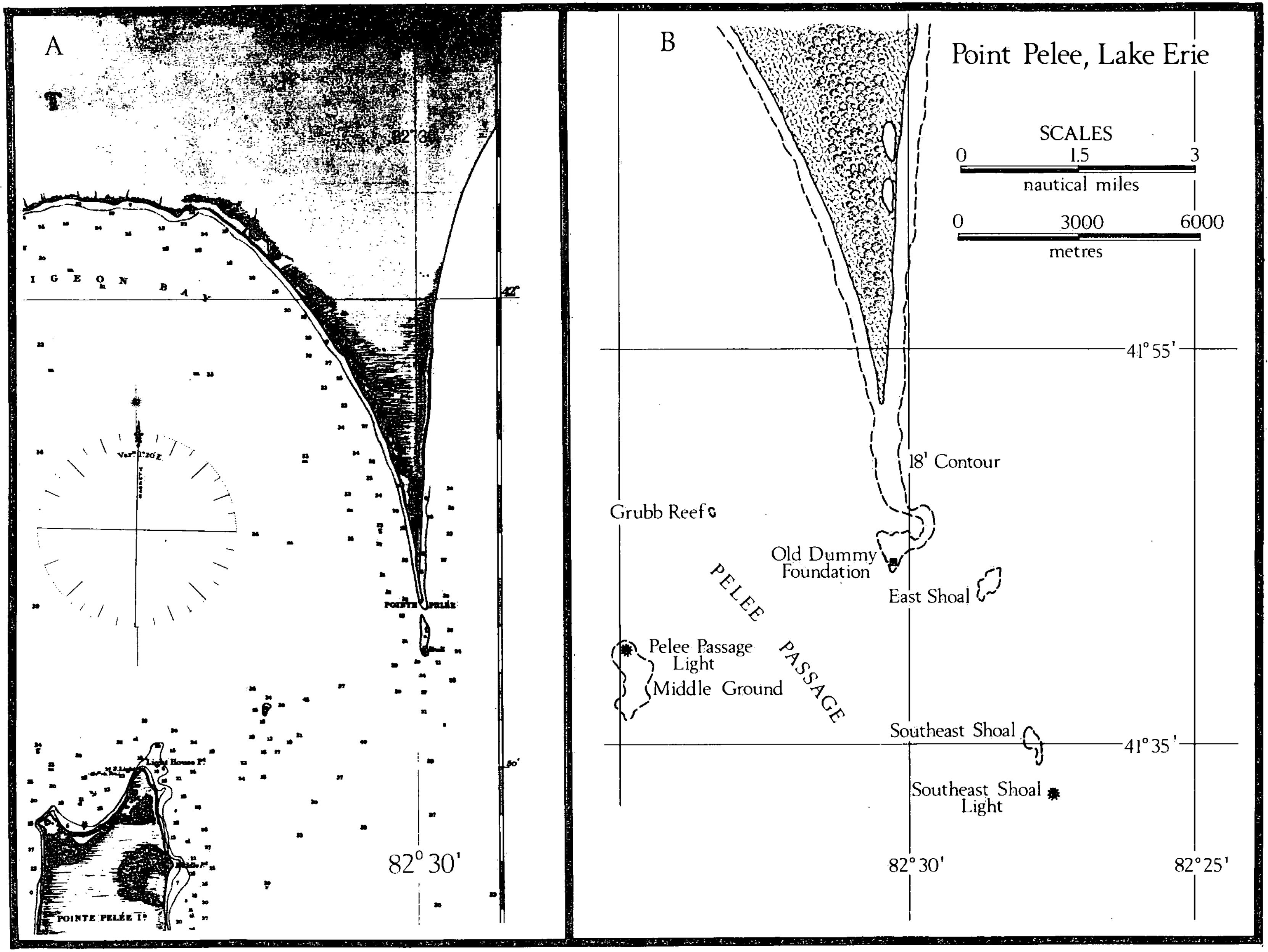

Figure 4. Comparison of hydrographic maps of the Point Pelee area. Map designated A was taken from "North America. Lake Erie West End. From the U.S. Coast Survey, 1849, published 1864" (Public Archives of Canada, Map no. PAC-31-1864). Map designated B was traced from U.S. Lake Survey chart no. 6, Lake Erie, a copy of which accompanied Ag. Distr. Engineer Craig's report of 1914.

Baird's[5] 1883 survey, which is not shown in Table 1 because of lack of latitude and longitude references) a natural outlet through the east beach ridge that is similar to the one opened a few years ago (1973) is shown. This feature is not evident on later maps so it would appear that the outlet was closed again by natural processes.

The feature on Point Pelee whose exact position has been best documented is the extreme tip of the Point (Table 1). Although there is some confusion about whether the maps refer to the tip of the sometimes submerged sand spit or to the end of the wooded portion, it is apparent that changes in position of this feature could not be measured at the resolution of the maps. Nonetheless, the maps based on the 1849 U.S. Coastal Survey do show considerable extension of the spit feature to more than 3 km south of the Point, which is lacking on the 1914 map.

On present-day maps (post 1950), the spit is still further reduced in length, and averages less than 0.5 km from the wooded tip of the Point. Apart from its changes in length, the mapped spit also showed a marked variability in orientation, ranging from southwest to southeast.

2.2.2. Comparison of Land-based and Topographic Surveys

For historical shoreline positional trends at Point Pelee, perhaps the most reliable indication is obtained by comparing the Department of Public Works shoreline survey of 1918[6] with recent topographic maps of the Point. The most accurate and recent map of Point Pelee is that presented in the Great Lakes Coastal Zone Atlas (Canada-Ontario Great Lakes Shore Damage Survey, 1976), derived from high-precision photogrammetric surveys carried out in 1973. Although the DPW survey was of a much lower precision (the traverse was not closed and apparently only compass and tape were used), it was related to some presently existing or documented landmarks, such as wharves and roads, thus making it a reasonably reliable historical reference. Furthermore, since the comparison interval spans 55 years and several "cycles" of high and low lake stages, the rates of change should reflect genuine long-term trends.

Table 2 presents the rates of change for the Point Pelee shoreline using this comparison, as well as other shorter-term rates that will be discussed in later sections. A correction was applied to the values to eliminate the horizontal displacement of the waterline brought about by differences in lake level in the years compared (assuming a uniform shore slope of 1 to 10). Although these data represent the most reliable and far-reaching for the area (Coakley and Cho (1972) used data extending only to 1931), they still are only time-averaged statistics and should be treated with caution, given the recognized unsteady nature of the shoreline changes. However, the following observations may be made.

(1) The west side of the Point, with the exception of the southernmost 5 km or so, has been stable or advancing over the past 55 years (average rate 0.3 m/yr). The latter area, comprising the western tip of the Point, shows a slight recession over the long term (av. 0.5 m/yr).

(2) On the east side, extremely high recession rates (av. 2.8 m/yr) occur in the northernmost portion of the Point as far south as the Park boundary (location

[5]Alex Baird, O.L.S.

[6]Department of Public Works Map No. 4803 to accompany report by Asst. Chief Engineer, dated December 13, 1918. The map was signed by Alfred Stevens, Acting District Engineer at Windsor. Scale 1 in. = 200 ft.

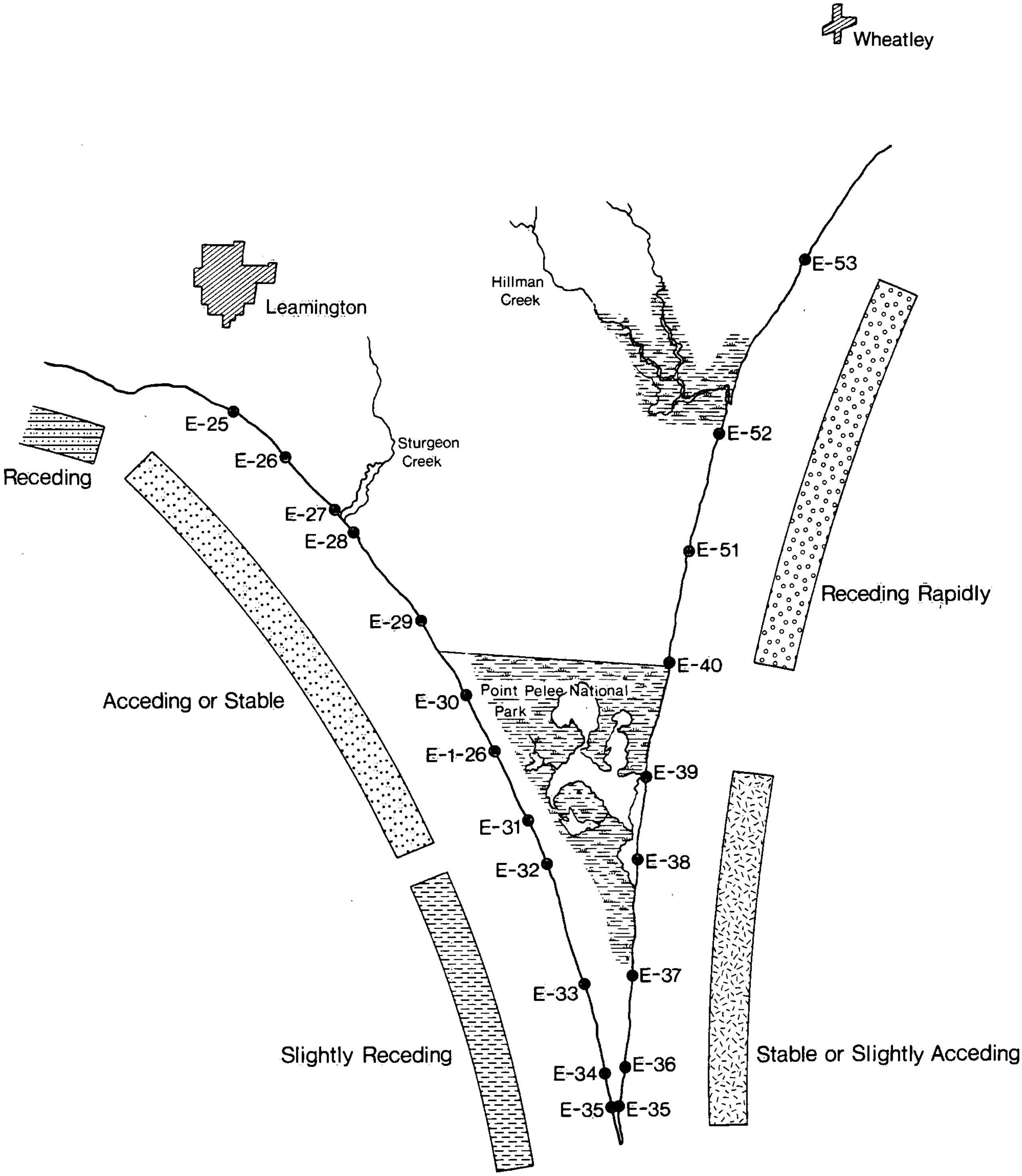

Figure 5. Summary of net shoreline changes at Point Pelee for the period 1918-1973 as tabulated in Table 2.

E-40, Great Lakes Coastal Zone Atlas, 1976). During this period, the northern portion of the Point has receded over 200 m in places. South of this area, rates of change are much lower and a slight accession (av. 0.5 m/yr) has characterized the east tip area since 1918.

(3) When compared with 1918 maps, the position and the length of the exposed spit south of the tip of the Point has apparently changed very little.

Table 2. Historical and Recent Rates of Change (m/yr) in Point Pelee Shoreline Positions*

Location†	1918-1973	1955-1973†	1964-1973‡
E–25	+0.2	Negligible	No meas. taken
E–26	−0.2	"	"
E–27	+0.2	+0.5	"
E–28	+0.4	+0.5	"
E–29	+0.4	+0.1	+1.5
E–30	+0.2	+0.1	+1.5
E–1–26	+0.2	Neg.	+1.5
E–31	−0.5	+0.2	+1.5
E–32	−0.3	−0.2	+1.0
E–33	−0.3	−0.3	+1.5
E–34	−0.7	−1.0	−3.4
E–35	−0.7	Neg.	−2.3
E–35E	+0.5	+1.4	+5.4
E–36	Neg.	+1.1	+4.9
E–37	+0.5	+0.4	−0.1
E–38	+1.1	+0.3	−1.2
E–39	Neg.	−0.3	−1.2
E–40	−1.6	−0.6	−4.0
E–51	−1.8	−0.1	−4.0
E–52	−2.5	−0.4	−4.0
1.5 km N of E–52	−4.4	Neg.	−9.5
E–53	−3.6	−0.1	Neg.

*All recession amounts, except those for 1955-1973 (years of approximately similar lake levels) were corrected for lake level differentials using the following mean yearly values: 1918, 173.8 m; 1965, 173.4; 1973, 174.8

†Locations and rates extracted from Great Lakes Coastal Zone Atlas (1976)

‡Obtained by superimposing Kerr's (1964) field sheet over that of the Coastal Zone Atlas

These overall trends in the evolution of the shoreline at historical time scales are summarized on Figure 5.

2.2.3. Administrative and Scientific Reports as an Indication of Historical Shoreline Trends

Compared with maps and surveys that are based on direct measurements, written reports are obviously of less value in indicating ongoing shoreline trends. This is because such reports are more subjective and usually refer to a short period of extreme events. However, they do give valuable indications of the nature of the events and of the years in which their effect was most pronounced.

The first reliable records of serious shoreline recession at Point Pelee are those of Kingsmill, Taverner,[7] Baird, Conover,[8] Stevens,[9] Craig,[9] and Kindle,

[7]P.A. Taverner, an ornithologist associated with the Geological Survey of Canada.

[8]Forest Conover, Hon. Superintendent of Point Pelee National Park, and a life-long resident of the area.

[9]DPW District Engineers.

all published between 1914 and 1923. Relevant observations by these men may be listed as follows.

(1) Kingsmill (1914) stated that a shortening of the spit by more than 1/2 mi (800 m) within the previous 2 years was linked to the onshore sand-mining operations in the vicinity of the spit.

(2) P.A. Taverner stated in 1915 that: "Men still in the prime of life can remember when they could walk out dry-shod nearly to the Dummy Light (some 4 km south of the Point)." In 1915 the length of the exposed spit was greatly reduced.

(3) In 1917, Baird noted a reduction of 1716 ft (523 m) in the length of the spit, and extensive recession of the east side approximately 5 km north of the tip.

(4) Conover, in a letter dated 1918, confirmed the observations made by Baird and estimated that "60 to 70 feet, more or less" had been lost to the east beach, apparently in that year.

(5) In contrast to the above observations, both DPW engineers were moderate in their assessment of shoreline changes at that time. Stevens reported that the Point had decreased in width by 150 ft (45 m) between 1889 and 1917 (a combined recession rate for both sides of 1.6 m/yr). Craig went further in stating that although recession was occurring at places along the east side of the Point, accession was occurring at others. The locations of both processes changed with time; therefore no statement could be made on the effect of erosion on the Point as a whole.

(6) Kindle (1918a) attributed the shore recession to natural causes, such as higher lake levels caused by steady isostatic rebound of the outlet at Buffalo from the weight of glacial ice, and the natural tendency of the point to migrate westward. He discounted dredging as a causal factor.

The loss of all Point Pelee National Park files for the period mid-1930's to the mid-1950's prevents the further tracing of historical observations related to local shoreline changes. However, the above observations and the evidence of maps after 1849 and prior to 1917, especially, suggest that the period 1900-1923 or thereabouts concided with an apparent increase in the rate of shoreline change, mostly to the east side and spit area of the Point.

2.3. SELECTED CAUSAL FACTORS IN ACCELERATED SHORELINE CHANGES AT POINT PELEE

There are a number of causes, both natural and man-induced that may be cited to explain the apparent accelerated shoreline changes at Point Pelee. The more possible ones may be listed in the following categories, allowing for a degree of overlap.

(1) Natural

(a) A significant increase in the rate of rise of Lake Erie levels during recent times compared with that of earlier (postglacial) times.

(b) Recent climatic changes resulting in an increase in the number and intensity of severe storms.

(c) A reduction in the rate of erosion in areas that supply littoral drift material to Point Pelee.

(2) Man-induced

(a) The removal of actual or potential littoral drift material from the coastal sediment system through dredging or diversion offshore of such materials (as at some shoreline structures).

(b) The lowering of the shore elevation through land-based sand mining or as a result of deforestation, thus permitting more frequent washover and loss of beach material from the system.

(c) Alteration in an adverse way of the groundwater regime in the beaches, caused by artificial draining of a large portion of the marshes that once comprised the central portion of the Point.

A thorough and exhaustive appraisal of the role of all these probable causal factors in the changes that have recently taken place in the long-term shoreline trends at Point Pelee is beyond the scope of this report, and lies at the limits of coastal zone research. None of the above causes has been definitively verified. It may be more productive to review two of these factors that have attracted much attention in connection with shoreline recession at Point Pelee, namely, high lake levels and the removal through dredging of sand and gravel from the shoreline and nearshore deposits.

2.3.1. Historical Lake Levels and Shoreline Changes at Point Pelee

Lake Erie average monthly levels (Port Colborne) have fluctuated between a low of 173.0 m above sea level in 1935 and a high of 174.8 m in 1973, based on records kept since 1860 (Fig. 6). However, Liu (1970) found no significant upward trend in similar records from Cleveland, with the exception of a vaguely defined 8-year cycle.

When one examines the respective durations of levels higher and lower than a value midway between the above extremes (173.9 m), the following pattern emerges. During the past 114 years of record, yearly average lake levels were above 173.9 m for 61 years (53%) and below 173.9 m for 53 years (47%). In other words, the record is almost evenly balanced between low- and high-water periods. The duration of consecutive years of high and low levels was as follows:

1860-1890,	considerably above median;
1891-1902,	slightly below median;
1903-1909,	slightly above median;
1910-1942,	intermediate;
1943-1961,	considerably above median;
1962-1967,	considerably below median;
1968-1974,	considerably above median.

Even on casual examination of these data, it is apparent that the original concern over abnormal recession in the period 1900 to 1923 (section 2.2.3) coincided with years of intermediate levels (around 174 m) on the average. Furthermore, Coakley and Cho (1972) showed that although overall recession of the west side was coincident with a rise in lake levels between 1931 and 1947, and a slight accession was evident between 1947 and 1970 (years of about equally high lake levels), recession was the rule on the east side for the entire 1931-1974 period, regardless of levels. Also, Table 2 further suggests that the <u>net rate</u> of shoreline changes (not the type of change) is the most sensitive feature with regard to changes in lake level. In other words, net accession tends to occur on the west side and recession on the east side regardless of whether lake levels compared are similar (1953, 1973) or had risen (1964, 1973). In other words, there was no consistent relationship between shoreline change and lake levels. What

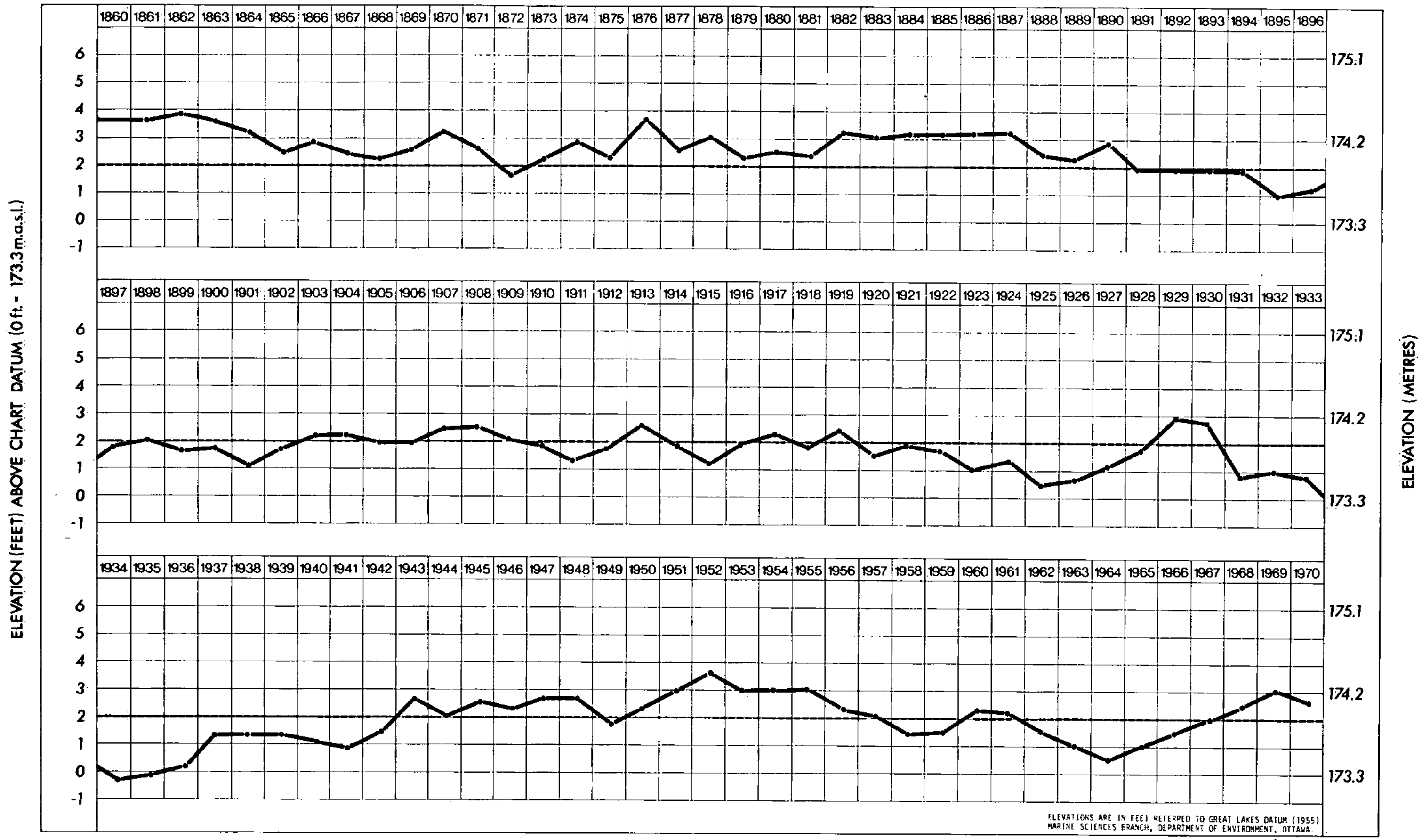

Figure 6. Time history of yearly mean lake levels for Lake Erie (Port Colborne gauge) for the period 1860-1970. The heavy line denotes a level midway between high and low extremes.

remains untested is the type and rate of shoreline change related to a <u>fall</u> in lake levels, for instance for the period 1955 to 1964, for which aerial photographs have not yet been compared.

In contrast to the above indications, Seibel (1972) detected a positive relationship between average lake levels and average erosion rates along the Lake Michigan shoreline (using post-1940 aerial photographs). However, the shores he studied were not representative of landforms such as Point Pelee. The Civil Engineering Department of the University of Waterloo (1976) made similar conclusions on the relationship between shore erosion in western Lake Ontario and the length of time that lake levels exceeded a certain value. For the same reasons, these results also cannot be applied directly to the situation at Point Pelee.

In summary, although much further work (especially on rates of change during low-level stages) is required before the role of lake levels and lake level changes are defined rigorously, the following comments appear valid at this time.

(1) The period 1900-1923, when drastic changes in the shore regime were first recorded, was a rather stable period of intermediate lake levels.

(2) Recession occurs along most of the east shore regardless of lake stage, but the rates are higher during rises in lake level or high-level periods.

(3) Rates of change for the west side are generally insensitive to lake stage and indeed indicate widespread shoreline accession during rises in lake levels and high-lake stages.

(4) The relationship between lake stage and shoreline changes at Point Pelee is not consistently positive, as has been found with other types of shoreline on Lake Michigan and Ontario.

Carrying the above observations further, there appears to be some basis for the contention that lake levels alone are not the decisive factor influencing net shoreline trends at Point Pelee. The Point has had 4000 years to adjust to rising lake levels since its formation and, as noted previously, no rising trend is evident in lake level records of the past 100 years. If the chronic recession occurring on the east side is viewed simply as a deficit in beach material supply to the Point, then this deficit would be incompatible with the increased erosion in the bluff areas to the east (and increased supply of sand) that would be expected to accompany higher lake levels, provided that this material reaches Point Pelee. It appears more likely, therefore, that factors other than those directly related to lake levels are worth examining, such as the interception and removal of littoral material at local harbour entrances, and by commercial sand and gravel operations.

2.3.2. <u>Harbour Maintenance Dredging</u>

Small craft harbours located at Wheatley, Leamington, and Sturgeon Creek all have protective jetties that can trap littoral drift. As a consequence, the channels between these jetties and the approaches must be kept open by dredging sand to depths suitable for navigation. The dredged material is dumped several kilometres offshore and is thus lost to the littoral zone. The quantities dredged at these sites thus provide a good indication of the impact of these harbours on littoral transport of granular material.

Records kept by the Department of Public Works show that periodic dredging is carried out only at Leamington and Wheatley. At Leamington the average amount dredged is approximately 14 000 yd^3 (10 700 m^3) per year (between 1932 and 1974); and at Wheatley, an average of approximately 8000 yd^3 (6000 m^3) per year (1950-1974).

Of all these small harbours, only that at Leamington was in existence prior to 1918. The present Wheatley harbour entrance was constructed in the 1950's, and that at Sturgeon Creek, sometime later.

2.3.3. Commercial Sand Dredging Operations in the Vicinity of Point Pelee

The dredging of sand and gravel from the lakebed and beaches in the vicinity of Point Pelee has been going on since at least 1907 or 1908 and probably since before the turn of the century. Licensed areas prior to 1974 are indicated on Figure 7. How much sand has been taken and from where it has been taken during the earlier years of operation are not precisely known. However, if early reports of as many as nine dredges operating simultaneously[10] are to be accepted, the quantities must have been considerable. Based on extrapolations of more recently recorded dredged volumes between 1965 and 1972,[11] the total quantity of material dredged from licenses on the shoal area south of Point Pelee was estimated at around 25 million cubic yards (19 million cubic metres) since 1910. Since 1965 the amounts extracted average approximately 350 000 yd^3 (267 400 m^3) per year.

Dating back to 1914, the dredging has been the subject of much public controversy. Over the years, the dredgers have been subjected to a gradual but steady curtailment of their activities. In 1910, for example, the provincial government began to limit dredging to an area beyond 1200 ft (366 m) from the shoreline. In 1912 and 1913, three licenses were issued by the federal government allowing the taking of sand right off the beaches of the Point, above the high-water mark. In 1918, these three licenses were cancelled. Concurrently, probably because of intense public pressure on the government to halt the activity, provincial authorities decided to extend the offshore limit to 5000 ft (1524 m). It is probable that the report by E.M. Kindle in 1918b, which suggested that dredging outside of that limit would not have any effect on the erosional regime, prompted these measures. Some time later, the dredging limit was extended to 2 mi (3.2 km) from the shoreline of the Point. The issue came to a head in 1974 with the provisional cancellation of all licenses in the immediate area by the Government of Ontario pending the outcome of public hearings on the subject.

The literature on the effect of offshore dredging on shoreline changes is very sparse and deals mostly with marine coasts. In Great Britain, Motyka and Willis (1974) used wave refraction patterns to demonstrate that the effect of dredged holes in modifying wave characteristics (in an adverse way insofar as coastal stability is concerned) was a function of the wave climate, the depth and size of the hole, and the distance offshore. At Point Pelee, Kindle (1933) focussed on the probability that the dredging might interfere with the normal flow of sediments from the dredging areas to Point Pelee. He concluded that dredging at a distance of 5000 ft (1524 m) would have no significant effect on shoreline recession. The weak point in his studies, however, was the lack of reliable data on lake currents on the Pelee Shoal near the focus of dredging.

The 1974 CCIW study was not meant to probe in detail the relationship between actual dredging operations and shoreline changes, as the licenses had already been suspended at that time. However, the insights obtained on physical

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[10]Kingsmill (1914).

[11]Personal communication, Lands Administration Branch, Ontario Ministry of Natural Resources.

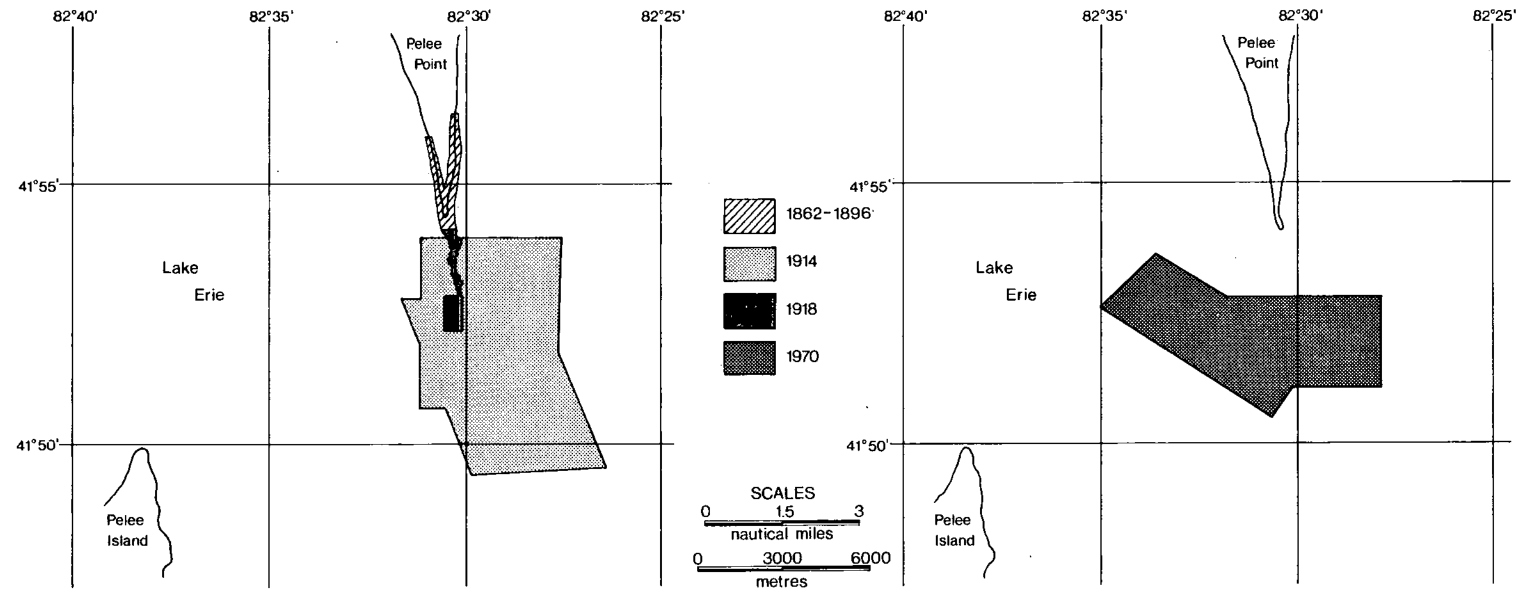

Figure 7. Location of commercial dredging licenses in the vicinity of Point Pelee since 1862, based on available information and maps from Department of Public Works, Ontario Ministry of Natural Resources, and the Public Archives of Canada.

processes and sediments on the shoal within the license areas should contribute to a better understanding of what these relationships might be.

2.4 SUMMARY

A recently published reconstruction of the mode of formation and evolution of Point Pelee places its origin at around 4000 years ago, while lake levels were at a lower position. Initially much more extensive than at present, the Point has retreated to its present position under the influence of slowly rising lake levels and other wave-energy-related factors. In general the Point has been receding along its eastern shoreline and advancing on its western shoreline. The tip has moved considerably northward.

The historical records, surveys, and maps (dating back to the mid-1800's) indicate that the above postglacial trend persists in all areas except near the tip, where the east side shows a net accession and the west side shows recession since 1918. Also it appears that the rate of shoreline change has accelerated considerably in historical time, especially at the spit and along the northeast portion of the Point.

In view of the coincidence of this apparently modified shoreline trend with the establishment of large-scale human settlement in the area, it is not surprising that a cause-effect relationship has been suggested. The factors most often cited as causes of shoreline changes are high lake levels and commercial dredging. As far as the former is concerned, there appears to be no consistent relationship with shoreline change. The effect of the latter will be examined in later sections of this report.

Sediments and Surface Aspect of the Pelee Shoal

3.1 INTRODUCTION

During the summer of 1974, detailed field studies were carried out into the three-dimensional character of the sediment deposits comprising the Pelee Shoal and surrounding areas (Fig.8). This section presents the results of this investigation organized into three main topics: (1) the character of the surficial deposits; (2) the stratigraphic sequence and volume of shoal deposits; (3) surface bed forms and structural features as indicators of the present physical aspect of the shoal surface. An examination of these topics will provide information on the present depositional conditions in the shoal area and indicate the major changes discernible in the postglacial sediment record.

3.1.1 Previous Work

The literature on sediment research in the Point Pelee area of western Lake Erie is very sparse. Kindle (1933) presents the first attempt at using sediment parameters and limited lake current data to define sedimentary processes at Point Pelee. Lewis (1966) mapped the bottom sediments of Lake Erie, including much of the nearshore sandy facies; however, his map made no attempt to resolve details in these areas. Kerr's (1964) survey of the Point Pelee area was the first, prior to the present study, to include bottom samples of the material on the shoal itself, although no attempt was made at interpretation. Coakley (1972) mapped nearshore sediment bodies around the Point out to a distance of several kilometres. He also used sediment tracers and textural parameters to detect trends in sediment dispersal along the sides of the Point and on the shoal. Kamphuis (1972) carried out littoral drift studies on the east side of the Point immediately north of the Park boundary, and concluded that littoral drift was reversible in direction, averaging approximately 19 000 m^3/yr toward the south. Finally, St. Jacques and Rukavina (1976) have prepared a further interpretation of nearshore sedimentation in this area.

3.1.2. Methods

The description and interpretation of the bottom sediment and physical aspect of the Pelee Shoal presented here are based on the following data sources.

(1) One hundred and seventy-nine Shipek grab samples collected at the intersections of rectangular grids (spacing 2 and 1 km) superimposed over the study area and adjacent areas (Fig. 8). These samples are representative of the deposit to a depth of 10 cm and were collected in 1974 for this study and others (St. Jacques and Rukavina, 1976). The samples were subjected to conventional particle-size analysis (Rukavina and Duncan, 1970; Rukavina and Lahaie, 1976). Moment statistical parameters and textural classifications were also derived by computer (Rukavina and Dolling, 1973).

(2) The textural character of the littorally drifted materials was based on a total of 16 samples collected in the vicinity of the Sturgeon Creek and Wheatley entrance jetties, in water depths of 2.5 to 7 m.

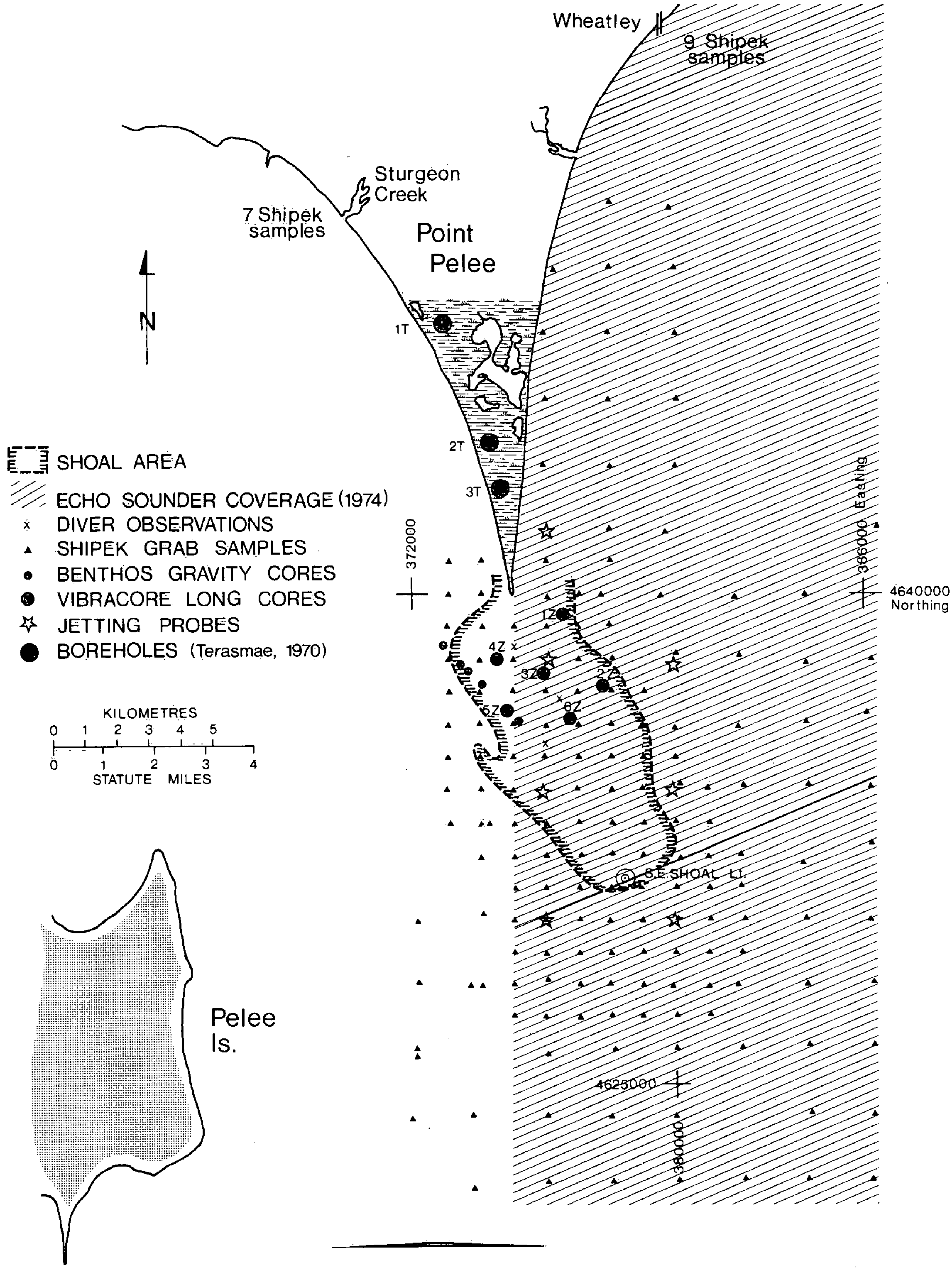

Figure 8. Location of sediment and bathymetric data collection sites. Echograms, cores, and Shipek samples were taken in 1974.

(3) The descriptions of the subsurface materials were based on the following.

(i) Six cores collected in 1974 using an Alpine Vibrocorer (Coakley *et al.*, 1975) at locations shown on Figure 8. Radiocarbon dates were also obtained on organic material found at various elevations on the cores. Particle size analyses were carried out at regular intervals (30 to 60 cm spacing) along the length of the cores.

(ii) Jetting probes carried out at seven locations (Fig. 8) as part of the CCIW Nearshore Sediment Inventory.[12] The technique involved water-jetting a graduated pipe down to refusal and recording the total depth of less-resistant sediments (usually sand or silt) penetrated.

(iii) Published reports by Terasmae (1969) and Lewis (1969).

(iv) Limited unpublished seismic and echo-sounder data showing sub-bottom features.

(4) The morphology and bed forms of the shoal were studied using echo-sounder records and diver observations taken during 1971-1974 (Fig. 8). The morphologic data extracted from the echograms were classified into arbitrary height and slope classes and compiled to produce a geomorphic map at a scale of 1:20 000 (Fig. 14). Resolution was limited by wave motion on the lake surface to features greater than 0.25 m in relief. Information on smaller features (mostly ripples) is based on diver observations and bottom photographs. Average positional accuracy is estimated at about 50 m.

3.2 DISTRIBUTION OF SURFICIAL SEDIMENTS

The surface distribution of sediment types (based on Folk's (1965) classification) on the Pelee Shoal and surrounding areas is presented in Figure 9. The approximate extent of the shoal is outlined.

3.2.1. Sand Deposits

By far, the dominant sediment type on the shoal and adjacent areas is represented by clean or muddy sand (clean sand contains <10% clay + silt). These well-sorted, clean sands occur along the shores of the Point as narrow beach and nearshore prisms (generally <1 km in width) which converge at the tip and continue southward for approximately 20 km. This continuous deposit measures only a kilometre in width in the vicinity of the tip of Point Pelee, but expands to a width of over 20 km at its southern extremity. Within the area shown on Figure 9, it comprises approximately 130 km^2. Assuming an axis passing through the Point and Southeast Shoal Light (the southernmost extremity of the shoal feature), the clean sand deposit has a marked asymmetry toward the east, with more than two-thirds of the sand body lying east of the axis. In texture, these deposits range from medium to fine sand and are well sorted. A plot of contoured values for mean (phi)[13] diameters is presented on Figure 10. The clean sands grade into muddy sands to the east, north, and south and more sharply into gravels and glacial sediments to the

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[12] N.A. Rukavina, Scientist in charge, kindly made these unpublished data available to this study.

[13] Phi (ϕ) units are a transform of grain size expressed in millimetres, i.e. ϕ value = $-(\log_2$ diameter in millimetres) or, the larger the Phi value, the smaller the particle diameter.

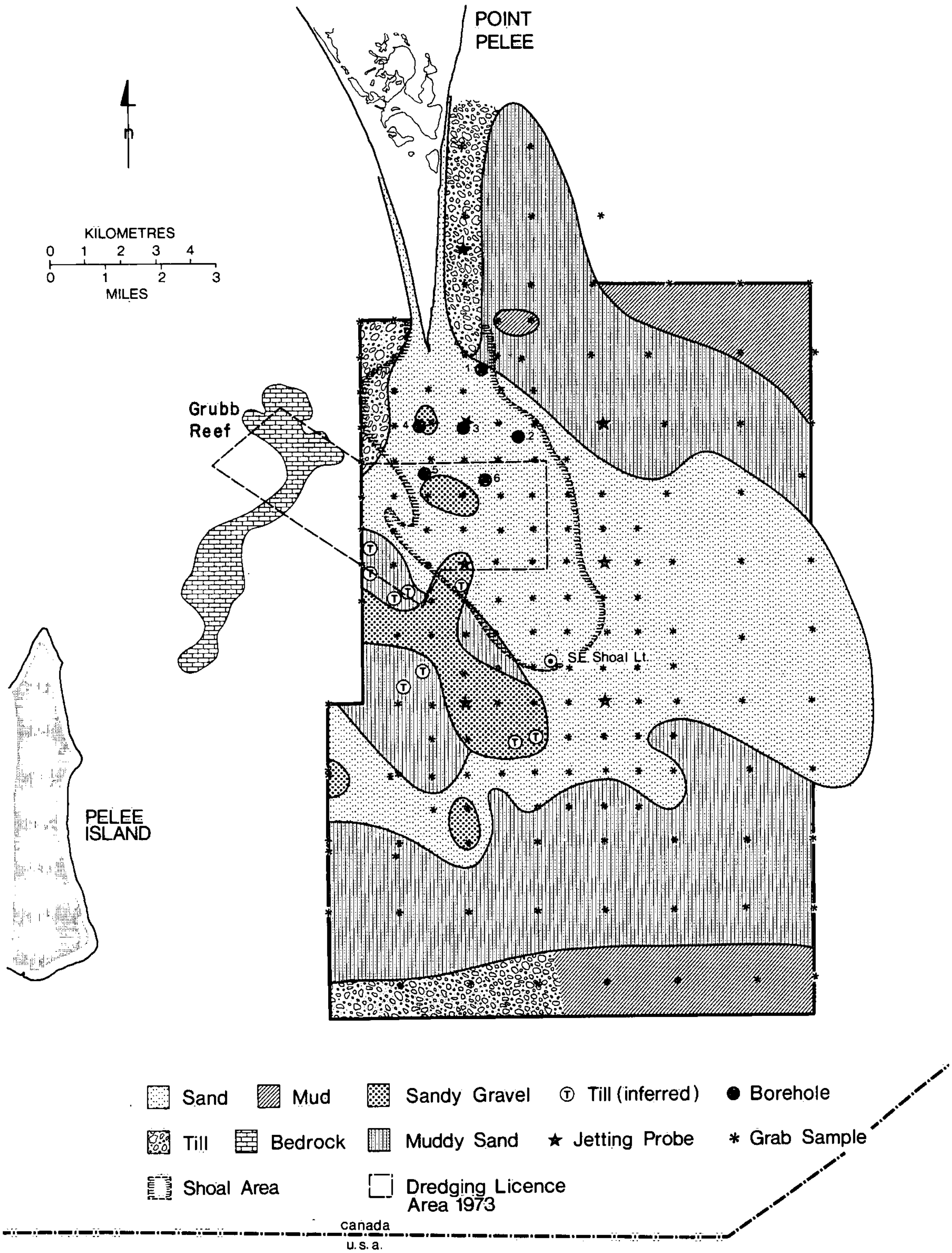


Figure 9. Bottom sediment types in the vicinity of the Pelee Shoal, using the classification scheme of Folk (1965).

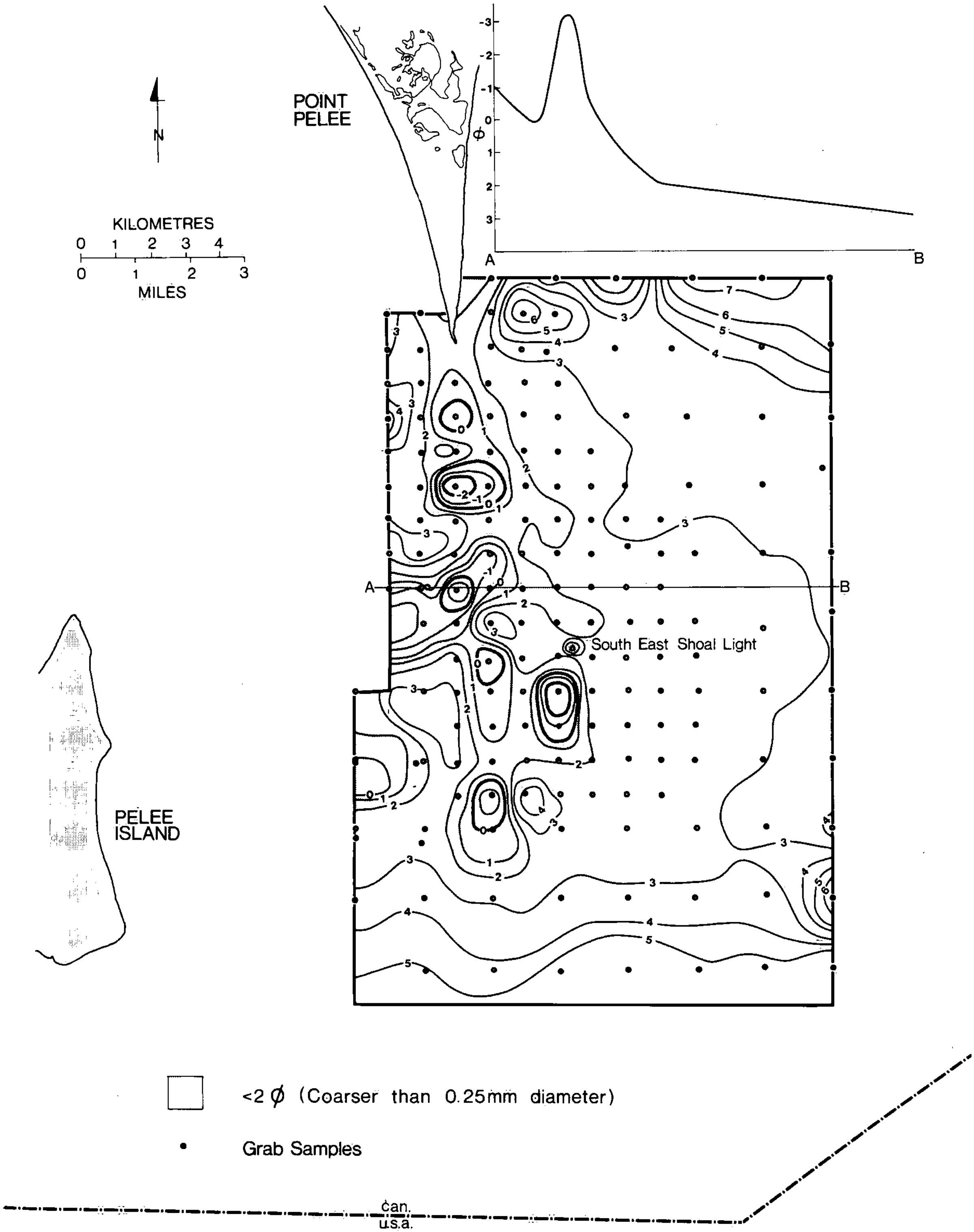


Figure 10. Distribution of mean grain diameters (in ϕ units) for samples collected in the vicinity of the Pelee Shoal. Contour interval - 1ϕ. Inset at top right shows a section through the contoured values along AB.

west. From the section plotted on Figure 10, there is a definite fining trend toward the east.

The muddy sands form a concentric band to the east and south of the clean sands, with a similar eastward bulge extending beyond the area of coverage. They fine out gradually toward the east into basin silts with increasing depths of water. The muddy sand facies is absent from the nearshore deposits flanking the Point itself and with minor exceptions, from the area west of the clean sand body.

3.2.2. Gravelly Deposits

Gravelly deposits comprising mostly sandy gravel (>30% coarser than 2 mm or -1ϕ) are restricted to the area directly south of the Point Pelee spit and occur as discontinuous bodies aligned roughly along a north-south line from the spit (Fig. 9). Total deposit area is estimated at 10 km^2. Gravelly materials also occur in the area between Point Pelee and Pelee Island. All of these deposits are associated with areas of glacial sediment and fall entirely within the area west of the Pelee - Southeast Shoal Light axis. They occur in water depths ranging from 4 to 11 m.

3.2.3. Glacial Till

Glacial till crops out in the extreme northern part of the shoal area, an obvious continuation of the extensive areas of exposed till on both sides of the Point (Coakley, 1972; Kindle, 1933; St. Jacques and Rukavina, 1976). Discontinuous exposures of glacial sediments also occur with or without a veneer of sandy or muddy sediments, slightly west of the shoal area around Grubb Reef, and in the extreme south of the mapped area.

3.2.4. Bedrock

Bedrock outcrops are confined to the western portion of the mapped area in the vicinity of Grubb Reef and off the eastern coast of Pelee Island. The bedrock comprises Devonian carbonate rocks (Sanford, 1969).

3.2.5. Littoral Drift Material

This material, collected at Sturgeon Creek and Wheatley, consists of well-sorted, medium-textured clean sands. Average water depths of the samples were 2.5 m and 4.2 m for Wheatley and Sturgeon Creek, respectively. The average texture of these sands (compared with Pelee Shoal samples of comparable depths) is presented below.

Sample location	No. of samples	Median ϕ	Standard deviation
Wheatley	8	2.04 ϕ	1.39
Sturgeon Creek	7	2.94 ϕ	1.05
Pelee Shoal (depth $\leq$ 6.5 m)	9	1.13 ϕ	1.24

The material sampled at both harbours is unmistakably littoral rather than fluvial, as sand is completely absent from the material entering the lake from streams at these locations.[14]

3.3 SUBSURFACE SEDIMENTS OF THE PELEE SHOAL

The previous section outlined the spatial distribution of the sediment types occurring on the shoal and adjacent areas. This section will add the third dimension to these distributions, namely vertical variations in sediment type. The main questions to be answered are: (1) What is the nature of the subsurface deposits and how does their probable mode of deposition compare with that of the surface deposits? (2) What is the geometry, thickness, and estimated volume of the sandy deposits exposed on the shoal? (3) What is the source of these sediments? (4) What are the present rates of sedimentation on the shoal?

Attempts to obtain continuous subsurface profiles over the shoal area were unsuccessful, for various technical reasons, so the answers to the questions posed above are based on a relatively thin coverage of the area by boreholes and jetting probes (Fig. 8) and on published reports by Terasmae (1969) and Lewis (1969). Nevertheless, the information presented here still represents the most detailed investigation to date into the stratigraphy of these deposits.

3.3.1. Borehole Logs

The oldest recognizable sediment penetrated by the boreholes is a clay till of Pleistocene age probably correlative with the Port Bruce stadial (Lewis, 1966). This sediment is overlain by deposits of Holocene (or Recent) age. The positive relief of the till surface as seen on seismic records south of the study area prompted Hobson et al. (1969) to interpret this feature as a moraine (the Pelee-Lorain moraine) laid down at the limit of a minor ice advance. This subsurface feature trends about N 150° from Point Pelee to Lorain, Ohio. None of the boreholes reached the underlying carbonate bedrock.

Cores from the six boreholes yielded a stratigraphic sequence for the postglacial sedimentation over the shoal. These, when supplemented by borehole logs from Terasmae (1969), are useful in tracing trends in the depositional history of the shoal deposits.

The elevation and type of sediments found in the cores are shown on Figure 11. Three radiocarbon dates on organic materials found in the cores are also shown. The stratigraphic relationship between these logs and those of Terasmae (1969) is interpreted as shown in Figure 12. In order of decreasing age, the units may be described as follows.

(1) Till - The till dips southward from a maximum elevation of 170.5 m at borehole 1T to less than 156 m above sea level at borehole 6Z. The latter location might represent a trough or local depression in the till surface, since the till outcrops on the lake bottom further south at an elevation of around 164 m. Consolidation tests on the upper several centimetres of till indicate a high degree of overconsolidation, taken to signify a post-depositional period of subaerial exposure and desiccation.

(2) Clay-silt unit - Within the depression in the till elevation, as noted in boreholes 2, 6, and 5Z and above the till in B.H.4Z, a complex unit of clays grading upward into silt occurs. This unit ranges in thickness from 1 m in

[14] Water Survey of Canada, Sediment Survey Section, personal communication.

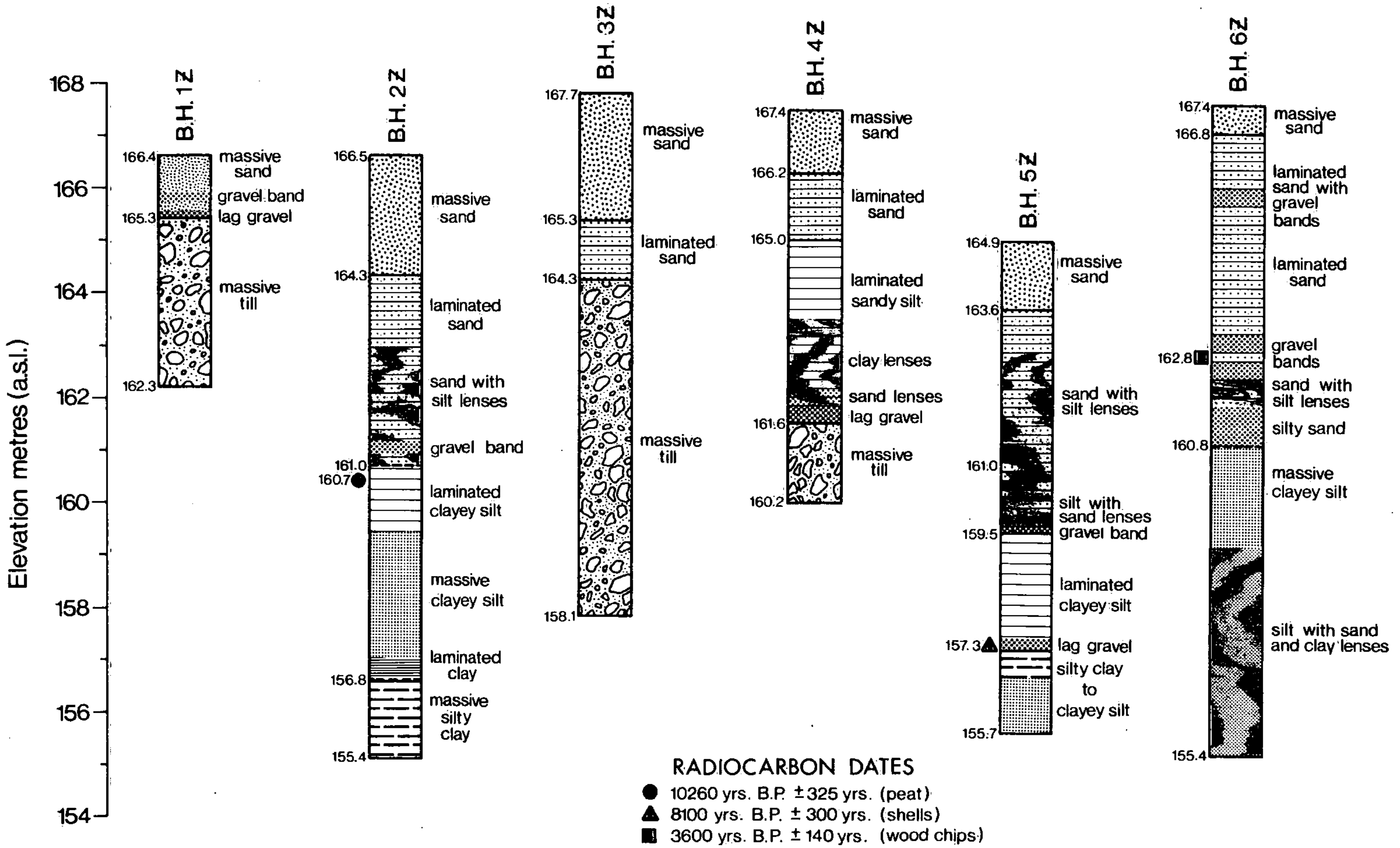
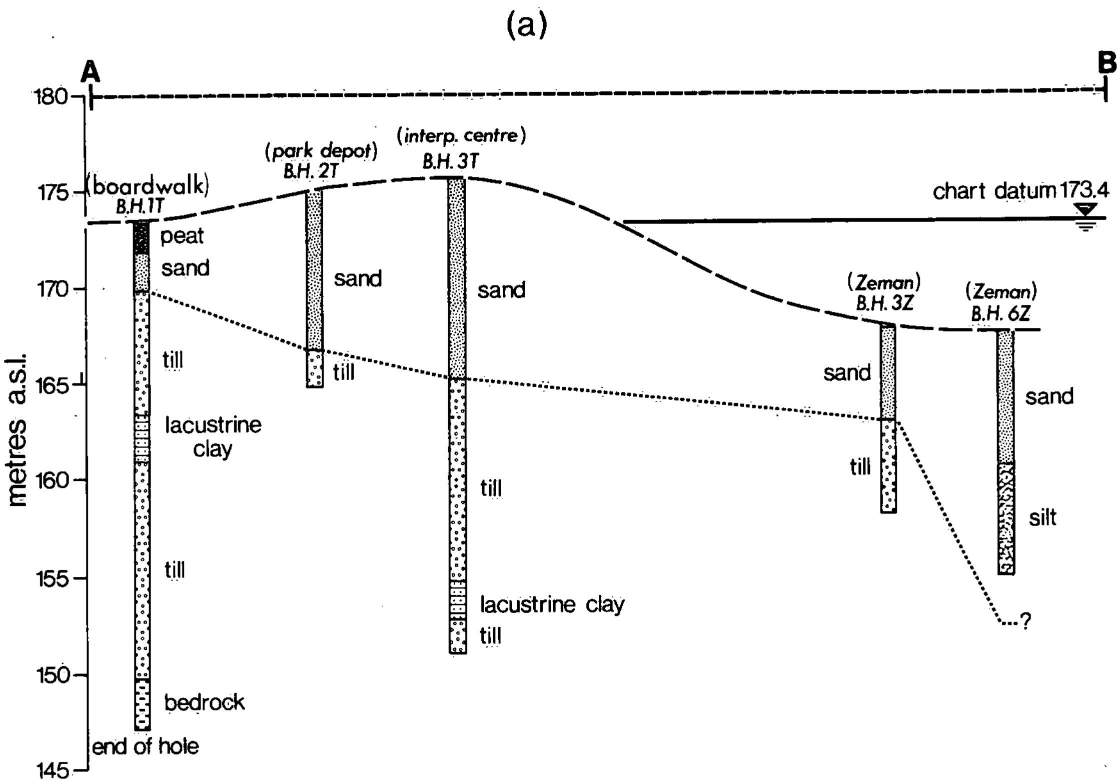


Figure 11. Logs of boreholes taken in 1974 using the Alpine Vibrocorer, showing sedimentary sequence, elevations (referred to Great Lakes Datum, 1955) and radiocarbon dates of Pelee Shoal sediments.



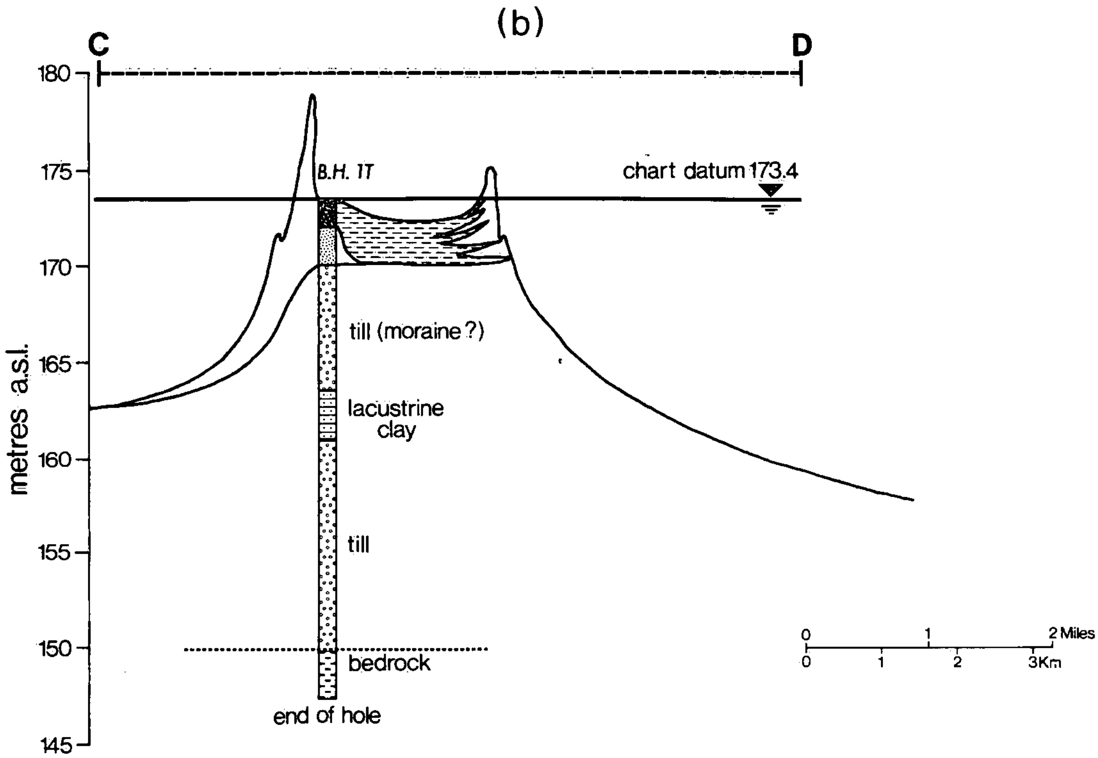


Figure 12. Longitudinal and transverse sections (AB, CD on Fig. 2) through Point Pelee subsurface deposits, using all available borehole logs. (Boreholes marked Z are those collected in 1974 whose elevations were referred to Great Lakes Datum, 1955.)

B.H.4Z to more than 7 m in 6Z. Within this unit are found clay, silt, and sand lenses, lag gravel layers, laminations, and other structures indicative of abrupt changes in deposition. This unit probably corresponds to deposition in a transitionary environment, such as a periodically flooded lagoon or creek mouth.

(3) Laminated sand - This unit, present in all cores but that of B.H. 1Z, is characterized by horizontal and cross-laminated zones with heavy minerals and pebbles usually making up the dark laminations. The unit ranges up to 4 m in thickness. The sand is for the most part medium in texture and shows moderate sorting. This unit was probably deposited in an open lake environment (as a beach or nearshore deposit).

(4) Massive pebbly sand - This is the top unit and corresponds to the surficial sediments presently exposed on the shoal. Thickness ranges from 0.5-2 m. In contrast to the laminated sands, structures are generally absent and the texture is definitely coarser and more pebbly than the laminated unit. The median grain size in this unit usually increases upward, while the sorting value shows no definite trend. In spite of this feature (which could be due to sampling inadequacies), the general character of the unit is most compatible with a depositional history in which in situ reworking of existing deposits is dominant over deposition of materials transported from sources elsewhere. The coarsening upward trend, in particular, suggests an energetic depositional environment whose current and wave regime has intensified with time, in spite of increasing water depths. Such a situation would also suggest decreasing sedimentation rates.

The only radiocarbon date at the base of the laminated sand layer (interpreted as near the beginning of Point Pelee - related deposition) was 3600 ± 140 years before present at a depth of 4.6 m in core 6Z (Fig. 11). This would provide a crude sedimentation rate at that location of 13 cm per century, if uniform deposition over that period is assumed. In view of the preservation of laminations in the laminated sand layer, it might be more accurate to interpret the laminated layer as having a somewhat higher rate of sedimentation than the massive layer, which, in fact, might be presently undergoing erosion. For this reason, the present sedimentation rate of the top massive layer (most representative of present conditions) could range from about 5 cm per century to less than zero.

3.3.2. Jetting Probe Data

Because the technique involved water-jetting a graduated pipe down to refusal, information on sediment types encountered is limited to inferences based on qualitative assessment of resistance characteristics of the sediments penetrated. Such information nonetheless provides fairly accurate estimates of the thickness of sandy (less resistant) deposits such as are found on the Pelee Shoal.

Thickness values obtained for the surficial sandy deposits varied very little at the sites probed (3.5 m to 5 m). Penetration at the site just northeast of the spit was approximately 1 m and confirmed other evidence of a thin sediment cover over dense glacial till. Furthermore, the behaviour of the probe at refusal indicated that the bottom of most of the holes was in glacial till.

3.4. BED FORMS AND BOTTOM FEATURES OF THE PELEE SHOAL

A detailed examination of the bed forms and bottom features found on the Pelee Shoal contributes to the study in the following ways.

(1) They may be linked directly to the local hydraulic regime, and thus provide additional evidence in elucidating the mechanics of deposition of the shoal sediments.

(2) Bottom features might cast light on the previous history of the landform, by indicating relict shorelines, for instance.

(3) Areas showing the influence of man might be delineated and the scale of such effects might be better evaluated.

For these reasons, the geomorphology of the shoal has been studied. The prime result was the preparation of a detailed geomorphic map, giving a graphic representation of the spatial relationships and physical characteristics of these features (Fig. 14).

3.4.1. General Bathymetry

Figure 13 presents the bathymetry of the area (referenced to chart datum - 173.3 m above sea level).[15] A less detailed (2-km grid) bathymetry of the area to the west appears in a recent publication by St. Jacques and Rukavina (1976), and in unpublished field sheets of the hydrographic survey by Kerr (1964).

In the bathymetric map, the positive relief comprising the Point Pelee platform and shoal is reasonably defined by the 10-m contour. The slope of the positive feature is consistently greater on the west side than on the east. Surface relief on the shoal is complex even at the relatively wide survey spacing used, and depths vary considerably from more than 8 m in places to less than 5 m. Two distinct channels transverse the shoal in an east-west direction (AA, BB, Fig. 13), in the northern portion.

3.4.2. Bed Forms and Bottom Features

From the bathymetric map (Fig. 13) and the geomorphic map (Fig. 14), it can be seen that the feature which best defines the extent of the shoal is the crest of the slope on its periphery. Within the area bounded by the peripheral slope, the surface of the shoal lies at a depth of 5-7 m, while the sides of the shoal slope down to the depth of the adjacent lake basin floors. The slopes bordering the shoal are very gentle, generally being less than 1° with the steepest slopes occurring on the southeast side of the shoal near Southeast Shoal Light. The shoal is broadest, with a width of 3.5 km, in the central portion of its approximately 10-km length. It is narrowest at the north end near the present-day spit.

In the shoal area there are a number of prominent geomorphic features and units. These have been discriminated on the basis of morphological distinctions and include the following.

(1) Submerged spit ridge - This feature extends southward for approximately 1.5 km from the end of the exposed spit. It is a narrow (100-200 m in width), high (2.5-5.0 m in relief) ridge trending approximately north-south with slopes of up to 3° on either side. At profile 1A-1B (Fig. 15) the ridge crest is present at a depth of 3 m. The slope on the east side of the ridge is slightly steeper than that on the west. The relief from the ridge crest to the base of the slope is 5 m on the east side and 3.5 m on the west. The ridge decreases in relief and becomes broader to the south away from the subaerial portion of the spit. The position,

[15] Some bathymetric data were made available to this study by D.A. St. Jacques.

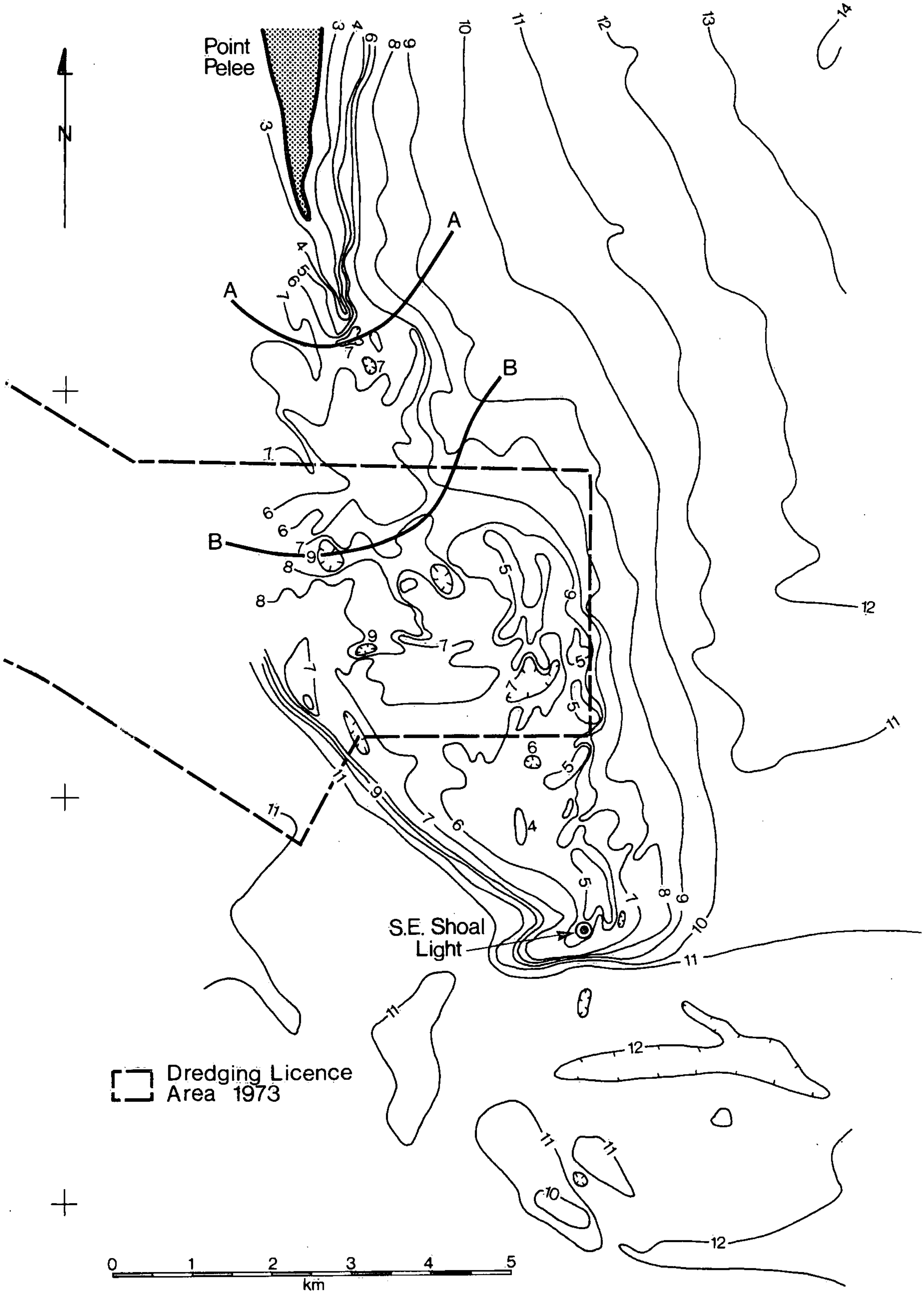


Figure 13. Bathymetry of the Pelee Shoal based on echo-sounder survey in 1974. AA and BB indicate the positions of transverse depressions across the northern part of the shoal.

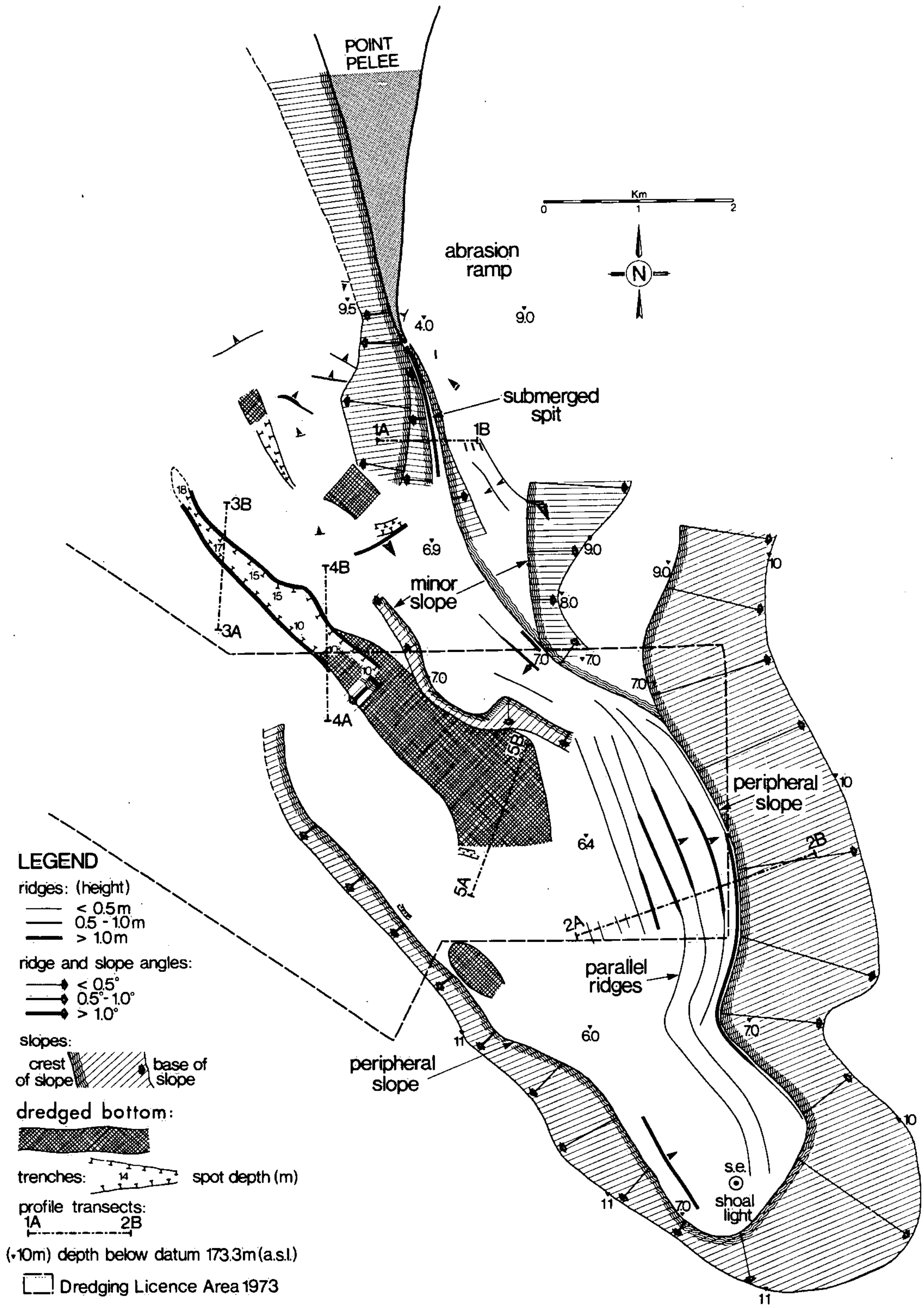
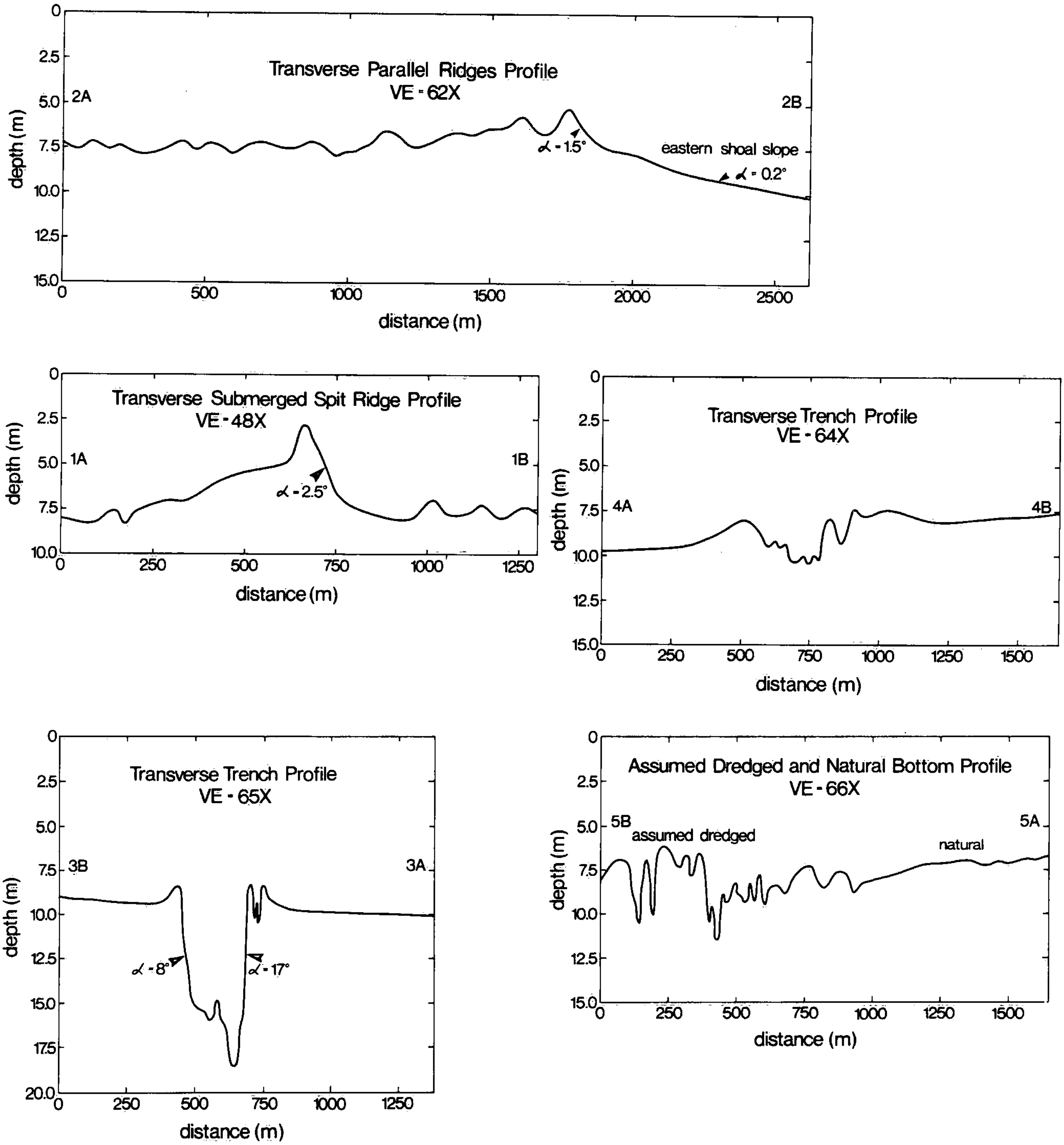


Figure 14. Subaqueous geomorphology of the Pelee Shoal, based on echograms taken in 1974. For vertical sections referred to, see Fig. 15.



α - surface slope angle.

Figure 15. Vertical sections through features on the Pelee Shoal, identified on Fig. 14.

size, and orientation of this feature have been observed (Kindle, 1933) to vary greatly with time.

(2) Featureless shoal areas - A significant area of the shoal is lacking in topographic features, except for small, discontinuous, isolated ridges with heights less than 0.25 m which show no predominant orientation or asymmetry of form. This featureless topography occurs at depths of about 6 m in the north and 7 m in the south-central portion of the shoal.

(3) Band of parallel ridges (Fig. 14) - The morphology of a large segment of the southeastern portion of the shoal platform is characterized by a series of pronounced ridges. Most of the ridges, although slightly sinuous in plan form, appear to be continuous for distances of 3-5 km. The series of ridges is aligned approximately in the same direction as the long axis of the shoal itself. The individual ridges are also parallel to the crest of the eastern shoal slope. The number of ridges ranges from 6 to 10 in a band 0.6-1.4 km wide. Typical ridge wavelengths (crest-to-crest distance between adjacent ridges) are in the order of 0.2 km. The four largest and most longitudinally persistent ridges are found on the east side of the band, nearest the crest of the shoal slope. Ridge heights vary along the ridges with a slight trend to decreasing heights from east to west across the band of ridges. The trough-to-crest heights of the largest ridges range up to 2 m, with 1 m being typical. Water depths over these features range from 6-7 m over the crests to 7.5-8 m over the troughs. Individual ridge slopes are less than 3° and normally 1°. The two largest ridges are slightly asymmetrical with steep sides towards the east, but in general there is no predominant asymmetry to the ridge forms.

(4) Minor slopes on the shoal platform - Besides the peripheral shoal slope and the relatively short, steep slopes on the sides of the submerged spit, minor slopes also occur on the central portion of the shoal (adjacent to the area of assumed dredging) and on the northeast side. The slope adjacent to the dredged area faces southwest and is located in water depths of 7.5 m (crest) and 9.5 m (base). The slope on the northeast faces east and is situated in water depths of 7.0 m (crest) and 9.5 m (base). The depths at which both these features occur vary only slightly along their length.

(5) Isolated ridges - A number of isolated ridges are present, most of which are situated on the shoal slopes and basin floor near the tip of Point Pelee. Some of these ridges are asymmetrical in cross section with the steeper side facing up the slope. Maximum slopes of asymmetric ridges are less than 5°.

(6) Assumed dredged areas - The main area of bottom morphology which is assumed to have been produced by dredging is situated southeast of, and merges into, the large trench in the northwest portion of the shoal. The topography of this area is very irregular with relatively narrow (50-100 m wide) depressions 3-5 m deep (Fig. 14). Other smaller areas of similar morphology, also assumed to have been produced by dredging, are scattered over the west side of the shoal.

(7) Trenches - The most striking feature on the shoal is the large trench on the northwest side. It is well defined for about 3 km of its length and runs from northwest to southeast (Figs. 14, 15), where it merges into the dredging area. At the narrowest point it is 200 m wide and 8 m deep below the adjacent flat lake bottom, with steep side slopes of up to 20°. The lateral margins of the trench are normally marked by levee-like ridges up to 2 m in height along the length of the trench. The trench bottom is uneven and hummocky and resembles closely the morphology of the assumed dredging areas. Other smaller scattered trenches are also located near areas of assumed dredging.

(8) Ripples - Approximately 25 diver observations of bottom current ripples were recorded at sites on the shoal during the period 1970-1974. It was noted that

ripples varied little in form from one observation to the next. The most common description was that they were incoherent and variable in orientation, giving the bottom a hummocky appearance. When the orientation was discernible, the dominant direction was N-S or NW-SE. Intercrest distance ranged from 10 to 20 cm, and trough-crest heights ranged from 2 to 7 cm. These patterns were consistent for the entire period.

3.5. DATA INTERPRETATION

3.5.1. Present and Past Sedimentation Patterns

Trends in various textural parameters such as mean and median grain size, sorting (as measured by the standard deviation), and percentage composition of the samples have been used in other studies as indicators of sediment dispersal patterns and mechanisms (Pettijohn and Ridge, 1933; Coakley, 1972; to name only a few). Coakley (1972), for instance, used trend surfaces based on depth-controlled mean grain size values for the west side of Point Pelee to indicate a predominantly southward mean littoral drift in the northern portion of the shoreline, changing to a net northward drift near the spit.

For the shoal sediments however, it is very difficult to use such techniques effectively, because of the overall complexity of both bathymetry and sediment distributions and the resulting inadequacy of the sample coverage. On the basis of limited analysis of the sediment distributions previously described, the following general inferences may be made.

(1) Depositional inferences - Large portions of the area studied exhibit features of non-deposition, or even bottom erosion. The latter areas coincide with exposures of bedrock and glacial till located mainly offshore on both sides of Point Pelee and extending from the shoal westward toward Pelee Island and Grubb Reef. Possible areas of non-deposition could include much of the western part of the shoal where gravelly deposits occur. In general, it appears that sedimentation rates elsewhere on the shoal are very low (less than 5 cm per century), based on the interpretation of radiocarbon dates on cores from the shoal. Coakley (1972) based a similar conclusion on diver observations made in the deep trench on the shoal.

(2) Sediment sources - In view of the relative coarseness of the Point Pelee beach deposits and that of the gravelly materials on the shoal, compared with present-day littoral material (sampled at Wheatley and Sturgeon Creek), the coarser fractions of the beach and shoal deposits must have been derived locally from the erosion and differentiation of adjacent till areas, or are deposits that owe their origin to processes no longer operative in the area. Therefore the shoal deposits are interpreted as being either residual or relict deposits that are now being reworked or uncovered by erosive forces on the lake bottom. The medium to fine sands occurring in the eastern portion of the shoal could be derived from either the finer fractions winnowed out of the gravelly deposits or from southwardly directed littoral drift, or both. In view of the eastern fining trend of these deposits and their spatial relationship to the gravelly deposits and the axis of the shoal, the net direction of transport of bottom materials on the shoal is interpreted to be toward the east. This agrees with conclusions drawn by St. Jacques and Rukavina (1976).

(3) Energy-sedimentation relationships - The upward-increasing trend in the median grain size of the topmost layer of the cores taken on the shoal indicates that either the energy of the depositional environment has been increasing with time to its present level or that sedimentation rates have decreased (thus allowing more reworking and textural differentiation to occur) with time, or a combination of both.

3.5.2. Geometry and Volume of Point Pelee Sand and Gravel Deposits

On the basis of boreholes, jet probes, and limited sub-bottom data, the geometry of the subsurface postglacial deposits may be inferred. The substrate on which these sediments lie is glacial till (apparently of late Wisconsin age), which was recognizable as a reflecting layer on sub-bottom records and echograms, as the layer of refusal in the jetting program, and as the basal unit in some of the borehole cores. Representative cross sections compiled from these sources and from Terasmae (1970) are shown on Figure 12 (a) and (b) (see also Figure 11). Disregarding the clayey units, which predate the recognizable Point Pelee sandy deposits and which are apparently restricted to depressions in the till surface, it is clear that the sands reach their maximum thickness (around 10 m) under the southern part of Point Pelee (Fig. 12). They thin to 4-6 m along the axis of the shoal. Across the shoal, the deposits vary from 1 m (B.H.1Z) to 6 m (B.H.6Z) in thickness (Fig. 11). Although no stratigraphic data were obtained in the southern portion of the shoal, the following observations may be made on the basis of existing information.

(1) The general shape of the Point Pelee sand deposit is lenticular on the shoal and bifurcates into two beach prisms around Point Pelee.

(2) The surface area and average thickness of the sand deposits may be estimated as follows.

	Area	Average thickness
Point Pelee foreland	5.4 km^2	9 m
Fringing nearshore deposits	4 km^2	2 m
Point Pelee shoal sandy deposits	140 km^2	4 m

(3) Based on these figures, the total volume may then be calculated as <u>approximately 630 million cubic metres (823 million cubic yards) for the clean sands and gravels</u>. This calculated figure may be enlarged by up to 25% depending on whether there are local depressions or infilled channels in the pre-sand depositional surface. There are indications to this effect in the location of the deep (10 m below lake bottom) trench on the shoal and from sub-bottom records. Also the inclusion into the calculation of sand within the muddy facies could add at least 100 million cubic metres to the total.[16] These two considerations could bring the total sand and gravel deposits at Point Pelee to a figure of close to 900 million cubic metres.

3.5.3. Interpretation of Shoal Relief and Bed Forms

The bathymetry and morphology of the Pelee shoal, when combined with other lines of evidence, may be used to make clearer the postglacial evolution of the structure, in addition to supplementing information on sediment distribution and transport patterns on the shoal. This approach is somewhat complicated by the

[16] Based on a surface area of 200 km, an average thickness of 1 m, and a sand content of 50%.

probability that the shoal morphology includes active, relict, and man-made features. The man-made features (dredged areas) are easily recognized. However, the distinction between features formed in response to present depositional conditions (active) and those preserved from an earlier period in the depositional history (relict) is often an obscure one. Relict features, which could provide useful insights into the evolution of the shoal platform and the Point Pelee foreland, may be altered to such a degree by subsequent depositional environments that interpretation is difficult. However, within these constraints and subject to confirmation by other lines of evidence, such as the wave and current regime, the following interpretation may be made.

(1) The peripheral slope and the minor slopes correspond to a sequence of shoreline positions at depths of approximately 9 and 8 m (below datum: 173.3 m above sea level (a.s.l.)), respectively (allowing for modifications due to deposition and bottom scour). This is supported by the association of coarse gravelly deposits with this feature on the southwest side and by the terraced profile in the northeast.

(2) The interpretation of the significance of the system of parallel ridges is more problematical. On the one hand, they could be active bed forms, reflecting the present hydraulic regime, and therefore capable of being used for assessment of the sediment transport rates and direction on the shoal. On the other hand, they could represent relict structures such as longshore bars or storm beach ridges that were preserved from an earlier stage in the evolution of the Pelee landform (Coakley, 1976). If the latter is the case, it is difficult to explain how they have survived so long in such a high-energy environment. For a further examination into the former possibility (i.e. that they are megaripples or sand waves), the reader is referred to Chapter 4, section 4.4.2.

Nevertheless, the asymmetry of some of these features (steep side facing east) suggests a net dispersal of sand toward the east, in agreement with the evidence of the sand lobe in the sediment distribution (Fig. 9). In the northern (apparently terraced) portion of the shoal, the indications of progressive narrowing of the shoal area from the east side (Fig. 14) support the published conclusions of Kindle (1933) and Coakley (1976) that in the long term, the Point as a whole is migrating toward the west, most likely as a result of the imbalance of eastward and westward wave forces, producing a net westward transfer of bottom materials from the east side. The obvious contradiction that this represents, with the eastward transport indicated to the south, would require further study to be resolved.

(3) Other directional bottom features such as sand ripples did not indicate the direction of movement of bottom materials. They were interpreted by Coakley (1972) as wave interference ripples, and thus indicative of surface wave patterns rather than mass sediment transport.

(4) The bottom features mapped do not indicate large-scale movement of bottom material in a north or south direction in spite of the fact that Coakley (1972) found short-term evidence for such movement using fluorescent tracers. One must then conclude that such movement is either infrequent or of minor long-term consequence or occurs mostly during periods of the year other than the survey period.

(5) Dredged areas, as interpreted using Figure 14, correspond closely to the location of gravelly deposits on the shoal (Fig. 9), except in the area occupied by the trench features. Because of its apparently close association with the dredged areas, and the resemblance between their bottom morphology, the initial impression is that the main trench was also produced by dredging. However, because of its location in an area of sparse sandy deposits over dense

glacial till (Fig. 9), the question of <u>what</u> was dredged remains unanswered. Assuming that sand or gravel was dredged, then the trench could mark the location of relict channel deposits. In short, the origin of the trench features has not been fully resolved.

Lake Processes in the Point Pelee Area

4.1. INTRODUCTION

Before any insights into the present sediment transport patterns at Point Pelee can be consolidated into a predictive model of any kind, it is necessary to relate the surficial sediment distributions of the Point Pelee and shoal entity to the present hydraulic regime. This is because the evidence examined in the surficial sediments and bed forms represents an averaged effect established over a period of time. This chapter deals with the major lake processes that combine to produce the sediment patterns noted, and although the measurements described were restricted in duration (no winter or spring data could be collected), they should add substantially to our understanding of the interaction between lake process and sediment response of the Point Pelee deposits.

4.2. THE WIND REGIME OF LAKE ERIE

In discussing the lake processes acting on the shoreline and sediments of Point Pelee, it is important to review briefly the natural cycle in the basic forcing mechanisms that drive these processes. Of these mechanisms, the most important is the wind regime. The winds responsible for wave action, storm surge, and wave-generated currents follow a seasonal cycle in Lake Erie and in other parts of the Great Lakes area. Table 3 shows the (10 year) summary of wind frequencies for western Lake Erie based on wind data collected at London and corrected for Lake Erie (Richards and Phillips, 1970). It is clear that southwest and west winds dominate the picture. However, especially during the spring and fall months, significant variations occur. These variations include severe northwest to east storms corresponding to seasonal shifts in the frequency and position of cyclone tracks (Klein, 1957) across the Great Lakes region (Fig. 16) during these months.

Table 3. Point Pelee Yearly Percentage Frequency of Occurrence of Wind by Direction and Speed Classes, for Ice-free Conditions (i.e. excluding January and February)

Speed class								
Knots	Midpoint, m/s	NE	E	SE	S	SW	W	NW
6-10	(4.1)	1.416	2.152	1.742	2.744	2.688	2.892	2.325
11-15	(6.7)	1.834	3.341	2.151	3.978	4.581	4.508	3.753
16-20	(9.3)	1.017	2.56	1.354	2.346	4.178	3.422	2.687
21-25	(11.8)	0.244	1.202	0.352	0.739	1.856	1.68	1.163
26-30	(14.4)	0.133	0.573	0.103	0.22	0.6	0.621	0.325
31-35	(17.0)	–	0.178	–	–	0.181	0.438	0.110

NOTE: Mean speed for each class in metres per second is given in parentheses. Where the total wind per year for a class was less than approximately 8 hr, it has been omitted, since there would be little contribution to wave generation (from Skafel 1975)

Hare and Thomas (1974, pp. 80-86) present an excellent outline of the sequence of climatic events related to the seasons of the year. The preferred path of cyclonic systems entering the area is determined largely by the position of the polar front and the zone of "upper westerlies", both of which migrate north of the Great Lakes in summer and to the south in winter. Along the margins of these broad high-pressure systems, cyclones originating either on the Pacific coast or the midwest

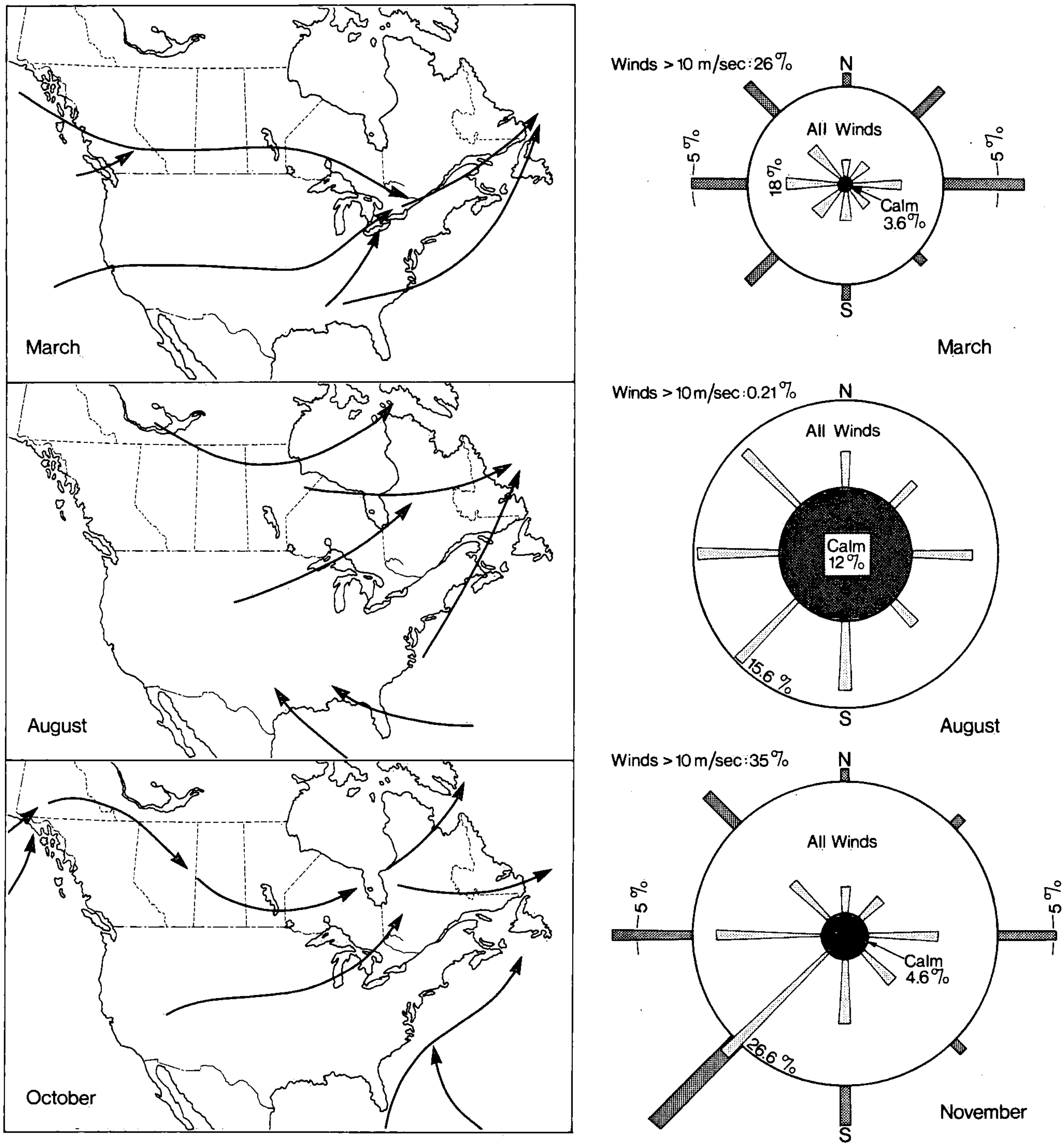


Figure 16. Principal tracks of low-pressure systems (cyclones) for March, August and October with corresponding wind roses for Lake Erie. Cyclone tracks were taken from Klein (1957) and wind roses wave based on 10-year average calculated by Richards and Phillips (1970).

United States move into the Great Lakes area from the west and southwest (Fig. 16), causing winds that can be severe. In the spring, when these cyclone systems generally pass almost directly over Lake Erie, intense winds from all quadrants may be generated. In addition, cyclones originating along the Atlantic coast and moving northward often affect the area with winds from the east to northwest quadrants. East and northeast winds are of particular importance for the western end of Lake Erie, as they have the greatest fetch distances of all (Table 4). The other stormy period, during the fall months, is characterized by a polar front position to the north of the Lakes. Cyclones traversing the area are mostly of Pacific origin and pass to the north of Lake Erie, generating winds that range from southwest to west to northwest as the disturbance passes. In these months also, infrequent but severe cyclones originating in the subtropical Atlantic regions and tracking northward to the east of Lake Erie exert a strong influence, bringing the occasional northeaster storm. In the summer, the cyclones generally track well to the north, resulting in a prevalent southwest to northwest wind regime of generally low intensity. However, there is a tendency during these months for locally severe thunderstorms and tornadoes in western Lake Erie. In addition, although more typical of fall conditions, extratropical cyclones or hurricanes have entered the Great Lakes area as early as June (Hurricane Agnes, June 1972).

Table 4. Effective Fetch Lengths and Mean Water Depths for Wave Generation at Point Pelee, for the Seven Wind Directions in Table 1 (from Skafel, 1975)

Direction	Effective fetch length, km	Mean water depth, m
NE	74	16
E	138	22
SE	72	19
S	47	12
SW	50	10
W	47	9
NW	14	8

The frequency of these cyclonic disturbances (average number of storms) in general has been estimated (Phillips and McCulloch, 1972) as follows: January, 8; April, 7; July, 4; October, 6; or 1 disturbance every 5 days approximately.

4.3. WAVE PROCESSES AT POINT PELEE

The wave climate generated by the winds described above is recognized as the major agent of shore erosion and sediment transport, either by direct action or by the currents and water motions they induce. No long-term measurements of the wave climate in the Point Pelee area are available, but Richards and Phillips (1970) published a wave climate for Lake Erie based on waves hindcast from a 10-year record of winds at London. Skafel (1975) refined these statistics to obtain a long-term wave climate for the Point Pelee area (Table 5).

Field monitoring of Point Pelee wave characteristics was carried out during the period May to December 1974 using two Wave Rider sensors moored off both east and west sides of the Point in water depths of 15 m and 11 m, respectively (Fig. 17). The data were processed by the Marine Environmental Data Service in Ottawa. Data recovery was good: approximately 94% for the east station and 83% for the station off the west side.

4.3.1. Wave Climate for May - December 1974

The data are summarized in Figure 18. The scatter diagrams at the top of the figure show the distributions of significant wave height versus period off the

Table 5. **Hindcast Waves for Each Wind Speed Class of Table 3, using Fetch Lengths and Water Depths in Table 4**

Wind speed, $m\ s^{-1}$	Direction	Fetch, km	Water depth, m	R.M.S.* wave height, m	Peak Wave Period, s
4.1	NE	74	16	0.3	2.40
	E	138	22	0.3	2.61
	SE	72	19	0.3	2.44
	S	47	12	0.2	2.22
	SW	50	10	0.3	2.20
	W	47	9	0.2	2.14
	NW	14	8	0.2	1.86
6.7	NE	74	16	0.6	3.15
	E	138	22	0.7	3.50
	SE	72	19	0.6	3.22
	S	47	12	0.5	2.87
	SW	50	10	0.5	2.82
	W	47	9	0.5	2.72
	NW	14	8	0.3	2.36
9.3	NE	74	16	0.8	3.69
	E	138	22	1.0	4.12
	SE	72	19	0.8	3.76
	S	47	12	0.7	3.33
	SW	50	10	0.7	3.25
	W	47	9	0.6	3.18
	NW	14	8	0.4	2.74
11.8	NE	74	16	1.1	4.10
	E	138	22	1.3	4.61
	SE	72	19	1.1	4.22
	S	47	12	0.9	3.70
	SW	50	10	0.9	3.60
	W	47	9	0.8	3.47
	NW	14	8	0.6	3.04
14.4	NE	74	16	1.3	4.44
	E	138	22	1.7	5.00
	SE	72	19	1.3	4.59
	S	47	12	1.1	4.00
	SW	50	10	1.0	3.89
	W	47	9	1.0	3.75
	NW	14	8	0.7	3.29
17.0	NE	74	16	1.5	4.76
	E	138	22	1.9	5.35
	SE	72	19	N/A	
	S	47	12	1.2	4.13
	SW	50	10	1.2	4.13
	W	47	9	1.1	3.98
	NW	14	8	0.8	3.52
19.6	NE	74	16	1.7	5.03
	E	138	22	2.2	5.65
	SE	72	1	N/A	
	S	47	12	N/A	
	SW	50	10	1.4	4.35
	W	47	9	N/A	
	NW	14	8	N/A	
22.1	NE	74	16	1.9	5.26
	E	138	22	N/A	
	SE	72	19	N/A	
	S	47	12	N/A	
	SW	50	10	N/A	
	W	47	9	N/A	
	NW	14	8	N/A	

NOTE: The wind speeds used are the midpoints of the speed classes of Table 3, converted to metres per second. (N/A: not applicable, as no wind from this direction occurs in the speed class (from Skafel, 1975).

*R.M.S. – root-mean-squared.

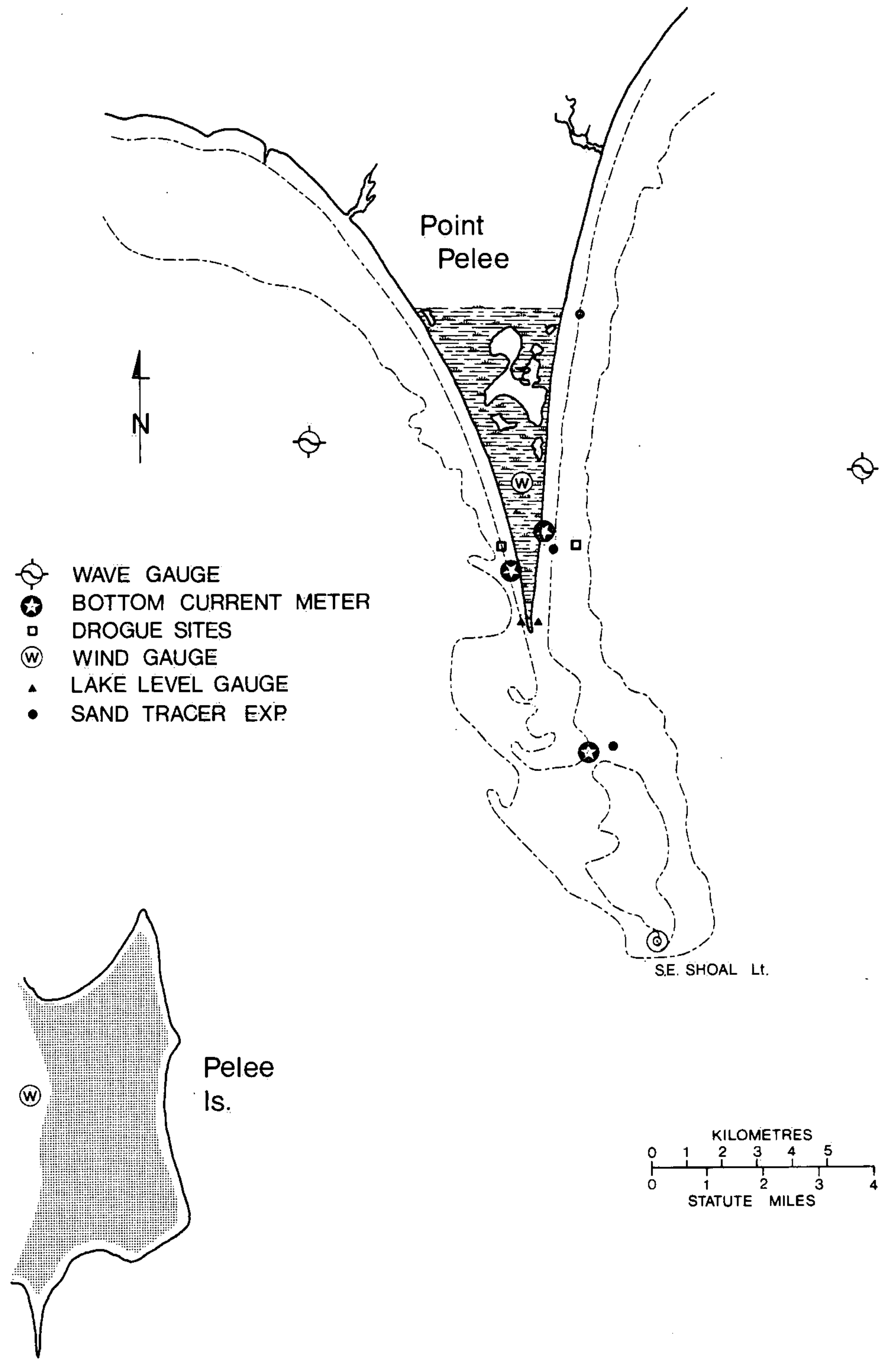


Figure 17. Location of process monitoring instruments in the vicinity of Point Pelee.

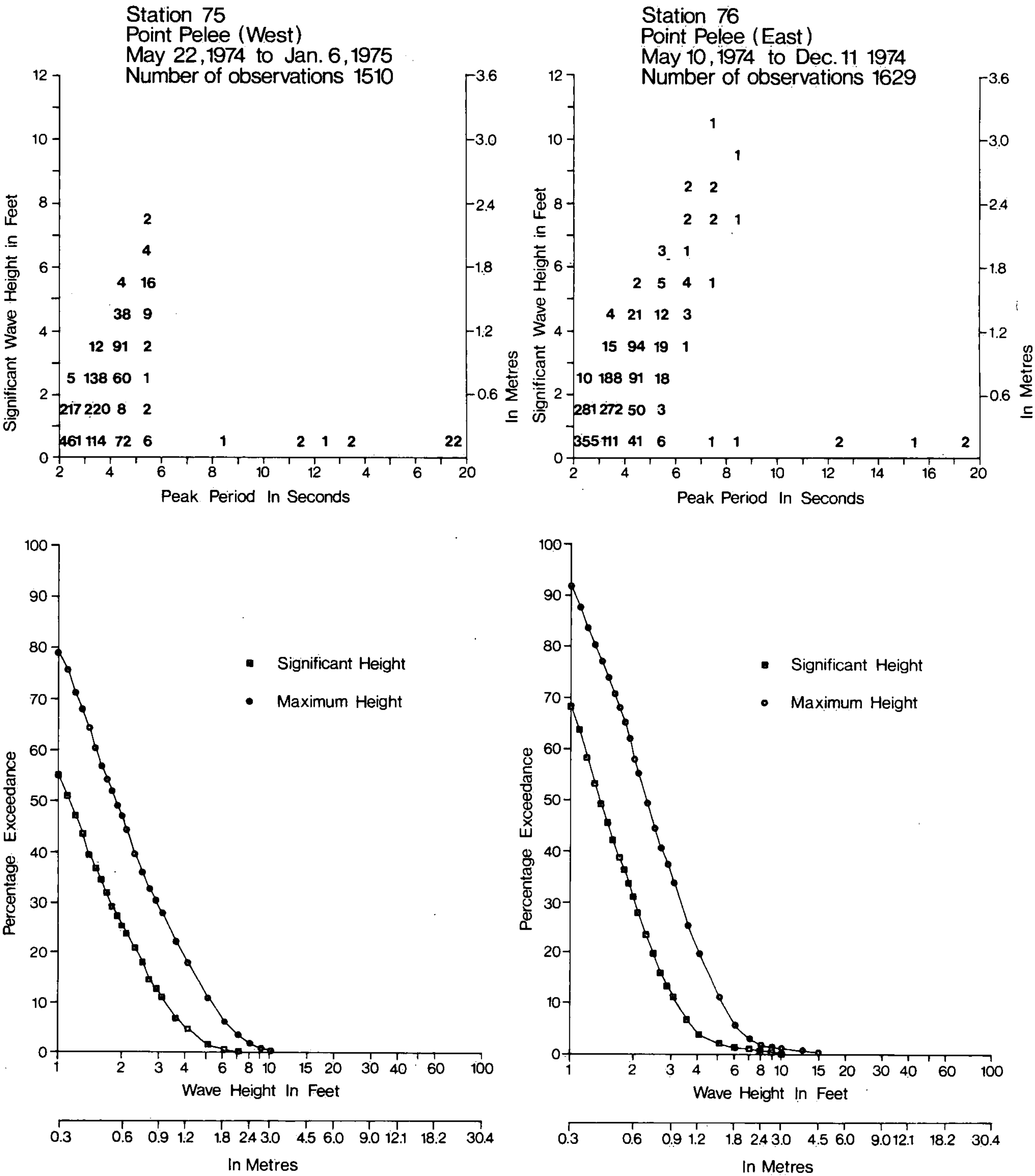


Figure 18. Summary of wave statistics for east and west sides of Point Pelee, May-December 1974, using Wave Rider sensors.

west and east shores of Point Pelee. For both stations the most commonly occurring waves are characterized by significant wave heights of less than 0.3 m (1 ft) and wave periods between 2 and 3 s. The distribution at the east station is more heavily weighted towards higher waves and longer periods. No waves higher than 2.4 m (8 ft) were observed at the west station, whereas at the east station waves up to 3.0 to 3.4 m (10 to 11 ft) were observed. Excluding waves less than 0.3 m (1 ft), no periods greater than 6 s were observed at the west station, while at the east station periods up to 8 to 9 s were observed.

The percentage exceedance diagrams at the bottom of Figure 18 show, in graphical form, that larger waves were measured at the east station. The significant wave heights are those obtained from the measurements. The maximum wave height curve should be interpreted as the most probable maximum wave height in a 20-min period, based on the work of Longuet-Higgins (1952) for the statistical distribution of wave heights for narrow spectra.

Closer examination of the data shows that on both sides of Point Pelee waves greater than about 1 m were equally common ($\simeq$ 12% of the records). However, waves greater than about 2 m were more than twice as frequent on the east side (0.9% of the records) as on the west side (0.4% of the records). Wave periods of 6 s or more (combined with wave heights greater than about 0.3 m) did not occur on the west side, but accounted for about 1.3% of the records on the east side.

The wave data do not provide information about wave direction, but the following observations can be made. From Figure 17, it can be seen that the west Waverider was sheltered from waves out of the northeast, east and to a less extent the southeast, while the east Waverider was sheltered from waves out of the west and to a lesser extent the southwest. Thus it is to be expected that large or storm waves recorded at the west station were due to winds from the west or southwest, and at the east station were due to winds from the east or southeast.

The data show that larger waves with longer periods, which tend to cause more shore damage, were recorded at the east station, and these waves can be assumed to have been caused by winds from the east and southeast, so that they were propagating towards the east shore of Point Pelee.

It is reasonable to assume, therefore, that the east shore of Point Pelee was more prone to erosion due to wave action during the study period than was the west shore, in spite of the fact that the prevailing winds for the area are out of the southwest.

4.3.2. Longshore Sediment Transport

Extending as it does into Lake Erie, Point Pelee is exposed to the prevailing southwesterly winds on its west shore and to storm winds out of the east on its east shore. The resulting wave action on the sand shores causes significant erosion or accretion of the shoreline.

The capacity of the waves to cause longshore sediment transport was evaluated and used to estimate the likely erosion and accretion of the shoreline. The procedure used is summarized as follows (for details of both procedure and results, refer to Skafel (1975)). A 10-year wind climate for Lake Erie (Table 3) was used to hindcast the wave climate in deep water for both sides of Point Pelee. A computer program was then used to calculate the refraction and shoaling of the wave rays toward the shore until a breaking criterion was met. The longshore sediment transport rates were related empirically to the wave energy flux for each wave ray, and the distribution of rates along the shoreline for each wave class was established. The likely long-term erosion and accretion effects were identified from the distribution, magnitude, and interactions of the transport rate due to waves, and are described below.

On the east shore, south, southeast, and east waves move the sediment back and forth with little apparent loss to the shore system, while northeast waves are responsible for losses from the shore system, beyond the tip of the Point. Some beach sediment losses also occur on the east side during east waves of high intensity through washover into the backshore and marshes during storm surges (Coakley et al., 1973). The gross amount of material moved as longshore drift was calculated to be about 180 000 m^3/yr. The net amount is about 26 000 m^3/yr towards the south. This represents material lost to the east shoreline as a result of northeast waves. The distribution of the transport rates along the shoreline indicates that erosion is roughly constant along the entire east shore. If the net transport rate of 26 000 m^3/yr indeed represents the total amount of material lost to the east shore as a result of the mechanism of wave-induced longshore sediment transport, then this value, when distributed evenly along the entire shoreline, does not represent a substantial loss from the Point. This figure, however, does not take into consideration undetermined washover losses during storm surges or non-uniformity of erosion incidence along the shore.

On the west side, waves from the south erode sediment along most of the Point, moving the sediment northward and westward, and depositing it near Leamington and further west. This material is moved back eastward by southwest waves to a nodal point just southeast of Leamington. Southwest waves also move material northward on the more southerly portions of the Point and deposit it near the same node. West waves cause erosion near the above-mentioned node and move the material southward along the Point, depositing it to the south, except near the tip, where increased transport rates cause erosion, and loss of material beyond the tip. Northwest waves cause some erosion along the central and southern portions of the west shore and the material is deposited beyond the tip.

Near the centre of the west shore the gross amount of material moved was calculated at 190 000 m^3/yr. The net amount is 4400 m^3/yr towards the north, which indicates low levels of erosion and northward sediment movement. The distribution of the transport rates along the west shore suggests that more erosion will occur at the south end of the Point than near the centre, and that some accretion will occur at the north end. The relatively small net transport rate suggests that the west shore is changing only very slowly in response to the longshore sediment transport caused by waves.

4.3.3. The Effect of the Shoal on Waves Reaching Point Pelee

The shallow waters and the irregular topography of the extensive shoal area south of Point Pelee could be expected to alter the waves traversing it en route to the Point, mostly in terms of the eventual wave height and direction after refraction and shoaling. The effects of the shoal itself or of modifications to it by dredging on waves reaching Point Pelee therefore require evaluation.

These problems were approached by considering the effects of the shoal on the largest waves from the east, southeast, and south, as hindcast by Skafel (1975). Waves from the west were excluded because those that cross the shoal do not reach the shores of Point Pelee. Waves from the southwest were excluded because they are generated in a short fetch because of Pelee Island, and are therefore of relatively short wave length. A computer program was used to calculate the wave rays across the shoal, and to list the wave height at intervals, as well as to list the locations and heights when (and if) the waves reached the shore of the Point.

It turns out that the shoal does not affect east waves reaching Point Pelee, as east waves which cross the shoal do not reach the Point.

Waves from the southeast that reach the east shore within 2 or 3 km of the tip are moderately affected by the northeast part of the shoal. The wave heights are reduced about 10% crossing the shoal. Some wave rays that would reach the tip of the Point if unrefracted, are refracted towards the south by the shoal and miss the tip completely. Southeast waves that travel over the main body of the shoal do not reach the east shore. It is conceivable that some of these waves could reach the west shore but their energy would be severely reduced by refraction and diffraction, so their effect on the west shore would be very small.

Waves from the south have to cross the main body of the shoal before reaching the shores of Point Pelee. Waves crossing the shoal are reduced by about 15% in height by refraction and tend to focus on the tip of the Point. Further west the waves are almost unchanged by the shoal: their directions are unchanged, and the heights reduced less than 5%. On the east shore north of the tip the results are not as easily interpreted because some of the rays cross. Some wave rays that would undoubtably arrive at the east shore in the absence of the shoal are refracted off to the east, while other rays that would arrive on the shore near Wheatley are refracted onto the shore much closer to the tip, but with severe reduction in wave height (over 50%).

To investigate the effect of a gross change in shoal depth, the bathymetry data for the computer program were altered such that from 2 km south of the tip of Point Pelee and southward all depths less than 10 m were set to 10 m. About 30 km^2 were affected and the water depth was increased by up to 4.2 m. The wave rays for southeast and south winds were recalculated with these new bathymetry data. The most obvious result was that wave rays no longer crossed because most of the bottom irregularities were removed.

The waves approaching from the southeast are not refracted southward as much near the tip of the Point, so within about 1 km of the tip there is an increase in wave energy at the shore. The wave heights are about 25% greater right at the tip compared to the case with the true bathymetry. Northward on the east shore the waves are not affected.

The wave rays from the south are now more evenly distributed along the east shore. North of the tip the wave heights are in some cases about 25% greater than with the original bathymetry. At the tip of Point Pelee the wave height is about 10% greater. On the west side of the tip the waves are not focused on the tip as much by the modified shoal, but the heights are about 10% larger, reaching the shore slightly north of the tip. Further west, and hence north on the west shore the waves are similar to those found with the original bathymetry.

The overall effect of removing shoal material down to the 10-m contour is to increase the wave heights at the tip of Point Pelee by as much as 25%. No significant changes would occur on the west shore. An increase of up to 25% in wave height would occur along the east shore, which implies that the wave energy level would increase by about 50%. Thus a gross reduction in the shoal elevation would definitely increase the wave energy reaching Point Pelee. However, the effect of dredging activities to date on the shoal elevation is by comparison very small and practically impossible to measure. Furthermore, since the major reduction in wave energy is due to refraction over the nearshore slopes of the Point, rather than over the shoal itself, dredging in the vicinity of the spit and other nearshore areas would have a much more significant effect.

Studies have been carried out in Great Britain on the effect on shore erosion of dredged holes offshore that alter the wave refraction patterns (Motyka and Willis, 1974). This effect could not be investigated at Point Pelee because of the time constraints of the study, and is recommended for future research. However, with the exception of the long, deep trench in the northwest portion of the shoal some 3 km offshore, such depressions on the shoal are small in area and much shallower than those used in the British study. Their effect could be assumed, therefore, to be minor and adequately covered in the above treatment of the effects of overall deepening.

4.3.4. Interaction of Waves with the Pelee Shoal Sediments

The oscillatory boundary layers generated at the bottom due to waves induce shear stresses which act on the sediments forming the bottom. If these stresses exceed the critical shear stress to move the particles, the sediment will be set into oscillatory motion, with a net drift in the direction of the waves due to the mass transport velocity.

The sediment distribution patterns and geomorphology of the shoal suggest that the net movement of sediments on the shoal is from west to east (Figs. 9, 10). In this section the results of a study (Krishnappan and Skafel, 1976) to estimate the net direction of sediment transport caused by waves are reported, so that this calculated direction can be compared to the geological evidence.

To simplify the analysis, only waves generated by northeast, east, southeast, south and west winds are considered. (The shoal is relatively well protected from southwest, northwest, and north winds.) Only the two most severe wind-speed classes are used: 14.4 m/s and 17.0 m/s. Wave rays are calculated, by computer, across the shoal and the maximum horizontal orbital velocity and orbital length found at various locations. Using the values of these parameters and the sediment size distribution, values of the shear stresses induced on the bottom sediments are determined. At the same locations the critical shear is also found. A sediment transport index is then defined, which is a measure of the sediment transport (zero and negative values of the index indicate no transport) over the shoal at that location. These indices are then weighted by the relative frequencies of occurrence of the winds used (Table 3). Figures 19A to 19D show the distribution of the weighted indices for four examples. The mean index for each wind speed and direction is found. Assuming that, to a first approximation, each mean index acts in the direction of its wind, the mean indices are summed as vectors to arrive at combined effect on the shoal sediments. The resulting index is 3.11 directed N 86° W. Thus, as a result of wave action, the principal direction of sediment transport on the shoal is towards the west. The transport to the north is an order of magnitude smaller.

The sediment distribution and the configuration of the parallel ridges on the shoal indicate that the net transport is towards the east. This is contrary to the findings for wave-induced motion, and so must be the result of another process. Such a process could be lake currents towards the east resulting from the return flow after the intense wind set-ups which occur with strong east winds. This possible mechanism is examined further in section 4.4.2 on bottom currents measured on the shoal.

4.4. BOTTOM CURRENTS IN THE POINT PELEE AREA

To assess further the pathways of sediment transport (bed load) in the study area, bottom currents were measured over the period mid-July to early November 1974 at three selected sites: off the east and west shores approximately 2 km north of the tip of Point Pelee, and on the eastern portion of the shoal, approximately 4 km southeast of the tip (Fig. 17). Self-powered recording current

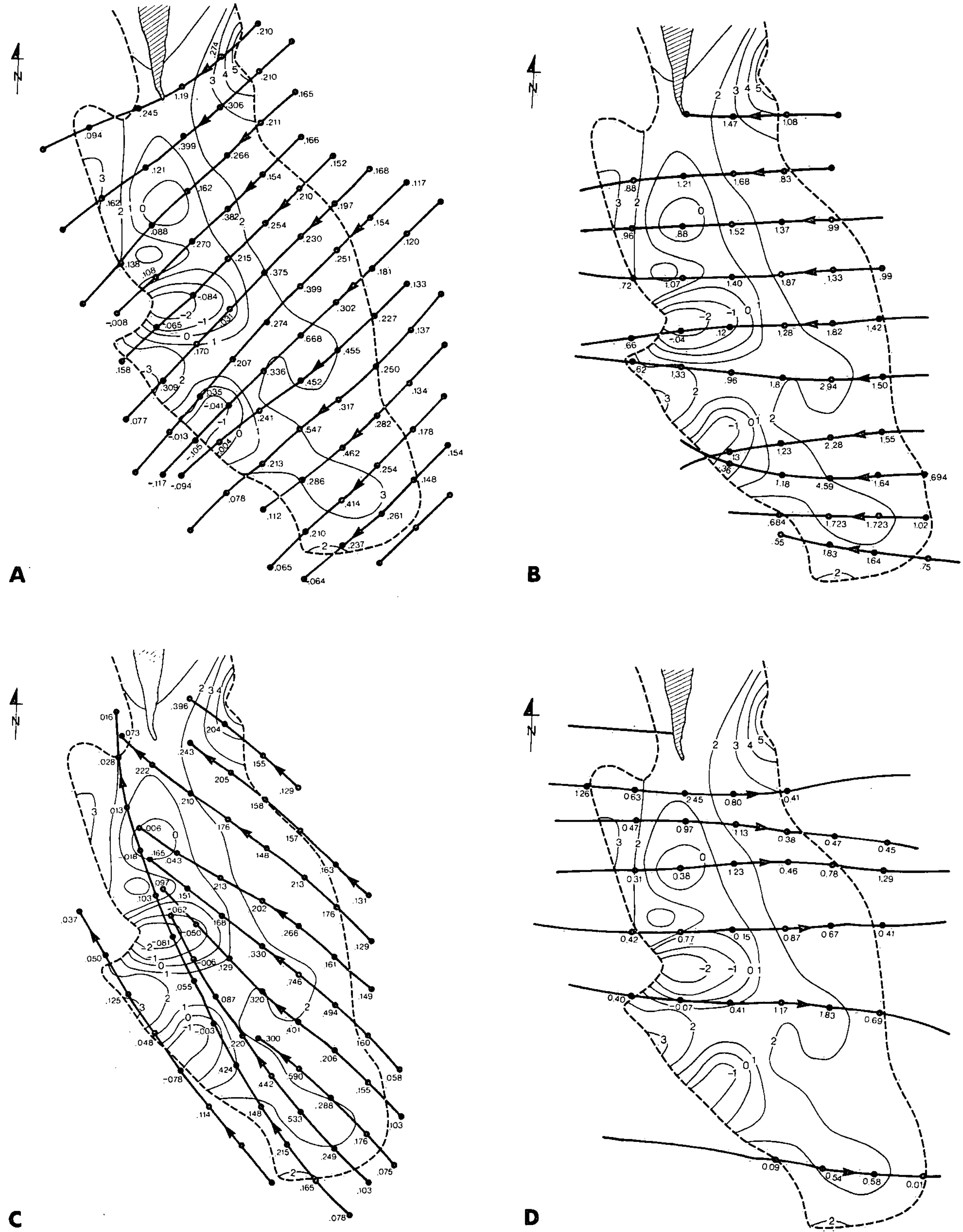


Figure 19. Distribution of sediment transport indices for refracted waves transversing the Pelee Shoal. (A) Waves from the northeast (wind speed 14.4 m/s); (B) Waves from the east (wind speed 17.0 m/s); (C) Waves from the southeast (wind speed 14.4 m/s); (D) Waves from the west (wind speed 17.0 m/s).

meter packages were jetted into the bottom in water depths of approximately 4 m (east and west site) and 7 m at the shoal site. Each package consisted of a Marsh-McBirney electromagnetic current sensor oriented to magnetic north and located 1 m above the bottom, and a sealed water-tight canister containing a timer, a Rustrac recorder, and a battery pack (Fig. 20). The analog records were subsequently digitized at 15-min intervals.

Data recovery was fair and averaged 57% of the total time period as shown below.

Site	Installed	Removed	No. days	Good data (days)	Recovery %
East	July 17	Nov. 1	105	49	47
West	July 17	Nov. 1	105	84	80
Shoal	Aug. 7	Nov. 1	85	55	65

However, much of the data included extensive uninterrupted periods of up to 1987 hr, and thus represent a valuable base of nearshore current data for western Lake Erie. Assistance in summarizing the data was provided by Drs. P.F. Hamblin[17] and E.B. Bennett,[17] and Mr. F. Chiochio.[17]

In addition to the continuous-current measurements, a total of 9 days (between June 12 and July 3) of drogue tracking experiments was obtained at sites (2-9 m water depths) off the east and west sides of the Point (Fig. 21) near the current meter sites. These data, supplied by W.S. Haras[18] will be examined here also.

4.4.1. Results of the Bottom Current Monitoring Study

The results of the current monitoring study are examined in this section from three points of view: (1) average current regime at all sites; (2) seasonal variations in the current regime; and (3) characteristics of the energy spectra and phase relationships between the data from all the sites. The continuity of the data, and their concurrency with other process time-series collected, present a considerable potential for much further research into the time-dependent aspects of bottom currents. However, much remains to be done on the evaluation of the error bands related to both speed and direction values of the current meters used. Because of these considerations, the results given here can only be regarded as an initial indication of the broad trends and patterns in bottom current distributions. It is encouraging that the directional data from contemporaneous drogue tracking experiments in the area agreed well with the current meter data.

(1) <u>Average current regime</u> - Table 8 and Figure 22 present summaries for each site, with the exception of the east site, where data were lacking for the period mid-August to mid-October, making a general summary of that site meaningless. At the west site, the bottom currents over the entire period (July-October) showed an average speed of 7 cm/s and preferred directions (>10% occurrence)

[17]Applied Research Division, CCIW.

[18]Shore Properties Section, Ocean and Aquatic Sciences Branch.

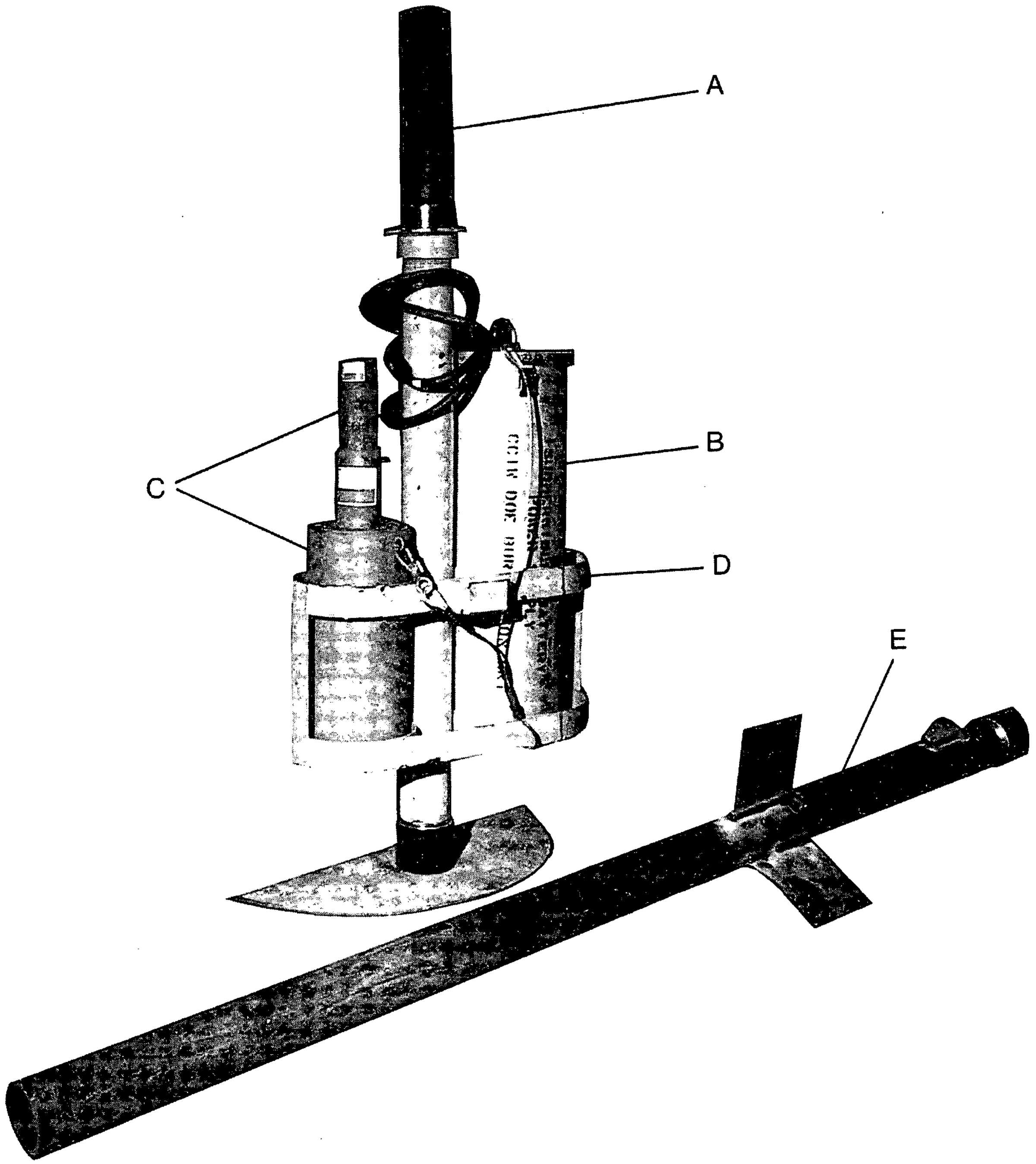


Figure 20. Example of self-recording current meter packages installed on the bottom near Point Pelee (refer to Fig. 17). (A) Marsh-McBirney electromagnetic current sensor; (B) power and recording canister; (C) Pinger for relocating the package; (D) mounting rack; (E) support pipe for anchoring the package.

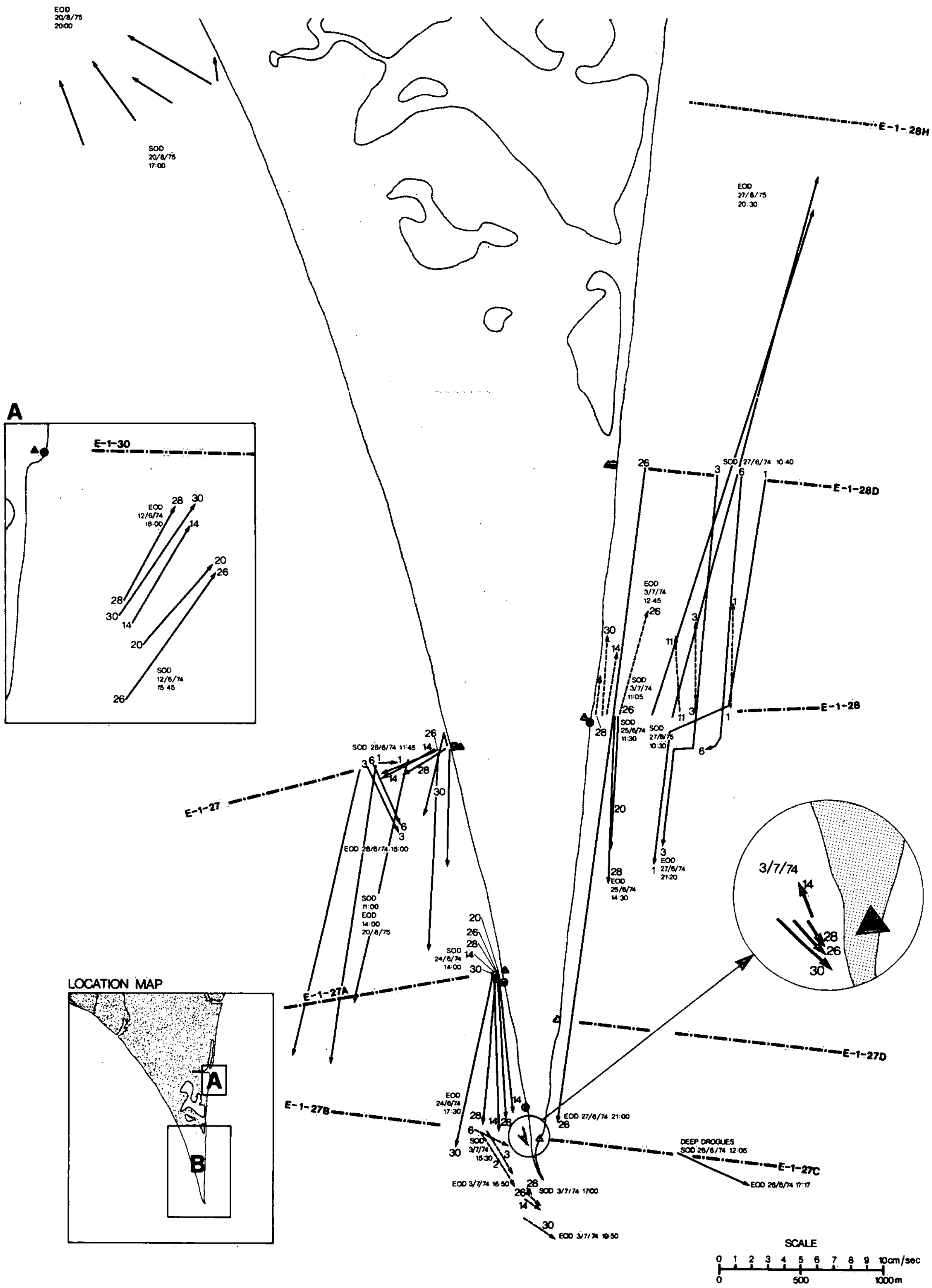


Figure 21. Drogue trajectories recorded at Point Pelee (June and July 1974).

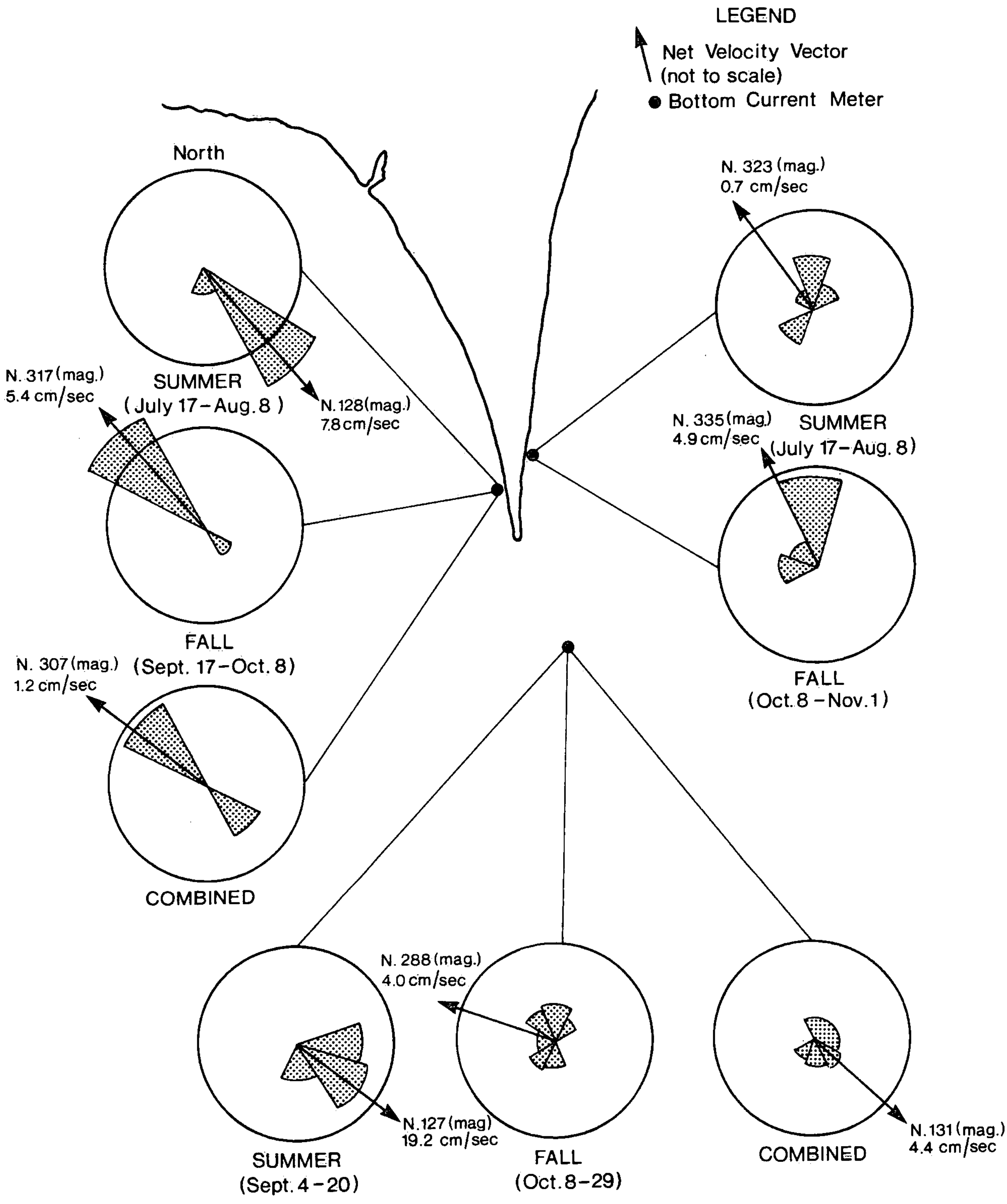


Figure 22. Summary roses of current frequency and direction for current-monitoring sites in the vicinity of Point Pelee. For percentage frequency data, refer to Tables 6-8. Circle represents 50% frequency.

strongly toward the northwest and to a lesser degree, to the southeast. In view of possible errors in the direction readings, such directions might more safely be termed "parallel to the shoreline", which trends roughly northwest to southeast. Maximum current speed was 26 cm/s toward the northwest. The shoal site, on the other hand, showed much higher average speeds for the period (Sept. 4 - Oct. 29), and a far greater variability in direction. The most frequent direction was toward the southeast. Maximum current speed 1 m above the bottom was 67 cm/s, toward the southwest.

The shoal values correspond reasonably with occasional measurements of currents reported in Kindle (1933). These reports, mostly anecdotal, describe surface currents of up to 2.33 mi/hr (105 cm/s) near Southeast Shoal Lighthouse. A bottom current of 67 cm/s (the maximum shoal current measured in this study) if extrapolated to the surface, corresponds with a surface current of approximately 150 cm/s (friction factor of 30). Kindle also noted that the often reversing nature of these currents (eastward then westward, or vice versa) had fairly regular periods of "4-8 hours", and were usually associated with wind set-up conditions during and immediately following the periods of strongest winds. It is noteworthy that the seiche currents in Lake Erie reverse every 7 hr. Other readings taken by Kindle off the west side of up to 1.7 mi/hr (76 cm/s) agree well with our bottom current values of around 33 cm/s.

(2) Seasonal variations - As noted in section 4.2, significant seasonal variation can be expected in the wind regime, which is ultimately responsible for current generation. This seasonal effect is also suggested in the current data separated into summer and fall periods. The clearest separation is noted at the west site, where the prevalent direction of the currents changes from mainly southeast in summer to mainly northwest in fall. There is very little difference in the mean and maximum speeds for the two periods, however. The east site shows a clear change only in current speeds, with the fall values averaging almost double those of the summer. The prevalent direction is toward the north in both cases. The shoal site shows quite distinct seasonal variation in currents. In the summer, currents are strongly oriented toward the east-southeast sector with the southeast direction dominant. Mean speed is also relatively high at 24 cm/s (64 cm/s maximum). In fall, however, the currents are more variable, with a net vector toward the west-northwest. Mean speed is around 18 cm/s with a maximum of 59 cm/s, indicating a fall energy regime that is surprisingly somewhat lower than that of the summer period. The drogue measurements taken in June-July confirmed the results of the west current meter data (Fig. 21), and showed a strong southeasterly component (67%) approximately parallel to the western shore. Seventy percent of the drogue tracks measured on the eastern side during this period were toward the north.

(3) Interpretation of spectral characteristics and interrelationships between sites - Representative plots of spectral density versus period/frequency are presented on Figure 23. Spectral characteristics due to wave oscillations were below the resolution limit of 1 hr. The important elements shown in the spectra are the following.

(a) Periodicities in all the records at approximately 4, 5, 6, 7, 9 and 14 hr. These 14- and 9-hr peaks were especially prominent at the shoal and west sites.

(b) For the west and shoal sites (the only sites having long records), the spectra showed that, whereas at the shoal site 18% of the total energy was in the periods less than 20 hr, energy in this band comprised almost 24% of the west site spectrum.

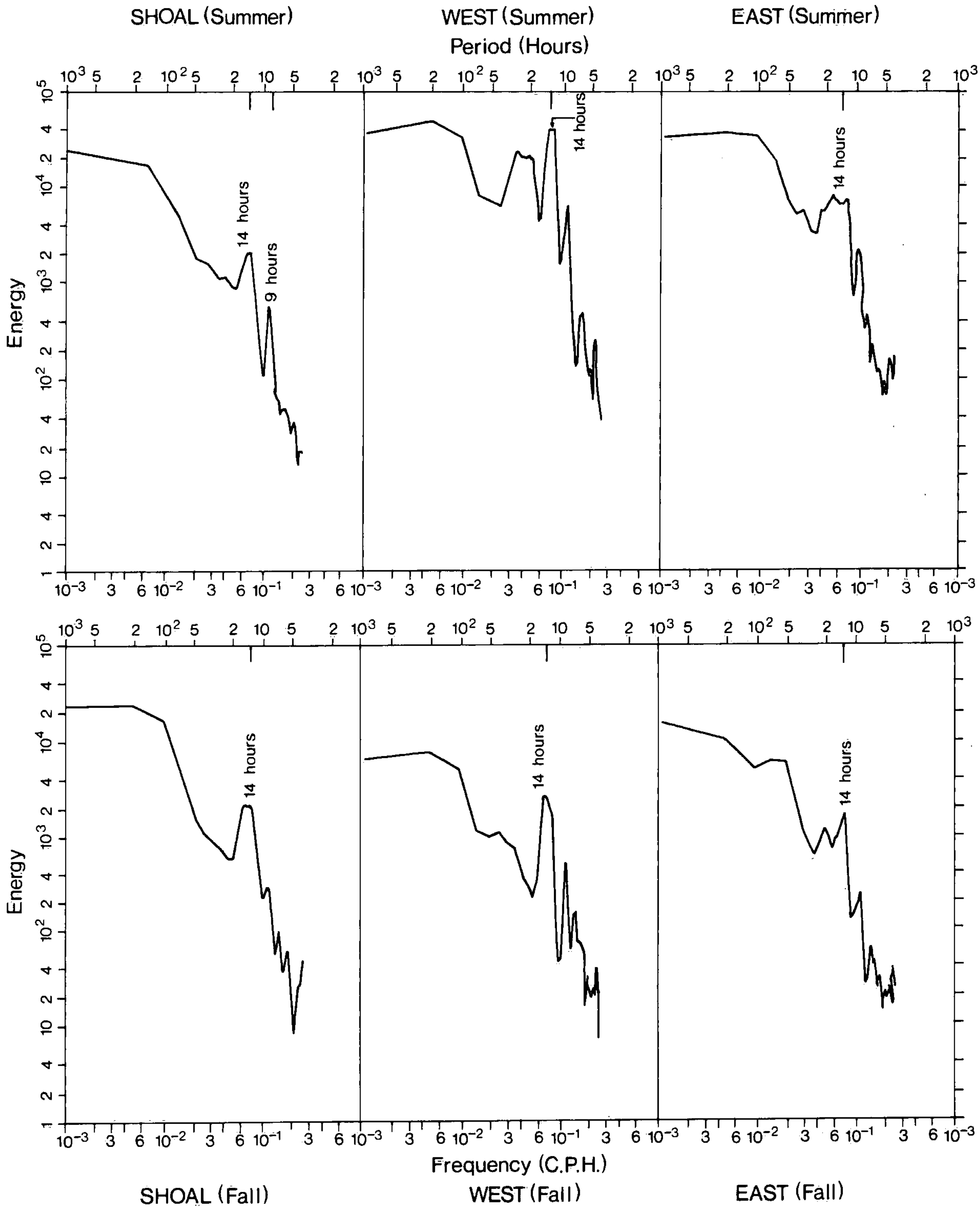


Figure 23. Representative energy density spectra for current vectors, Point Pelee. Hourly data used in computer program by F. Chiochio.

These spectral characteristics indicate possible relationships with process events having comparable frequencies of occurrence. For instance, the strong peak at 14 hr appearing on all the spectra represents the effect of the longitudinal seiche in Lake Erie (period 14.2 hr). This physical phenomenon, most pronounced after strong winds and set-up conditions, is most likely the cause of the strong reversing current noted by Kindle (1933) in the Pelee Shoal area. Calculations by B.G. Krishnappan[19] of the velocities attainable by return seiche flows through the Pelee Passage from the western basin after a set-up of approximately 1 m showed values of around 32 cm/s at 1 m above the bottom. Such flows would be initially directed toward the southeast over the shoal and are probably an important factor in the dispersal eastward of sediment put into suspension by the preceding storm waves.

Other periods noted on the spectra at 9 and 7 hr most likely represent higher modes of seiche oscillations.

The relative energy totals contained in the bands of periods greater than 20 hr and less than 20 hr are significant because they show that oscillations of periods greater than 20 hr are more important on the shoal than on the west side. This is reasonable, as wave- and seiche-related processes (less than 20-hr periods) can be expected to be more important in the nearshore west site than on the shoal, where more intense storms of lower frequency would be a major factor. However, the seiche-related peak is especially prominent in the spectra of the east-west components of the shoal site, further supporting the regularly reversing east-west nature of currents there.

In summary, preliminary interpretation of the spectral characteristics of the bottom current data collected at Point Pelee indicates the following.

(a) West-to-east currents associated with the longitudinal seiche oscillation of the lake after wind set-up and barometric pressure differentials are the dominant sediment transport mechanisms on the shoal.

(b) At the nearshore sites on both sides of the Point, wave-induced longshore currents become more important, especially on the east side. The west side is affected by both types of current mechanisms to a degree compatible with considerable sediment transport.

4.4.2. Bottom Currents and Bottom Deposits

The prime objective of the study to monitor bottom currents was to assess their capacity to transport the sand-sized sediment found in the Point Pelee area and the directions favoured by such transport. The scope of this report and time constraints did not permit any estimation of quantities transported. However, the maximum current speeds for each direction will be assessed at each site in relation to the sediment transport indices that correspond to the grain size at each site (calculated by B.G. Krishnappan[20]). The percentage frequency data in Tables 6-8 were used as input.

Table 9 shows the sediment transport indices for all the sites for directions having maximum speeds above the minimum threshold level for sediment transport (calculated to be 11.5 cm/s). Direct comparison between the values of the indices is difficult because of the use of percentage data in their preparation. However, their levels can be compared, and these show that transport intensity on the shoal is very much greater than in the locations closer to shore. Also, it is clearly indicated that over the period studied, the bulk of sediment

[19]Hydraulics Research Division, personal communication.

[20]Hydraulics Research Division, Canada Centre for Inland Waters.

transported was toward the north on both sides of the lower portion of Point Pelee, and toward the southeast on the shoal.

How do these values compare with the other indicators of sediment transport described elsewhere in this report? In section 4.3.2 the longshore sediment transport calculations showed a net southward transport of materials on the east side of the Point. The current meter data, on the other hand, suggest northward transport at this site. The apparent conflict could be explained by the fact that the meters recorded conditions relating only to the summer - fall period when westerly winds predominate. The sediment transport calculations were based on average yearly winds, including the winter - spring months when easterly winds (and presumed southward transport) are more important. This would also account for the surprisingly low intensity of transport there compared to the west side (Table 9). The west side current meter results agree well with the longshore transport calculations, both showing a net (or combined) transport toward the north (or northwest).

On the shoal, the results of the current analysis show clearly the predominance of southeasterly transport of sediments. This agrees well with the sediment distribution patterns, but is contradicted by the expected direction of

Table 6. Seasonal Current Meter Summaries, Point Pelee, Summer, 1974

Direction toward (mag. north)	% observed	Max. current speed, cm/s	Mean duration, hr	Mean current speed, cm/s
West site (July 17 – Aug. 8)				
45	0.4	1.5	2.0	1.0
90	1.3	4.3	1.2	1.8
135	72.9	23.0	11.0	10.5
180	12.9	10.2	1.9	4.5
225	4.5	5.6	1.5	3.3
270	3.8	4.8	1.5	3.1
315	2.8	13.6	1.7	4.8
360	1.3	3.7	1.7	2.0
Mean scalar speed, 8.7 cm/s Mean velocity, 7.8 cm/s at N 138°				
East site (July 17 – Aug. 8)				
45	12.7	12.4	2.6	5.6
90	4.9	10.9	1.4	2.6
135	5.5	8.1	1.6	3.3
180	12.1	12.5	2.8	5.5
225	19.5	12.4	2.7	4.9
270	8.0	6.6	1.5	3.4
315	10.4	8.0	2.0	3.3
360	26.9	14.8	3.8	4.8
Mean scalar speed, 4.6 cm/s Mean velocity, 0.7 cm/s at N 323°				
Shoal site (Sept. 4 – 29)				
45	3.9	30.7	3.0	17.7
90	34.4	57.7	9.4	22.3
135	39.6	63.8	6.9	24.2
180	18.7	41.7	6.0	30.5
225	1.0	20.8	1.3	13.3
270	0.8	17.5	1.5	12.5
315	0.5	20.1	2.0	19.6
360	1.0	26.0	4.0	22.0
Mean scalar speed, 24.2 cm/s Mean velocity, 19.2 cm/s at N 127°				

sediment transport suggested by the analysis of wave effects on the shoal (section 4.3.4). This is not a serious problem, however, because the relative magnitudes of the transport indices calculated in each case show that the sediment transport associated with the predominantly southeast currents monitored by the current meters would outweigh, by a large amount, those due to the oscillatory, shearing action of the waves. Also the relatively high summer values of the sediment transport indices is surprising in view of the lack of storm during this period, and might be due more to pressure-generated seiche currents than to wind set-up.

The magnitude of the maximum currents on the shoal might also be a factor in the bed forms encountered there, especially the bank of parallel ridges described in section 3.4.2. Krishnappan[21] used calculations based on the spacing and amplitude of these bottom features to calculate the current regime that could lead to their formation. His results indicate that such features could well be dunes formed transverse to the major flow direction in response to unidirectional current velocities of 16.5 cm/s or greater. However, in view of the orientation of

[21] B.G. Krishnappan, personal communication.

Table 7. Seasonal Current Meter Summaries, Point Pelee (Fall, 1974)

Direction toward (mag. north)	% observed	Max. current speed, cm/s	Mean duration, hr	Mean current speed, cm/s
West site (Sept. 17 – Oct. 8)				
45	4.1	3.9	1.9	2.4
90	2.7	4.6	1.4	1.7
135	14.3	9.1	3.2	3.2
180	1.0	1.4	1.0	0.5
225	0.0	0.0	0.0	0.0
270	1.0	1.8	1.2	1.0
315	69.9	25.6	12.8	8.3
360	7.0	4.4	2.0	2.6
Mean scalar speed, 6.6 cm/s Mean velocity, 5.4 cm/s at N 317°				
East site (Oct. 10 – Nov. 1)				
45	4.0	21.4	2.1	8.8
90	0.0	0.0	0.0	0.0
135	0.0	0.0	0.0	0.0
180	0.6	3.3	1.5	3.0
225	9.8	23.0	3.2	10.4
270	19.5	16.8	3.4	6.4
315	15.3	9.6	2.0	4.8
360	50.8	22.1	7.0	8.6
Mean scalar speed, 7.8 cm/s Mean velocity, 4.9 cm/s at N 335°				
Shoal site (Oct. 8 – 29)				
45	12.3	29.9	5.6	17.8
90	2.2	11.5	2.2	6.4
135	8.3	47.8	4.2	15.8
180	14.3	58.8	4.2	20.7
225	16.5	34.6	4.9	18.9
270	10.1	33.1	5.7	17.8
315	17.5	34.0	4.9	17.8
360	18.8	32.7	3.8	18.6
Mean scalar speed, 18.1 cm/s Mean velocity, 4.0 cm/s at N 288°				

Table 8. Seasonal Current Meter Summaries, Point Pelee (Combined Summer and Fall, 1974)

Direction toward (mag. north)	% observed	Max. current speed, cm/s	Mean duration, hr	Mean current speed, cm/s
West site (July 17 – Oct. 8)				
45	1.7	3.9	1.5	2.1
90	2.6	9.9	1.5	2.5
135	32.4	23.0	6.4	8.1
180	5.2	10.2	1.5	3.6
225	1.8	5.6	1.4	2.9
270	4.6	10.0	1.6	3.6
315	47.7	25.6	8.8	8.1
360	4.0	6.5	1.7	2.7
Mean scalar speed, 7.1 cm/s Mean velocity, 1.2 cm/s at N 307°				
Shoal site (Sept. 4 – Oct. 29)				
45	13.9	41.8	4.5	17.7
90	13.8	57.7	5.5	20.5
135	17.9	63.8	5.5	20.7
180	14.9	58.8	4.9	24.3
225	10.7	67.1	4.5	21.0
270	7.1	45.6	5.2	18.1
315	9.8	34.0	4.2	15.5
360	11.9	32.7	3.3	16.8
Mean scalar speed, 19.6 cm/s Mean velocity, 4.4 cm/s at N 131°				

Table 9. Sediment Transport Indices for Current Meter Sites, Point Pelee

Location (season)		Weighted* net S.T.I. (direction)	Max. S.T.I. (direction)
West:	summer	105.3 (S 45° E)	105.3 (S 45° E)
	fall	142.9 (N 45° W)	142.9 (N 45° W)
	combined	*50.5* (N 45° W)	*97.7* (N 45° W)
East:	summer	0.4 (N 0°)	0.4 (N 0°)
	fall	59.3 (N 12° W)	64.5 (N 0°)
Shoal:	summer	609.5 (S 58° E)	367.9 (S 45° E)
	fall	99.2 (S 15° W)	110.7 (S 0°)
	combined	*277.4* (S 62° E)	*166.3* (S 45°)

*Weighted according to the percentage frequency of currents toward the direction for which S.T.I. was calculated.

these ridges subparallel to the measured net flow direction, and the relatively short (5.5 hr) mean periods of steady unidirectional flow (Tables 6-8) in an easterly direction (at right angles to these features), this mode of origin is no more convincing than one involving preexisting or relict features.

In summary, the intensity of the currents recorded is sufficient to transport sediment in varying quantities over the study area. These quantities could not be estimated except in a relative sense. However, it would appear that currents on the west side are relatively intense during the summer months, while those on the east side are relatively mild during the summer season and the early fall. The shoal intensities were consistently far higher than those of the nearshore sites and were higher in summer than in the fall. However, the lack of data for the ice-free portions of the late fall, winter, and spring months makes the drawing of further conclusions risky. Also, sufficient data on other dynamic processes such as vortices and eddies (Bukata et al., 1973) are lacking.

4.5. MODERN LAKE LEVELS AND STORM SURGES

Although processes associated with waves and currents are the most prominent in erosion and sediment transport, the effects of other processes of a more intermittent nature must also be examined. Among these processes are those related to the change in elevation of the lake surface. In addition to altering significantly the depth of water in nearshore areas, thus increasing incident wave energy, these changes can affect the extent of wave action on a sloping shoreline, and generate strong response currents in the lake.

Fluctuations in lake level having periods ranging from decades to hours are characteristic of all the Great Lakes. The historical changes in Lake Erie levels have been described in section 2.3.1. This section deals with those fluctuations in lake level that occur more frequently and have a greater potential for amplifying the effect of other processes described elsewhere in this chapter.

4.5.1. Seasonal Fluctuations

In Lake Erie, as in all the Great Lakes, there exists a seasonal pattern of lake levels, represented by levels rising in spring to a peak in early summer, then falling in autumn to a low in winter. The range between high and low (taken from records of daily mean values) varies from year to year, but is approximately 40 cm. The high levels during the relatively calm summer months are recognized to play only a minor part in erosion compared to the late fall and early spring months, when intense storms are more common. This is true in spite of the relatively low lake levels at these times.

4.5.2. Storm Surges at Point Pelee

Because Lake Erie is much shallower than the other Great Lakes, and since it has a long east-west fetch length, it is particularly susceptible to large wind set-ups or storm surges when sustained winds blow parallel to this direction. At the ends of Lake Erie the difference in lake elevation has exceeded 5 m on occasion as a result of storm surge (Saville, 1953). When such rises in lake level are combined with storm waves and above-average spring or fall lake levels, the result can be disastrous for a low-lying landform such as Point Pelee.

Shore erosion during such a storm surge episode was investigated by Coakley and others (1973). They found that in response to a severe northeaster in November 1972, the level of the lake on the eastern side of Point Pelee rose some 60 cm within hours of the onset of the storm, and combined with waves as high as 4 m to completely submerge and breach the narrow beach bar. The result was a loss of considerable beach material to the back shore and marsh behind, and a landward shift of the beach berm crest of more than 10 m. Recession of the shoreline attributable to this single event was as high as 13.8 m in places along the eastern shore of the Point. In all, an estimated 5.7 m^3 of material per metre of beach onshore was removed from the beach face and adjacent nearshore areas and transported either inland or to the south. Although some lakeward movement is also to be expected, the magnitude of this transport could not be estimated.

In spite of the unavailability of hourly readings of the November 1972 storm surge for opposite sides of the Point (because of storm damage to the gauge station), readings at other times in 1974 showed that simultaneous levels on opposite sides of the Point (Fig. 17) differed significantly. Lake levels on the west side were recorded in summer 1974 as high as 50 cm above those on the east, due to sustained winds from the southwest piling water against the western shore. Similar relative values (as high as 27 cm) were noted for the east shore during northeast winds.[22] The effects of this aspect of wind set-up have not been investigated, but it would clearly cause strong currents around the tip of the Point.

4.6. ICE CONDITIONS AT POINT PELEE

Ice has been recognized to have a potential both for protecting beach areas from erosive waves, and for causing changes in the nearshore bottom topography that can intensify later erosion. The present studies did not include investigation of winter conditions, so use was made of the literature on a related investigation.

The combined effects on Point Pelee beaches of winter processes such as shore ice, frozen beaches and winter storms were investigated by Dickie and Cape (1974). In this section their observations on ice conditions at the Point will be summarized.

Ice formation began in early January 1974, as thin sheets on the west side and as a series of ice ridges (up to 6 m high) on the east side. While the ice on the west side moved on- and off-shore in response to wind direction, the east side ice remained attached to shore and progressively accreted lakeward by the addition and incorporation of floe ice. The width of the ice platform on the east side ranged from almost zero at the tip of the Point to 45 m at the east beach (3 km to the north). No movement of this ice was detected until break-up in early March.

Dickie and Cape concluded that at Point Pelee, ice protected the beach and where it was absent, as at the tip of the Point, considerable erosion took place. They contended that the steep face of the ice wall on the east side caused scouring of the bottom during wave action, making the beach more vulnerable to erosion by spring storms. The west side, not having a fixed ice sheet, showed only minimal post-ice effects.

[22] J. Shaw, Shore Properties Section, Ocean and Aquatic Sciences Directorate, personal communication.

Summary of Modern Sediment Dynamics of Point Pelee Deposits

5.1. INTRODUCTION

This chapter will attempt to synthesize shoreline trends (both long-term and short-term), bottom sediments, and major physical processes into a conceptual model of sedimentation for the Point Pelee - Pelee Shoal area. It is recognized that the data base for this synthesis is deficient in some important areas, namely physical processes during late fall to spring. It is to be hoped that further research may be possible so that this gap will be filled. Nevertheless, the firm outlines of the sedimentation picture for the area can be deduced.

The results presented have definitely shown that the sedimentary deposits comprising Point Pelee and the adjacent shoal and nearshore areas are related in a complex way to both the present environmental conditions and those existing at earlier periods in the evolution of the shoreline of Lake Erie. Furthermore, as far as present conditions are concerned, there appears to be a direct relationship between seasonal changes in the hydraulic regime of the lake and responses in the shorelines and sediment deposits. The sections that follow will summarize these relationships and comment on sediment budgets and the effect of dredging on the sedimentation system.

5.2. THE INTERRELATIONSHIP BETWEEN LAKE PROCESSES AND SEDIMENTATION AT POINT PELEE

The major agents of sediment transport appear to be the following.

(1) Surface waves and non-periodic changes in the surface elevation of the lake - The processes most identified with these phenomena are wave suspension and bottom drift of bed materials, longshore current generation, and washover of beach materials into backbeach areas. These agents, although significant on the shoal (wave drift of bottom materials), are most pronounced in effect in the beach and nearshore areas of Point Pelee itself, especially on the east side.

(2) Normal lake circulation - This includes currents generated by seiches or net flow conditions in Lake Erie (west to east). From the current meter data, these currents appear to play a larger role on the west side and on the shoal than on the east side.

(3) Intermittent dynamic phenomena - Vortices and eddies have been recorded off Point Pelee (Bukata *et al.*, 1973). The effects of these features have yet to be defined, but judging from the turbidity levels associated with them, such effects also merit consideration.

It is also apparent that these agents operate on varying frequency scales and that their intensities vary according to the season of the year. For the purpose of this discussion, therefore, it is useful to subdivide the year into the following modified seasons: winter (ice-covered), January and February; spring (rising lake levels, northeaster storms), March, April, and May; summer (calm, peak lake levels, west winds), June to September; fall (falling lake levels, storms), October, November, and December. In this way, we can examine the yearly sequence of events at Point Pelee, in the context of the frequencies and intensity of these agents, at each of the three subdivisions of the study area: east side, west side, and shoal.

5.2.1. Winter

During the winter, the lake processes are controlled by the presence of an ice cover, which reaches maximum extent in January and February. In spite of a high storm frequency, the effects on the shoreline at Point Pelee are minimal, because of the restriction of open-water fetch distances and wave generation by the ice cover and the protection given to the shoreline by the ice from any wave action that does occur. The main effects during this season are restricted to the scouring of the nearshore lake bottom directly in front of the ice sheet. Dickie and Cape (1974) also noted severe damage and eventual breaching of the low spit after a winter storm destroyed the "ice wall" on the east side of the tip. On the shoal, wave and current levels for this period are as yet undetermined, but they are expected to be low, at least after the formation of an ice cover. For this reason, the general effects of bottom transport by currents are expected to be at a minimum. In other words, this period is believed to be one of minor significance insofar as shoreline and nearshore processes are concerned.

5.2.2. Spring

In contrast to the winter, the spring period is characterized by an intensification of lake processes and presumably of sedimentary responses. March has long been recognized as a bad month for shore erosion at Point Pelee. Several factors contribute to this development.

(a) This is the season in which the influence of the northeasters due to cyclones tracking up the Atlantic coast is greatest (Fig. 16). As a result, east winds with their long fetch generate high waves and surges, which cause considerable erosion damage along eastward-facing shores. Winds greater than 10 m/s (20 knots) comprise 26% of the total in March (Fig. 16).

(b) Lake levels are rising steadily as a result of the spring thaw, and beaches are saturated because of high ground-water tables; therefore beach erosion is encouraged.

In the shoal and nearshore areas, this period of the year is therefore likely to be a period of energetic changes. The nearshore lake bottom has been modified by winter wave action at the foot of the ice sheet, so this modified profile must be adjusted to the spring wave climate. Also, northeast and east storms generate waves of sufficient size that they affect even the outer nearshore zone. Although no process data were collected during this period in such areas, the exposed scoured surface of the till found off the eastern side of the Point attests to the presence of effective wave action and bottom scour out to water depths of more than 10 m. The expected net result of such intense activity would be to erode and separate out the coarser fractions (sand, gravel) from the till and transport them shoreward by wave drift to the breaker zone. There longshore currents would transport this material and material originating in the northern portion of the Point southward at rates up to 50 000 m^3 per storm (Coakley _et al._, 1973), although the _net_ rate is estimated at 25 000 m^3/yr (Skafel, 1975). In addition, considerable beach-face material would be washed into the backbeach and marsh areas by storm surges that accompany these storm events. In short, spring represents the period of most erosion on the east side of Point Pelee. The material eroded from the east side would be deposited off the tip of the Point, where it would tend to be moved further westward by wave drift over the subaqueous portion of the spit, to the area just southwest of the exposed spit, and in fact, an undetermined amount would be expected to be transferred directly to the west side of the spit by washover at the low-lying spit itself. The transverse depression immediately south of the spit (AA on Fig. 13) could also be a major conduit for east-west transfer by wave drift and currents.

In the absence of spring field data on the shoal, one is obliged to rely on the theoretical calculations of wave effect on the shoal (section 4.3.4) to estimate the behaviour of shoal sediments during this period. According to the criterion used in these calculations, even the largest waves estimated for east winds do not break on the shoal. Therefore, wave-induced longshore currents are not generated and any sediment transport there would be due either to wave drift or seiche currents or a combination of both. At this time we do not know whether these two processes operate concurrently; however, in section 4.4.2, it has been shown that the more steady seiche-related currents would considerably outweigh those due to the orbital motion of waves. Therefore all that can be said at this time is that the waves generated by east or northeast storms are capable of considerable resuspension of the shoal sediments. Under these conditions, the eastward return flow along the bottom from the lake set-up would tend to transport this suspended material toward the east or southeast. Also of undetermined importance are the spirals and vortices that tend to occur south of Point Pelee during the spring.[23] They rotate counterclockwise and thus could be expected to distribute material toward the east.

During the spring period, the western side is relatively undisturbed by storm activity from the southwest, the direction it faces. Also, ice cover tends to remain in place there after it has disappeared from the east side. It is expected, therefore, that the effect of waves generated by southwest winds would be of minor significance and that sediment transport would be small. However, some of the east side drift material transported southward during east storms and deposited near the tip could be transported northward along the west side mainly as a result of currents caused by the lake level differential (section 4.5.2), causing a degree of accretion there. A similar conclusion was expressed by Dickie and Cape (1974) on the basis of profile monitoring in spring, 1974.

In summary, the spring months are characterized by a relatively high incidence of storms from the east and northeast. The effects of such storms are exacerbated by rising lake levels and saturated beaches, resulting in intensified erosion of the eastern shores of Point Pelee. Sediments supplied to the breaker zone by erosion and by onshore transport of eroded till material tend to move southward, being eventually deposited near the tip of the Point. The material transported down the east side and deposited at the tip is believed to be transferred in large measure to the littoral drift system of the west side. A significant amount of beach material is washed into the backbeach and marsh areas and is effectively lost from the coastal drift system. Sediments put into suspension on the shoal are probably transported eastward by seiche currents generated by wind set-up at this end of the lake.

5.2.3. Summer

The summer, June, July, August, and September, is the season for which most data have been collected. Statistics for August illustrate that winds during these months are the least energetic of all, with calm periods exceeding 12% and winds over 10 m/s only 0.21% of the 10-year average. The strongest and most

[23] R.P. Bukata, Applied Research Division, CCIW, personal communication.

frequent winds blow from the northwest and west. The lake reaches its peak levels at this time and vertical stratification occurs intermittently in the shallow western part of the lake.

The data on bottom currents collected in the area are surprising in that they show that both the west site and the shoal site have relatively high levels of current speeds during this seemingly quiescent period. Also both sites record currents capable of transporting sediments in quantity toward the southeast at both locations. This level of transport cannot be explained only by the northwest-to-west oriented wave climate, which is relatively insignificant. Furthermore, the current meter on the west side is located in 4 m of water, outside the zone of maximum longshore wave-generated currents (maximum depth of breaking waves is 1.8 m). Therefore, it appears that other processes, most likely those associated with the reversing longitudinal seiche currents or with the net west-to-east flow in Lake Erie, play the most important role at the two sites. Evidence of this is the strong 14-hr peak periods in the bottom current energy spectra for these sites. Also since this season is the only one apart from winter in which thermal stratification takes place, it is conceivable that flows due to the longitudinal seiche would be confined mainly to the bottom layer over the shoal, with a resulting increase in speed compared to unstratified periods of the year.

The east side shows a marked variability in direction and a general low level of current activity during this period. Net transport is small and directed toward the north. This is taken as a reflection of the virtual absence of strong east winds in these months, and the lack of any channelling (and amplification) of the seiche currents by either geographic constriction (as through the Pelee Passage on the west) or vertical stratification (as on the shoal).

How do the above bottom current patterns agree with the sediment depositional patterns observed at these locations? First of all, on the shoal the relatively strong, consistently southeast directed currents agree well with the predominantly eastward trend of bottom sediment deposition as shown on Figure 9. However, in spite of the high speeds recorded during the summer, it is difficult to visualize peak sediment transport coinciding with these months, as wave action on the shoal is minor compared with during the spring, and resuspension of bottom sediments would be correspondingly low also. On the west side, erosion profiles monitored in 1974[24] show moderate accretion of onshore profiles (Figs. 24 and 25), with accretion volumes decreasing as one travels north from the tip of the Point. This pattern is consistent with northward transport, thus indicating a reverse flow to that recorded at the current meter site. However, the profile data are open to alternative interpretations, and any resolution of this apparent inconsistency must await the published interpretation of the profiles. The volume changes on the east side profiles show slight erosion in the extreme southern profiles, and accretion in the middle profile. Here again, the reconciliation of these data with those of the current meter records is not yet available.

In summary, during the summer months, the locations expected to show the most sediment transport are the shoal (toward the southeast) and along the west side of Point Pelee (either northward or southward depending on the direction of wave approach). Because east or northeast storms are absent, the overall level of sediment resuspension and transport on the shoal during the summer months is believed to be much less than in the spring in spite of the high summer transport indices calculated. On the east side, transport is expected to be low, with a slight net transport toward the north. Sediment inputs through shore and bottom erosion should be low and both erosion and accretion are expected to occur along the shoreline.

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[24] J. Shaw, Shore Properties Section, Ocean and Aquatic Sciences Directorate, personal communication.

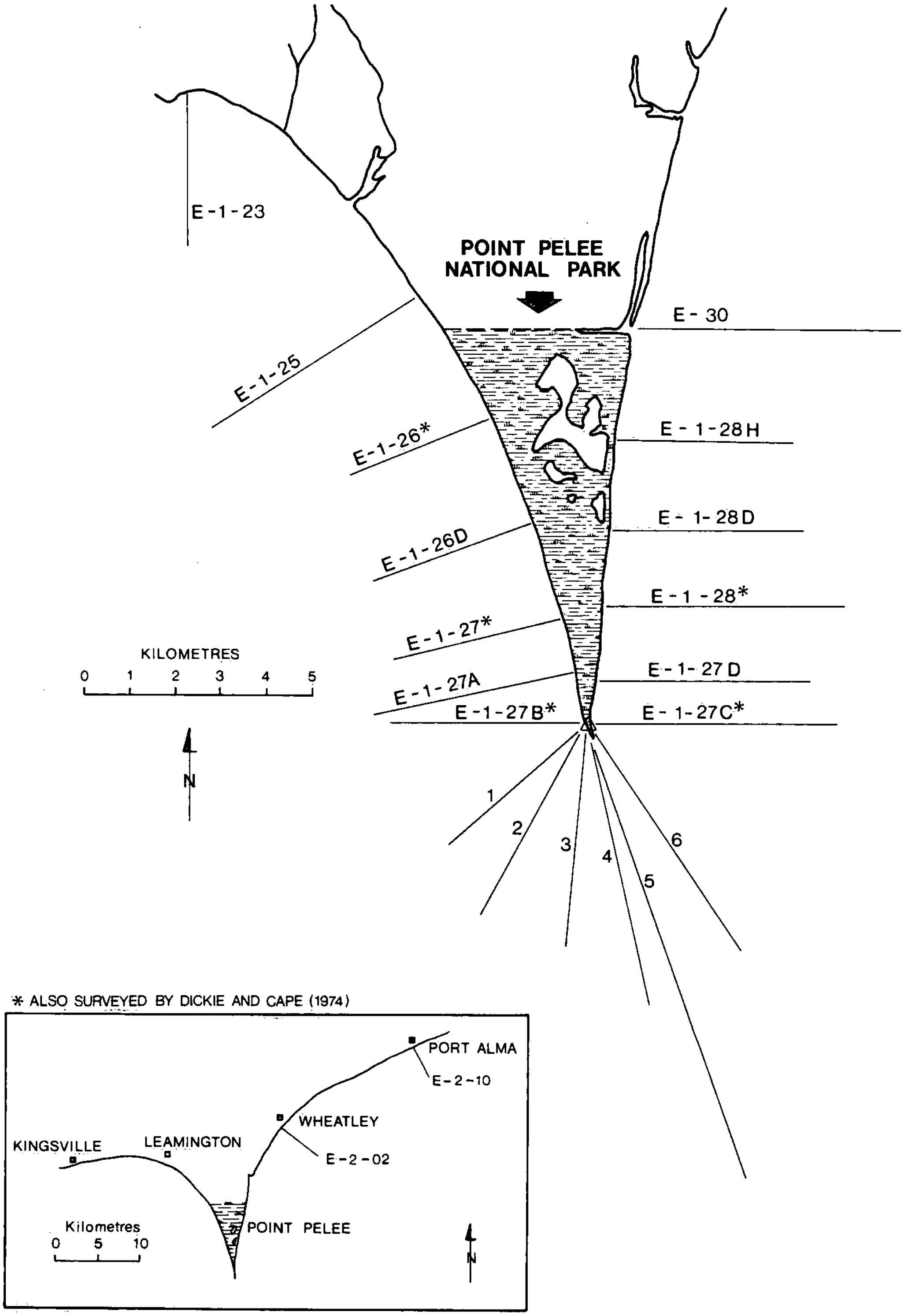

Figure 24. Location of shore erosion monitoring profiles on Point Pelee. Profiles established by Shore Properties Section, Ocean and Aquatic Sciences Directorate.

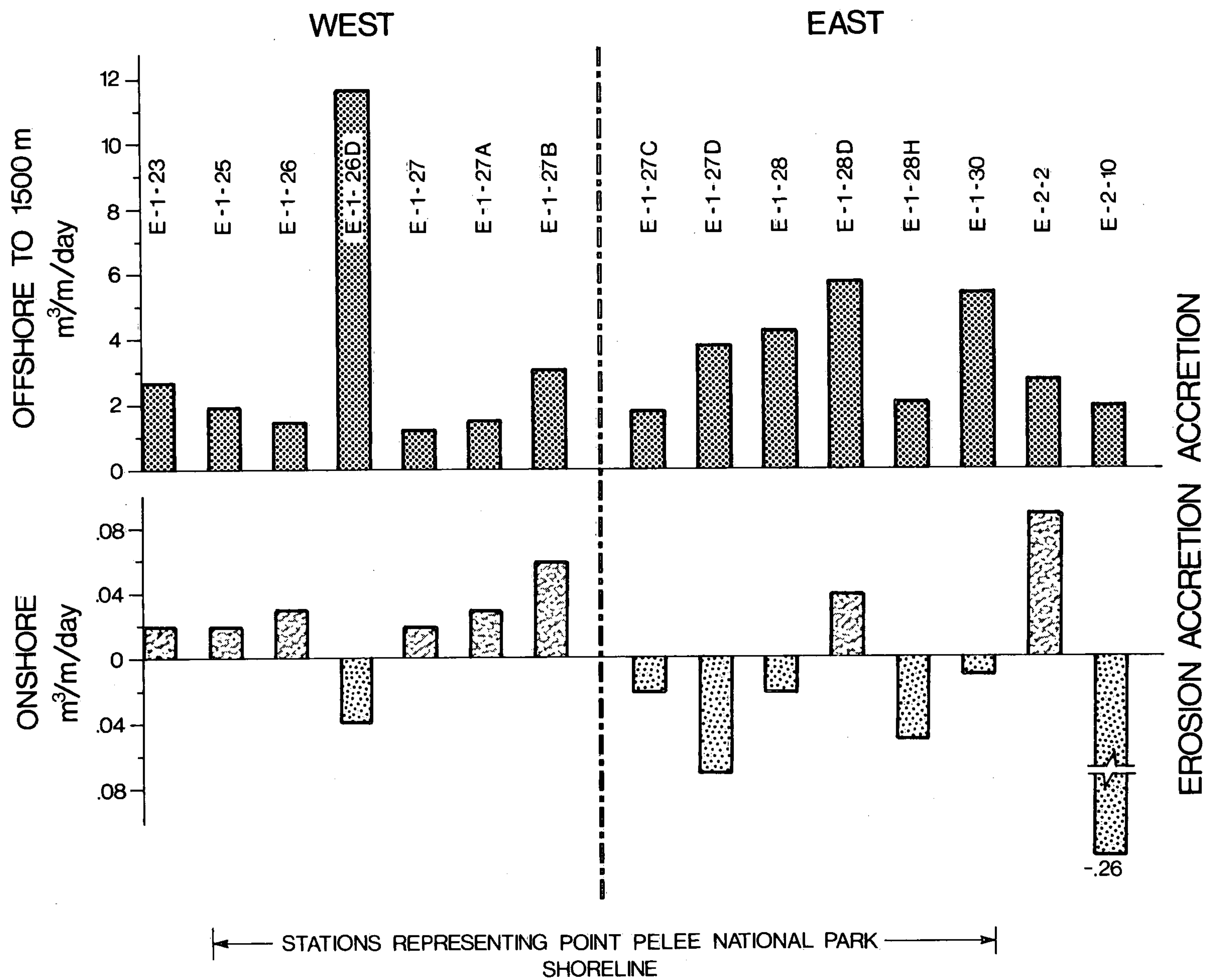

Figure 25. Summary of volumetric profile changes at Point Pelee (June to September 1974).

5.2.4. Fall

In Lake Erie, the fall months are characterized by the following conditions (November is used as an example). (a) Calm periods comprise only 5% of the 10-year record, and winds exceeding 10 m/s comprise 35%. Predominant in frequency and intensity are the winds from the southwest (11% over 10 m/s). This month also has the highest percentage of strong southeast and south winds (1.4 and 3.6%, respectively, above 10 m/s) (Fig. 16). (b) Lake levels are falling and beaches are not saturated. (c) The lake is not vertically stratified but the shallow western basin is cooler than the central basin.

Data on bottom currents were restricted in this study to the early part of the fall (up to the end of October) and as a result the usually severe mid-November storms were not included in the record. However, the records collected for this period were considerably different from those of the summer months. Currents at the west site were predominantly toward the northwest at slightly reduced average speeds (compared to the summer values). The west site current records for the fall season included the latter part of September, so they might not be as typical of fall conditions as those of the other two sites. The shoal bottom currents show a variability in direction (northward as well as southward directed currents) and a reduction in average speeds. This reduction in energy level is not clearly shown in the transport indices (Table 9). Net transport was toward the south and relatively low. The bottom current speeds at the east site are higher than the summer values, and are more consistently toward the north.

While looking for an explanation for this trend toward northward transport, it must be realized that seiche currents would not be as important during fall, because of the infrequent occurrence of east storm conditions, and the unstratified nature of the lake. It therefore appears most likely that the predominant south-oriented (southwest, south, and southeast) wind (and wave) regime might be the most important factor at the nearshore sites. No explanation can be suggested at this time for the alternating north-south currents on the shoal, noted on the fall records.

In any event, the fall period appears to favour net northward transport of bottom sediments at the two nearshore locations and considerable northward transport on the shoal. In view of the lack of any data on late fall conditions (a period of high storm incidence) nothing more conclusive may be said on the subject of general sediment transport patterns for the fall months.

5.3. SEDIMENT SOURCES AND BUDGETS

In section 3.5.1, the principal sources of sediment for Point Pelee and shoal deposits were listed as: (1) unconsolidated glacial material comprising the shoreline to the northeast and northwest of Point Pelee; (2) tills exposed on the bottom within the zone of shoaling waves; (3) relict deposits on the shoal. Quantitative assessment of these sources into a valid sediment budget is difficult because of the lack of sufficient data on sediment transport rates. However, the broad picture of sediment sources and pathways can be sketched out.[25]

5.3.1. Erosion of Unconsolidated Glacial Material Shorelines

Glacial shorelines in the vicinity of the Point contain sand and gravel in amounts ranging up to 40%, and are eroding at average rates of more than 1 m/yr. St. Jacques and Rukavina (1976) estimate that the bluff shorelines east of Wheatley

[25]For further reference, see St. Jacques and Rukavina (1976).

supply about 40 000 m^3 and 19 000 m^3 of sand-sized material to the littoral zone. This figure contrasts with those of Skafel (1975) and Kamphuis (1972) for net littoral drift southward along the east side of Point Pelee: 25 000 m^3 and 19 000 m^3 per year, respectively. Although no attempt will be made here to explain this discrepancy, evidence (such as the maintenance dredging figures for Wheatley harbour) indicates that the latter figures, around 50 000 m^3/yr, are more realistic.

On the west side, Skafel estimated a slight net drift northward from the tip of the Point up to a location near Leamington, where sand eroded from the bluffs to the west is also deposited. The net littoral drift for the west side is estimated at approximately 4 000 m^3/yr. This material apparently originates in the southern portions of the western shoreline, and in the vicinity of the tip.

5.3.2. Bottom Erosion of Tills

The erosion by storm waves and currents of tills exposed on the lake bottom can also be regarded as a significant but undetermined source of sand and gravel for the Point Pelee deposits. The magnitude of this contribution is difficult to assess accurately, but if one assumes an average rate of erosion of 0.1 cm/yr (which appears to be on the conservative side) over a total area of 150 km^2 (100 km^2 on the east and 50 km^2 on the west) of tills averaging 20% sand and gravel, then one arrives at a rough total contribution of approximately 30 000 m^3/yr (or more realistically, somewhere between 15 000 and 45 000 m^3/yr). Such material would largely be transported by wave drift onshore or added to the longshore drift system, thus partially making up for the losses due to overwash of the beach berm or lakeward transport by rip currents.

Since till is also exposed over large areas of the Pelee Passage, it is conceivable that a degree of bottom erosion is occurring there as well. Much of this material is probably contributed to the west side of the Pelee Shoal deposit.

5.3.3. Relict Deposits

Relict deposits on the shoal apparently contribute to the growth of the lobe of fine sand deposits trending east from the main shoal body, through the winnowing out and transport of finer fractions by waves and currents. In spite of the possibility (discussed in section 5.3.4) of some northward transport of such shoal materials toward the Point in the fall, there is little physical indication of such transfers.

5.3.4. Summary

Figure 26 summarizes in a schematic way the main concepts of sediment transport in the Point Pelee area. The littoral drift supply to the east side apparently represents the largest contribution to the sediments making up the Point and adjacent nearshore deposits. There is little sign that this material is deposited entirely along the shoreline, since erosion occurs consistently along this side. One must therefore conclude that a portion of this drift goes toward making up for the 4000 m^3 transported northward on the west side annually. The rest is probably deposited in the vicinity of the tip either on the northern portion of the shoal or around the spit itself. This would therefore represent a temporary storage deposit, along with the nearshore system of longshore bars, and could explain why the spit section of the Point is so variable in size and orientation. According to the wave climate and other seasonal process factors, this stored sediment would be expected (depending on wave conditions) to be

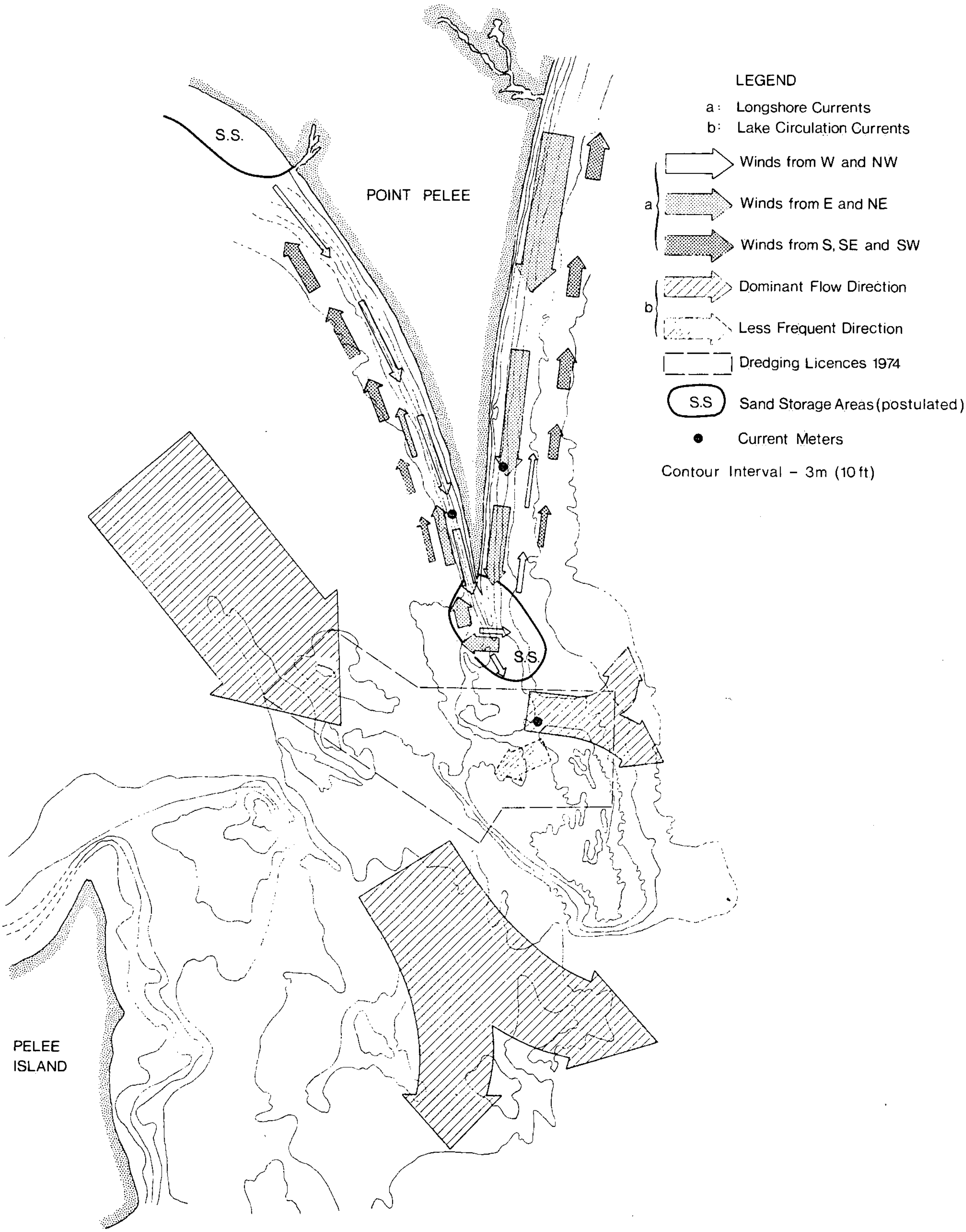

Figure 26. Interpretation of the major patterns of sediment transport and deposition in the Point Pelee - Pelee Shoal area.

returned up the east side or to be transferred to the west side drift system. The portion of the shoal south of this storage area (i.e. in the vicinity of the dredging licenses) does not appear to be a significant source of sediment for littoral drift along Point Pelee.

5.4. PROBABLE EFFECTS OF COMMERCIAL DREDGING SOUTH OF POINT PELEE

Section 2.4 outlined the historical development and scope of commercial dredging operations to the south of Point Pelee. In considering the effect of such operations on coastal processes, a clear distinction must be made between operations prior to 1918 and those after that time. These two periods will now be examined in the light of the process regime outlined in Chapter 4 and the sediment sources and pathways described in section 5.3.

5.4.1. Dredging Prior to 1918

During this period, an undetermined volume of sand and gravel was extracted from the shoal area and even directly from the spit itself (Fig. 7). The result (apparent within a few years) was a drastic reduction of the length of the subaerial spit (of between 500 and 800 m), and the severe erosion of sections of the east shore, according to various reports cited in section 2.2.3. Changes occurring in the subaqueous areas were not recorded. Moreover, this activity might have been the original cause of the two transverse channels crossing the spit ridge at AA and BB(Fig. 13), although there is no recorded evidence of this.

Such operations undoubtedly had a profound effect on the wave climate near the tip of the Point and on the then-existing pathways of littoral sand transport. In the case of the former, incident wave energy would be increased, making the spit more prone to washovers and causing a considerable lowering in elevation. The dry-land spit that had extended almost out to the Dummy Light would have disappeared. In the latter case, i.e. regarding littoral transport, the area of temporary storage for the littoral drift brought down from the east side would be almost eliminated and the presence of the transverse channels would alter greatly the movement of sand reaching the tip.

In short, such operations would definitely have contributed to intensified erosion of the east shore of Point Pelee.

5.4.2. Dredging after 1918

In response to public outcry over shore erosion, dredging operations were restricted to beyond 1.5 km of the shore, and later, to 3.2 km (Fig. 5). This relocation moved the sphere of operations to the central portions of the shoal, away from the littoral zone of the Point. However, the continuing reports of severe erosion leads one to believe that much of the damage was already done, and the littoral transport system had been affected in a fundamental way. Since these later operations were located at such a distance from shore, the only process factors that they could conceivably influence would be the wave climate and the supply of sediments transported northward from sources within the dredging license areas. These factors were examined in sections 4.3.3 and 5.2.4. In the simplifying (but extreme) case of increasing the depth of water over the shoal to 10 m, some accelerated erosion, confined mostly to the tip, could be expected. However, such an excavation would entail the removal of around 60 000 000 m^3 of material, or about 200 years dredging at 1973 rates. For this reason, and the small size of the existing dredged holes, erosion due to intensified wave action because of these holes is considered unlikely.

With regard to the possibility of interference by dredging operations with the northward transport of sediments from a source area within the scope of dredging operations, the crucial issue here is the sources and quantities of sediment involved in such transport. This is, unfortunately, one of the areas in which data are sparse and indirect. It is clear, however, that the northern boundary of the license areas is close to the area postulated as a storage area for east side drift (Fig. 26). The shoal current data (the meter was located within the northern portion of the license area) indicated some northward transport (although the net transport was southward) especially during the fall months. In view of the fact that the extent of the storage area would vary from year to year, it is possible that these two areas would sometimes overlap to some degree, with the possibility of all or part of the stored sediment being removed by dredging.

Another factor is that the relative scarcity of suitable aggregate materials in the western portions of the license area (Fig. 9) would tend to encourage concentration of dredging efforts on the shoal, thus increasing the possibility of unintentional incursions into the storage area. Since the actual temporary storage volumes at a given time are probably small (less than 20 000 m^3/yr or a fraction of one year's dredging volume), such a possibility assumes considerable importance. For these reasons, it must be concluded that dredging in or near such areas could have a definite effect on the incidence of erosion along the shores of Point Pelee. The effect cannot be assessed precisely at this time because of lack of direct data on rates of northward transport on the shoal, and because of probable lingering effects of the dredging operations prior to 1918 on sediment movements near the tip of the Point.

In summary, it appears probable that the changes in the coastal processes at Point Pelee, of which shore recession is an obvious example, are to some undefinable degree related to the intense inshore dredging operations up to 1918. Since that time dredging operations have been restricted to the more offshore areas of the shoal, but the potential for these operations to influence the incidence of erosion along the east side of Point Pelee remains a real one.

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